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SUMMER FACULTY RESEARCH PROGRAM (SFRP) REPORTS

VOLUME 2

ARMSTRONG LABORATORY
WILFORD HALL MEDICAL CENTER

RESEARCH & DEVELOPMENT LABORATORIES

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The purpose of this program is to develop the basis for continuing research of interest to the Air Force at the institution of the faculty member; to stimulate continuing relations among faculty members and professional peers in the Air Force; to enhance the research interests and capabilities of scientific and engineering educators; and to provide follow-on funding for research of particular promise that was started at an Air Force laboratory under the Summer Faculty Research Program.

During the summer of 1991 170 university faculty conducted research at Air Force laboratories for a period of 10 weeks . Each participant provided a report of their research, and these reports are consolidated into this annual report.

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PREFACE

Reports in this document are numbered consecutively beginning with number 1. Each report is paginated with the report number followed by consecutive page numbers, e.g., 1-1, 1-2, 1-3; 2-1, 2-2, 2-3.

This document is one of a set of 13 volumes describing the 1991 AFOSR Summer Research Program. The following volumes comprise the set:

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	Summer Faculty Research Program (SFRP) Reports
2	Armstrong Laboratory, Wilford Hall Medical Center
3	Phillips Laboratory, Civil Engineering Laboratory
4	Rome Laboratory, Arnold Engineering Development Center, Frank J. Seiler Research Laboratory
5	Wright Laboratory
	Graduate Student Research Program (GSRP) Reports
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1991 FACULTY RESEARCH REPORTS

Armstrong Laboratory, Wilford Hall Medical Center

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Body Composition In Rodents and Humans for P-Pbk Modeling

Mary L. Crittenden PhD Candidate Faculty

Abstract

The purpose of this research was to search the literature extensively to better define and characterize the body weights and compartments of the F-344, and Sprague-Dawley Rats, B6C3F1 Mice, Hartley and Hairless Guinea Pigs and the Human by sex, and age. The results were to be generated in a form suitable for use in the Physiologically Based Pharmacokinetic Models. The literature was searched from 1979 to the present for values. Data from laboratory necropsy studies of controls were surveyed. Data from a current request to a vendor were surveyed. Human values were ascertained from medical literature and from information on organ transplantation. Information was successfully obtained on the F-344 and Sprague-Dawley Rats, the B6C3F1 Mice, and Humans with limited success on the Hartley Guinea Pig and no success on the Hairless Guinea Pig.

Introduction

The Body compartments to be researched were defined as the Lungs, VRG (very richly perfused including the Heart, Brains, Kidney, and Glands), Fat (slowly perfused), MG (muscle group including skin and muscles), GI (includes the GI system except the liver) and Liver compartments.

The Environmental Protection Document provided values that were not well documented statistically. Computerized literature searches yielded very few studies defining normal. Additionally, few studies were available which utilized females of the species of interest except, where reproduction was the goal. To get normal values, it was necessary to search the literature for any studies on the species of interest and quantitate values using only the controls in those studies.

In Humans the use of transplant recipients and donor information was explored and letters were sent out for information to each of the transplantation centers in Michigan. It was necessary to narrow such requests to only heart recipients. Information on kidney transplant recipient values would not be of value since the erythropoietin, pH, and electrolyte values would be altered by the kidney disease process. One of the transplant centers has a data base with the requested information, however they have only completed eight heart transplants since the data base was completed. They have accepted my information request and will send information when they have more completed heart transplants. The leading transplant center with over eight hundred reported transplants has accepted my request for information and will send information as it becomes available from their database, with an anticipated completion date of approximately six months.

Requested information from the transplant centers and the human literature included the following Sex, Age, Occupation, Race, Height, Weight,Blood type ABO and RH of recipients, and for Donors weight of the donated organs along with Sex, Height, Weight, Age of the Donors. Sequential Multiple Analysis (SMA) SMA 17, or SMA 24 results if available, FEV1, Lung and Spirometry Function Tests, Cardiac Output, and Cardiac Catheterization results, Upper and Lower GI tests Results (as a measure of total fluid intake check). A similar request for information was given to Mr. C. Flemming for purposes of obtaining similar information from a Navy database. (Human values are difficult to obtain directly i.e. humans will volunteer only for certain procedures, and there is a great difficulty in the procurement of organs after death.) Values from the SMA 17 or SMA 24 Spirometry, Cardiac Catheterization and Gastrointestinal will yield Blood volume, GFR, CO, Liver function, rates of urea formation and BUN levels (a result of detoxification). The BMR can be determind by comparing O2 and CO2 levels with Hematocrit. The requested HDL and LDL will along with Occupation can give a correlation of fitness of the Humans to be normed.

Discussion:

Th%wfollowing data are a compendium of literature surveyed from 1979 to the present are statistically significant.

Distribution of cardiac output to body organs(Dunnill & Colvin 1989)

	AVG wt(kg)	% body weight	Blood flow (ml/min)	% Cardiac output	O2 consumption (ml/min/organ)
Brain	1.4	2.0	775	15	46
Heart	0.3	0.43	175	3.3	23
Kidneys	0.3	0.43	1100	23	18
Liver	1.5	2.1	1400	29	66
Lungs	1.0	1.5	175	3.5	5
Muscle	27.8	39.7	1000	19	64
Rest	38.7	55.34	375	9.7	33

Cardiovascular Pressures(Dunnill & Colvin 1989)

	Systolic (mmHg)	Diastolic (mmHg)	Mean (mmHg)
Peripheral venous	-	-	6-12
Right atrium(CVP)	-	-	0-7
Right ventricle	14-32	0-7	12-17
Pulmonary artery	14-32	2-13	8-19
Wedge or Left atrium	-	-	6-12
Left ventricle	100-150	2-12	
Arterial	100-150	60-90	80-100

Body compartment volumes(Dunnill& Colvin 1989)

Adult M=Male F=Female

Total body water	55-60 % M	50-55 % F
Fat	11-26 % M	- F
Lean body mass	90-74 % M	- F
Blood volume	5.5%-7%(55-72 M - F ml/kg)	
ECF	20-25 %	

Metabolic rates in energy/m^2 body surface/hour(reproduced from Robertson JD&Reid DD(1952) Lancet, i, 940(Dunnill & Colvin 1984)

Age	Males		Females	
(yrs)	kcal	MJ	kcal	MJ
16	33.7-46.9	0.141-0.196	31.3-40.8	0.131-0.171
19	32.7-45.0	0.137-0.188	29.7-39.3	0.124-0.164
22	32.4-43.1	0.135-0.180	29.2-38.8	0.122-0.162
30	31.4-41.4	0.131-0.173	29.2-38.9	0.122-0163
40	30.5-40.5	0.127-0.169	27.8-37.5	0.116-0.157
50	28.8-38.8	0.120-0.162	27.1-36.7	0.113-0.153
60	28.1-38.1	0.117-0.159	26.5-36.1	0.111-0.151
70	27.4-37.4	0.114-0.156	25.9-35.5	0.108-0.148

(Dunnill & Colvin 1984)

Renal Plasma Flow		500-800 ml/min(calculated per 24 hours)	
Volume,	Blood	49-75ml\kg body wt.Male 2500-400ml/m^2	56-75ml/kg body wt.Female
	Plasma	31-55ml/kg body wt.Male 1400-2500ml/m^2	36-50ml/kg body wt.Female

Red cell	18-33ml/kg body wt.Male	20-27ml/kg body wt. Female
		Values in SI units
pH venous	7.32-7.42	38-48nmol/l
Arterial pH		
PCO_2	7.36-7.45	36-44nmol/l(H^+ ion) heparinized
	34-46 mm Hg	4.5-6.1 kPa (conversion fac. 0.133)
PO_2	90-110 mm Hg	12-15kPa (conversion factor 0.133)
Haemoglobin (Hb)	men	13.5-18.0 g/dl
	females	11.5-16.5 g/dl
RBC count	men	4.5-6.0 x 10^{12} /L
	women	3.5-5.0 x 10^{12}/L
Hematocrit(HCT)	women	0.36-0.47

After noting that some of the values reported by Dunnill and Colvin in the third edition of their text were documented more effectively than in the current volume of their text, a call to the publisher revealed that these physicians collected data from the hospitals, where they serve as consultants, and extensive literature searches. A cross check of this data with other sources failed to reveal errors.

The following Human Body weights and organ blood flow rates were reported in the literature were documented from many sources:

Liver 1200-1600g Hepatic Artery Oxygenated Blood 400-500ml/min (25% Cardiac Output(CO) Hepatic Portal Vein receiving deoxygenated blood from the inferior and superior mesenteric veins, and splenic veins, 1000-1200ml/min or seventy percent of Portal Venous Blood Supply

700-1200ml bile/day (Hardy 1983), (McCance & Huether 1990)

Kidney (Adult) 150g per kidney (Right 25ml larger than left)

Renal Blood Flow 1000-1200ml/min (20-25% CO)

600-700ml/min with normal hematocrit

Renal Plasma Flow 120-140ml/min

Glomerular Filtration= glomerular/renal plasma filtrate 120/1000 or 0.20 Filtration Fraction (Robbins & Cotran 1979) and (McCance and Huether 1990)

Lung 300-400g 10,000L/air/day(Robbins & Cotran 1979)

Particulate distribution greater than 10microns lodging in nose & upper airways

" " 3 to 10microns lodging in trachea & bronchi

" " 0.5-3.0 microns deposited in terminal bronchioles

Pancreas 80-90 g (Hardy 1983)

Spleen (Adult) 100-150g Blood Flow 350L/24Hrs (Hardy 1983)

Brain (Adult) 900-1800g Avg 1300g or 2% Body Weight receiving 20% CO (Robbins & Cotran 1979), (Tortora & Anagnostakos 1990)

Heart (Adult) Values from Robbins & Cotran 1979

Female 250-300g Male 300-350g (Robbins & Cotran 1979)

Normal physical parameters insuring normal Cardiac Output

Right Ventricle thickness 3-5mm

Left " " 1.35-1.5 cm

Valvular Circumference

Tricuspid Valve	12.0 cm
Pulmonic Valve	8.5 cm
Mitral Valve	10.0 cm
Aortic Valve	7.5 cm

Heart Blood Flows From Seeley, Tate & Stephens 1989

End Diastolic volume (atria to ventricle) 120/130ml/cardiac cycle

End Systolic volume 50-60ml/cardiac cycle

Blood flow per/cardiac cycle 70ml/beat

CO = 70ml/beat * 72beats/min= 5050ml/min or approximately 5L/min

Ovaries 4-8g(in nubile females) (McCance & Huether 1990)

Testes 10-15g(Tortora & Anagnostakos 1990)

The two most common methods used to measure cardiac output are the Fick and indicator dilution method (Hardy 1983). Fick's principle states that the rate at which a substance distributed in a fluid delivered by a moving stream is equal to the flow rate and concentration difference of the substance at the proximal and distal site (Hardy 1983). The Direct Fick technique uses oxygen as the substance, assuming that at rest, oxygen uptake in the lungs is equal to that used by body tissues. A complete mixed venous sample is used from the pulmonary artery and is compared with systemic arterial oxygen content. Oxygen uptake(QO_2) is measured by analysis of a three minute collection of expired air, and cardiac output is calculated as (Hardy 1983):

CO= QO_2/Ca-Cv where Ca= arterial blood and Cv= venous content

The relationship between lung surface area and body weight has a direct effect on ventilation. Larger animals having larger lungs and increased lung surface area also have increased Oxygen uptake (Eckert 1988). The ratio of the rate of CO_2 production/rate of O_2 consumption defines the respiratory quotient (RQ). The exact value of the RQ is determind by using molecular equations for the oxidation of Carbohydrates 1.0, Fats 0.71, and Proteins 0.80 (Eckert, 1988). Assuming a RQ of 0.8 the Basal Metabolic Rate (BMR) or Basal Energy Expenditure (BEE) can be estimated by using the Harris-Benedict equations (Braunwald et. al, 1988 P.182):

Men, Kcal/day

BEE= 66 + 13.8*WGT(kg)*5*HGT(cm)-6.8*Age(yrs)

Women, Kcal/day

BEE= 665 + 9.6*WGT(kg)+1.8HGT(cm)-4.7*Age(yrs)

The distribution of body water is important in the determination of perfusion to body compartments.

Distribution of Total Body Water From Robbins & Cotran 1979

	Volume in Liters	% Lean Body Weight
Total Body Water	42	60
Extracellular Water	14	20
Plasma	3	4-5
Interstitial Water	11	16
Intercellular Water	28	40

Formulas are often used based on analysis of literature surveys, the following formulas are from CRC Handbook of Physiology in Aging P.413

Males Total Body Weight(L)* 100/Body Weight (kg)= 79.45-0.24(Body Weight)-0.15 age(years)

Intracellular Weight/Total Body Weight* 100+ 62.3-0.16 age(years)

Females Total Body Weight(L)* 100/Body Weight(kg)= 69.81-0.26(body weight)-0.12age(years)

Intercellular Weight/Total Body Weight* 100= 52.3-0.07age in years

These formulas provide a good estimate of lean body mass and correspond well when using the 70Kg 20 year old male referenced in the EPA documentation. The amount of adipose tissue in humans and rodents is not very well defined. Measurement of fat by the skinfold thickness and X-ray tests in humans, reveals the following trends(CRC Handbook of Physiology in Aging)

1. Adipose tissue increases until the sixth decade of life
2. In American Men large increases in subcutaneous fat masses occur in the chest and abdomen, while in women there is an increase in subcutaneous fat in the abdomen, chest, chin and knee with increasing age.

The Framingham Study, a 34 year longitudinal study of a 5,209 sample population of males and females aged 28-62 for assessment of coronary disease risk has developed regression equations based on quetelets, that correlate well with inner obesity. Subscapular skinfold is highly correlated to quetelets. A ratio of subscapular skinfold to tricep skin fold is used as a measure of the degree of inner to outer obesity. The subscapular skinfold to quetelet ratio is used as a measure of inner obesity relative to total body weight. The body mass index (weight in kilograms and height in centimeters) can be computed from a quetelet by multiplying by a factor of 7.0307.(Kannel et. al. 1989).

The amount of adipose tissue in the individual influences the rate of oxidation of foodstuffs, tissue perfusion, flow in compartments (water component).

The alveolar ventilation rate is the amount of gas perfused at the alveoli per unit of time. Distributions of ventilation perfusion ratios are based on the partial pressure of the gas in end-capillary blood and the blood gas coefficient. The end- capillary blood divided by the mixed venous partial pressure is known as retention. When an inert gas dissolved in saline is steadily infused into the venous circulation, the proportion of the gas which is eliminated by ventilation from the blood of a given lung Unit depends on the solubility of the gas and ventilation-perfusion (West 1985). West has drawn imaginary lines delineating different perfusion ratios for the same gases in different parts of the lungs(Ex. Alveoli at base of lung are slightly over-perfused in relation to their ventilation where as the alveoli at the apex are greatly under-perfused in relation to their ventilation. The degree of over or underperfusion is expressed by the Ventilation to Perfusion ratio (Va/Q). This ratio determines the gas exchange in any lung unit or region of the lung. A measure of alveolar ventilation is the forced expiratory volumes and percentages over a given time period.(West 1984) and (Miller 1986).

The Michigan equations are recommended for lung evaluation because they are derived from a representative sample of the general population of a large state.

The following information details the Michigan equations:

Investigator	Subjects	Equations(+- SEE)
Miller	511 subjects;204 nonsmokers,	M(nonsmoker)=0.418Ht(in)-
	218 smokers,89 ex-smokers;	0.229 Age+12.9113(+-4.84)
	random selection of State of	M(smoker)=0.418Ht(in)-0.229
	Michigan	Age+7.5195(+-4.84)
		M(exsmoker)=0.418Ht(in)-
		0.229 Age+10.6546(+-4.84)
		F(nonsmoker)*=0.407Ht(in)-
*NOTE:Includes exsmokers		0.111 Age+2.2382(+-3.95)
		F(smoker)=0.407Ht(in)-0.111
		Age-1.3227(+-3.95)

The Michigan Equations reference the measurements of Forced Expiratory Volumes for one minute (FEV_1), Forced Expiratory Flow after X percentage has been exhaled ($FEF_{50-75\%}$), and the $FEF_{50\%}$/FEV (Miller 1983).

Normal values are defined as Vital Capacity greater than 80%, FEV_1 greater than 80%, $FEF_{25-75\%}$ at 2 liters per second and $PaCO_2$ at 40 units (Hardy 1983). If the FEV_1, the $FEF_{50\%}$/FVC of 0.70, the $FEF_{25-75\%}$ greater than or equal to 2.6 liters per second tests are given independently, then the probability of of error in determining abnormal function becomes 0.0001 (Miller, 1986).

The Human adult Liver has a weight range of 1200-1600g, receiving oxygenated blood from the Hepatic artery at the rate of 400-500ml/min., receiving up to 25% of Cardiac Output(CO)(McCance & Huether 1990).

The Hepatic Portal Vein receives 1000-1200ml/min of deoxygenated blood from inferior and superior mesenteric veins and the Splenic vein(McCance & Huether 1990). By inference the Gastrointestinal Tract receives the oxygenated blood draining into the Hepatic Portal circulation. The liver secretes 700-1200 ml bile daily(McCance & Huether 1990).

The material available on humans that could be used to better quantitate human norms for P-PBK modeling was limited to volunteers, who initially presented the clinicians with some abnormality to be explored.

Few health persons volunteered. By using some medical studies with a default to controls, some data was obtained. A clinicians version of a control is an individual who is without the disease or related complications of his disease study. One study, focused on a group of controls N=6, males, age range 56+- 13 years, initially presenting with atypical chest pain, where no coronary artery blockage defined them as controls. In this study, three healthy volunteers were used as experimentals. Both, the controls and experimentals were infused with Thallium-201, which provided an excellent tool for the assessment of normal organ perfusion(Adachi et.al. 1984. The results were not all within normal currently accepted limits (4-8L/min.) with a cardiac output ranging from 3.2-6.4L/mkn4-8L/min.

Humans will volunteer for very invasive tests when a medical problem presents. Often an individual with a GI problem can think that he/she has a Heart problem and vice-versa. The clinician often will find normalities of one parameter but an abnormal parameter in another system to justify the proper diagnosis. Specialist clinicians often perform very invasive tests to be as certain as possible about abnormalities or the lack of an abnormality. Literature values on norms must be consulted.

A search of the medical literature revealed some interesting invasive tests that merit further searches for normal values. The following are a sampling of some invasive tests and purposes:

1. Endoscopic Retrograde Cholangiopancreatography(ERCP) Purpose: To expose irregularities of the GI tract and Accessory organs.
   Procedure: Individuals are given an anesthesia, then basically a tube with camera and sampling capabilities (Colonoscope) is introduced into the GI tract, and up the biliary tract, up to the intestines. Another tube the (Sigmoidoscope) may be introduced through the anus for similar study of the sigmoid regions of the colon.
2. Cystoscopy Purpose: To detect problems of the urinary tract
   Procedure: Individuals are given an anesthetic, then a tube

(cystoscope) with camera and tissue sampling capabilities is introduced into the urethra and the ureters and kidneys can be directly visualized, to the point of observation of urine flow.

3. Cardiac catheterization Purpose: to detect heart abnormalities

   Procedure: A tube with camera capabilities is introduced through a large artery ex. abdominal aorta and threaded upward until the heart is visualized after the individual is given some anesthetic agent.

Similar tubes with camera capabilities exist to explore bronchi and trachea, brain and other body parts for diagnostic purposes. Normal values for interior and exterior characterization of normal sizes and flows should exist as a basis clinical diagnosis. Specialized journals in Gastroenterology, Nephrology, Pulmonary, and Neurosurgical Medicine merit further study for such values.

As a measure of fat, currently Cosmetic and Reconstructive surgeons are performing the liposuction procedure (suctioning out of adipose tissue for cosmetic purposes). Liposuction is performed on individuals who are not obese, and if they have lost weight must have maintained that weight loss for at least a year before cosmetic procedures may be performed. Such surgeons could reasonably be expected to follow some norms on fat distribution and location with reference to age and sex of individuals.

The information on Sprague-Dawley Rats was obtained by searching the literature for controls used in different studies, but assessed for the parameters of interest. The characterization of the fat compartment by age and sex was easily accomplished with males, however females studies on adipose distribution were available on those in reproductive studies.

The following table summarizes a study of fat in male Sprague-Dawley rats by age and sex with dietary manipulation (Crandal et.al, 1984)

Group	N	Age days	Body Wt, g	Cardiac output ml/min	Cardiac index ml/min/kg
Young	6	90	386.8 -+12.6	133.0 -+ 8.7	345 -+20.0
Restricted	7	450	390.3 -+8.4	119.2 -+13.2	305.0 -+32.2
Obese	8	450	713 +-23.1	209.5 +-22.7	295.0 +-31.5

Data from this article included a characterization of adipose cells by, number, adipocyte cell size, and location with respect to the age of each Sprague-Dawley male rat. Based on the article the following percentages of body fat were calculated:

Young 16.5% +- 1.032

Restricted 15.74% +- 1.07

Obese 19.24% +- 0.940

These values were based on means of given literature values +-SE with P less than 0.05 noted as significant. Male Sprague-Dawley Rats as a group for the purposes of this study were categorized as young, restricted, and obese on the following basis :

1. Young rats were fed ad libitum Ralston Purina Laboratory Chow and sacrificed after 90 days into this study with brown fat discarded and alloquots of fat selected from the Epididymal, Subcutaneous, Mesenteric, and Retroperitoneal regions
2. Restricted rats were fed the same brand of food but 60% of the ad libitum amount with the same procedure for analysis of fat initiated after sacrifice on day 450.
3. Obese rats were fed the same brand of food but allowed food ad libitum for the duration of the study with sacrifice on day 450.

Restricted Sprague-Dawley rats made a good model for Human controlled diet while the ad libitum feed rats made a good model for Humans on a non-controlled diet or experiencing an increased ratio of adipose to lean tissue via the normal aging process.

The methods of experimentation were of particular interest, for P-PbK modeling, because no matter how through the fat extraction process, one could not account for every fat cell. The method utilized by these researchers basically involved using Microspheres labeled with ^{51}Cr were treated as per the literature then analyzed using a Packard 5260 (^{51}Cr) gamma counter. Size of fat cells was directly observed and measured using standard microscopic procedures.

Calculations were derived using the following formulas:

$$CO(ml/min) = \frac{\text{radioactivity injected x blood withdrawal rate}}{\text{blood radioactivity}}$$

$$ATBF(ml/min) = \frac{\text{depot radioactivity x blood withdrawal rate}}{\text{blood radioactivity}}$$

adipose tissue blood flow= ATBF

Although the alloquots were of differing size the gamma-counter was standardized to account for differing sizes. Such a procedure might be useful for determining fat percentages in the laboratories here, but instead of using a gamma counter, using an appropriate bioluminescing compound.

Distribution of cardiac output to body organs(Dunnill & Colvin 1989)

AVG	% body	Blood flow	% Cardiac	O2 consumption	
	wt(kg)	weight	(ml/min)	output	(ml/min/organ)
Brain	1.4	2.0	775	15	46
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Cardiovascular Pressures

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Right atrium(CVP)	-	-	0-7
Right ventricle	14-32	0-7	12-17
Pulmonary artery	14-32	2-13	8-19
Wedge or			
Left atrium	-	-	6-12
Left ventricle	100-150	2-12	
Arterial	100-150	60-90	80-100

Body compartment volumes(Dunnill & Colvin 1989)

Adult M=Male F=Female

Total body water	55-60 % M 50-55 % F
Fat	11-26 % M - F
Lean body mass	90-74 % M - F
Blood volume	5.5%-7%(55-72 ml/kg) M - F
ECF	20-25

Renal Plasma Flow 500-800 ml/min(calculated per 24 hours)(Dunnill and Colvin 1989)

Further values from Dunnill and Colvin 1989 include the following

Volume, Blood 49-75ml\kg body wt.Male 56-75ml/kg body wt.Female

2500-400ml^2/m

Plasma 31-55ml/kg body wt.Male 36-50ml/kg body wt.Female

1400-2500ml^2/m

Red cell 18-33ml/kg body wt.Male 20-27ml/kg body wt. Female

		Values in SI units
pH venous	7.32-7.42	38-48nmol/l
Arterial pH		
PCO_2	7.36-7.45	36-44nmol/l(H^+ ion) heparinized
	34-46 mm Hg	4.5-6.1 kPa (conversion fac. 0.133)
PO_2	90-110 mm Hg	12-15kPa (conversion factor 0.133)

Haemoglobin (Hb)	men	13.5-18.0 g/dl
	females	11.5-16.5 g/dl
RBC count	men	4.5-6.0 x 10^{12} /l
		12
	women	3.5-5.0 x 10^{12}/l
Hematocrit(HCT)	women	0.36-0.47

The following values are based on a literature searches by the Editors of over six hundred and seventy seven articles, where rodent control animals values were averaged (Fox et. al.1984)&(Baker et.al. 1979)

Heart rate 300-500 beats/min

Cardiac output 50 ml/min

Blood volume 6 ml/100 gm body weight

Table II

Body and Organ Weights at 1 Year in F3 Sprague-Dawley Rats Fed Purified or Natural Ingredient Diets (From Baker et. al.1979)

N=30		Body	Weight(% of body weight)				
Diet	Sex	weight(gm)	Liver	Kidney	Heart	Gonads	Pituitary
Purified	M	658	2.5b	0.56	0.31	0.52	0.002
	F	474	2.6b	0.58	0.28	0.02	0.004
Natural ingredient	M	640	3.2	0.67	0.28	0.57	0.002
	F	437	3.3	0.64	0.32	0.03	0.004

a From Newberne et al. (170)

b Difference from rats fed natural ingredient diet significant P<0.01.

Table III(From Baker et. al. 1979)

Cardiovascular Parameters for the Rat

Arterial blood pressure	
Mean systolic(mm Hg)	116
Mean diastolic(mm Hg)	90
Heart rate average(beats/min)	300
Cardiac output(ml/min)	50
Fractional distribution of cardiac output	
Heart(%)	5
Kidney(%)	19.0
Brain(%)	1.5

Adrenal(%)	0.33
Testes(%)	0.71
Splanchnic(%)	19.0
Stomach(%)	1.4
Intestine(%)	13.0
Liver(%)	1.6
Pancreas(%)	1.7
Spleen(%)	1.7
Muscle,skin,bone(%)	47
Other(%)	7.0
Blood volume(ml/kg body weight)	54.3

The following information was supplied by the Harlan-Sprague Dawley Inc. in a July 23, 1991 Fax(Marjukka Gordon (317)894-4473) on organ weights for the F-344 and Sprague-Dawley Rats, B6C3F1 Mice, and Hartley Guinea Pigs.

AVERAGE ANIMAL ORGAN WEIGHT CHART

Mouse	Average Weight (Grams)
Heart	0.183
Brain	0.430
Spleen	0.131
Pancreas	0.168
Kidney	0.262
Liver	1.970
Lungs	0.266
Small Intestine	1.844

Rat(F-344 & Sprague-Dawley)	Average Weight (Grams)
Brain	2.100
Testicles	1.855
Spleen	0.880
Pancreas	0.600

Guinea Pig	Average Weight (Grams)
Small Intestines	11.277
Liver	21.254
Back Leg Muscle	5.646
Heart	2.000

From necropsy studies of control animals used in the studies here the following data was compiled: (*Denotes N=12, Values are averages of weight in grams, SD is sample SD)

SEX	ANIMAL	N	AGE	UNFSTWGT	FSTWGT	LUNG	LIVR	BRAIN	THYM	SPLEEN
M	B6CF1	18	24	34.36	32.17	0.30	1.44	0.46	0.047	0.077
		SD		7.71	6.32	0.057	0.217	0.034	*0.020	0.015
F	B6CF1	18	24	29.58	28.24	0.30	1.25	0.49	0.053	0.093
		SD		5.94	5.38	0.062	0.171	0.037	*0.012	0.020
M	F-344	18	24	326.8	322.47	1.617	8.930	1.845	0.287	0.601
		SD		46.58	40.83	0.147	1.821	0.131	0.067	0.053
F	F-344	18	24	185.24	177.31	1.162	4.545	1.742	0.224	0.416
		SD		11.38	10.73	0.106	0.358	0.053	0.030	0.029

The data from the laboratory, correlates well with the data reported from Baker et. al, however 24 weeks is a very short window for analysis. Additionally, the skin, GI, Muscle, and Fat from different portions of the controls were not analyzed. A suggested standard protocol for control animals with analysis by the RS1 computer program might provide a customised database.

Conclusion

In conclusion databases for Medical Human Values are very limited in scope. The Fels Institute a Division of Wright State Medical has a database on human values as they relate to the analysis of Fat. The Framingham study, publishes results on data in humans as it relates to coronary disease, with parameters of twenty-one medical tests recorded and analyzed for a period of over thirty years. The Fels and Framingham studies, both longitudinal and published results were the only relevant studies found.

A human database for heart transplantation was located, but unfortunately not enough procedures were available to be statistically significant. Contact was initiated with a national transplantation database, however access to it will be available only, after a written proposal is submitted and approved by their committee. A copy of the proposal form is attached to this document. A good reference for human values tests etc. is Harrisons Principles of Internal Medicine, one of the references listed.

For Rodents no database on normal values was uncovered, although at CDC in Atlanta, one office was contacted that is in the process of developing a database. The particulars of the database and CDC office are attached to this document. Values on Rodents may also be requested from the vendor Harlan-Sprague Dawley, via their account executives request to their surgical unit. Lastly, exploration of the possibility, of Toxic Hazards using information from the "Pathtox" system data on controls, coupled with the database analysis capabilities of "RS1" is an avenue worth further investigation.

DESIGN OF A THREAT SITE/EMITTER LAYDOWN DATABASE AND THREAT EMITTER PARAMETERS DATABASE FOR THE ADVANCED DEFENSIVE MISSION PLANNING SYSTEM AND B1-B ENGINEERING RESEARCH SIMULATOR

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ABSTRACT

The primary goal of the Advanced Defensive Mission Planning System (ADMPS) is to allow rapid Mission Generation - integrating terrain information, routes, and threats - by a non-expert Mission Planner. The ADMPS should provide a realistic and accurate model of threat/site laydown using current doctrine, strategy and practices. At the same time, each threat model should simulate realistic threat emitter characteristics and operation. Together, the digitized terrain database, threat site laydown and emitter simulation should provide a realistic simulated electronic warfare environment that can be used in various Defensive System simulations. Once fully implemented, the ADMPS will be able to easily and quickly provide total mission scenarios - including training and EWO missions - for use in studies in various aircraft simulations.

ACKNOWLEDGMENTS

I wish to thank the Air Force Systems Command and Air Force Office of Scientific Research for sponsorship of this research. Research & Development Laboratories deserves mention for their concern and assistance regarding the administrative and directional aspects of the program. A special thanks goes to Lt. Col. William Marshak whose support, hospitality and assistance allowed me to participate in a very interesting and rewarding project. I also would like to express my appreciation for the efforts of Earl Sharp, Michael McNeese, Michael Sargent, and Dick Smith in creating an enjoyable working environment, sharing their expertise, and providing guidance and technical assistance.

I. INTRODUCTION

The Armstrong Aerospace Medical Research Laboratory is involved with ongoing human factors research and studies concerning the analysis of defensive crewstation design for strategic aircraft including the B-52, B-1B, and B-2 bombers. The laboratory uses high fidelity defensive crewstation simulators to simulate defensive crew member avionics, including visual displays and aural cues, in order to investigate, analyze and evaluate the decisions and actions performed by a Defensive Systems Officer. One of the primary requirements of the evaluations is the use of a realistic simulation of threat emitters. The threat simulation must provide a realistic and accurate model of threat/site laydown using current doctrine, strategy and practices. Historically, the placement of threats for a mission has been accomplished manually, site by site, requiring a high degree of expertise and knowledge of threat characteristics and tactical/strategic deployment. At the same time, each site should simulate realistic threat emitter characteristics and operation. The purpose of the ADMPS is to allow rapid Mission Planning by a non-expert by automating threat placement during the mission build process and providing highly detailed threat emitter models.

My background includes several years experience in the area of crew training, threat simulation and modeling, and avionics systems design. My knowledge and experience concerning strategic and tactical threat modeling and requirements were contributing factors in the performance of task analysis, requirements definition, and database design for this assignment.

II. ADMPS DESIGN

An analysis of the ADMPS tasks resulted in a proposed design that includes several major functions, requiring five major software components (See Figure 1). Several items were completed during this summer session and there are some areas that require further effort. The software areas and their functions are identified below.

A. COMMAND STRUCTURE PARAMETERS

1. Command Level Laydown Database

The threat system command structure of major threats was defined for different levels, with the various systems associated with the command level specified. Each associated system was assigned to a location by

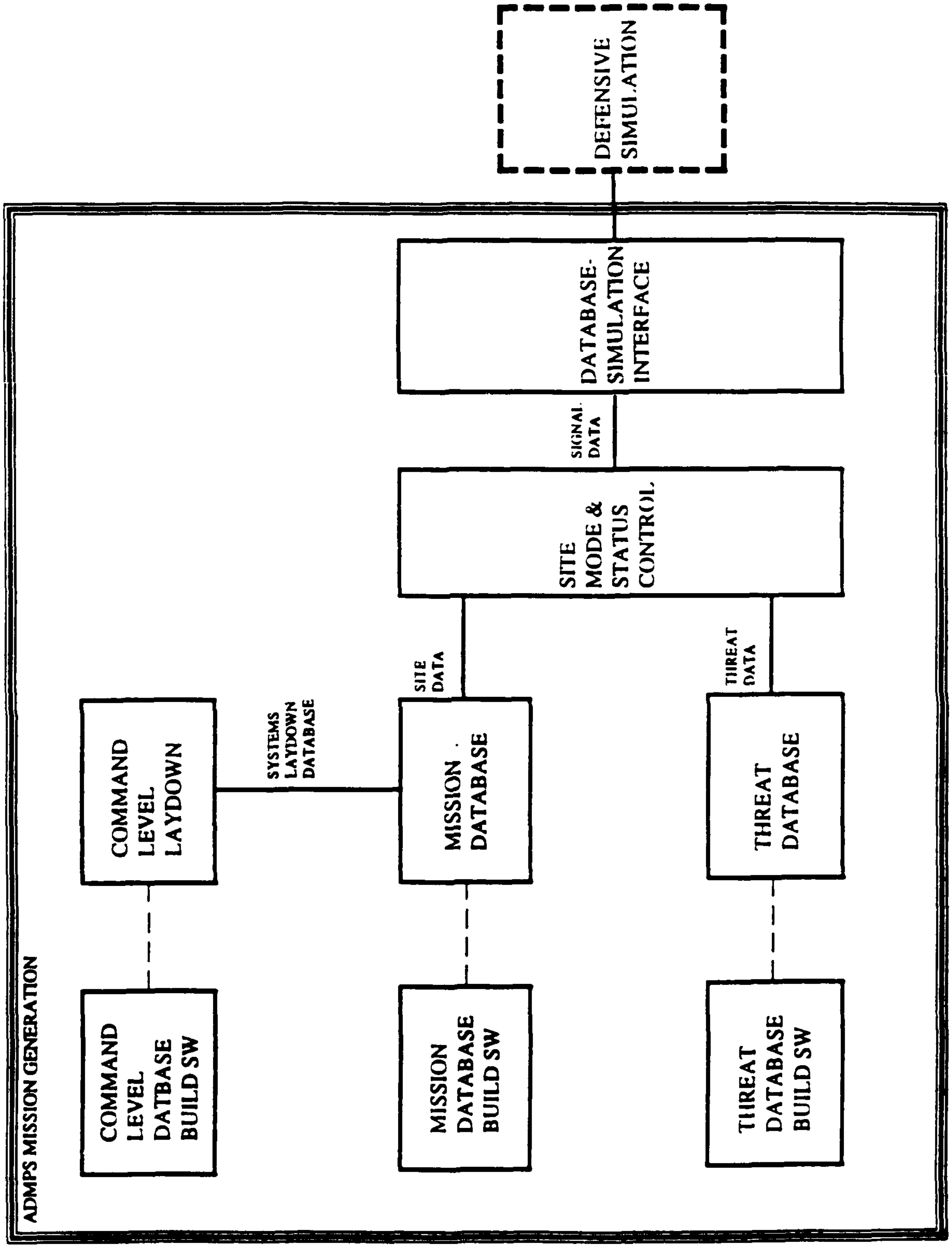

FIGURE 1 - ADMPS DESIGN

relative bearing and range from a common center point, with all the systems oriented along a defense axis direction. Each command level was designated as a site that includes all the system associated emitters that belong to it. Several command structures were modeled for each threat system.

2. Command Level Laydown - Database Build Software

The Command Level Laydown library/database files must be created by the Command Level Laydown Database Build Software. These files will be created offline and initialized during Mission Build. No work was done in this area.

COMMENTS/RECOMMENDATIONS:

1. Development of the software required to enter the Command Level data can involve a significant effort and expense - depending upon the degree of user friendliness. If the database is not used as a training tool then the currency and accuracy of particular threat parameters will not be of primary importance, changes should be rare, and a simple (crude) database build software model can be implemented. A crude data entry method approach is less expensive and makes entering data more difficult since it requires a high degree of software familiarity to properly enter data. The actual database build is a very time consuming, labor intensive effort, that requires manual data entry and meticulous manual error checking afterwards in order to verify the data. A hard copy capability would be very desirable for both validating the database and for maintaining a record of the current database.

2. The current ERS threat database does not include several threat systems which should be modeled. A list and general description of those threats is included in the classified notebook.

B. MISSION PARAMETERS

1. Mission Laydown Database

ADMPS shall provide a mission file containing the mission laydown and site parameters. Particular mission site data will include attack/defense axis direction, site types and locations, activation and deactivation criteria (time, range), initial modes, and net assignments. The Command Level Database will provide a resident set of default initial conditions that will become an overlay for the Mission Laydown files. Individual parameters can then be modified by the Mission Planner for specific conditions. No work was done in this area.

2. Mission Laydown Database Build Software

The Mission Laydown library/database files must be created by the Mission Laydown Database Build Software. The Mission Laydown will be created offline through the use of the Command Level Database. No work was done in this area.

COMMENTS/RECOMMENDATIONS:

1. Development of the software required to enter the Mission Laydown data will involve a relatively higher effort and expense than the software used for developing the other ADMPS databases. Since the intent of the ADMPS is to allow non-expert Mission Planning the software will require a large degree of user friendliness. The mission

generation system should allow the builder to easily and quickly generate and modify mission plans and laydowns and should be as automated as possible to minimize planner tasks and decrease mission build times. The actual mission planner displays and mechanization is a separate issue from the threat environment, but will need to be addressed in order to implement the Mission Planner software. A hard copy capability would be very desirable for both validating the mission and for maintaining a record of a library of missions.

C. THREAT PARAMETERS

1. THREAT DATABASE

The Threat Database must provide sufficient data to support high fidelity threat simulations for the defensive displays and aurals used on various aircraft. The database should allow for simulating a wide range of emitters including ground based and airborne jamming systems (JAMMER), Early Warning/Surveillance (EW) systems, Surface-Air Missile (SAM) systems, Airborne Interceptors (AI) systems, Anti-Aircraft Artillery (AAA) systems, and miscellaneous auxiliary emitters (IFF, GCI, Data Links etc.).

To accomplish this the Threat Database must contain the threat characteristics data that will allow the simulation of emitter electronic parameters that are apparent to the defensive systems simulation. In particular, signal characteristics must be provided to allow the simulation of the display and audio characteristics of each threat signal. The database should include mode and performance characteristics of the threat that accurately model threat responses and operation. It is extremely important that threat mode characteristics are modeled so that threats are allowed to transition through various operational modes with changes to affected emitter parameters. For this reason, the database must be sufficiently detailed to provide information for defensive displays, instructor/operator displays, and most importantly, audio responses for the crew members. The audio simulation is usually the most challenging part of the simulation and is the primary driver behind the database design. Audio response is typically harder to implement than display data for complex systems having peculiar characteristics that are difficult to simulate such as multiple beams, signal and scan synchronization, and various PRF agile emitters.

A primary concern is that the database contain sufficient data to model the threat system, without being unnecessarily large or complex. Normally, threat simulations are designed towards particular defensive systems/aircraft simulations and include just the data necessary to present information that is provided to the crew. Because the ADMPS database will be used for different applications, the database must contain enough information to provide adequate threat emitter characteristics for use in different aircraft threat audio and threat display simulations. Additionally, the Threat Database design must be flexible enough to allow easy modification of existing threat systems and the addition of new threats.

2. Threat Database Build Software

Threat emitter library/database files must be created by the Threat

Database Build Software. These files will be created offline and initialized at runtime. No work was done in this area.

COMMENTS/RECOMMENDATIONS:

1. Determine the Threat Database Build software requirements including the computer language and data structure to be used. The basic design can be determined prior to identifying specific database parameters and implemented once specific parameters are defined.

2. Determine which systems should be included on the threat list.

3. Define specific parameters of the threat database - identify required parameters including parameter description, units, resolution, and range. The individual threat parameters must be determined from the classified source data and entered on some type of parameter record. These records must be developed and completed as part of the database generation. The database design must be flexible enough to allow modeling complex features of emitters like RF, PRF, and Scan agility and synchronization capabilities.

4. In addition to database additions and modifications based on user requests, I recommend a periodic (annual) update of emitter data based on a review of EWIR change items.

5. Design the Threat Database so that all threat system emitter data is based on a Category-System-Type-Beam-Mode implementation. This approach is very flexible and efficient in modeling complex systems and allows modes and parameters to be easily added and modified. More importantly,

since many emitter beam characteristics are mode dependent, a Beam-Mode database allows complete flexibility in changing emitter parameters from mode to mode. In many cases emitter parameter values do not normally change from mode to mode (i.e. power levels), however, there are a number of very flexible, complex, and sophisticated systems using unique techniques, that are very capable and dynamic, that can be easily modeled using the Beam-Mode approach. The disadvantage to this approach is that the database is usually larger than can be created using different implementations. However, a Beam-Mode approach has the advantage of being extremely simple and consequently easy to understand and modify.

6. Determine the method to be used for real-time use and modification of threats. The implementation of the threat database is a software design decision based upon the simulation and ADMPS design. Two techniques could be used: 1) Modify the ADMPS threat data base directly; 2) Load the ADMPS database into a simulation database and create a run time data base that can be modified within the simulation, leaving the ADMPS database intact. A much simpler solution - and one I recommend - would be to provide no capability to change threats parameters during real-time operations.

7. Development of the software required to enter the threat data can involve a significant effort and expense - depending upon the degree of user friendliness. If the database is not used as a training tool then the currency and accuracy of particular threat parameters will not be of primary importance, changes should be rare, and a simple (crude)

database build software model can be implemented. A crude data entry method approach is less expensive and makes entering data more difficult since it requires a high degree of software familiarity to properly enter data. The actual database build is a very time consuming, labor intensive effort, that requires manual data entry and meticulous manual error checking afterwards in order to verify the data. A hard copy capability would be very desirable for both validating the database and for maintaining a record of the current database. The current ERS threat database tool has some of these features and I recommend that it be used as the baseline data entry tool.

8. The existing B-1B ERS threat database was completely reviewed, corrected and updated. The ERS database parameters will provide a validated base line for future expansion or incorporation into the ADMPS design.

9. The current ERS threat database does not include several threat systems which should be modeled. A list and general description of those threats is included in the classified notebook. In addition, the database does not include several parameters that are necessary in order to allow a high fidelity simulation for many threat emitters. In particular, the database and aurals hardware do not properly simulate threat audio for several types of signals.

D. SITE & EMITTER CONTROLS

Site Mode and Status Control

A high fidelity threat simulation can be provided if emitters are allowed to transition from one mode to another in the same way that actual threats change mode. The ADMPS should allow the threat to simulate the emitter mode transitions and actions performed for various modes (i.e. search, acquisition, track and launch modes) during engagement. The mode change criteria will be defined within the Threat Database and implemented during real-time by the Mode Control software. Software must be developed to control mode changes, and consequently update the emitter parameters based on the new mode. In addition to the mode related parameters, the software must calculate received signal strength (at the aircraft) for each emitter based on sector coverage, occulting, effective radiated power, and ground clutter. No work was done in this area.

COMMENTS/RECOMMENDATIONS:

1. I recommend a simple control of mode changes where the Mode Controller ignores countermeasures effects and changes modes based only on range. It will be difficult to establish the criteria for countermeasures effectiveness (unless EID data is the only criteria used) and the overhead involved in analyzing every emitter will be high. A high fidelity simulation of mode changes would require that the Mode Controller calculate detection and break-lock conditions based on received signal strength (based on range, effective radiated power, ground clutter, and aircraft radar cross-sectional area),

occulting,and countermeasures effects, for each active beam. It will be simpler to allow the simulation instructor/operator to manually change threat modes to simulate countermeasure effectiveness.

2. The method of passing parameters from the Site Mode and Status Control to the simulation must be determined.

3. Determine the amount of real-time threat control that can be performed manually by the simulator instructor/operator. I recommend that the control be kept to a minimum and limited to site activation and deactivation and manual site mode control.

4. A method of reinitializing threats upon simulation freeze and repositions must be determined.

E. DATABASE-SIMULATION INTERFACE

1. ADMPS-Simulation Interface Software Modules

The purpose of the ADMPS-Simulation Interface Software Modules is to provide a real time interface between the ADMPS scftware and the defensive systems simulation. Because the ADMPS will be used with several different aircraft simulations, the need for particular threat parameters is entirely simulation driven: different defensive systems present different displays and aural cues - therefore, data must be specifically provided for each system.

Each simulation will need those parameters that are required for simulating observable/perceptual visual or aural cues for the defensive system simulation. Data must be provided for support of the aircraft simulation instructor/operator requirements, defensive displays, and aurals generation.

Another requirement is that the interface software perform any conversions necessary is passing data from the database to the simulation. Data can be conditioned, scaled, or otherwise converted to the proper units (i.e. knots, watts, milliseconds, etc.) and specific emitter identification information can be performed by the software.

Another function the interface software can perform is that of modeling emitters that require unusual processing. My experience has been that no matter how detailed the design, there are always a few systems that perform differently than any others, or have extremely unique characteristics that either do not fit the structure of the existing model, or are difficult to simulate. For those special cases the ADMPS-Simulation model can provide the parameters and processing necessary for the threat simulation.

No work was done in the ADMPS-Simulation Interface Software Modules area.

COMMENTS/RECOMMENDATIONS:

1. Determine the particular requirements for each simulation based on the data needed by the defensive station simulation. The design of each module will be unique, with varying levels of complexity based on the information needed by the defensive station simulation model.

GENERAL COMMENTS/RECOMMENDATIONS:

1. Ideally, the threat database and Site Mode Control should reside completely within the ADMPS system. This would allow the ADMPS to be a completely self-contained mission planning tool that includes all pertinent threat information - and becomes highly transportable from one simulation to another.

2. If current conditions do not allow for redesign of the ADMPS - I recommend that the ERS database be refined, updated and expanded until it can be incorporated into the ADMPS. If the ADMPS contains the complete threat database and threat modeling it will then be portable from simulation to simulation and could be used for B-2 and future studies.

A PROPOSED METHODOLOGY FOR COMBUSTION TOXICOLOGY TESTING OF HALON REPLACEMENT AGENTS

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ABSTRACT

An international consensus to remove Chlorofluorocarbon (CFC) compounds from production and U.S. national policy to implement the resulting protocols has motivated the U.S. Air Force to embark on a program to find a suitable replacement for Halon 1211, currently used to extinguish flight line fires. This research addressed the feasibility of conducting a combustion toxicology (CT) program to assess the toxic products of the combustion interaction of JP-8 and the Group 1 or so-called "Near Term" candidate replacement agents for Halon 1211: HCFCs 123, 124, and 142b. A laboratory scale experiment benchmarked on large scale testing of a 150 ft^2 pool fire was developed on the basis of Froude scaling of the full scale fire to a 15 x 15 cm pan fire. A prototype apparatus was developed and investigation into the use of animal behavior methods as an indicator of human incapacitation was conducted. The result is a new method which may potentially be utilized for future toxicity studies of the combustion interaction of current and future U.S. Air Force fuels with various fire extinguishants.

1. INTRODUCTION

The threat of ozone depletion and greenhouse warming has motivated the international community to mandate the replacement of halocarbon compounds used by various sectors of industry and the military. The Montreal Protocol, which went into effect in January 1989, limits the production of Halon and sets a schedule for its eventual phaseout. The U.S. Air Force (USAF) is a major user of chlorofluorocarbons (CFC's) such as Halon 1211 and Halon 1301 for fire suppression roles in aircraft, in computer and communications facilities, and in flight line fire fighting and has initiated replacement programs for the Halons. USAF discharges of Halon 1211 amounted to 783,000 pounds in 1986, over 28% of the U.S. total. The vast bulk of these discharges was due to the use of Halon 1211 in flight line fire suppression training. Today the use of Halons in training is virtually nonexistent as a result of USAF compliance with a national plan to replace CFC's with substances which have low Ozone Depletion Potential (ODP) and low Greenhouse Warming Potential (GWP). A USAF Near Term program to replace Halon 1211, used in suppressing flight line Class B fuel fires, is progressing and various candidate hydrochlorofluorocarbon (HCFC) agents are being considered as candidate agents. Future programs will assess Medium Term and Long Term replacement strategies for the Halons. Other than the primary requirement that the replacement compounds have a significant capability to suppress Class B fires, the candidate agents must also meet certain ODP, GWP, and toxicity criteria. Toxicity testing of the replacement gases is mandated by the U.S. Environmental Protection Agency (EPA) and has in fact been partially carried out for a number of the leading candidates. The combustion toxicology (CT) of these candidates, both in a thermal degradation sense, and in combination with burning fuels, is not mandated by the EPA. The USAF is examining the need for a CT program which will determine the threat to mission performance caused by exposure of unprotected flight line personnel who often must initiate fire suppression actions prior to arrival of appropriately equipped fire department personnel, so-called "band-aid" fire suppression efforts. A CT program had not been conducted in the past on the interaction of Halon 1211 with fuels because CT is a newly emerging discipline with many uncertainties as to test procedures and collection, evaluation, and interpretation of data.

2. DISCUSSION

2.1 General Research Procedures

The initial stages of research consisted of gathering information on the physical characteristics, fire suppression and combustion characteristics, toxicity, thermal degradation products, and combustion toxicity of JP-8, Halon 1211, HCFC-123, HCFC-124, and HCFC-142b. An on-line search of all relevant major databases was conducted to include the University of New Mexico Engineering Research Institute (NMERI) Halocarbon Database. The major thrust of analyzing the information obtained from these sources was to determine where gaps in knowledge about these substances occur and to determine if research should be conducted to provide the missing data.

The major standard CT models which are utilized by agencies which conduct CT research were reviewed for their applicability to the JP-8/HCFC CT program. These included the NBS, DIN, FAA, USF/NASA, and University of

Pittsburgh methods. All of these methods rely on animal testing to provide end-point analyses of toxicity, usually lethality. Current trends provide significant motivation to minimize the use of animals in CT research and the use of analytic techniques will be emphasized wherever possible.

2.2 Flight Line Fire Fighting Scenarios

The series of CT experiments must approximate actual flight line fires as realistically as possible. This is true not only for the Series 3 large scale tests, but also for the Series 1 and 2 laboratory scale tests. Issues such as oxygen availability, fire type and geometry, amount of fuel consumed, time to initial extinguishing actions, and the amount of Halon 1211 used on a typical fire must be assessed.

Contacts with the USAF Safety Office at Norton AFB, the Civil Engineering Center at Tyndall AFB, and with the Wright-Patterson AFB Fire Department provided some insights as to scenarios which are realistic. In this regard a few major points need to be observed to produce a reasonable facsimile of a real world flight line fire.

First, hangar fires involving fuel and Halon replacement gases are considered to be rare because fueled aircraft are not allowed in hangar spaces. Additionally Halon is prohibited from being discharged in the hangar space. Consequently indoor fire scenarios are not worthy of consideration and laboratory simulations of fuel fires should provide for a free flow of air to the fire.

Second, flight line personnel are trained to approach to no closer than about 30 feet of the fire. Consequently the products of interaction from the laboratory scale experiments should provide for dilution of the interaction products to a level which corresponds to this nearest approach distance. Large scale fire scenarios should have instrumentation located to correspond somewhat to this most likely fire fighting distance.

Third, the nominal flight line fire occurs either due to accidental venting of fuel due to a malfunctioning fuel relief valve, or due to nacelle fires on the aircraft. The former type of fire is called a "running fuel fire." Both fire types involve a significant amount of combustion at human eye level and consideration should be given to the effects of this type of geometry on the development of all experiments.

2.3 JP-8 Characteristics and Considerations

JP-8 is a kerosene jet fuel which is rapidly becoming the primary jet fuel for the USAF. It is a mixture of straight and branched chain paraffins, naphthalenes (cycloparaffins), and aromatic hydrocarbons, with carbon chain lengths that range from C8 to C17 carbon atoms per molecule. It is a yellow to straw colored, mobile, low volatile, oily liquid with a kerosene-like odor. Its physicochemical properties include:

Molecular Weight: 170.35 for $C_{12}H_{26}$

Specific Gravity: 0.81

Boiling Point: 175 to 325 ^{o}C

Flash Point: > 38 ^{o}C

JP-8 is miscible with absolute alcohol, ethers, chloroform, carbon disulfide, and carbon tetrachloride. It more effectively resists gunfire crash-induced fuel fires and explosions compared to other fuels, has more BTU's per gallon, and a lower vapor pressure. As a result of these properties, aircraft range is increased and evaporative fuel losses are decreased. On the negative side, JP-8 has slightly degraded capabilities in ground starting and altitude relight for jet aircraft due to its lower volatility.

Although JP-8 has numerous advantages over JP-4, the fuel which it is replacing, although it is more expensive. JP-8 has ranged from $0.015/gal to $0.045/gal more expensive to procure than JP-4. JP-8 was derived from commercial Jet A-1 fuel, a low-freezing point kerosene fuel. JP-4 is a mixture of gasoline and kerosene fractions, has a high volatility which gives a high probability of fire in post-crash scenarios of combat aircraft, in excess of 80%. JP-8 differs slightly from commercial Jet A-1 fuel in that it contains a fuel system icing inhibitor and a corrosion/lubricity improver as additives. Table 1 shows some of the major differences between these two fuel types.

Parameter	JP-4	JP-8
Density (kg/m^3)	751 - 802	775 - 840
Normal Average (lb/gal)	6.34	6.71
Distillation Range, ^oF	50 - 500	300-500
Flash-point, ^oF minimum	N/A	100
Reid vapor pressure, psi at 100^oF	2.0 - 3.0	N/A
Aromatics, volume %, max.	25	25
Freeze Point, ^oF, max.	-72	-53
Heat of Combustion, BTU/lb, min.	18,400	18,400
Normal Average, BTU/lb	18,710	18,550
Heat of Combustion, BTU/gal,	118,600	124,500

Table 1. Comparison of JP-4 and JP-8 Properties

In summary, JP-8 is expected to provide significant savings over JP-4 through reduced evaporation losses, reduced handling costs, reduced fuel related fires and explosions, reduced aircraft maintenance and downtime costs, and a reduction in combat and peacetime aircraft losses.

3. RESULTS

3.1 Experimental Data on Pool Fires

The laboratory small scale experiment is envisioned to be designed to reasonably approximate a typical shallow pool fire as this is a typical scenario for a flight line fuel fire. Much of the work done to determine the burn rates and heat release rates from fuel fires was carried out by Russian researchers in the 1950's. Their investigation covered hydrocarbon liquid fires ranging in diameter form 3.7×10^{-3} m. to 22.9 m. In general pool fires exhibit differing dominant heat transfer mechanisms depending on the size of the pool. For diameters less than 0.03 m., the flames are laminar and the rate of burning falls with increasing diameter. For large diameters, greater than 1.0 m., the flames are fully turbulent and the burn rate is independent of diameter. In the range, $0.03 < D < 1.0$ m., transitional behavior between laminar and turbulent mechanisms occurs. In small diameter fires conductive heat transfer is the dominant mechanism while in large diameter fires radiation predominates. The governing equations for pool fires are:

$$\dot{m}'' = \dot{m}''_{\infty} \left(1 - e^{-k\beta D}\right) \qquad (1)$$

$$\dot{q} = \Delta h_c \cdot \dot{m}'' \cdot A \qquad (2)$$

where:

$\dot{m}''$ = burn rate, $Kg/m^2 \cdot s$
$\dot{m}''_{\infty}$ = burn rate, infinite pool, $Kg/m^2 \cdot s$
D = diameter, m
$k\beta$ = extinction-absorption coefficient of the flame
$\dot{q}$ = heat release rate, MJ/s
Δh_c = combustion energy, MJ/Kg
A = pool area, m^2

The variation of burning rates of pool fires with pool diameter is shown in Figures 1. and 2. using cylindrical pans to simulate the pool geometry. In Figure 1. burn velocity and the ratio of flame height to pan diameter are plotted for a range of fuels for pool diameters from 0.37 cm to 22.9 m. The lower set of curves gives burning velocity in mm/min as a function of pan diameter while the upper set gives the flame height to pan diameter ratio. The diagonal lines on the lower curve are constant Reynolds numbers based on pan diameter. The flame geometry of a pool fire is such that the flame diameter is a function of the spill size and the rate of burning and the flame height is directly related to the flame diameter and type of fuel, the latter having a characteristic burn rate.

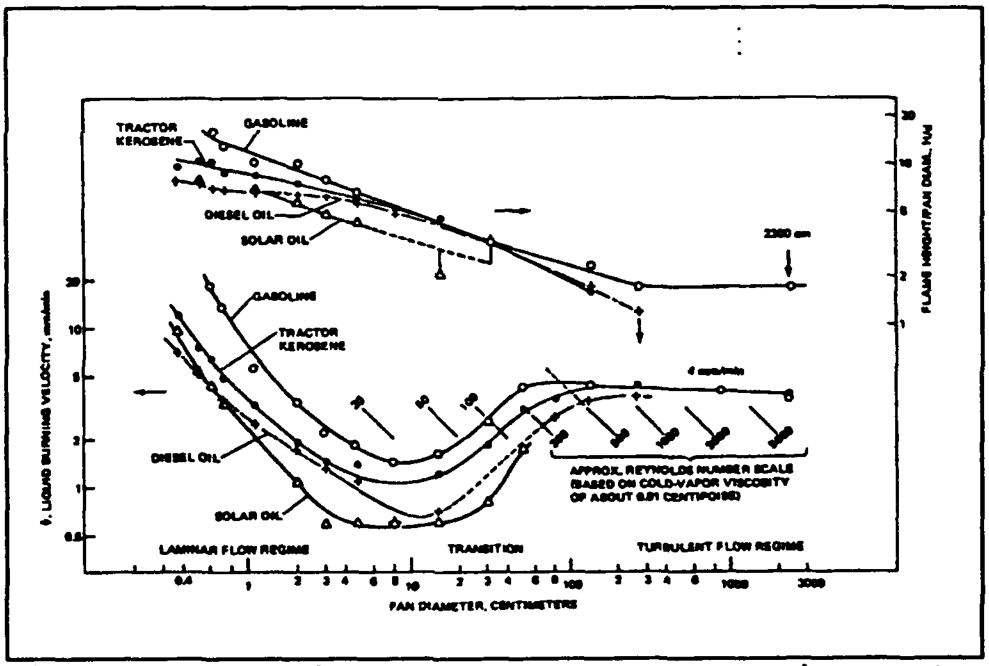

Figure 1. Burning Rates and Flame Heights for Hydrocarbon Fuel Fires

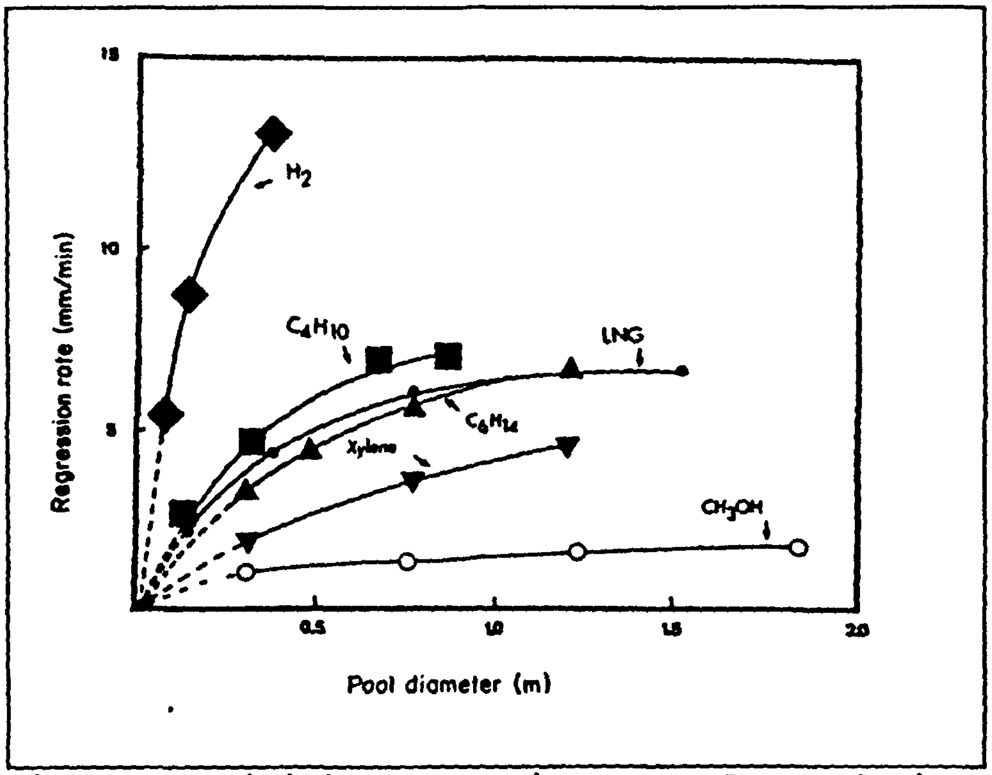

Figure 2. Limiting Regression Rates for Pool Fires

3.2 Scaling of a Pool Fire Experiment

The following physical parameters for JP-4 and kerosene were utilized in preliminary studies of scaled pool fires because similar data for JP-8 has not yet been developed.

	Kerosene	*JP-4*
ρ, kg/m^3	820.0	760.0
Δh_c, MJ/Kg	43.2	43.5
$\dot{m}_\infty$, $Kg/m^2 \cdot s$	0.039	0.051
$k\beta$, m^{-1}	3.5	3.6

For the purposes of creating a lab scale experiment, two pool trays were fabricated to determine a suitable scale JP-8 fire which would adequately simulate a large scale fire and which could be readily handled in a laboratory. The trays were 15 x 15 cm and 30 x 30 cm in size, approximating a laminar fire and a transition fire respectively. The scale of the fires was observed and the burn rate was determined both analytically and experimentally.

As a consequence of conducting the test burns the basic size of a laboratory scale fire were set at a 15 x 15 cm tray. The 30 x 30 cm tray produced a fire size and energy output which were greater than what could be reasonably handled in a laboratory setting. One difficulty is that the equivalent diameter of this tray size places it in a laminar range in terms of flame behavior and combustion activity. However it is believed that in terms of the CT aspects the issue of laminar versus turbulent convection is a second order effect which does not have appreciable effect on the experiment.

The selection of a suitable sized pan to simulate a pool fire requires that the physical dimensions, flows, temperatures, and pressures be scaled by a process know as Dimensional Analysis using Buckingham's Theorem. The strategy is to select the dimensionless groups, such as the Reynolds and Prandtl numbers, which must be preserved in order to have a suitably scaled model. The number of dimensionless groups which should be preserved in order for the model to have the same response as the real flightline fire is quite large. Therefore two methods involving dimensionless groups have evolved in the study of fire dynamics in order to simplify the modeling process: Froude modeling and pressure modeling.

Froude modeling is suitable where viscous forces are relatively unimportant and velocities are scaled with the square root of the principal dimension. In Froude modelling the geometry of the system must be preserved. The Froude number is expressed as follows:

$$\text{Froude Number } (Fr) = \frac{u_\infty^2 \rho}{l \, g \, \Delta\rho}$$

where: u_∞ = maximum velocity
ρ = density
l = flame height
g = acceleration due to gravity
$\Delta\rho$ = density change

The Froude number has a physical interpretation as the ratio of:

$$\frac{\text{inertia forces}}{\text{viscous forces}}$$

Interestingly there are correlations which give the flame height of the fire as a function of thermal output:

$$l = 0.23\, \dot{Q}_c^{2/5} - 1.02D$$

where: $\dot{Q}_c^{2/5}$ = rate of heat release
D = fire diameter

The rate of heat release may be calculated as follows:

$$\dot{Q}_c = \dot{m}'' \cdot \Delta H_c \cdot A_t$$

where: $\dot{m}''$ = mass loss per unit area
ΔH_c = energy output per unit mass
A_f = fire area

Pressure modeling handles both laminar and turbulent flow and preserves the Grashof number, defined as:

$$\text{Grashof Number } (Gr) = \frac{g}{\mu^2} \left(\frac{\rho}{\Delta \rho}\right) \rho^2 l^3$$

where: g = acceleration due to gravity
μ = dynamic viscosity
ρ = density
$\Delta\rho$ = density change
l = flame height

Physically the Grashof number may be described as the ratio of:

$$\frac{\text{buoyancy forces x inertiaforces}}{(\text{viscous forces})^2}$$

Although there are advantages to either modeling method, the pressure method requires that the pressure be varied to maintain similitude between physical reality and the laboratory model. Thus a scaling of an object 1 m. high to a 0.1 m. experimental scale would require a pressure scaling from 1 atm to 31.6 atm. This would be highly impractical for the models envisioned here. Consequently since it can be assumed that viscous forces are not important in the pool fire scenario, Froude modeling would suffice for the modeling of the pool fire. The calculation of the modeling parameters utilizes the following equation set:

$$\dot{Q}_c = \dot{m}'' \, \Delta H_c \, A_f$$

$$l = 0.23 \, \dot{Q}_c^{2/5} - 1.02 \, D$$

$$u_o = \dot{Q}_c^{1/5} \, k \left(\frac{z}{\dot{Q}_c^{2/5}} \right)$$

$$\frac{2 \, g \, \Delta T_o}{T_o} = \left(\frac{k}{c} \right)^2 \left(\frac{z}{\dot{Q}_c^{2/5}} \right)^{2\eta - 1}$$

where: $\dot{Q}_c$ = *thermal output, Kw*
$\dot{m}''$ = *surface burn rate,* $Kg/m^2 \cdot s$
ΔH_c = *thermalcapacity, MJ/Kg*
A_f = *Fire Area,* m^2
u_o = *Flame Velocity, m/s*
k, c, η = *Constants*
g = $9.8 \; m/s^2$
z = *Flame Height at Centerline of Fire, m*
T_o = *Ambient Temperature,* $20^\circ C$
ΔT_o = *Temperature Rise of Flame,* $^\circ K$

Using the pool fire modeling technique described above, the NMERI full scale burn will be a 150 ft^2 which provides the following predicted parameters, using JP-4:

Fire Area, m^2	= 13.94
Equivalent Diameter, m	= 4.21
Mass burn rate/area, Kg/m^2-s	= 0.051
Heat Release Rate, KJ/s	= 30,925
Flame Height, m	= 10.1
Flame Centerline velocity, m/s	= 21.51
Centerline Temperature, ^oC	= 873.5
Froude Number	= 4.67

4. CONCLUSIONS

The apparatus which is being designed to establish the combustion toxicity of the interaction of JP-8 and the candidate Halon replacement agents must be able to adequately portray a realistic fire scenario by producing a concentration of fumes and particulates which is reasonably close to the real fire. As a consequence of this scaling problem, a number of important issues need to be resolve to adequately design the CT apparatus for these studies.

The first issue is the collection of large scale experimental data and the design of a laboratory scale experiment to mimic the large scale results. To accomplish this, a full scale fire scenario is being created by the New Mexico Engineering Research Institute (NMERI). The fire will be a combination of a running fuel fire and a 150 ft^2 pool fire. This constitutes a very likely flight line fire scenario. Data will be collected from this fire by the Midwest Research Institute. The critical data will be to determine the variation of CO and particulates at a distance from the fire which is a likely fire fighting distance. The laboratory scale fire for CT testing can then be created to mimic the conditions found in the large scale fire. The question then remains as to whether the exact conditions found in the large scale fire should be replicated or whether the concentrations should be increased or decreased because animal threshold effects for lethality and incapacitation differ from human effects by significant amounts for many compounds.

A second issue is whether lethality or incapacitation should be used as the measure of CT effects. Each product of combustion will have a significant difference in concentration for lethality versus incapacitation. The use of incapacitation as a measure of CT effects runs parallel with general USAF desires to assess mission capability. Unfortunately incapacitation experiments are much more involved to execute because animals may have to be trained in one or more behavioral patterns, the degradation of which is a measure of incapacitation. This involves a significant amount of additional time and expense to ready and execute the experiment. The potential use of cage behavior as a measure of incapacitation would significantly reduce the preparation time. One final point is that the degradation of behavior is a fairly subjective measure of performance while lethality is a very straightforward measure of effect. It can be argued that the relationship between lethality and incapacitation is known for some of the major combustion constituents such as CO and HCN. Thus it may be possible to forecast the overall concentration of combustion atmosphere at which incapacitation would occur. Another possibility is to design the experiment with enough flexibility to accept either incapacitation or lethality studies.

A third issue is the burn time and fire suppressant injection timing of the CT experiment. Preliminary rudimentary experiments with JP-8 indicate that it will be difficult to obtain burn times in excess of 10 minutes. Thus the exposure time of the animals will be limited to approximately this amount of time or less if one considers the need to inject the fire suppressant and generate the new combustion atmosphere which results. Another possibility is to create an experimental scenario which exposes the animal chamber to a sequence of clean air, JP-8 combustion atmosphere, JP-8/fire suppressant atmosphere, and finally clean air. This sequence would reasonably approximate a real world fire.
At the present time it would appear that a 40 minute cycle would be appropriate for the JP-8/HCFC interaction:

0 min	Animals In
0 - 10 minutes	Fresh Air Circulation
10 min	Ignite JP-8
10 - 20 minutes	JP-8 Burn
20 minutes	Inject HCFC
20 - 25 minutes	Fire Suppression/Gas Interaction
25 - 30 minutes	Purge Gases
30 - 40 minutes	Fresh Air Circulation
> 40 minutes	Animals Out

A fourth issue is whether or not a dose response curve can or should be generated for these CT experiments. A nominal dose response curve would involve a fairly simple scenario such as would be the case for the thermal degradation of one of the HCFC's conducted in an NBS or FAA test apparatus. The JP-8/fire suppressant CT experiment does not lend itself very well to generation of a dose response curve because in fact two or more sets of events are occurring. The first event is a JP-8 fire while the second is a JP-8/fire suppressant interaction event. A dose response curve would be a plot of concentration-time (C*t) versus time employing Haber's Rule which hypothesizes the product of concentration and time for a given effect such as lethality is approximately a constant. The question here is what is the product whose concentration is being utilized to generate the curve. Initially it would be the concentration of JP-8 combustion atmosphere and particulates and later it would also include the addition of the products of JP-8/fire suppressant interaction. A carefully qualified C*t relationship could be generated which is specific to the experiment and the combination of fuel and fire suppressant involved.

A number of features of the CT experiment can in fact be forecast ahead of time, prior to the acquisition of large scale fire test experimental data. The animals must receive an adequate supply of oxygen during the course of the experiment to insure that oxygen deprivation is not a cause of lethality. The temperature of the animal chamber must also be maintained to insure that the animals do not perish as a consequence of heat stress.

Lethality should be a result of toxic gases and aerosols alone.

Finally, this research program concludes that CT testing of JP-8/[illegible]C is feasible with the proviso that comparative studies of JP-8 alone, JP-8 with Halon 1211, and JP-8 with the HCFC candidates should be conducted to determine if there are statistically significant differences in toxicological effects among these various groupings. Otherwise the complexity of the experiments would not allow ready analysis and interpretation.

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FINAL REPORT

Statistical Uncertainty of PBPK Model Predictions for Methylene Chloride

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STATISTICAL UNCERTAINTY OF PBPK MODEL PREDICTIONS FOR METHYLENE CHLORIDE

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Abstract. A Monte Carlo study on the reliability of the Physiologically Based Pharmacokinetic (PBPK) model for methylene chloride was conducted. It is noticed that the prediction errors for some of the model output variables could be three times greater than the parameter errors. Also, some of the model output variables were highly correlated. therefore, it is not profitable to just use a particular output as a dose surrogate in the risk assessment of chemical carcinogenesis for methylene chloride. Two recommendations were proposed as a result of the present study.

INTRODUCTION

The development of physiologically based pharmacokinetic (PBPK) model is useful in the study of the time course for the absorption, distribution, metabolism, and elimination of a chemical substrate in a biological system. It offers a promising approach for scaling up animal data to predict kinetic behavior in humans (Himmelstein and Lutz 1979). The dose surrogates predicted by the PBPK model were used as the delivered dose in the risk assessment of chemical carcinogenesis (Anderson 1987). However, the reliability of the predictions of PBPK Models has remained largely undetermined, given that model parameters can only be measured with uncertainty. Only a few recent studies addressed this problem(e.g., Bois et al 1990; Farrar et al 1989; Portier and Kaplan 1989). If the model prediction errors can be understood, and to some degree, controlled, then confidence levels for model predictions can be developed. This information would allow refinement of existing models, and improvement in sampling methods used to estimate parameter values.

Our previous study of parameter error (Lee et al 1990) has adopted a sensitivity analysis approach based on the partial derivatives of model output with respect to individual parameters. Sensitivity techniques assume that measurement errors are small or, if large, do not change the patterns shown by the first order partial derivatives. These assumptions can be relaxed by adopting a Monte Carlo approach which will estimate more realistic prediction errors by accounting for larger measurement errors.

In the present study, both the error propagation in the model predictions and the interdependency of the model output variables were studied by Monte Carlo simulation of the PBPK Model for Methylene chloride. Throughout the study our purpose is to ask questions about the reliability of the PBPK model predictions.

PBPK Model

The model used (Fig. 1) is the same as that of Anderson et al (19897). The tissues are grouped as follows: fat, slowly perfused (muscles and skin), rapidly perfused (central nervous system and viscera, except liver), and metabolizing (liver). The model is mathematical described by a set of Mass-balance differential equations. For methylene chloride, metabolism is assumed to occur only in the liver and the lung by following two different enzymatic pathways, the Mixed Function Oxidases (MFO) and the glutathione S-transferase (GST). The MFO pathway is assumed to be saturable according to the Michaelis-Menten relationship, whereas the GST pathway follows only a first-order kinetic reaction.

The functional equations of the PBPK Model are given as follows:

1. Gas Exchange Compartment

CA1 = (QC * CV + QP * CI)/(QC + (QP * PB))
CX = CA1/PB
CA = CLU/PLU

2. Lung Tissue Compartment

dALU/dt = QC * (CA1 - CA) - dAM1LU/dt - dAM2LU/dt
dAM1LU/dt = A1 * VMAX * CA * (VLU/VL)/(KM + CA)
dAM2LU/dt = A2 * KF * CA * VLU
CLU = ALU/VLU
dAUCLU/dt = CLU

3. Liver Compartment

dAL/dt = QL * (CA - CVL) - dAM1L/dt - dAM2L/dt + KZER
dAM1L/dt = (VMAX * CVL)/(KM + CVL)
dAM2L/dt = KF * CVL * VL
CL = AL/VL
CVL = CL/PL
dAUCL/dt = CL

4. Fat Compartment

dAF/dt = QF * (CA - CVF)
CVF = AF/(VF * PF)
CF = AF/VF

5. Rapidly Perfused Compartment

dAR/dt = QR * (CA - CVR)
CVF = AR/(VR * PR)
CR = AR/VR

6. Slowly Perfused Compartment

dAS/dt = QS * (CA - CVS)
CVS = AS/(VS * PS)
CS = AS/VS

MONTE CARLO SIMULATIONS

The uncertainty analysis in this paper was based on 500 Monte Carlo simulations of the PBPK model for methylene chloride. Not all the model parameters are assumed to be subject o uncertainty. Only the cardiac output (QCC), the alveolar ventilation (QPC), the rapidly perfused (QRC), the slowly perfused(QSC), and the liver(QLC) blood flow rate, the blood/air (PB) and liver/blood (PL) partition coefficients, all the metabolic constants, including KF, KM and VMAX, and the tissue volumes are assumed to be random. The probability distributions for the blood flow rate, the partition coefficients and the metabolic constants are all assumed to be lognormal with the mean as given in Table 1 which was taken from Anderson et al 1987 and the standard deviation to be 10% of the mean value, i.e., the coefficient of variation (C.V.) equals to 0.10. The parameters of tissues volume were assumed to follows a Dirichlet distribution with 0=1451 and 0=1621, respectively, for mouse and human(Farrar et al 1989). Numerical Integration of PBPK Model was conducted with the Gear's Algorithm.

STATISTICAL ANALYSIS

Statistical Analyses of the results utilized the SAS procedures (Barr et al 1976). PROC UNIVARIATE was employed in computing the basic statistic about each model output and also testing whether the probability distribution of each out variable is normal/lognormal. PROC PRINCP was used to calculate the correlation coefficients and their principal components wrong the model output variables including AM1L, AM1P, AM2L, AM2P, AUCL, and AUCLU.

RESULT

From Table 2, it seems that the coefficients of variation (C.V.) for the Model outputs do not vary over time. Yet the C.V.'s for the model outputs range from 5% to 30% depending on the output variable. Remember that the C.V.'s for the model parameters were set uniformly equal to 10%. This indicates that prediction error could be 3 times greater than parameter error. Among the output variable, AM1P, AM2L and AM2P has the highest uncertainty.

From Tables 3-5, it is seen that the output variables AM1P and AM2P were the most highly correlated with correlation coefficients .74, .82 and .71 for mouse, rat and human, respectively. the output variables AM1L and AM2L were highly correlated for mouse and human, but not for rat.

DISCUSSION

From the present study it is noticed that the model prediction errors in some output variables could be three times greater than the parameter errors. This night reader the model predictions very unreliable, and even worse totally useless. Therefore, it is imperative to find a better sampling design in estimating the parameter values to minimize the parameter errors. Also, the output variables are not statistically independent. Instead, they are highly correlated. Therefore, it is not impeccable to use just a particular output variable as a dose surrogate used in the risk assessment of methylene chloride.

It seems appropriate to propose two recommendations arising from the present study: (i) Apply the Monte Carlo technique to identify the importance of the individual model parameter, and then allocate resources to calibrate the identified parameter in order to minimize the parameter errors; (ii) Use the multivariate analysis techniques, e.g. Factor Analysis, to find a proper combination of the principal components, obtained from the correlation matrix resulting from the Monte Carlo simulations on the model output variables, which account for a large proportion of the model prediction errors.

ACKNOWLEDGEMENT

The simulation package, PBPK_SIM, used in the this study were developed by K. S. Crump division, Clement International Corporation. Dr Lee would like to thank Von Rix on getting familiar with the computer. The manuscript was prepared by Jackie Shine.

TABLE 1

KINETIC CONSTANTS AND MODEL PARAMETERS USED IN THE MONTE CARLO SIMULATION OF THE PHYSIOLOGICALLY BASED PHARMACOKINETIC MODEL FOR METHYLENE CHLORIDE

	B6C3F1*	F344 rats*	Human
Weights (Kg)			
Body (BW)	0.0345	0.233	70.0
	Percentage of body weight		
Liver (VLC)	4.0	4.0	3.14
Rapidly perfused (VRC)	5.0	5.0	3.71
Slowly perfused (VSC)	78.0	75.0	2.1
Fat (VFC)	4.0	7.0	23.1
Flows (liters/hr) (Scaled)			
Alveolar ventilation (QPC)	28	15	15
Cardiac Output (QCC)	28	15	15
	Percentage of cardiac output		
Liver (QLC)	0.24	0.24	0.24
Rapidly Perfused (QRC)	0.52	0.52	0.52
Slowly perfused (QSC)	0.19	0.19	0.19
Fat (QFC)	0.05	0.05	0.05
Partition coefficients			
Blood/air (PB)	8.29	19.4	9.7
Liver/blood (PL)	1.71	0.732	1.46
Lung/blood (PLU)	1.71	0.732	1.46
Rapidly perfused/blood (PR)	1.71	0.732	1.46
Slowly perfused/blood (PS)	0.960	0.408	0.82
Fat/blood (PF)	14.5	6.19	12.4
Metabolic constants			
Vmax (mg/hr)	1.054	1.50	118.9
Km (mg/liter)	0.396	0.771	0.580
KF (/hr)	4.017	2.21	0.53
A1	0.416	0.136	0.00143
A2	0.137	0.0558	0.0473

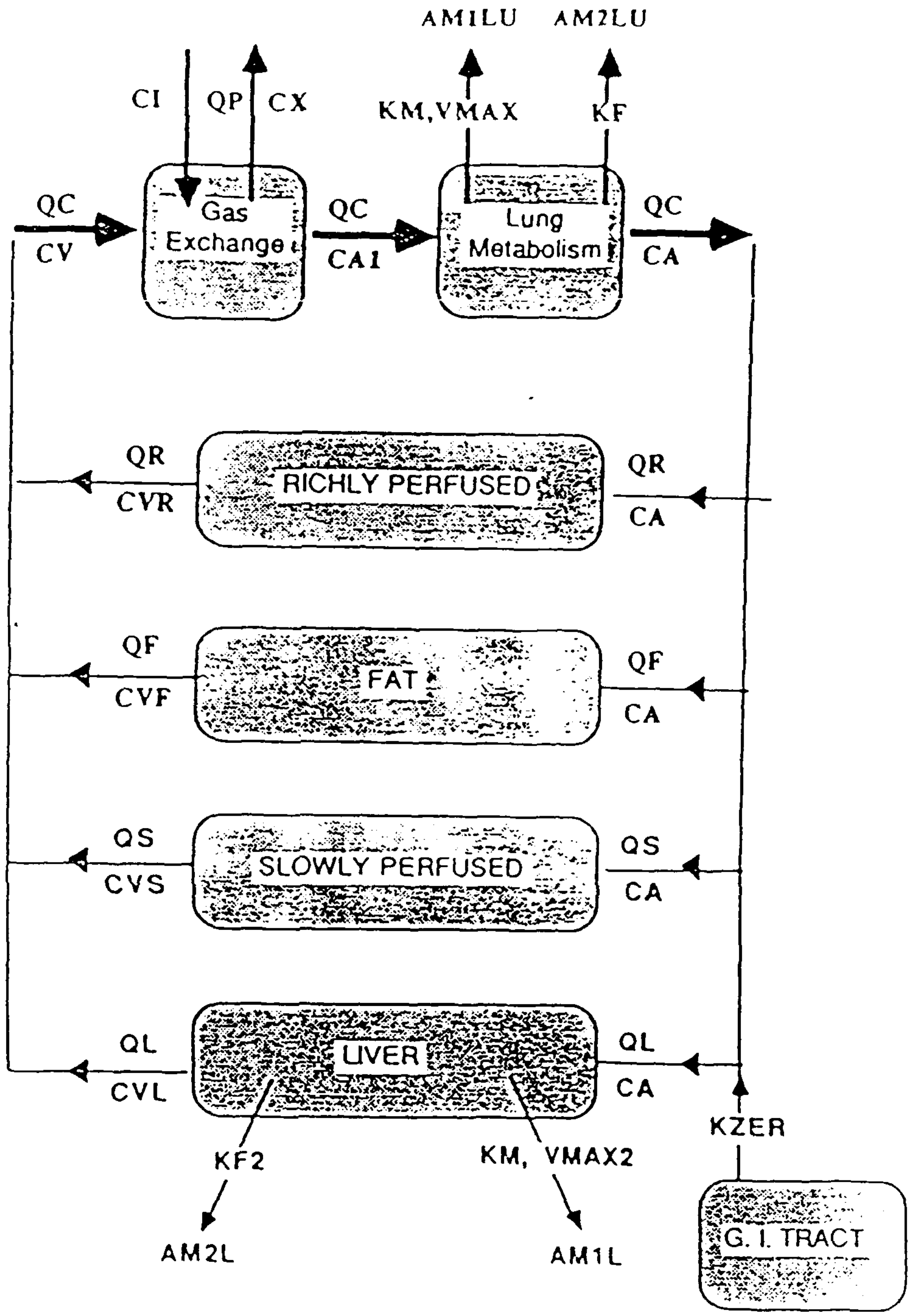

Figure 1. Diagram of Physiologically-Based Pharmacokinetic Model Used for the Methylene Chloride Risk Assessment. Two metabolic pathways are described in both liver and lung, sites in which tumors were found in the rodent bioassay.

TABLE 2

COEFFICIENT OF VARIATION AT DIFFERENT TIME POINTS FOR THE MODEL OUTPUT

COEFFICIENT OF VARIATION (%)

	TIME POINT (HRS)	AM1L	AM2L	AUCL	AM1P	AM2P	AUCLU
Mouse	3	13	25	19	32	29	8
4000ppm	6	12	24	19	31	28	8
	12	9	26	20	28	28	7
Rat	2	8	15	13	29	25	5
1000ppm	4	8	14	12	29	26	4
	12	8	14	12	29	25	3
Human	2	11	28	21	27	28	7
100ppm	4	10	27	22	27	28	7
	12	9	28	21	27	28	7

TABLE 3

CORRELATION COEFFICIENTS AMONG THE MODEL OUTPUTS AT DIFFERENT TIME POINTS FOR MOUSE AT DOSE = 4000 PPM

	TIME POINT (HRS)	AM1L	AM1P	AM2L	AM2P	AUCL	AUCLU
AM1L	3	1.0	.09	.37	-.03	.56	-.001
	6	1.0	.08	.37	-.02	.59	-.07
	12	1.0	.06	.52	.06	.66	.16
AM1P	3		1.0	-.38	.68	-.15	.19
	6		1.0	-.37	.69	-.17	.14
	12		1.0	-.27	.74	-.04	.08
AM2L	3			1.0	.27	.56	.12
	6			1.0	.28	.52	.11
	12			1.0	.28	.64	.26
AM2P	3				1.0	.07	.31
	6				1.0	.005	.28
	12				1.0	.08	.29
AUCL	3					1.0	.15
	6					1.0	.15
	12					1.0	.31
AUCLU	3						1.0
	6						1.0
	12						1.0

TABLE 4

CORRELATION COEFFICIENTS AMONG THE MODEL OUTPUTS AT DIFFERENT TIME POINTS FOR RAT AT DOSE = 1000 PPM

	TIME POINT (HRS)	AM1L	AM1P	AM2L	AM2P	AUCL	AUCLU
AM1L	2	1.0	.23	-.04	-.06	-.09	-.07
	4	1.0	.29	-.03	.01	-.14	-.23
	12	1.0	.25	-.09	-.07	-.11	-.03
AM1P	2		1.0	-.44	.80	-.03	-.03
	4		1.0	-.34	.82	-.06	-.004
	12		1.0	-.44	.81	-.09	.001
AM2L	2			1.0	.08	.09	.27
	4			1.0	.16	.04	.09
	12			1.0	.06	.05	-.03
AM2P	2				1.0	.04	.12
	4				1.0	-.03	.09
	12				1.0	-.05	.06
AUCL	2					1.0	.42
	4					1.0	.35
	12					1.0	.25
AUCLU	2						1.0
	4						1.0
	12						1.0

TABLE 5

CORRELATION COEFFICIENTS AMONG THE MODEL OUTPUTS AT DIFFERENT TIME POINTS FOR HUMAN AT DOSE = 100 PPM

	TIME POINT (HRS)	AM1L	AM1P	AM2L	AM2P	AUCL	AUCLU
AM1L	2	1.0	.08	.56	.10	.70	.33
	4	1.0	.09	.48	.05	.67	.27
	12	1.0	.03	.51	.05	.68	.22
AM1P	2		1.0	-.23	.71	.01	.04
	4		1.0	-.27	.69	-.03	.02
	12		1.0	-.30	.70	-.07	.03
AM2L	2			1.0	.35	.63	.33
	4			1.0	.32	.63	.28
	12			1.0	.32	.67	.31
AM2P	2				1.0	.12	.23
	4				1.0	.09	.20
	12				1.0	.14	.25
AUCL	2					1.0	.47
	4					1.0	.41
	12					1.0	.37
AUCLU	2						1.0
	4						1.0
	12						1.0

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A One-Degree-of-Freedom Master-Slave Device Based on a Shape Memory Alloy Actuator

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Abstract

A one-degree-of-freedom master-slave device was built using shape memory alloy (SMA) wires for actuation. A bang-bang control scheme was used for both the position control of the slave and the force control of the master. A prototype was built to demonstrate stability and other aspects of the design concept.

Air cooling of the SMA wires proved inadequate, causing the slave to lag behind the master when the slave wires were being returned to extended length. An experiment was performed to determine the cooling time constants for the SMA wire in air, water, and a 50/50 mixture of water and glycerol.

It was necessary to limit the driving voltage of the SMA wires of both master and slave to prevent over-heating. Unfortuntely, the voltage limitation does not allow minimum contraction time. Therefore, a test was performed to examine the feasibility of an infrared phototransistor for temperature detection.

Introduction

The shape memory effect (SME) exhibited by certain alloys has been known for a number of years. Unfortunately, a host of problems hindered most early applications of SME. The problems include cost, slow response, and difficult characterization of properties and behavior. A new wave of activity was initiated with the discovery of the shape memory effect in an alloy of titanium-nickle, by Buehler, et.al. (1963) [1]. The new alloy was named "nitinol," an acronym of Nickle, Titanium and NOL, for U.S. Naval Ordinance Laboratory. Although an improvement over other SMA's, nitinol also proved problematic, without many practical applications. In 1985, the Toki Corporation, Tokyo, Japan, announced an improved, but proprietary version of nitinol under the trade name "BioMetal[2]." BioMetal has an improved grain structure which results in longer fatigue life and a 200 percent reduction in recovery force. The improvement in fatigue characteristics is significant not only in terms of life, but also in terms of the allowed percent contraction of the wire. BioMetal is available only in 150 micron wire which appears to be an approximately optimum diameter with regard to adequate force levels and cooling.

As is characteristic of SMA's, Biometal is capable of delivering large forces with small actuator size. A solenoid, for example, capable of delivering a comparable force, would be quite large and heavy. The favorable force-to-weight ratio of BioMetal makes it a possible candidate for use as an actuator. The goal of the present work is to explore the feasibility of incorporating BioMetal in a bilateral, force-reflecting, master-slave device.

Development of a Prototype

A brief review of the properties of BioMetal did not reveal any inherent limitations that would prevent its use as an actuator. With the small diameter of only 150 microns, and by avoiding complete austenitic transition, it was thought that air cooling might allow sufficiently rapid return to uncontracted length. If necessary, it would be possible to introduce liquid cooling. Inventiveness appeared to be to main requirement for the solution of most problems. Therefore, it was decided to plunge ahead with the development of a crude prototype. The prototype would be sufficiently flexible to allow for an evolutionary development.

First, it was necessary to develop a concept for accomplishing the master-slave function. The basic operation requires position control of the slave and force control of the master. There was also the design and selection of hardware from the standpoint of both electrical and mechanical components. It was decided that a single degree of freedom prototype would be built to test various aspects of the concept. The effort needed for a compact, knucklesized design did not seem warranted until the basic operational feasibility was established. Thus, the prototype was built without spatial constraints.

The basic mechanical configuration is shown in Fig. 1. Both master and slave links consist of simple levers made of balsa wood. Photographs of the original device are shown in Fig. 2. The displacement transducers labeled in Fig. 1 consisted of an infrared transister fixed in one end of a tube and an infrared LED that was free to move in the other end. The motion of the LED was caused by the displacement of the master or slave. As expected, the transducers were highly nonlinear. However, the nonlinearities had enough similiarity to provide a reasonable correspondence between the motions of the master and slave.

The circuit for the position control of the slave is shown in Fig. 3. The bridge is balanced with both master and slave in the same angular position. Any subsequent motion of the master causes the bridge to be unbalanced causing a correction in the slave position by either turning on or turning off the slave SMA wires. The rubber band on the slave in Fig. 1 provides a force of roughly 50 grams, which is sufficient to stretch the SMA wires when cooled. Due to the large initial stretch of the rubber band, the force remains fairly constant over the range of motion of the slave. The power transistor which drives the SMA wires is theoretically on or off due to the switching of the op amp comparator. It was demonstrated that the on/off or bang-bang

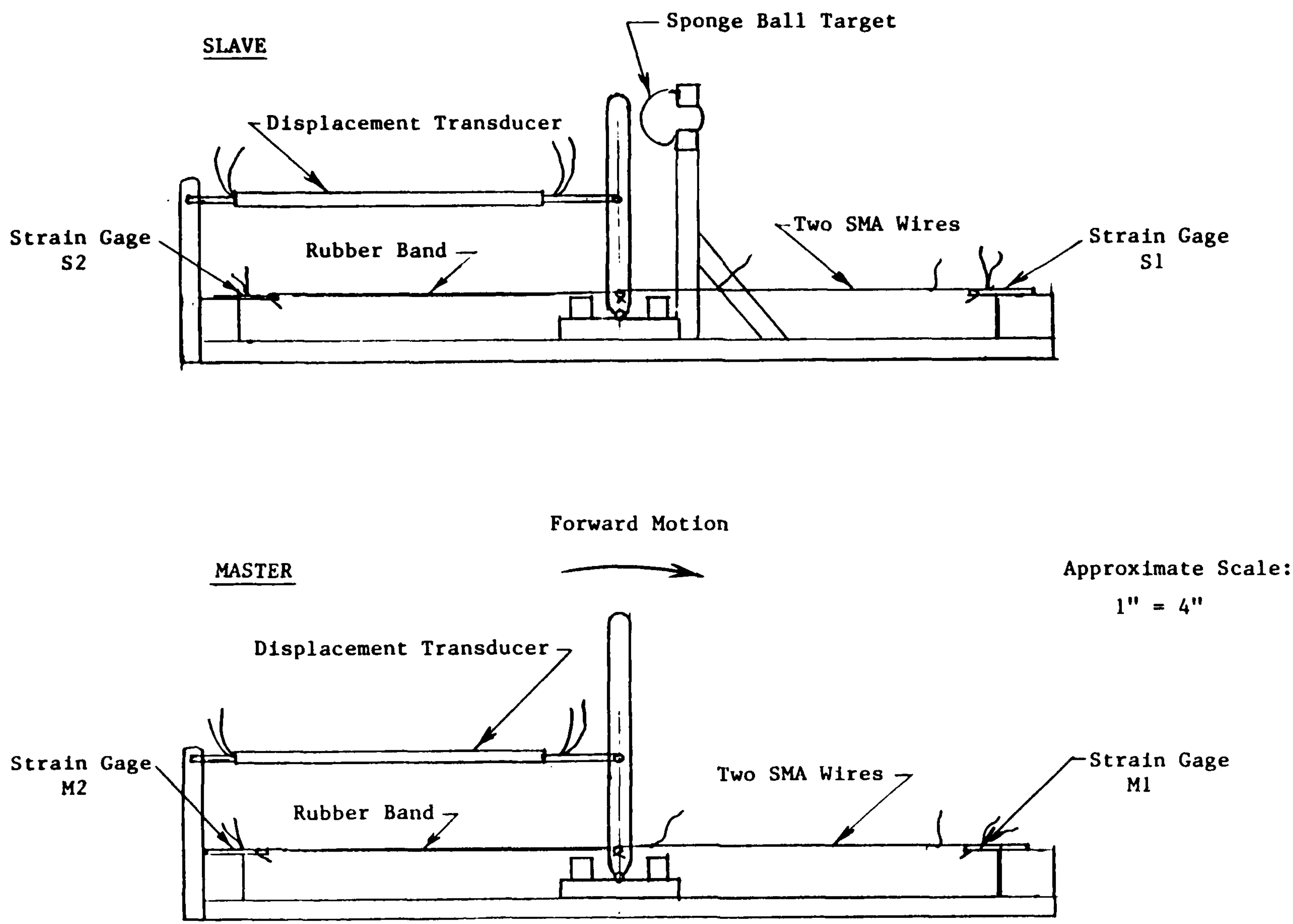

Fig.1. Schematic of Basic Mechanical Configuration for Master-Slave Device

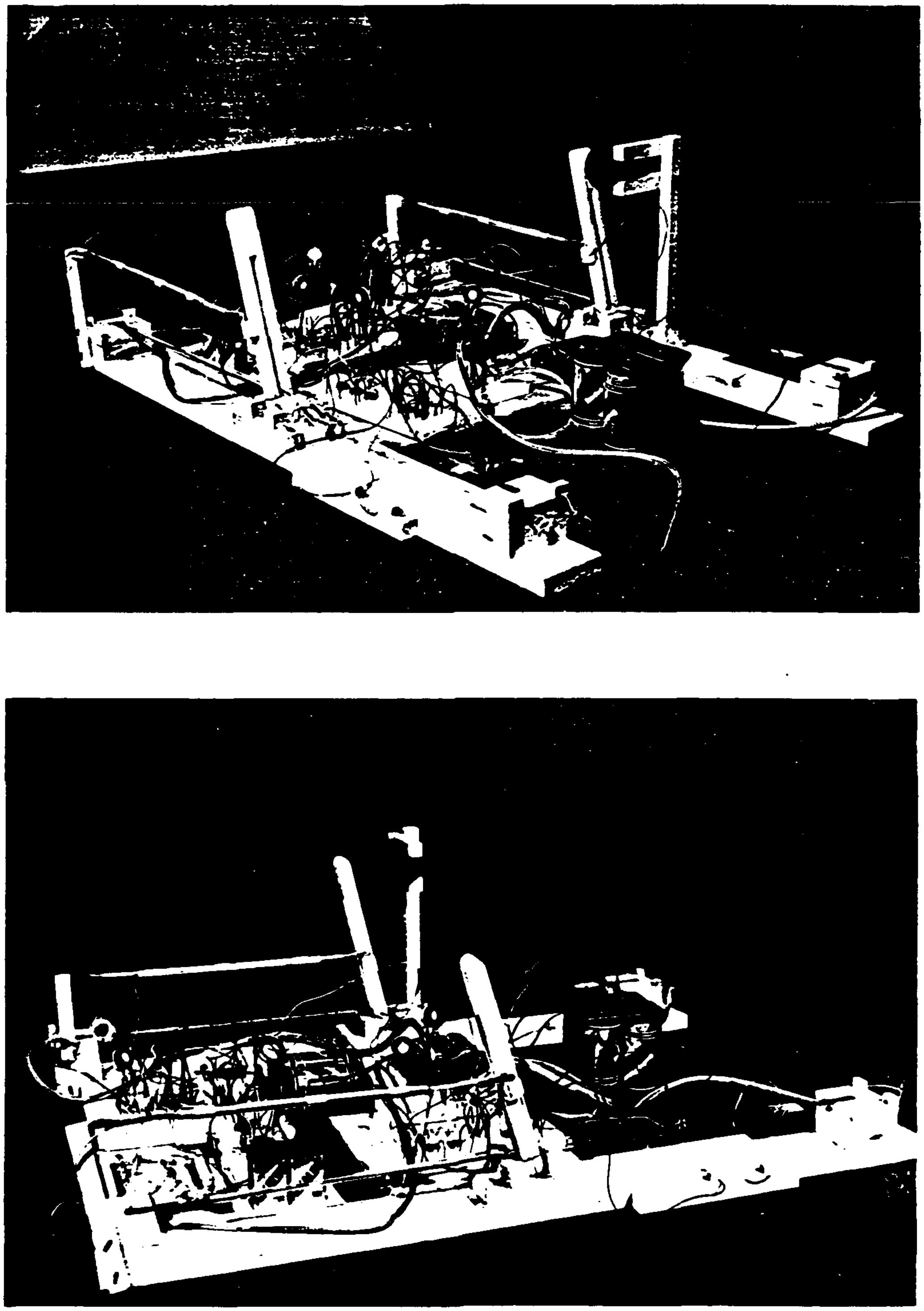

Fig. 2. Photographs of Master-Slave Prototype

POSITION CONTROL

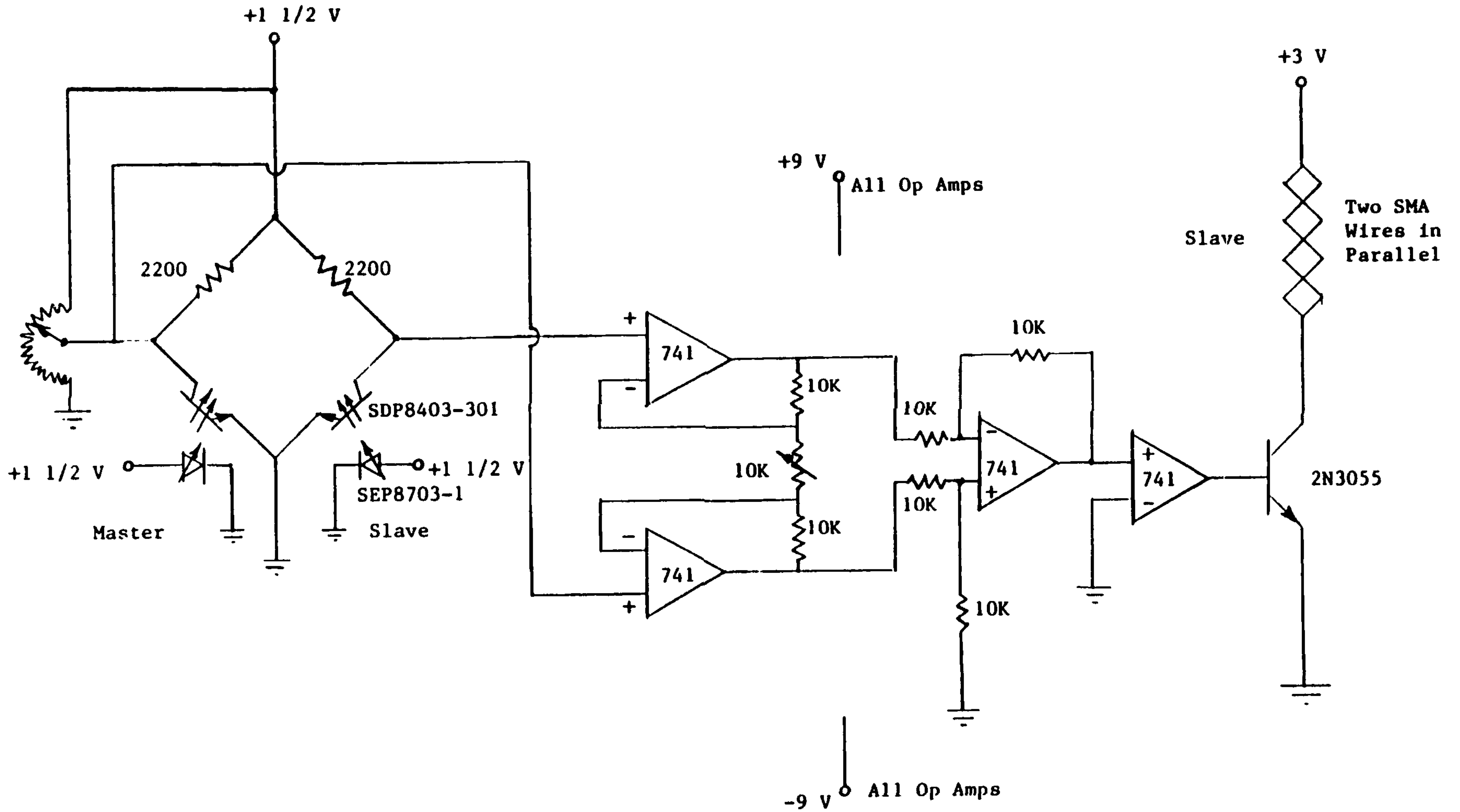

Fig. 3. Circuit for Slave Position Control

control provided stable response. Equilibrium positions were achieved with no detectable limit cycling.

The circuit for the force control of the master is shown in Fig. 4. The four strain gages in Fig. 1 constitute the four legs of the bridge in Fig. 4. Each gage has the same label in both figures. The procedure to balance the bridge is as follows: The SMA wires on both master and slave are adjusted so that neither of the levers is in contact with the stops. Also, neither lever is subject to any external force, i.e., the slave is not touching the target. The combined force in the two SMA wires is exactly equal to the force in the rubber band in both the slave and master. The 100K ohm potentiometer is then used to balance the bridge.

The operation of the force reflection will now be explained. When an attempt is made to move the master lever, there is an instantaneous change in tension in the SMA wires. For example, if the motion of the master is to the right in Fig. 1, the tension in the SMA wires will be reduced. There will only be a very slight increase in the tension in the rubber band due to the much lower spring constant. Since the change in resistance of the strain gages is proportional to the tension, the bridge becomes unbalanced causing the SMA wires of the master to become activated. The net effect is that only a very slight force is required to move the master. When the slave contacts the target sponge ball, the tension in the slave SMA wires increases, causing the bridge to again be unbalanced. The unbalance increases the tendency for the

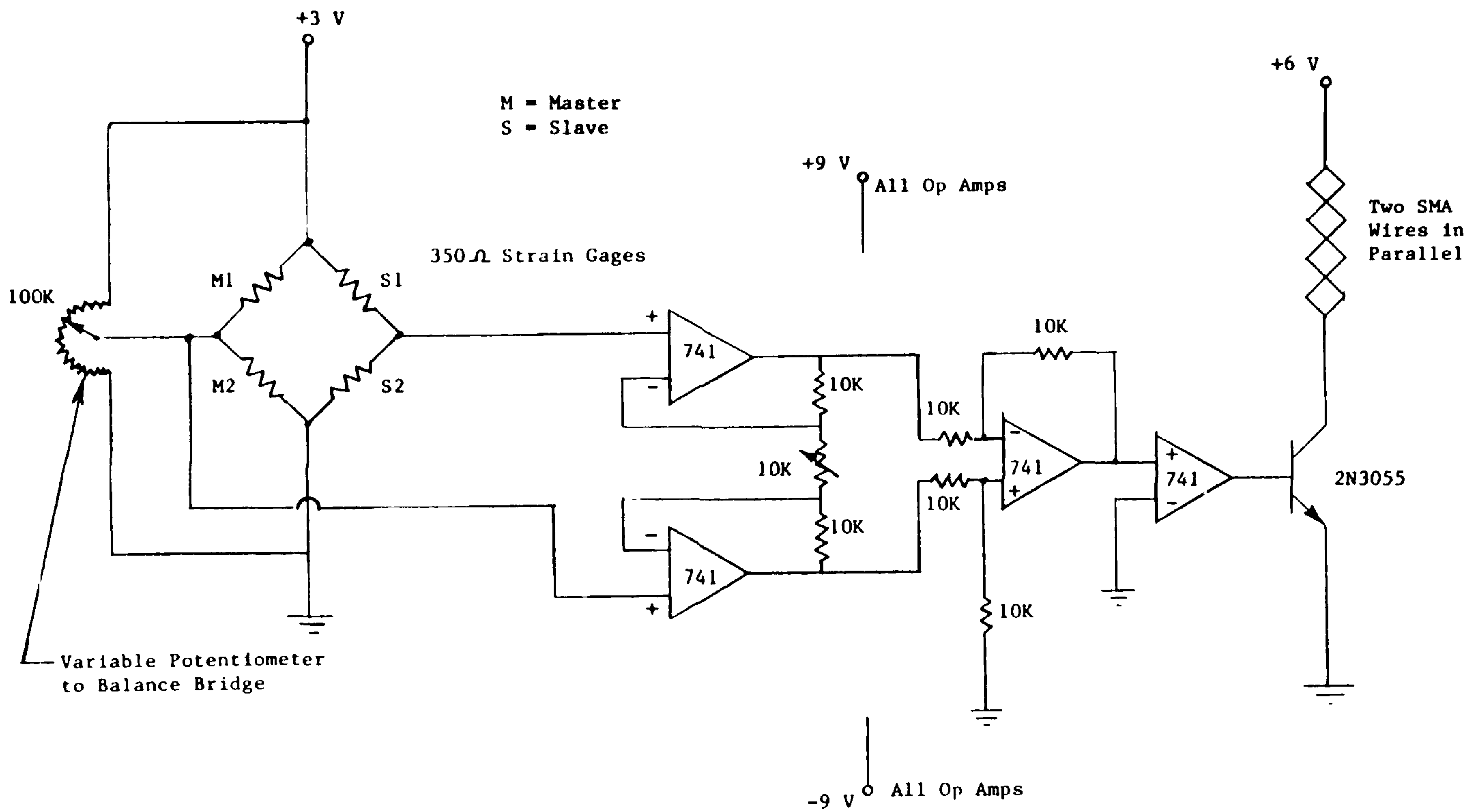

Fig. 4. Force Control Circuit

SMA wires of the master to be off unless the tension in the rubber band of the master is greater than the tension in the SMA wires. The difference in tension is maintained by the force of the human operator. The force felt by the human operator is the same force that the slave exerts on the sponge ball. It is assumed that the force applied by the human operator is at roughly the same location on the master as the sponge ball contact on the slave.

Cooling the SMA wires

A rapid return motion of the master caused the slave to follow with a discernable lag. The lag occured because the natural convection of the slave wires in air provided an inadequate rate of heat transfer. It was anticipated that this problem might exist but would have been difficult to predict due to inadequate knowledge of the response times for incomplete transitions of the SMA. It was estimated that the cooling rate needed to be at least ten times faster. It would be difficult to obtain the necessary increase in the rate of cooling without introducing a liquid coolant. Since water is one of the best coolants, and since BioMetal is highly noncorrosive, it was decided to perform some tests to compare the rate of cooling in water to the rate of cooling in air.

Figure 5 shows the test set up. A four inch length of SMA wire was held in tension by a rubber band. A voltage was applied to the SMA wire producing a .1 inch contraction. Just before opening the switch, a data aquisition program was started on the PC. The return motion to uncontracted length by the SMA wire was detected by the LVDT, and fed to the PC through an A/D converter. Since the motion is essentially a first order response, the time constants serve as the basis for comparison.

Data were obtained for three cases of cooling. The SMA wire was cooled in air, in water, and in a 50/50 mixture of glycerol and water. The results are shown in parts a,b and c of Fig. 6. The numbers on the vertical axes of the graphs reflect the eight-bit resolution of the A/D converter. The time constant in air based on these data is .62 seconds. For water, the time constant was .04, and for the 50/50 water-glycerol mixture, the time constant was .06 seconds.

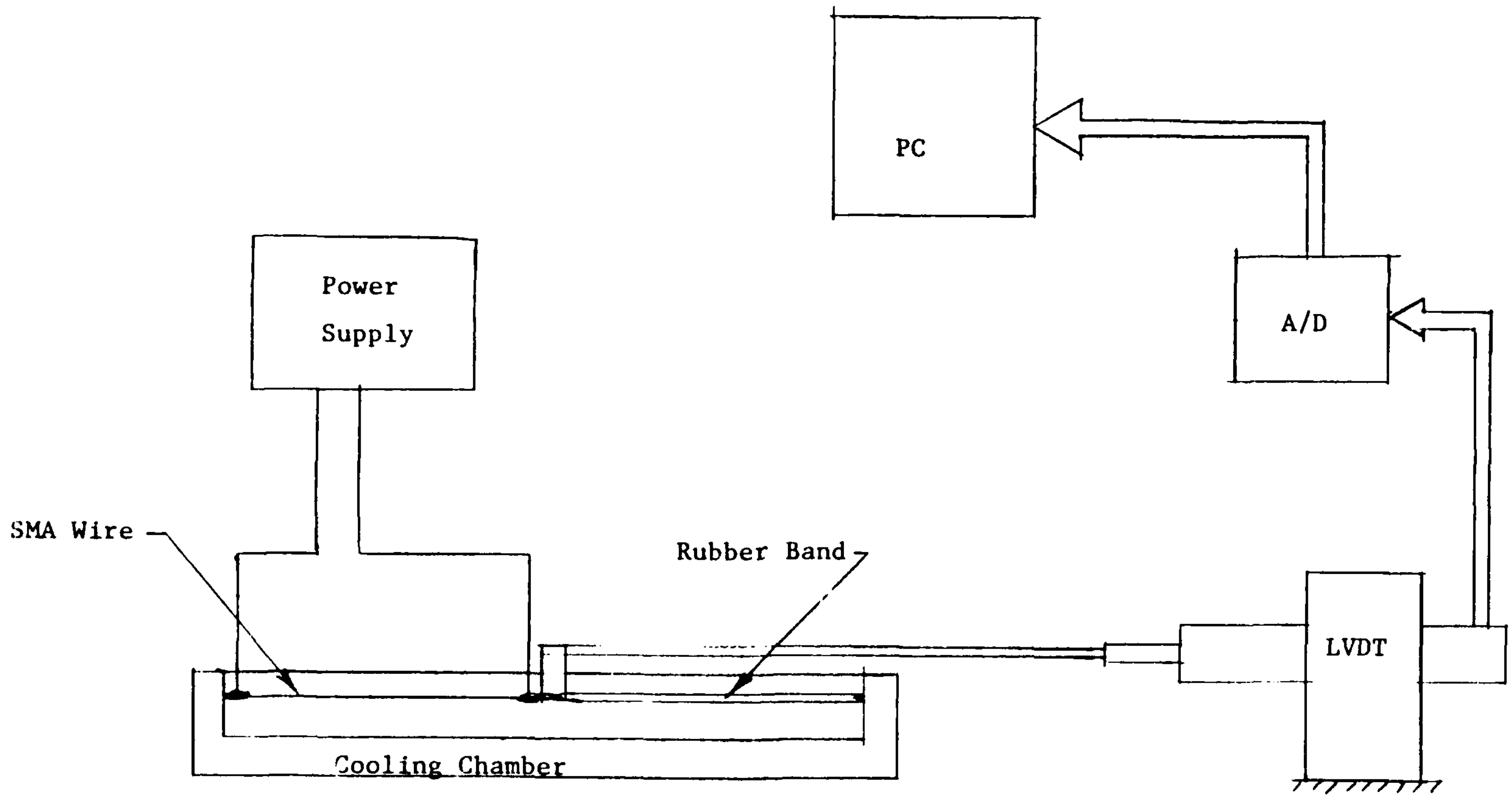

Fig. 5. Test Setup to Obtain SMA Response Due to Cooling

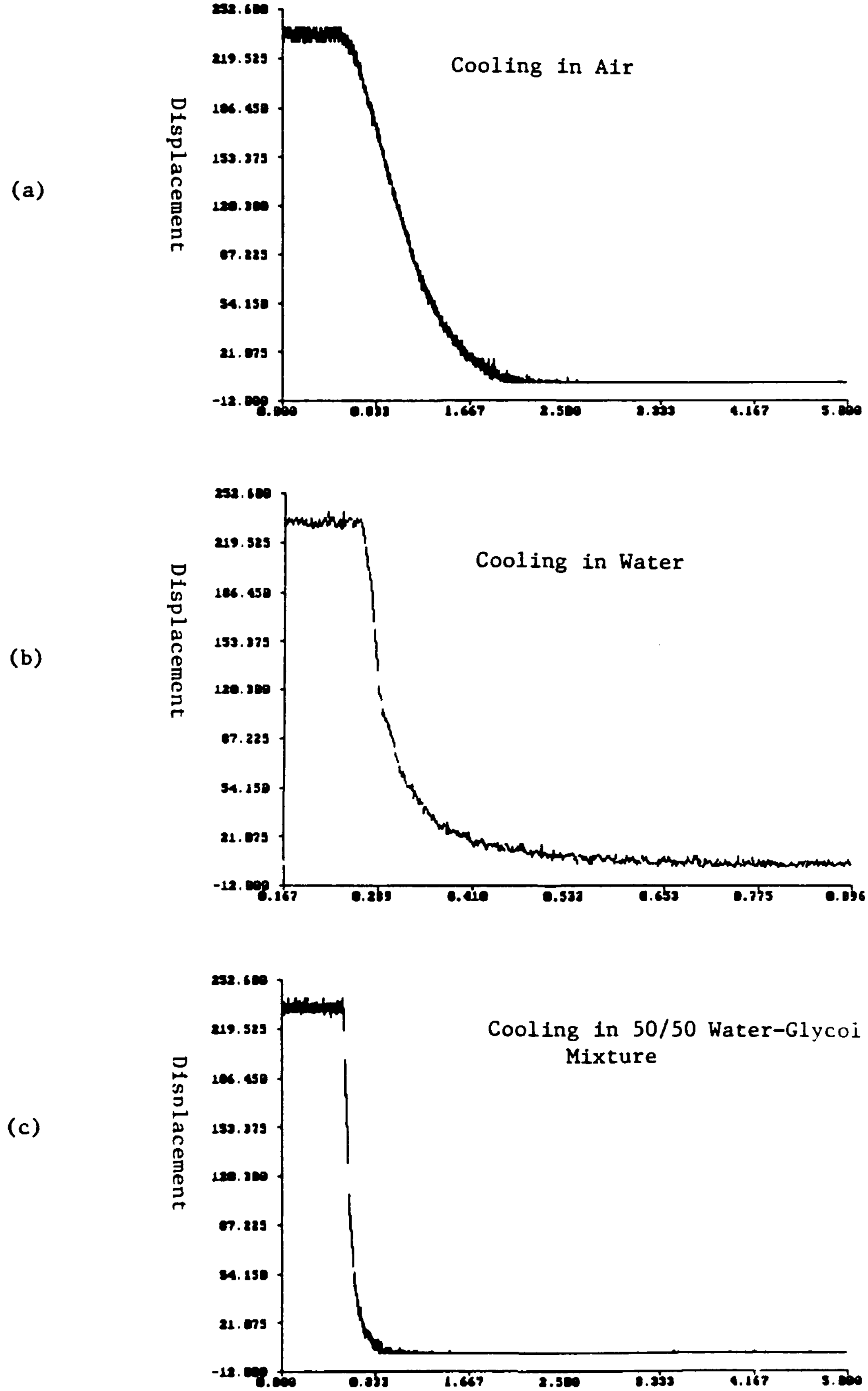

Fig. 6. Data from Cooling Tests (a) Air (b) Water
(c) 50/50 Water and Glycerol

Temperature Sensing by Infrared Detection

The contraction time for the SMA wire can be optimized by using high voltages to heat the wires. However, to avoid damage to the wire, the voltage must be immediately reduced to zero if the temperature of the wire exceeds a safe level. The sensing technique used must be capable of fast response and also must not interfere with the heating and cooling of the SMA wire. To meet these requirements, the sensing of temperature by infrared detection was investigated.

An experiment was performed using an infrared phototransistor from Radio Shack, part number SDP8403-301.[3] The device costs less than one dollar, and unlike many devices for infrared detection, has the compact size needed for use in a compact actuator design. Unfortunately, the spectral response of the phototransistor was unknown, as well as threshold detection levels. Since only a small effort was required to build the circuity, it was decided to test the responsiveness of the phototransistor for detecting infrared radiation from the SMA wire.

Figure 7 shows the test arrangement. The infrared transistor served as a variable resistor in a bridge circuit as indicated in Fig. 7. The output of the bridge was fed into a high-gain amplifier. The gain was set as high as possible without picking up background noise by the unshielded leads. The gain was estimated to be between

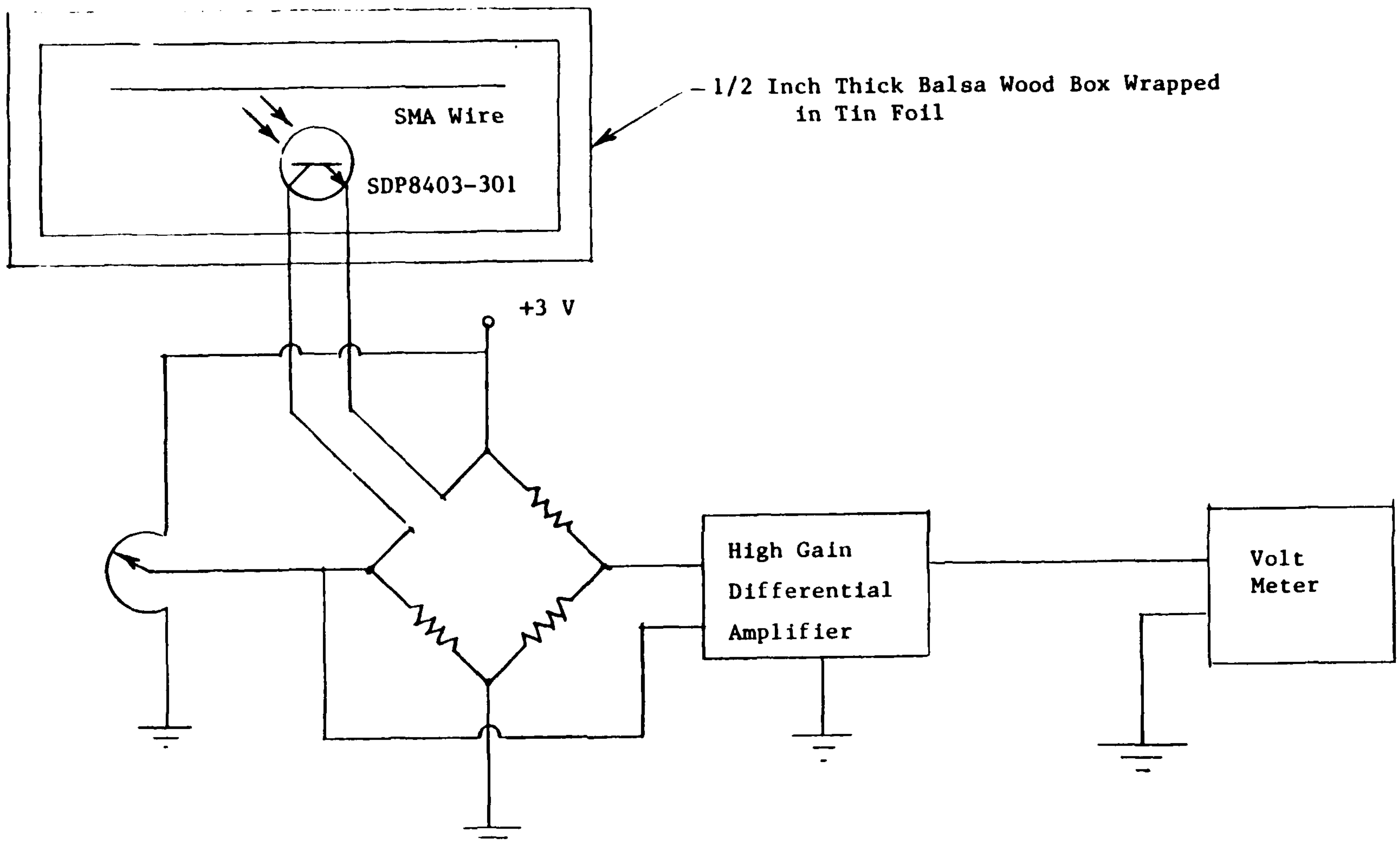

Fig. 7. Test Setup for Infrared Thermal Detection

10,000 and 100,000. The SMA wire was placed as close as possible to the P-N junction of the infrared transistor by drilling a small hole in the plastic lens of the transistor and running the wire through. The transistor and the SMA wire were mounted inside a box made of 1/2 inch thick balsa wood. To shield all ambient radiation, the box was wrapped with several layers of tin foil. Before applying the tin foil, the transistor inside the closed box was found to be extremely sensitive to ambient lighting. For example, with the voltmeter set at .25 volts full-scale, wide swings in voltmeter reading could be produced by waving a hand over the box. With the box closed and wrapped in tin foil, the SMA wire was heated up to and beyond the damaging temperature level. Unfortunately, no detection was evidenced by a movement of the volt meter.

The lack of thermal detection by the infrared transistor may have been due to radiation levels below a threshold, or due to spectral mismatch, or both. The electromagnetic radiation frequency for peak response for the transistor was unknown, as well as the distribution of the frequency spectrum. However, the transistor is commonly used in combination with the Radio Shack infrared emitting diode, SEP8703-1, which has a peak output at 915 nm. Planck's equation for the spectral radiant emittance W_λ, expressed in watts cm^{-2} μm^{-1} at a wavelength λ(μm) from a blackbody at absolute temperature T (Kelvin) is given as [4],

$$W_\lambda = \frac{2\pi hc^2}{\lambda^5}\left(\frac{}{\exp\left(\frac{ch}{\lambda kT}\right) - 1}\right) \tag{1}$$

Where,

h = Planck's Constant in watts·sec^2

c = Velocity of light in m/sec

k = Boltzmann's constant, in watts·sec·K^{-1}

The peak emission wavelength λ_M, is obtained from Wien's displacement law,

$$\lambda_M T = 2898 \ \mu m \cdot K \tag{2}$$

which can be derived from Planck's equation.

The maximum safe temperature for the SMA wire is around 300 C, or 573 K. Substituting this value into Eq. 2 gives a peak emission wavelength of 5 microns. A lead selenide infrared detector[5] from Infrared Industries, Inc., series 4080, having a spectral response from 1 to 4.7 microns, has been acquired but not yet tested. Infrared detectors for longer wavelengths require a built-in cooling system and are therefore, bulky and expensive.

Conclusions

The conceptual feasibilty of a master-slave device, based on a SMA actuator, has been demonstrated. However, the prototype design was simplified by disregarding spatial constraints. One performance weakness of the device was a noticeable lag in the return motion of the slave due to slow cooling of the SMA wire in air. The cooling rate experiments described above show that water cooling provides roughly a 15-fold increase in the cooling rate. The time constant for the return motion in air was .62 seconds, whereas the time constant in pure water was .04 seconds.

The low energy efficiency of BioMetal poses a challenge to the design of a compact actuator capable of delivering useful work. It is an unavoidable requirement to place as much of the SMA as possible into the smallest volume possible. SMA wire diameters must be small to avoid slow response times, even with water cooling. An actuator design must also "work around" the 5 to 6 percent contraction limitation of the SMA wire to provide a useful range of displacement with adequate force levels. In addition to the cooling requirement for dynamic response, low energy efficiency requires that 98 to 99 percent of the energy input be carried away as heat. Therefore, each actuator must have tube to deliver cooling water and another tube to carry away the water when heated. In addition, peripheral heat exchanger equipment is needed to discard the heat. Although feasible, it seems that SMA actuator would have difficulty competing with some other means of actuation, such as hydraulics.

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FINAL REPORT

Simulation of Head/Neck Response to +Gz Impact Acceleration due to Additional Head Mass

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by

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ABSTRACT

This work was to extend research initiated at the Armstrong Laboratory (AL) to investigate the effects of added head mass on the dynamics of the neck and head during +Gz impact acceleration. The original effort was conducted to provide an analytical modeling foundation for a better understanding of the dynamic response of the head/neck system when encumbered with additional masses such as helmet, night vision goggles, mask or other performance enhancing or protective equipment. The summer effort include a literature search and the validating of a modelling methodology for +Gz impact response. The emphasis was on modelling experimental data obtained from tests on human volunteers for head acceleration and neck flexion. The work predicted loading at the occipital condyle interface, and performed extensive model parametric studies to explore the changes in acceleration, flexion and neck loading due to variations in the amount and placement of mass on the head.

ACKNOWLEDGEMENTS

We wish to thank the Air Force Systems Command, the Air Force Office of Scientific Research and the Armstrong Laboratory (AL) for sponsorship and support of this research. Research and Development Laboratories must be mentioned for their concern and help in all administrative and directional aspects of this program.

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The encouragement and help of Ms. L.A. Obergefell clearly added to every aspect of this research project.

INTRODUCTION:

The concern about the problem of neck injury during ejection was addressed by an 1984 AGARD working group. Their findings showed that non-ejection high manoeuvering loads resulted in cervical fractures more frequently than ejection situations. The introduction of night vision goggles, helmet mounted sighting and display systems in advanced military aircraft environments can be expected to exacerbate the injury risk to aircrew and perhaps increase the likelihood of cervical injury. Unfortunately there exist limited useful data in the published literature to provide guidelines for allowable added mass on the head.

Computer models in the published literature primarily deal with occipital condyle (C1-C2 region) shear and torque forces due to flexion and extension of the head/neck systems. There exist considerable data on the response of the human neck to -Gx impact acceleration. These data were accumulated from human volunteer studies, cadavers and computer simulations. Mechanical dummies were also used to compile data for higher acceleration exposure levels. Unfortunately, the data on the response of human head/neck due to +Gz acceleration are limited and almost non-existent for situations with head mass.

This summer AL/CFBV conducted a review of the existing data for +Gz acceleration exposures in the published literature to provide an overview of the present biodynamical knowledge. With the aim of developing limits on allowable added headmass, the effects of added mass and its location on the head were evaluated. Computer simulation, parameter selection and validation with the experimental data collected at AL were attempted. The specific aspects of human neck response investigated included human and analog +Gz accelerations response; injury mechanisms; tolerance levels; measurements and/or calculation of forces in the head/neck joints; effects of added mass on the head due to helmet and/or helmet mounted devices; and modelling of impact acceleration and vibrational effects.

OBJECTIVES & LITERATURE REVIEW:

The scope of our summer research effort was to identify pertinent information available or lack of it relating to head/neck response due to +Gz impact acceleration in the literature. Some forty publications in this field were reviewed, list of which is appended in the reference section. These papers were grouped according to their major subject areas. Publications focusing on epidemiological relationships, experimental investigations, review of current knowledge of the subject materials, added mass criterion on the impact situation, computer simulations etc., were reviewed.

Number of papers overviewed historical knowledge relating neck injuries, kinematics, clinical biomechanics, use of electromyography for muscular loading phenomenon in head/neck response. Guill and Herd (2) analyzed ejection related neck injuries for the 1949-1988 period, and suggested caution relating integration of systems into aircrew helmets. Clark (3) investigated positive effects of botulinum toxin in cervical muscles dystonia. Shanahan and Shanahan (10) reviewed kinematics of US Army Helicopter Crashes during 1979-85. They compared their data with existing design standards and suggested standards be modified, based not only on horizontal velocity but also in roll, to crashworthiness of helicopters. Phillips and Petrofsky (31,32) used volunteer electromyography to investigate neck musculature signals due to helmet loading. They showed definite effects of cg off-sets and addition of extra mass on head. But Tennyson et al. (22) showed, using electromyographic signals, that there may not be enough time for the muscle forces to provide effective restraint in case of a high g exposure. Coffee et al. (33) and Panjabi et al. (27) investigated in vitro loading to failure of human cervical spines. The differences in the data obtained varied widely. The compressive and tensile stiffness on an average were much larger (1435 and 224 N/mm) in (33) when compared to (140 and 53 N/mm) in (27) respectively. The difference can be attributed to the two different techniques used for experiments; in (27) the cervical spine were severed as the experiment progressed but in (33) the spine were kept intact.

Brinkley (13) reviewed operational efficacy of USAF flight helmets used during 1963-1967; suggesting better shoulder harness and presence of helmet were major factors for head injury prevention. Sandstedt (11) reviewed all cases of ejections in the Swedish Air Force during 1967-1987. His findings show that even with a heavy helmet the percentage of survivable ejections was excellent, even though a high velocity ejection were common among the reported cases. A design with lower DRI also helped with the improvement in survivability. Over 90% of the ejected pilots returned to active duty of flying.

Procedures to determine the cg and moment of inertia of the human head and neck were presented and a standard for co-ordinate systems was defined by Becker (17). An approach to modelling human head/neck response to -Gx impact accelerations was attempted by Becker(16). Walker et al. (25) reported mass, volume, center of mass and mass moment of inertia of head and head/neck joints for human cadavers. Findings were similar to those presented by Becker(17). But Ewing and Thomas (26) study was first to report systematic standards of anatomic parameters used in impact studies.

Foust and his co-workers (19, 20, 21) presented a series of neck muscles response data for cervical motion due to car crash situations. Human volunteer response and simulation modeling suggested dependence of reaction time to mitigate forces effected on a collision; major findings were, higher age would lower the muscle strength, and muscle response were strongly related to sex.

Effects of whiplash on cervical spine due to head accelerations were documented by McKenzie and Williams (35), Mertz and Patrick (34) and Ewing and Thomas (26). A discrete parameter model of head, neck and torso were used by McKenzie and Williams to predict kinetic forces within established published experimental methods (35). Kinematics of whiplash, based on an actual car crash acceleration pulse, were reproduced using a volunteer, cadavers, and dummies (34). Ewing and Thomas (26) compared human test data with those of Mertz and Patrick (34). The standardized methods of collecting dynamic response parameters in this -Gx study, suggest methods for analyzing future dynamic responses in other impact directions (i.e., +Gz).

Settecerri et al. (36) used a Hybrid-III dummy to evaluate inertial loading effects due to head encumbering devices. Their study, although no cg shift effects were considered, supported the theory that added mass on the head would increase severity of loading on the cervical spine.

Verona and his co-workers (8, 9) compared the two types of imaging techniques based on two different optical principles, image intensification and thermal imaging, being used for night vision goggles in army helicopters. The excess weight (5.3 lbs) due to NVGs was analyzed on the basis of human factors and safety considerations. Majority of accidents (28 out of 37) reported were sensor and/or display system related. Analysis of night vision goggles for military helmet mounts presently being used were reported in a series of articles (28, 29, 30). Comparisons between AN/PVS-5 and ANVIS showed reduction of added head mass (from 680 gm to 463 gm) and lower eye relief (from 21.6 mm to 16 mm) for ANVIS system.

Thurston and Fay (39) built a mechanical model of the head/neck to simulate neck motion due to impact acceleration. A non-linear harding spring was used for the simulation model. Mertz et al. (12), using a Hybrid-III dummy head, tested different football helmets. They reported that the position of the torso at the time of impact would affect the bending moment at the neck joint. Verona et al. (9) cited Glaister (15) for an upper value of added mass on the head as 4.4 lbs (2.0 kg). Glaister's concern was with respect to head injury and protection based on penetration resistance, shock absorption, rotational acceleration, but did not specify why 2.0 kg added mass should be the ideal weight.

Mertz and Patrick (34) attempted to develop an index for severity of impact using human static tolerance limits as a basis. Mertz et al. (12) also developed an injury reference curve based on qualitative observations from dummy tests. From historical data Glaister (15) studied tolerance of human the head to direct impact acceleration. The linear G-value for tolerance for head injury was reported to be 300-400 Gs. Darrah and co-workers (4-7) developed a computer model of head/neck simulation for +Gz acceleration incorporating asymmetrical loading. Using human centrifuge experimental data, the model was validated. They simulated three head loads and five offsets from the atlas. The results predicted maximum tolerance of +3.5 Gz with any added weight. The model with NVG resulted in increased applied neck torque to 267.7 in-lbs. The human volunteer study showed possible head motion at +6.0 Gz unloaded and +5.5 Gz with any kind of loading. The fatigue tolerance curve simulated by Darrah and co-workers (4) was obtained as a function of seat back angle, +Gz load and duration of stress. Their physiological limits were set by the cardiopulmonary system limits.

Using the ATB model, Freivalds and McCauly (1) simulated helmet assembly mass and center of gravity effects during ejection. Among the variables looked into were head acceleration, torque and flexion angle which were assumed to be of importance and were shown to be significantly correlated to CG offsets. The relationship of ejection seat back angles with head rotation was significant too. Raddin and his co-workers (41) using the concept of relative velocity suggested a neck protection system for aircrew in high performance aircraft.

Using a 10 G pulse in both -Gx and +Gz directions and 3 lbs helmeted weight, King et al. (24) simulated head and neck response. It was shown that simultaneous impacts of both -x and +z directional accelerations increase neck shear and moment, head acceleration, head displacement, and neck muscle forces. Privitzer and co-workers (37, 38) made analysis of dynamic inertial loading of head mounted systems due to +Gz acceleration on the head/neck system. They implemented a spinal injury function and baseline response criteria using a three dimensional head-spine model for head mounted devices.

Mertz and Patrick (14) performed a static and dynamic response study of neck strength on volunteers and cadavers. Non-injurious tolerance values for hyperextension and flexion of neck for different G values were plotted using equivalent moments and head position as parameters. A response envelope was drawn. Tolerance levels for the neck in flexion and extension were developed using physiological responses from the volunteers and from x-ray views of the damage at the cadaver neck. Injuries applicable from animal studies were suggested by Ewing (23) for extrapolating to human neck. Ewing developed an envelope using a comparative model between man and human analog (primates) to validate the analytical human head/neck response.

VonGierke (18) and Anton (40) made overviews to discuss recent advances in +Gz acceleration impacts. Topics focused included, application of ATB model in ejection simulation, body deformation under ejection forces simulated with HSM, neck muscle responses by King et al.(24), development of injury criteria, and analysis of epidemiological data compared with simulations. Their findings emphasized the accumulated knowledge but also highlighted the short comings of our data base.

DISCUSSION:

Most of the information available for impact acceleration are for -Gx. There exist little data either for the Y or the Z direction. The Y-directional motion is minor and thus can be neglected for detailed study. Z-directional motion on the contrary is of significant importance to Air Force due to pilot ejection concerns. The lack of existing pertinent data indicated that the Air Force should undertake a human volunteer study and develop a simulation methodology to predict injury likelihood due to added head loading during ejection.

Following the human volunteer protocol developed by Ewing et al. (26) for -Gx acceleration a method to study human head/neck response in the +Gz direction has been developed by AL. Among the data recorded are head and chest accelerations. The photographic records are also analyzed to determine the kinematics of the head, shoulder, and neck. The Articulated Total Body (ATB) model has been used to simulate the head and neck response for +Gz impact using the experimentally obtained chest acceleration as input.

The simulation uses certain specific parameters, i. e., neck stiffness, damping force etc. as inputs for validation with the experimental results are not clearly defined. The added head weight of 6.8 lbs due to fielded night vision goggles (e.g., AN/PVS-5) should be recommended as an upper limit in the simulation (8,9). The maximum off-set of head load placement was presented by

Glaister (5) as 152 mm forward of the atlas in the only human volunteer experiments for +Gz acceleration reported. The maximum +Gz sled acceleration experienced by the volunteers was 6.0. The combination of added head mass and +Gz acceleration would be controlled by the maximum safe neck torque. A value of 267.7 in-lbs was used by Darrah et al. (6). The neck torque of 270 in-lbs could be used as a limit for experimentation. This value is about half of Mertz and Patrick (14) x-directional volunteer data for 8.0 G sled acceleration. An angular acceleration of 50 rad/sec was used by Ewing (23) equivalent for concussion in humans. This could be used as an upper limit of the simulation. Mertz and Patrick (14) suggested an envelop using the initial slope of the volunteer response of neck strength as 3 ft-lbs/degrees. This was based on -Gx sled acceleration, but since no similar data is available , this can be used as a guide for +Gz sled acceleration also. The neck muscle force response can be neglected in the simulation, at least at the beginning, as reaction time is generally longer than the ejection critical acceleration exposure time (19-22, 31-32). The loadings on the cervical spine were reported as 18 N-m (33),and 57 N-m (14) bending moment, the tensile stiffness was 224 N/mm (33), and 53 N/mm (27), and the compressive stiffness was 1435 N/mm (330 and 140 N/mm (27), providing a wide choice for the working range. The simulation should be validated from within these values.

The development of a tolerance envelope would constitute some problem. In the x-direction, where there are enough data available, the envelope suggested by Mertz and Patrick (14) is at best questionable. In the +Gz direction, data are limited. The computer simulation and predictions made by different investigators (1, 7, 24, 34) were mostly not validated by experimentation. The little data that are available suggests limited range of operation. The historical data analyzed by Sandstedt (11), on the contrary, suggests that most ejections with proper helmets are survivable with over half of the ejections causing minimal injury to the pilots.

The major findings of some of the papers underline some key results. Mertz and Patrick (34) for the first time suggested a injury envelope based on their cadavers and volunteers studies. Darrah and his co-workers (4-7) attempted computer simulations and experimental validation of added head mass due to helmets and helmet mounted devices. They documented effects of cg offsets and their contributions to cervical stress and strain due to head loading. Sandstedt (11) in his research investigated survivability from actual ejections and suggested 100% survival rate with proper head protection. All the reported cases of the pilots ejected made return to active duty status, although the loading on the neck due to the heavy helmets used in the actual ejection was high. Privitzer and Kaleps (38) developed a three dimensional computer model of head and spine that could successfully predict kinematics of the spine. The opens the door to further developments of other body parts motion in a similar manner.

RECOMMENDATIONS:

A mathematical model of human motion provides an inexpensive source of database for impact acceleration assessments for crash situations. The scope of the project allowed only simulations using one directional acceleration data to be completely investigated. Therefore, the simulation is recommended for use in predicting qualitative motions of the head acceleration and head pitch under added load conditions. In using the ATB model for predicting loading at the occipital condyle interface due to additional Head Mounted Devices (HMDs) it is recommended that a study of torque characteristics of the head and neck joints first be conducted and included in the program.

Once a methodology for using the ATB model for +Gz impact is complete, extensive model parametric studies could be performed to explore the changes in acceleration, flexion and neck loading due to various amounts and placements of mass on the head. An injury tolerance limit envelope and severity index criterion for ejection should then be attempted, using the validated simulation model.

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COORDINATION OF POSTURAL CONTROL AND VEHICULAR CONTROL

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1.0 Abstract

The objective of this report is to reveal some of the factors that affect the perception of self motion during changes in the velocity vector. The report focuses on multimodal perception of self motion in the context of the forces implicit in curved trajectories. It is argued that theories and experiments on the perception of self motion must consider the multiplicity of perceptual systems that are sensitive to forces and motions. It is recommended that the relation between displayed roll-orientation and heading should be experimentally manipulated so that changes in orientation can be investigated in relation to changes in the direction and magnitude of centripetal acceleration. The extent to which such events can be perceived as *self motion is determined by the sensitivity* of the nonvisual perceptual systems to the presence or absence of variations in constraints on postural control. The relation between orientation and centripetal acceleration determines which nonvisual systems should be most sensitive to the attendant constraints. The introduction of novel dependent and independent variables in an otherwise familiar flight-simulation paradigm is recommended in order to reveal the role of postural control in the multimodal perception of self motion.

2.0 Background

2.1 Flight Simulation and the Perception of Self Motion

The *sine qua non* of flight simulation is generally considered to be the capacity to induce perception of self motion through an environment without moving the observer. This capacity becomes useful if the observer is allowed to control the simulated self motion;

that is, the observer-actor can achieve goals. Most goal directed motion through the environment requires perception of objects and surfaces that are distant from the observer. Visual perception is thus crucial for goal directed motion and, thus, there is no question that visual display systems are necessary in flight simulation. Furthermore, there is general agreement that further developments in visual display systems are important because recognition of familiar objects and layouts increases the range of flight tasks that can be performed in the simulator. For example, the detail on a tanker aircraft is important in the approach and docking phases of in-flight refueling; the depth of a ravine or the presence of telephone wires is important in low level flight. The issue in flight simulation over which there is the greatest controversy, and for which there is the greatest design consequences, is whether there are any situations in which visual display systems are not sufficient (e.g., Cardullo & Sinacori, 1988; Hosman & van der Vaart, 1981; Lintern, 1987).

The controversy about the sufficiency of visual displays in flight simulation has theoretical, as well as, practical relevance. The general theoretical issues are concerned with the multimodal perception of self motion. The research sugested in this report is based on the assumption that multimodal perception must be considered in all experiments on self motion. Multimodal perception is relevant even when the experiments do not involve actual movement of the subject relative to an inertial reference frame (cf., DiZio & Lackner, 1986). Vestibular and somatosensory systems are involved in the perception of orientation and self motion even when experimental manipulations are limited to visual displays. Additional assumptions in this report are that there are fundamental relations between perception and the control of behavior, and that these relations indicate the sources of information that are relevant in a given experimental or natural situation (see Riccio, in press; Riccio & Stoffregen, 1988, 1990, 1991; Stoffregen & Riccio, 1988, 1990, 1991).

The issues that are relevant to the perception of self motion are discussed in the context of real and simulated flight: movement of the aircraft relative to an inertial reference frame (section 2.2), management of kinetic and potential energy (section 2.3), and coordination of postural and vehicular control (section 2.4). The relevance of these issues to multimodal perception and control are summarized in section 2.5. The perception-action relations that should be considered in real and simulated flight are represented in conceptual block diagrams (Figures 1-2). It is assumed that these perception-action relations generalize beyond flight control, although they vary in importance across different types of propulsion and movement.

2.2 Movement Relative to an Inertial Reference Frame

A relatively neglected issue is the perception of accelerative self motion. Motion cannot be controlled without producing variations in velocity. Goal directed motion requires that these variations are observable. The question for flight simulation is *whether these variations (i.e., acceleration) can be perceived visually, and if so, whether they are attributed to motion of the environment or motion of the observer*. It is important to note that there is very little research that is relevant to this issue (although see Warren, Mestre, Blackwell, & Morris, 1991). The basic research on visual perception of acceleration generally concentrates on object motion (Todd, 1981). Basic research on the visual perception of egomotion generally involves situations where acceleration is either small, nonexistent, or irrelevant to the task (e.g., Warren & Owen, 1982; Warren & Riccio, 1986). Moreover, the visual perception of accelerative self motion is rarely mentioned as a theoretically important issue. It is especially surprising that the visual perception of vehicular acceleration has been largely neglected in flight simulation research.

If the visual perception of vehicular acceleration were in some way deficient, it would be important to exploit vestibular and somatosensory perception in flight simulation. The sensitivity of these systems to acceleration is well established. In this respect it is important to note that deficiencies in the visual perception of vehicular acceleration would not necessarily be due to limitations in the visual system. Such deficiencies may exist because vehicular acceleration is fundamentally a *multimodal phenomenon*. By way of analogy, perception of vehicular acceleration without multimodal stimulation (i.e., with only the visual system) may be like perception of color without stimulating the "cone" cells of the retina (i.e., with only the "rod" cells). The visual perception of accelerative self motion may be limited (like the function of rod cells) to low levels of stimulation, perhaps as in special cases of postural sway (Stoffregen & Riccio, 1990).

2.3 Management of Kinetic and Potential Energy

Other issues are motivated by the existence of coordinated maneuvers (i.e., correlation between heading and orientation). An approach that is based on coordinated maneuvers is to be contrasted with one that is based on the degrees of freedom that potentially can be controlled independently in an aircraft. For example, a degree-of-freedom approach might consider perception of roll, pitch, yaw, and airspeed to be fundamental (lift, drag, and thrust might be considered most fundamental but they would be difficult to relate to perceptual sensitivity). Data on the sensitivity of perceptual systems to these degrees of freedom of motion could be exploited in the design and integration of visual and nonvisual display systems for flight simulators. The advantage of the degree-of-freedom approach is that there is a considerable body of basic research that can be used to quantify the design process and objectify design decisions (Brown, Cardullo, McMillan, Riccio & Sinacori, 1991). However, there are several disadvantages to this approach: (a) an additional step is needed to reduce these data to a form that directly relates to actual flight control tasks (i.e., maneuvers); (b) there may be interactions among the degrees of freedom that alter sensitivity to the individual degrees of freedom of motion; (c) new dimensions of control may emerge when motions in various degrees of freedom covary.

A maneuver-based approach would consider the aircraft's trajectory or flight path through the environment to be more basic than the mediate control parameters. Control of the trajectory involves changes in altitude and heading that constrain the covariation among roll, pitch, yaw, and airspeed. (It follows that adjustments of the stick, rudders, and throttle are also constrained to particular patterns of covariation.) The way in which covariation is constrained depends on the evaluation function for control. While the function (or criteria) on which control is evaluated (or guided) can vary, a generally important criterion that guides control is energy management. With respect to this criterion, efficient flight requires that the pilot monitor (directly or indirectly) the kinetic and potential energy of the aircraft. In particular, the pilot should be sensitive to the rate of change in, and exchange between, these parameters.

Management of kinetic energy requires control of the aircraft's velocity. The issues that pertain to perception of changes in velocity were mentioned above. Management of potential energy involves control of the so-called G forces acting on the aircraft. The magnitude and direction of these G forces are controlled primarily in curved trajectories (e.g., a "pull up" or a "coordinated turn"). The curvature of the trajectory determines the magnitude of the G forces. The attitude (i.e., roll and pitch orientations) with respect to the trajectory (e.g., angle of attack) determines the direction of the G forces on the aircraft. The magnitude and direction of the G forces, in turn, influences the trajectory of the aircraft. It is not known to what extent perceiving the magnitude and direction of G forces is required to produce efficient (coordinated) trajectories. Since the G forces are lawfully related to the radius and orientation of the trajectory, perceiving the trajectory kinematics could be sufficient. In principle, kinematic information is available to the visual system whenever optical structure is available. The question for flight simulation is *whether the radius and orientation of the aircraft trajectory can be perceived visually*. Again, the paucity of relevant data is noteworthy. This is surprising since the relevance of trajectory radius extends beyond flight control (e.g., perception of trajectory radius for the head would be useful in understanding the coordination of body segments during stance and pedal locomotion; Riccio & Stoffregen, 1988; Stoffregen & Riccio, 1990).

If the visual perception of trajectory radius and orientation were in some way deficient it would be important to exploit vestibular and somatosensory perception in flight simulation (Figures 1-2). The relationship between canal and otolith stimulation would seem ideally suited for perception of trajectory radius. Unfortunately there are few data that directly relate to this hypothesis (Ormsby & Young, 1977; Zacharias & Young, 1981). There would be important implications for simulator design if people were actually sensitive to this relationship. Perception of G forces could substitute for perception of trajectory radius and orientation. The sensitivity of vestibular and somatosensory systems to the direction and magnitude of G forces is not controversial (although the basis for this sensitivity is in question; Howard, 1986; Stoffregen & Riccio, 1988; Riccio & Stoffregen, 1990; Riccio, Martin, & Stoffregen, in press).

It should be noted that curved trajectories are fundamentally multimodal phenomena. Again, an analogy to color vision may be useful. Instead of the electromagnetic spectrum, the relevant continuum would be trajectory radius. Pure linear motion would be at one end of the continuum and pure angular motion at the other. Different kinds of sensors (i.e., with ranges of sensitivity to motion that differ with respect to their dependence on trajectory radius) are an efficient way to pick up information about the distribution of activity along the continuum. Together, different sensors are sensitive to information that is not available to individual sensors. In this way, the diverse response characteristics of the visual, vestibular, and somatosensory systems may be complementary with respect to complex patterns of self motion.

2.4 Coordination of Postural Control and Vehicular Control

A neglected issue in flight simulation is that the pilot's body is not a single rigid structure attached rigidly to the aircraft. This has *important consequences for perception and control whenever the velocity vector or orientation of the aircraft changes*. Consider the effect on the pilot's body when the aircraft undergoes a linear acceleration or a change in orientation. Torques are produced in different ways in different parts of the body. These torques give rise to uncontrolled body movements unless they are resisted by muscular action (and, to some extent, by restraints in the cockpit). When the head moves relative to the cockpit, visual stimulation will not be specific to motion of the aircraft through the environment, and vestibular stimulation will not be specific to motion of the aircraft relative to an inertial reference frame. Stimulation of the somatosensory system (and to some extent, the visual system) will be specific to motion of the body relative to the cockpit. Multimodal stimulation is not redundant in these situations, it is complementary (Riccio & Stoffregen, 1988, 1990, 1991; Stoffregen & Riccio, 1988, 1990, 1991). *The overall pattern of stimulation is specific to the acceleration event, an event in which motion of the aircraft and motion of the body cannot be considered independently.* The event must be considered in its entirety because imposed motion of the head can frustrate the pick up of optical information; imposed motion of the torso or arms can frustrate manipulation of the control stick (Figure 1).

Consider also the effects on the pilot's body when the aircraft moves along a curved trajectory. It is often desireable for the z-axis of the aircraft to be parallel to the G vector. When they are not parallel, the various segments of the pilot's body must be tilted with respect to the cockpit in order to maintain a state of balance. The direction of postural balance in the cockpit provides information about the attitude of the aircraft relative to the G vector. Vestibular and somatosensory systems are sensitive to this information (Riccio, Martin, & Stoffregen, in press). Sensitivity to this information could help the pilot fine tune the maneuver (e.g., coordinating orientation and airspeed). Attention to the direction of balance is also important for postural control in the aircraft seat. The pilot must detect imbalance in various body parts and detect the relative orientation of the support surfaces used to maintain balance (Stoffregen & Riccio, 1988). Postural control stabilizes the platform for the perception and action systems (Riccio, in press; Riccio & Stoffregen, 1988). *Deficiencies in postural control could compromise perception and control of the aircraft maneuver.*

Focused attention on the orientation of the body and the aircraft relative to the G vector could cause the pilot to loose orientation with respect to the terrain. The terrain generally will not be perpendicular to the G vector or the aircraft z-axis. Managing (a) the orientation of the aircraft relative to the G vector and the terrain, and (b) the orientation of the body relative to the G vector and the aircraft, would seem to be an important component of skilled flight control. This skill cannot be acquired in a simulator that does not allow the relative orientations of aircraft, G vector, and terrain to be manipulated independently. Motion platform simulators allow these orientations to be manipulated independently. However, they do not allow rotation to be manipulated independently of tilt with respect to the G vector. This is required for accurate simulation of curved trajectories. For example, the perception of rotation without a change in tilt is veridical during a coordinated turn.

Another important aspect of curved trajectories is variation in the magnitude of the G vector. Variation in G magnitude can be large enough to have significant physiological and biomechanical consequences (Kron, et al., 1980; Figure 1). Many of these effects impose hard limits on perception and action. For example, "gray out" precludes peripheral vision; increases in the weight of the limbs may render movement impossible. The aircraft control problems that arise because of hard limits can be viewed as errors of omission; required control actions are precluded. However, even small variations in G magnitude change the environmental constraints on perception and action. Such constraints are soft in the sense that they do not necessarily preclude perception and action. They change the dynamics of body movement; that is, they change the muscular actions required to achieve a particular interaction with the environment (Riccio & Stoffregen, 1988; Figure 1). This can lead to control problems if the pilot does not have motor skills that are appropriate for the new dynamics. The aircraft control problems that arise because of soft constraints can be viewed as errors of commission; inappropriate control actions are induced. It is important to emphasize that *learning to control an aircraft also involves learning to control the interaction of the body and the aircraft.* The latter is probably a nontrivial component of piloting skills in many flight scenarios. Inappropriate skills may be acquired in a simulator that does not include the soft biomechanical constraints encountered in variable G maneuvers (Figure 2).

The inter-dependencies between postural and aircraft dynamics also influence the response to transients. For example, there are several ways in which the pilot can minimize the deleterious effects of changes in aircraft velocity or orientation. Muscular effort can be exerted in the direction opposite to the anticipated force due to aircraft motion. Alternatively, muscular co-contraction may stiffen the body sufficiently when forces cannot be anticipated. If neither of these strategies can be used, less massive parts of the body may be used to "take up slack" in the imposed motion. For example, eyes can move in such a way that fixation on a distant object can be maintained; the arms can move in such a way that the positions of the hands are maintained with respect to the controls. These skills of coordinated motion are important when the intent is to maintain posture (or fixation) and when the intent is to change posture (or fixation). For many flight scenarios, learning the inter-dependencies between postural and aircraft dynamics should be as important as learning the dynamics of the aircraft alone (Figure 1). Simulations may be seriously deficient if these inter-dependencies are not included (Figure 2). There is no reason to believe that fidelity of postural dynamics is any less important than fidelity of the aero model in flight simulation.

2.5 Multimodal Perception and Constraints on Control

The issues that are most important in this perspective on flight simulation have to do with the consequences of variations in the orientation and/or velocity vector of the aircraft. These consequences involve the forceful interaction of the aircraft with the pilot's body. For example, the forces imposed on the pilot's body stimulate multiple perceptual systems. It is a common assumption in many areas of research, including those concerned with flight simulation, that multimodal stimulation is either redundant or conflicting. However, this assumption is inappropriate given that nonredundancies are both common and informative for a nonrigid body (Riccio & Stoffregen, 1988, 1990, 1991; Stoffregen & Riccio, 1988, 1990, 1991). *Multimodal stimulation is more accurately described as complementary.* The complementarity of multimodal stimulation has nontrivial implications for the perception of self motion. While redundant stimulation may be considered unnecessary in many situations, complementary stimulation would be necessary if it provided information not available to individual perceptual systems.

The forces imposed on the pilot during flight not only change the stimulation of perceptual systems but also change the constraints on body posture and movement. *Both imposed stimulation and biomechanical constraints provide information about the flight situation.* Sensitivity to these constraints requires that the pilot is active in the cockpit (cf., Riccio, in press). For example, head movements, arm movements, and balance reveal the dynamics of the environment in which they occur. The balance and movement of the head would seem to be particularly informative because of its multiplicity of motion sensors and because of its relative lack of support. It follows that control of the head should be an important consideration in flight simulation.

Stimulation in the aircraft and the simulator are different because the actual motion of the pilot and cockpit are different. A major design problem in flight simulation is that increasing the fidelity of some modes of stimulation often reduces the fidelity of other modes of stimulation. The designer must assess the relative importance of various modes of stimulation (e.g., particular devices and drive algorithms) as sources of information about orientation and motion. Multimodal stimulation and constraints on control may provide additional criteria on which to assess the relative importance of various modes of stimulation. For example, mechanical devices that move or restrain the body (Kron, et al., 1980; Brown, et al., 1991) may increase fidelity of simulated acceleration with respect to the control of a nonrigid body (i.e., postural control), while a wide field-of-view visual display may reduce fidelity with respect to the same criteria (Figure 2).

Fidelity criteria that are based on postural control may require more justification than criteria that are based on aircraft control. This emphasizes the need for basic research on the issues mentioned above. However, there are other factors that may influence whether postural criteria will ultimately appear in flight simulation. For example, consider the problem of simulator sickness. In spite of decades of speculation about the role of sensory conflict in motion sickness, there has been a notorious lack of progress in understanding or predicting these phenomena (Stoffregen & Riccio, 1991). A recent theory of motion sickness argues that the malady is due to a prolonged interference with postural control (Riccio & Stoffregen, 1991). The theory accounts for a much greater range of nausogenic and non-nausogenic phenomena than do other theories. Stated simply for the case of simulator sickness: postural control will be disrupted in the simulator to the extent that it is based on simulated motion (e.g., optic flow) that is not related to the dynamics of balance in the simulator cockpit (cf., Dichgans & Brandt, 1978; Lestienne, Soechting, & Berthoz,1977). It should also be noted that there seems to be increasing interest in postural control outside the simulator after adaptation to the simulator (e.g., Hamilton, Kantor, & Magee, 1989). After-effects on postural control outside the simulator would have to explained in terms of the postural control strategies acquired in the simulator.

3.0 Recommendations

It is recommended that research on flight simulation be broadened to investigate the factors that affect the perception of self motion during changes in the velocity vector. Unlike previous research on the perception of curvilinear self motion (Warren, et al., 1991), the proposed research should focus on multimodal perception given the forces implicit in curved trajectories and on the consequences of these "virtual" forces for the control of behavior. Unlike previous research on the control of simulated self motion, the proposed research should also address the coordination of postural control and vehicular control. The experimental design and predictions could be based on an extensive foundation of theory (Brown, Cardullo, McMillan, Riccio, &Sinacori, 1991; Riccio, in press; Riccio & Stoffregen, 1988, 1990, 1991; Stoffregen & Riccio, 1988, 1990, 1991) and flight-simulation experiments at the Armstrong Aerospace Medical Research Laboratory (Flach, Riccio, McMillan & Warren, 1986; E.M. Martin, McMillan, Warren, & Riccio, 1986; McMillan, E.M. Martin, Flach, & Riccio, 1985; Merriken, Johnson, Cress, & Riccio, 1988; Riccio & Cress, 1986; Riccio, Cress, & Johnson, 1987; Riccio, E.J. Martin, & Stoffregen, in press; Warren & Riccio, 1986; Zacharias, Warren, & Riccio, 1986). This integrated body of work also allows for predictions about discomfort arising from, and postural after-effects of, perception and control of simulated self motion.

The apparent dynamics of the simulated aircraft could be determined by the relation between the controlled and perceived aircraft states. Subjects could control the roll-orientation of the aircraft, and the displayed changes in roll-orientation could vary across conditions. Thus, the relation between displayed roll-orientation and centripetal acceleration could be experimentally manipulated. This would lead to informative nonredundancies between visual and nonvisual stimulation (section 2) in the simulator that would bevary across conditions. They would also be different than the patterns of stimulation that would arise from the corresponding motion in actual flight. Sensitivity to these nonredundant patterns of multimodal stimulation allow a simulator or an aircraft to be perceived as such. Insensitivity to nonredundancies precludes differentiation of the aircraft and the simulator and allows for a compelling experience of self motion. The extent to which such events can be perceived as self motion is determined by the sensitivity of the nonvisual perceptual systems to the presence or absence of variations in constraints on postural control. The relation between orientation and centripetal acceleration determines which nonvisual systems should be most sensitive to the attendant constraints.

It is recommended that, in addition to the measurement of manual control behavior (E.M. Martin, et al., 1986; McMillan, et al., 1985; Riccio, et al., 1987; Warren & Riccio,

1986) and experimential effects (Flach, et al., 1986; Hettinger, Berbaum, Kennedy, Dunlap, & Nolan, 1990; Riccio & Cress, 1986; Riccio, et al., in press), postural control should be measured inside and outside the simulator (cf., Riccio, in press). Inside the simulator, postural measurements should focus on movements of the head and torso and their relation to changes in simulated aircraft states. Outside the simulator, postural measurments should focus on stability of stance over perturbations in the support surface and the optic array (Nasher & McCollum, 1985). A more complete description of an experimental design that could be implemented in the Armstrong Laboratory, and elsewhere, will be provided in a follow-on grant proposal to the AFOSR-sponsored Research Initiation Program.

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Coordination of Postural Control and Vehicular Control in an Aircraft

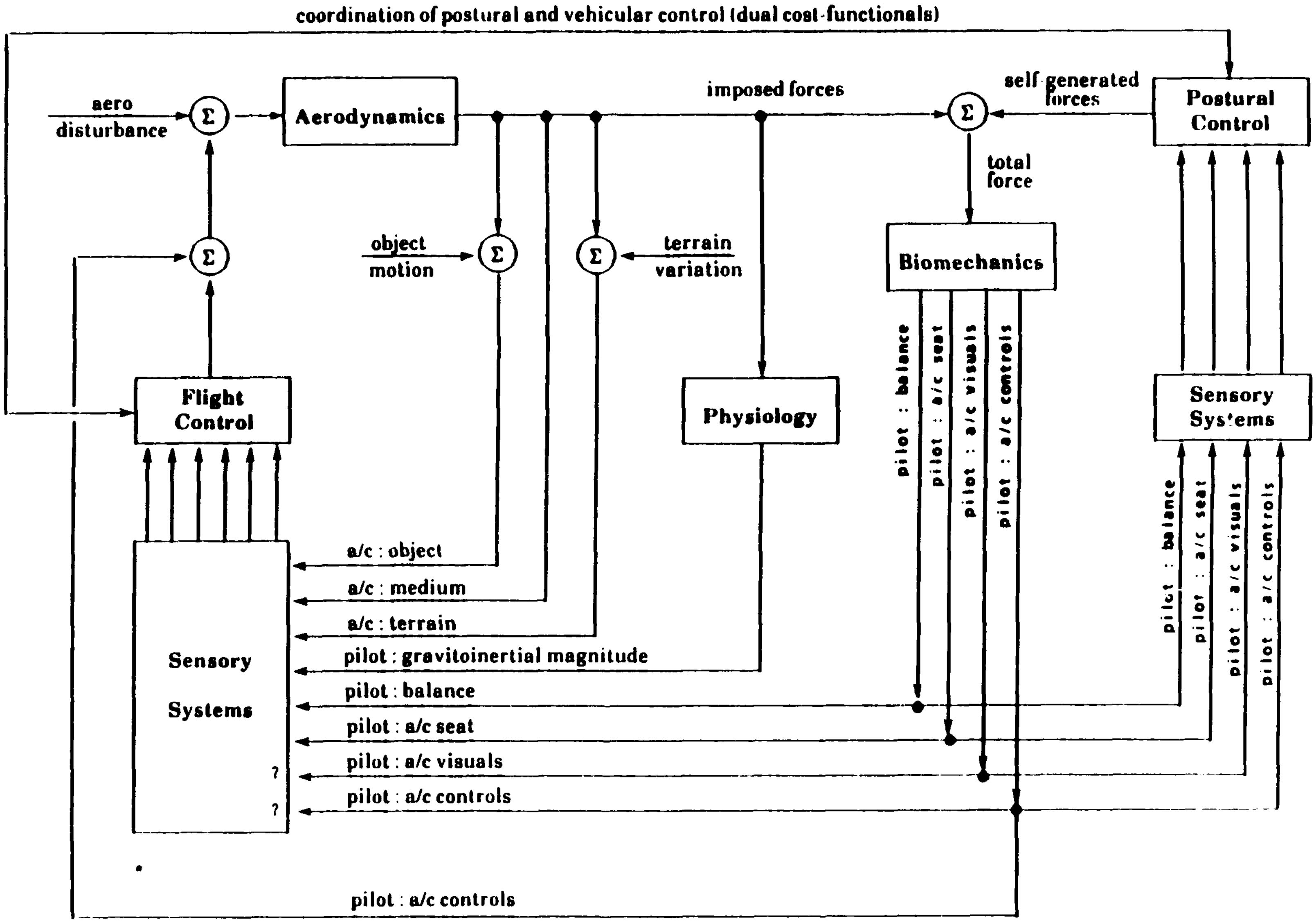

Fig. 1

Coordination of Postural Control and Vehicular Control in a Flight Simulator

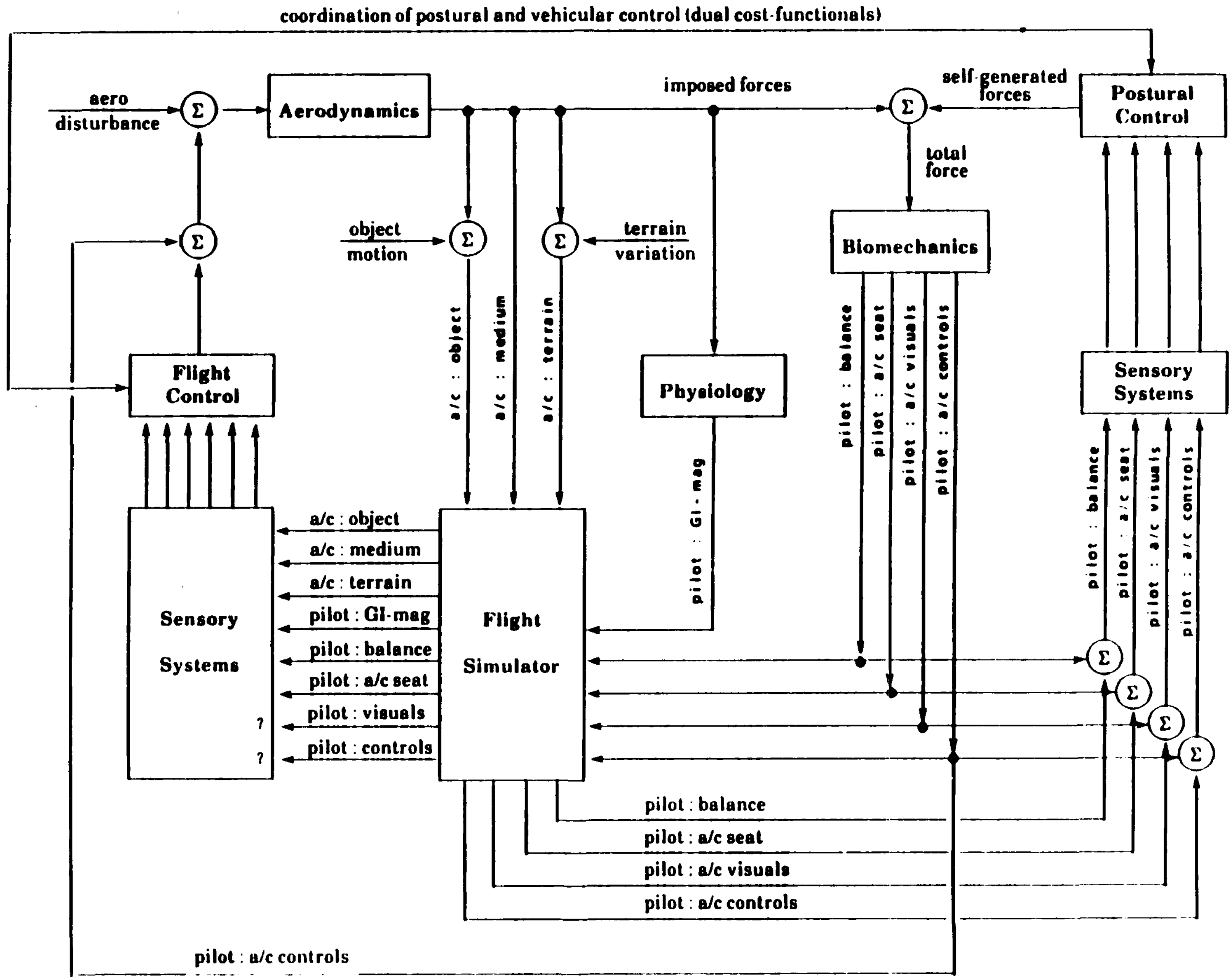

Fig. 2

Glossary

Aerodynamics. The relationship between aircraft motion and the combined effects of commanded motion and changes in the air mass. To simplify the block diagrams, the automatic flight-control system and classical aerodynamics due to movements of the control surfaces and those due to changes in the air mass have not been differentiated

Aero Disturbance. Changes in the air mass relative to the aircraft

Aircraft (also a/c). An object that is capable of movement above ground through buoyancy or aerodynamics.

A/C Controls. The parts of the cockpit that can be moved or modified by the pilot in order to change or maintain the states of the aircraft

A/C Visuals. Optical information from inside the cockpit: including the layout of surfaces in the cockpit as well as instruments

A/C : Medium. Resistance of the medium of support (total aerodynamic environment) to particular aircraft states.

A/C : Object. States of the aircraft relative to another object.

A/C : Terrain. States of the aircraft relative to the ground

Balance. Maintaining the orientation (or attitude) of a controlled system with respect to the vector sum of forces imposed on that system

Biomechanics. The relationship between the motion of, and the total force acting on, various parts of an organism

Coordination. Control of a part of an organism and/or its environment that takes into account the constraints imposed by concurrent control of another part of the organism and/or its environment

Cost Functional. The effect of organismic and environmental parameters on the efficiency of action in a controlled system

Disturbance. Changes in the states of aircaft relative to the terrain, other aircraft, or the air mass (including wind gusts)

Distal Layout. The parts of the substantial environment with which an organism is not in contact.

Environment. Surfaces of support (e.g., the terrain or the ground), media of support (e.g., an air mass or a non-contact force), detached objects (e.g., aircraft or projectiles), attached objects (e.g., trees or buildings).

Flight Simulator. A controlled system that recreates the motions and forces to which a pilot is subjected in an aircraft.

Flight Control. A system that moves, or resists the movement of, the aircraft on the basis of information about the aircraft states (this is always the human in our block diagrams)

Gravitoinertial. The vector combination of gravity and acceleration, which can be conceptualized as an unitary force or as a potential for acceleration.

Imposed Forces. Vector combination of all forces acting on a particular part of an organism, excluding forces internal to the organism.

Glossary (continued)

Manipulanda. The parts of the environment that can be moved or modified

Medium. Parts of the environement that are nonsubstantial (i.e., afford passage through).

Object. Any substantial part of the environment that is distinct from the terrain or the ground (e.g., aircraft or projectiles).

Orientation of the Pilot. $\theta(t)$ and $\phi(t)$

Physiology. The systems internal to the organism that are effected by gravitoinertial magnitude.

Pilot: Balance. Orientation of various parts of the pilot's body (i.e., head, torso, arms, and legs) with respect to direction of balance

Pilot: Controls. States of the pilot's manipulators (e.g., hands and feet) with respect to the a/c controls

Pilot: Gravitoinertial Magnitude (also GI-mag). Physiological responses of the pilot to increases or decreases in the magnitude of the gravitoinertial vector.

Pilot: Seat. States of the pilot's body (i.e., torso and legs, including bottocks) with respect to a/c seat.

Pilot: Visuals. States of the pilot's eyes with respect to a/c visuals

Postural Control. A system that, on the basis of information about body states, moves or resists the movement of the various parts of an organism that subserve balance.

Seat. Surface that can completely support the weight of the body through contact resistance at the buttocks, and that may resist the motion of the body through contact resistance at various parts of the torso and extremities (e.g., in an a/c seat)

Sensory Systems (also Perceptual System). Systems that can acquire information about states of an organism and its environment.

Self-Generated Forces. Forces internal to the organism that are responsible for moving, or resiting the movement of, parts of its body.

States of the Pilot/Aircraft. $\theta(t)$, $\phi(t)$, $\psi(t)$, $x(t)$, $y(t)$, $z(t)$

Terrain (also Ground). Surfaces that can completely support the weight of, and are large in scale relative to the action capabilities of, an object.

Vehicle. A controlled system that can transport an object from one place to another.

$\theta(t)$. Time history with respect to roll axis

$\phi(t)$. Time history with respect to pitch axis

$\psi(t)$. Time history with respect to yaw axis

$x(t)$. Time history with respect to longitudinal axis

$y(t)$. Time history with respect to lateral axis

$z(t)$. Time history with respect to gravity axis.

THE MISSING FUMDAMENTAL ILLUSION

Benjamin R. Stephens, Ph.D.

Summary. The detectability, apparent contrast, and appearence of sine, square, and missing fundamental waveforms were measured using standard psychophysical techniques. The results suggest non-trivial modifications to models of low spatial frequency pattern vision. However, stimulus artifacts require replication of the results before publication.

Introduction

Current models of spatial vision attempt to account for both threshold and suprathreshold performance. Typical data to be described by these models include contrast sensitivity, contrast discrimination and/or apparent contrast functions (e.g. Cannon & Fullenkamp, 1991). Although these models have been useful, little direct evidence exists to allow application of these models to more complex perceptual judgments. Most attempts to account for these judgments rely on heuristics concerning the perceptual effects of the presence or absence of bands of spatial frequency information. For example, Campbell et al have demonstrated that the ability to detect the third harmonic of a high frequency square wave grating predicts the contrast at which the square and sine grating (of the same fundamental frequency) can be discriminated. Campbell et al applied a similar style of reasoning to account for the missing fundamental illusion. Figure 1 presents the intensity profile and amplitude spectra for a sine, square, and missing fundamental grating. The missing fundamental grating is simply a squarewave grating with the fundamental (F) removed. The missing fundamental grating is nonetheless perceived as a squarewave grating under low contrast, low spatialfrequency conditions. Campbell et al's explanation of this missing fundamental illusion is that F is not normally detectable under these conditions, so its removal does not alter the appearance or detectability of the square wave.

This account of the illusion seems to be inconsistent with Ginsburg et al's (1980) explanation of apparent contrast in squarewave gratings. Their contrast matching data show that adults require roughly 27% more contrast in a sinewave grating to be equal in apparent contrast to a squarewave grating of the same fundamental frequency. Since the fundamental of a square wave is 27% higher in contrast than the physical contrast of the grating, they interpreted their results as indicating that the fundamental mediates apparent contrast, even under lowcontrast, low frequency conditions.

This inconsistency could be due to the higher harmonics of the squarewave, which might mediate both detection and apparent contrast under lowfrequency conditions. Alternatively, judgments concerning the quality of a pattern (e.g. apparent contrast) may not involve identical mechanisms as those involving detection or discrimination. Thus in a preliminary study, we conducted matching, adaptation and discrimination experiments with sine, square and missing fundamental gratings (Stephens, Niles, Thomas, & Gonzalas, 1989; Stephens, in press). The contrast matching experiment employed a two interval method of adjustment procedure. Naive subjects (N=21) matched the apparent contrast of a 0.5 cy/deg sinewave grating (F) to 6 different contrasts of a 0.5 cy/deg squarewave and MF grating. The sine/square contrast ratios at matchpoint were 1.27 or greater, which indicates that subjects required more contrast in the sine wave to equal the apparent contrast of a square wave. This result replicates Ginsburg et al. The sine/MF ratios were lower than the sine/square ratios at all contrast levels by a factor of 1.3. Since the only difference between the square and missing fundamental gratings is the presence of the fundamental, these results suggest that the fundamental does influence squarewave apparent contrast, even at low contrast levels where the illusion exists. This interpretation was confirmed in an adaptation experiment, where subjects adjusted the contrast of a 0.5 c/deg square wave to match the apparent contrast of an lowcontrast, illusory missing fundamental grating. The ratio of square and missing fundamental contrasts at the match point without adaptation were reliably higher than the square/missingfundamental ratios after adaptation to a 0.4 contrast fundamental. This difference in adapted and unadapted ratios suggests that the fundamental does influence the apparent contrast of a squarewave grating since adaptation to the fundamental has a greater effect on apparent contrast of a squarewave grating than a missing fundamental grating. These two experiments suggest that Campbell et al's explanation of the missing fundamental illusion is incorrect.

On the other hand, we have replicated and extended Campbell et al's data in a third experiment, using a contrast discrimination task employing identical stimuli and a two interval, forcedchoice procedure. Trained subjects provided contrast detection and discrimination functions, for 0.5 cy/deg square and MF gratings, defined over eight background contrasts. The square and MF functions were essentially identical for all three subjects, providing no evidence that F influences detection or discrimination.

These experiments support Ginsburg et al's notion that the fundamental influences apparent contrast. We also replicated and extended Campbell et al's observation that the fundamental does not influence detection or discrimination. This difference in matching and detection/discrimination data may reflect differences in pattern processing mechanisms associated with the two tasks. Judgments of the quality of a stimulus (matching task) may reflect processes that are independent of, or subsequent to, processes that mediate detection/discrimination judgments.

The purpose of the present project was to replicate and extend the matching and detection results to a larger range of spatial frequencies and contrasts, and to obtain more rigorous and quantitative data to estimate the contrast level at which the missing fundamental illusion "breaksdown". The results described below are qualitatively similar to our previous findings. Our results are inconsistent with predications of models that relate contrast threshold and apparent contrast functions, as well as simple heuristics that relate visibility of pattern information to the judgments of pattern structure. However, potential stimulus artifacts, discovered near the completion of the project, make it difficult to support a clear interpretation of the data. Therefore the conclusions stated below are only tentative.

METHODS

Subjects. Data were collected from five trained subjects. Three were aware of the hypotheses.

Stimuli and Apparatus

The stimuli are represented in Figure 1. Four cycles of a sine, square, and missing fundamental gratings were generated on the face on a Conrak monitor (P31 phosphor) using a custombuilt pattern generator board housed in a microcomputer. Luminance of the monitor was calibrated using an Spectra Research Photometer. The display was linear up to contrasts of approximately 0.5. At the viewing distance of 35 cm, the display subtended 32 x 28 degrees of visual angle, and the grating corresponded to 0.125 c/deg. Spatial frequencies of 0.25, 0.5, and 1.0 c/deg were obtained by increasing the viewing distances to 70, 140, and 280 cm respectively. A spaceaverage luminance border of 0.1 degrees immediately surrounded the grating, and the outer surround was dark.

The luminance profiles represented in Figure 1 were actually not the luminance profiles that were obtained using this apparatus. An undetected voltage transient was present in the system, and corrupted the edge of the waveforms. Therefore, the stimuli are difficult to characterize.

RESULTS

Contrast Sensitivity

Contrast sensitivity estimates for each of the three waveforms were collected at 0.125, 0.25, 0.5, and 1.0 c/deg using a two interval, forcedchoice, 3down 1 up staircase procedure. The order of the three gratings, and the order of viewing distance, was counterbalanced within and across subjects. Four estimates of each condition were collected for BRS and SCF; two estimates per condition were provided by KD. The other two subjects provided one estimate per condition. The results for the three subjects are qualitatively similar. At low spatial frequencies, sensitivities for the square and Mfund gratings are similar and both yield higher sensitivity than the sine grating. At higher spatial frequencies, contrast sensitivity for the Mfund grating tends to drop relative to the square, and the sine sensitivity tends to increase relative to the square grating. These observations are in qualitative agreement with results reported previously by other laboratories (e.g Campbell et al, 1982).

Contrast Matching

A two interval forced choice contrast matching task was used with the method of constant stimuli to estimate the point of equal apparent contrast for square and MF gratings. The MF grating was fixed at 8 contrasts for each of the 4 spatial frequencies. The lowest contrast of the MF was set to a value 1.5 greater than the contrast threshold of the MF. The other contrasts were increased by 2 dB, yielding a 16 dB range of fixed contrasts. During each trial, a square grating was presented in one interval, and the MF grating was presented in the other. The subject indicated by button press which interval contained the greater maximum contrast. For the purpose of this matching task, subjects were instructed to define apparent contrast as the difference between the brightest and darkest point in the waveform. For each contrast of the MF, eight contrasts of a square grating were paired with the fixed contrast MF grating. Each pairing was presented in a block of eight trials in random order. Ten blocks per condition were presented. The point of equal apparent contrast was taken as the contrast of the square associated with 50 %.

Although the data demonstrated nontrivial individual differences in the matching functions, they are similar. For all spatial frequencies and contrasts, subjects require less contrast in the square grating to match the apparent contrast of the MF. This effect is much stronger for BRS compared to the other two subjects, but the pattern is quite clear. In addition, all subjects tend to show larger effects as the spatial frequency of the stimuli are increased. Relative to 0.125 c/deg, subjects require much less square wave contrast at higher frequencies to match the apparent contrast of same frequency MF gratings.

The Existence Region of the Missing Fundamental Illusion

To estimate the contrast at which the MF illusion begins to "breakdown", subjects were presented with 8 contrasts of the mf and square grating in single presentations, and asked to indicate whether the stimulus exhibited a uniform or scalloped brightness distribution across the light and dark bars. The eight contrast levels for both the MF and square gratings were identical to the MF contrast levels presented in the matching task. The stimuli were presented in five, 32 trial blocks. Each block contained two presentations of each stimulus at each of the eight contrast levels, in random order. This trial sequence was selected to reduce the ability of the subject to use apparent contrast level as a cue to identify the stimulus being presented. The contrast of the MF grating associated with 50% correct labeling was taken as the "scallop" threshold. In general, all subjects show a larger existence region for the illusion than one would expect based on the assumption that the illusion is due to poor sensitivity to the fundamental. These results then do not replicate Campbell et al.

DISCUSSION

The results of these three experiments have implications for models of contrast processing, as well as the relationship between pattern information and the perception of pattern structure. First, there is clear evidence that the apparent contrast of squarewave gratings is judged higher than the apparent contrast of missing fundamental gratings, even under lowcontrast, low frequency conditions. This result, taken together with the replication of the observation that square and missing fundamental stimuli have the same contrast threshold. presents a problem for models that attempt to account for both threshold contrast sensitivity and suprathreshold apparent contrast data. For example, the model of Cannon and Fullenkamp (1991) can be used to predict the relative contrast sensitivity and apparent contrast for these stimuli.

Consider first the 0.125 c/deg condition. The predicted response of the model as a function of stimulus contrast for the squarewave and missing fundamental grating is very similar for low contrasts, which suggests that contrast threshold would be similar for both wave forms. Our data, as well as previously reported data, are consistent with this prediction. Above threshold, however, the model predicts little difference in response to the two stimuli, suggesting that the apparent contrast of the two should be similar when the physical contrast of the stimuli are identical. To compare our contrast matching data with the predictions of the model, we assumed that the two gratings would be judged equal in apparent contrast when the response to the two gratings was equal. We calculated the predicted response to the square grating for the contrast match value, and plotted the contrast of the missing fund at equal apparent contrast value at the same response level.

Although the model is a reasonable first approximation to the data for most subjects, it is clear that the predicted responses to the missing fundamental stimuli, relative to the square, are too high. These observations suggest that the model gives too much weight to the harmonics, relative to the fundamental, for judgments of apparent contrast, but not for predicting contrast sensitivity.

These interpretations must remain tentative due to the stimulus artifact described above (see methods). However, if the pattern of the results replicates with corrected stimuli, the results of these experiments suggest that a simple explanation of the missing fundamental illusion in terms of sensitivity to the fundamental is not correct. Most subjects indicate that the illusion persists at contrasts higher than predicted by the estimates of contrast sensitivity for the fundamental. Thus it is unlikely that the illusion exists because, at low contrasts, the fundamental of a square wave grating is not detectable. Furthermore, the contrast matching data indicate that the fundamental does contribute to the apparent contrast of a square wave grating across both illusory and non-illusory contrast levels. Both results suggest that the visual system has information available that indicates the presence of the fundamental in the square wave grating. Therefore the illusion can not be due to the absence of such information.

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TITLE: RAPID COMMUNICATION (RAPCOM) DISPLAY FORMATS FOR INTEGRATION AND FOCUSED ATTENTION TASKS

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RAPID COMMUNICATION (RAPCOM) DISPLAY FORMATS FOR INTEGRATION AND FOCUSED ATTENTION TASKS

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ABSTRACT

RAPCOM (rapid communication) displays have been shown to have useful potential human-computer interactions involving high information transfer rates (cf., Matin and Boff, 1988). An experiment was conducted to evaluate the relative effectiveness of various spatial and temporal display formats for presenting information pertaining to the likelihood of aircraft stall using the simulated dynamics of a light aircraft. Specific spatial and temporal characteristics of the display formats were based on the proximity compatibility principle (PCP) which attempts to integrate findings regarding the benefits and limitations of displaying multiple sources of information in similar or "proximal" ways (Wickens and Andre, 1990; Carswell and Wickens, 1990).

The effectiveness of these display formats were compared for judgments which required the **integration** of three display parameters (airspeed, bank, and flap angle) to determine stall probability with those requiring **focused attention** necessitating the recall of the specific value of one of the parameters. Overall, the RAPCOM display format was generally associated with the best performance, but the findings were not consistent with design guidelines suggested by the PCP.

INTRODUCTION

Computer-driven instrumentation systems and informational displays have the potential to enhance the amount and rate of human information transfer in situations ranging from dynamic tasks involving high mental workloads and attentional switching (e.g., avionics, nuclear power plant control, biomedical monitoring) to those requiring extremely fast repetitive tasks (e.g., document processing or quality control). Issues related to information formatting are especially relevant in avionics with the advent of multi-function CRTs and head-up and helmet-mounted displays. Effective implementation of these display technologies requires research into formats for presenting information at fast rates in limited space. Such formats should take advantage of computer automation and graphics, as well as be compatible with optimal human information processing capabilities.

Recently, Matin and Boff (1988) have suggested a sequential format for automated displays which has the potential for increasing rates of information transfer. Their research compared conditions involving presentation of arrays of numbers in a "normal" spatial display mode with those involving presentation of the arrays in a sequential mode which they called RAPCOM for "rapid communication." They found a substantial decrease (approximately 50%) in the time required to read and recall numbers displayed serially. Subsequently, there have been additional reports of performance benefits associated with serial compared to simultaneous presentation formats (Swierenga, Boff and Donovan, 1988; 1991; Matin and Boff, 1990; Swierenga and Donovan, 1990; Uhlarik and Renfro, 1990; 1991).

The primary purpose of the present experiments was to evaluate RAPCOM display formats in the context of an integration task that was prototypical of complex monitoring/warning tasks (cf., Wickens and Andre, 1990). Specifically, observers had to monitor three variables (airspeed, bank, and flap angle) necessary to appreciate the likelihood of light aircraft stall. On the one hand, each variable in isolation is of operational importance (focused attention), yet on occasion they also must be integrated to create a derived variable of critical importance. In the case of focused attention, information must be extracted from a single variable without being distorted or disrupted by the other variables or display characteristic; in the case of the integration task the information from the three variables had to be combined to determine a complex higher order variable (stall likelihood).

In addition to exploring potential performance advantages of RAPCOM displays, specific spatial and temporal parameters were choosen to examine the generalizability of the of the "proximity compatibility principle" (PCP) for display design suggested by Wickens. et al., (1988, 1990.) This principle attempts to relate the processing of displayed information to the nature of task information-processing characteristics. It asserts that tasks involving information integration will benefit from "close mental proximity", whereas task that require independent monitoring of several independent variables (focused attention) will benefit from "low mental proximity".

According to Wickens and Andre (1990), successful employment of the PCP "... requires a careful, objective specification of what is meant by display proximity." (p. 62). Spatial proximity (defined by physical metrics for extent) is clearly an important display variable, yet Wickens and Andre found no systematic effects for spatial proximity on either focused attention or integration performance. In a RAPCOM display information is presented in the same spatial location (high spatial proximity), but at different points in time (low temporal proximity). In a more traditional spatial display information is presented simultaneously (high temporal proximity) at different spatial locations (low spatial proximity). Table 1 summarizes four display formats utilized in the present studies. Table 1 indicates that in addition to the RAPCOM and spatial display formats, there was a spatial-temporal condition in which the equivalent information was presented sequentially (low temporal proximity) and in different spatial locations (low spatial proximity) and a single spatial condition in which all of the information was presented simultaneously (high temporal proximity) very close together within the range of foveal vision (high spatial proximity). Figure 1 shows schematically these same four display formats. Both analog and digital versions of the RAPCOM, spatial, and spatial-temporal display were utilized, but because of size constraints single-spatial format was feasible only in a digital version.

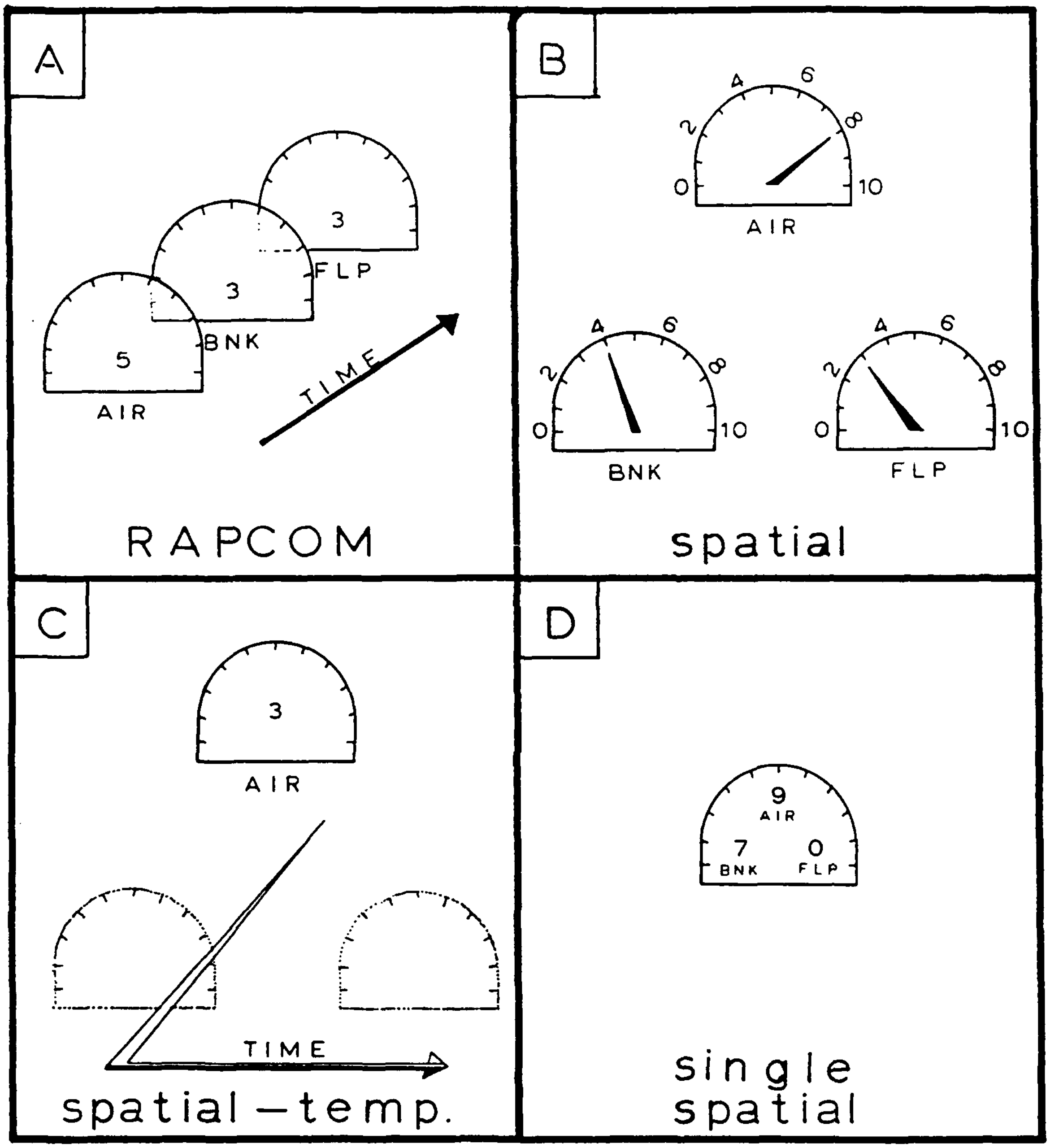

Figure 1. Schematic representation (not to scale) of the four different display formats. Panels A, C and D are shown with digital indicators, whereas Panel B is shown with analog indicators. With the exception of single-spatial format (Panel D) which was too small for analog indicators, both analog and digital versions of the formats shown in Panels A thru C were utilized.

Table 1. Spatial and Temporal Proximity-Compatibility Relationships for the Display Formats

Display Format	Proximity Compatibility	
	Temporal	Spatial
Spatial-temporal	low	low
RAPCOM	low	high
Spatial	high	low
Single-spatial	high	high

METHOD

Task. Initially the observers were given instructions regarding the stall simulation and, within a certain degree of uncertainty, how to utilize the three variables to determine stall likelihood on a scale from 1-10. Each indicator value could take on a integer value from 0 to 10. They were instructed to be as accurate as possible ("an error greater than 1 was considered dangerous"), but to also respond as quickly as possible. Feedback was provided after every trial, and the first session (280 trials) was considered practice. Information regarding airspeed, bank and flap angle was presented in one of the seven formats.

A retrospective probe technique (Carswell and Wickens, 1987) was used to prompt information processing requiring either focused attention (specific values of airspeed, bank and flap angle) or integration (stall likelihood).

Observers were required to fixate a small spot of the display and then to initiate a trial by pressing a key. The fixation spot was always positioned in the center of indicator for airspeed. Performance accuracy was measured as the absolute difference between the actual response and the correct response; speed was assessed in terms of the latency between the prompt for either "stall likelihood", "airspeed," "bank" or "flap angle" and a keypress indicating the subjects response. Eight subjects from a paid subject pool participated in three session lasting approximately an hour each. The subjects had experience with computed automated displays based on participation in previous research, but had no formal flight training.

Stimuli. An IBM-compatible 80286 computer with EGA graphics (640 by 480 pixel resolution) and a NEC Multisync Plus monitor were used to present the stimuli and record the observers response. A chin rest fixed the viewing distance at 64 cm from the screen. The height of all integers used to display indicator values subtended 0.6 deg of visual angle, and the centers of the three indicators formed an equilateral triangle that was 11 deg on a side in the spatial and spatial-temporal conditions.

The presentation time for each trial was 0.75 or 1.5 s during the first (practice) session and 0.525 or 1.05 s for the second and third sessions. In the two "spatial" conditions (i.e., spatial and single spatial), all three indicator values were presented simultaneously in different spatial locations for the total duration of the presentation time. Whereas, the RAPCOM display format involved sequential presentation of individual integers in the same spatial location (the center of the screen), and the spatial-temporal format involved sequential presentation in the three different spatial locations used in the spatial format. For these two "temporal" conditions each of the three indicator value was presented for one-third of the total presentation time so that amount oi information per unit time was equivalent for all conditions.

Design. Each session was 280 trials and consisted of seven blocks of 40 trials. Seven different display formats were made up of the incomplete factorial combinations of the within-subjects variables for **indicator type** (analog and digital) and **display format** (RAPCOM, spatial-temporal, spatial and single-spatial which was feasible only with digital indicators). Subjects were queried for an integration judgement (stall likelihood) for 70 percent of the trials, and for one of the three judgements requiring focused attention for the remaining 30 percent of the trials.

RESULTS

Figure 2 shows the mean absolute error for both focused attention and integration probes for displays using analog indicators. This figure shows that focused attention performance ($\underline{M}$ = 0.64) was much better than integration ($\underline{M}$ = 1.64; $\underline{F}[1,14]$ = 236.9 $\underline{p}<.0001$). Display format also produced significant variation ($\underline{F}[2,14]$ = 17.48, $\underline{p}<.0002$), and the 95 percent confidence intervals shown in Figure 2 indicate that the RAPCOM format was associated with the best performance in that it

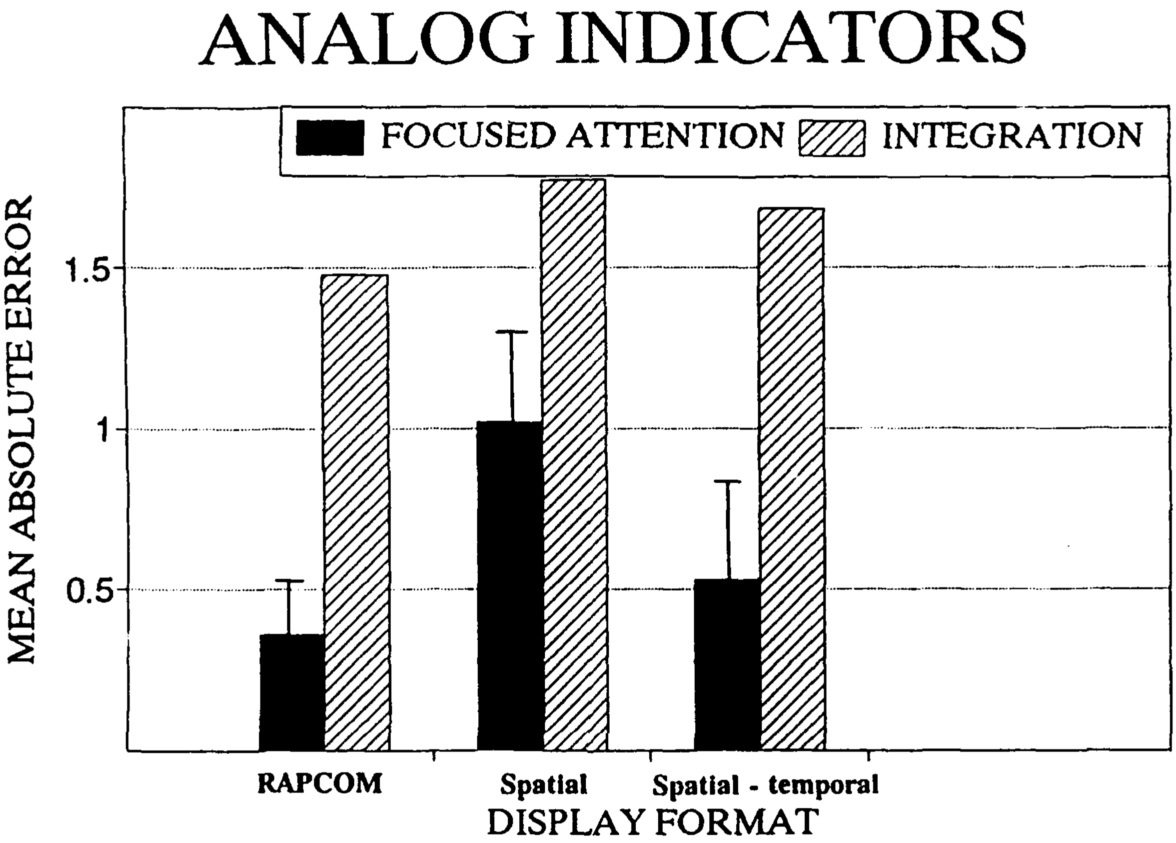

Figure 2. Mean absolute error for the three analog display formats. (The brackets surrounding specific bars represent 95% confidence intervals.)

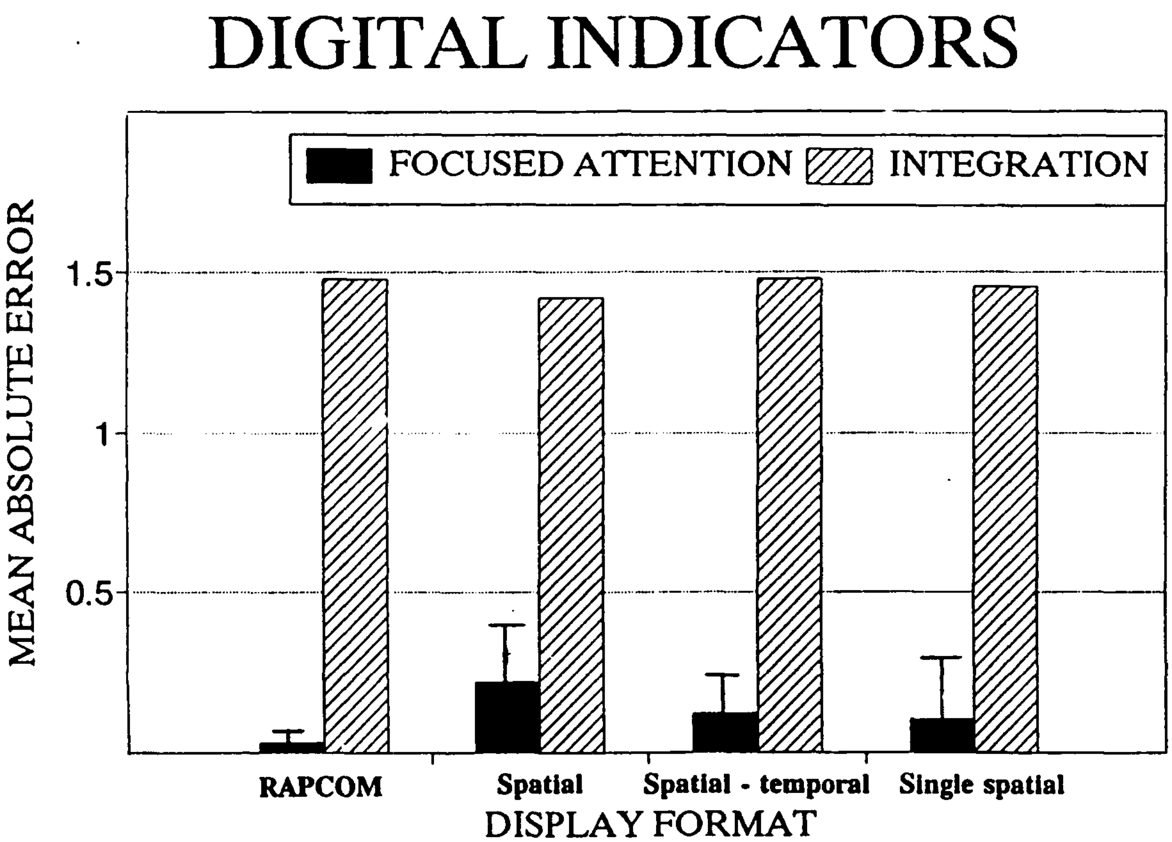

Figure 3. Mean absolute error for the three digital display formats. (The brackets surrounding specific bars represent 95% confidence intervals.)

produced the lowest average error for both focused attention (*M* = 0.36) and integration (*M* = 1.48). Analyses of the chronometric data revealed that focused attention performance (*M* = 2.12 s) was faster than integration performance (*M* = 3.51 s; *F*[1,7] = 6.86, *p*<.03), but there were no systematic chronometric differences for the three analog display formats.

Figure 3 shows the mean absolute error for the digital indicators. Again focused attention (*M* = 0.11) was superior to integration (*M* = 1.5; *F*[1,14] = 308.54, *p*<.0001). For digital indicators the main effect for display format was not statistically significant (*F*[3,21] = 1.11, *p*> .05). However, the 95 percent confidence intervals indicate that again the RAPCOM display produced substantially more accurate performance (*M* = 0.03) for focused attention compared to the other conditions. Again focused attention judgments were significantly faster (*M* = 1.76 s) than was the case for integration (*M* = 3.84 s; *F* [1,7] = 15.68 *p*<.005). Furthermore RAPCOM performance was the fastest of the four digital display format; it was on the average 199 ms faster than the other formats.

DISCUSSION

The RAPCOM display format generally produced the best performance for judgments requiring focused attention, and although not statistically significant, RAPCOM was associated with the best integration performance for displays involving analog indicators.

It appears however, that the integration task which required observers to combine airspeed, bank, and flap angle was not a good discriminator among the various display formats. Despite extensive training (588 integration trials with feedback for each observer), performance averaged at only 30 percent correct for integration. The heuristic needed to derive the answer was complicated, and was always associated with some degree of uncertainty of the part of the subjects. It should also be noted that the results of the present experiment failed to provide support for the PCP suggested by Wickens and Andre (1990). Specifically, the PCP predicts an interaction between focused attention and integration on the one hand, and degree of proximity on the other; i.e., high proximity should facilitate integration and low proximity (high separability) should facilitate focused attention. A number of predictions based on the relations in Table 1 failed to be supported by the findings of the present study. In addition, the general superiority of the RAPCOM display, as opposed to the single-spatial condition, indicates that spatial and temporal factors are not interchangeable in terms of performance benefits and limitations. Further, the findings that the spatial-temporal conditions were generally superior to the spatial conditions suggest that temporal separation per se, has merit in terms of optimal information display formatting.

Follow-on research that explores these spatial and temporal parameters using integration tasks that are more straightforward would appear to be in order. Utilization of an integration algorithm that is more intuitive and straightforward for the subjects would lead to overall higher levels of accuracy and thus allow more sensitive assessment of performance.

ACKNOWLEDGMENTS

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MODELING COMPOSITE WINGS: AN OBJECT ORIENTED SIMULATION APPROACH USING MODSIM II

Dr. Addagatla Babu

ABSTRACT

In this report, we develop a discrete event simulation model of an United States Air Force base-level aircraft maintenance organization serving a composite wing of aircraft. A composite wing is a mix of multiple types of aircraft under one commander. In contrast, a monolithic wing is homogeneous and contains several aircraft of the same type.

An arriving aircraft goes through flight line check and maintenance, obtains service at a selection of intermediary shops and finally gets reconfigured to take off. There are more than twenty such intermediary shops. A simplified model is conceived for ease of prototyping. It consists of airframe repair shop, electrical shop, and environmental control shop in addition to flight line and reconfiguration shop. For a composite wing consisting of F-16, F-15, and KC-135 aircraft, a prototype simulation model is constructed using a modular object-oriented design and the MODSIM II programming language.

The prototype provides an understanding of the nature and scope of the problem as well as modularity and flexibility of the object oriented simulation approach. While demonstrating the modeling feasibility, it makes a case for the development of the complete model. A full scale model would help assess the maintenance resource requirements versus the sorties per aircraft. It can also be used to compare the cost and contributions of maintaining composite versus monolithic wings.

INTRODUCTION

The Air Force is implementing General McPeak's plan of creating composite wings at key bases [1]. A composite wing consists of various types of aircraft under a single command. Traditionally Continental United States (CONUS) based wings are monolithic, containing many aircraft of the same type. In addition to the establishment of composite wings overseas at the forward bases, McPeak [3] opines that there should be some CONUS based composite wings for rapid deployment of the whole range of air capabilities to any part of the world. But the Air Force would still need to maintain monolithic wings - for example with 72 of the same aircraft -because of economies of scale [4].

Mountain Home Air Force Base (AFB), Idaho, and Pope AFB, N.C. will now house composite wings [2]. Two wings at Seymour Johnson AFB will be merged to form a composite wing consisting of KC-10 Extender tankers and F-15E Strike Eagle fighter-bombers [1].

The traditional Air Force structure consisting of monolithic wings do not readily form an efficient composite strike package. On the other hand it may be more expensive to operate and maintain composite wings.

DECISION PROBLEMS

The following considerations are to be taken into account in formulating the decision problems associated with the formation of the composite wings. For each candidate composite wing formation, 1) assess the operational benefits in terms of reduction of force vulnerability and planning cycle time as well as increased tasking effectiveness, 2) assess the reduction of operational costs by streamlining the management, especially, the upper level management, and 3) assess the cost increase in the procurement and maintenance of aircraft maintenance resources (manpower, facilities, and equipment) and spare parts inventory for a given type of maintenance structure. Both the maintenance cost and sortie rate per aircraft are very sensitive to the type and extent of maintenance performed at base level and depot level. Since a composite wing is formed of some or all of the aircraft from certain monolithic wings, the resulting reduction of aircraft would result in reduction in maintenance expenses. Another important consideration is the economies of scale obtained with size or the number of composite wings formed. The interaction effect of geographically related composite wings may be significant.

With all these considerations, the overall problem (P1) is to decide on the formation of composite wings: when, where, what type and size? Where are these constituent aircraft drawn from? What is a sensible maintenance policy, i.e., how are the levels of maintenance defined and who should be authorized to perform these levels? The problem is dynamic in nature. It should respond to technological advancements as well as the ever changing political, military, and economic environments.

THE CURRENT USAF APPROACH

The integrated problem P1 above needs to be addressed simultaneously for an efficient solution. The United States Air Force seems to have made a critical decision in selecting the first three CONUS-based composite wings. The initial solutions look attractive in a short time horizon, but a sound long term strategic plan should take maintenance as well as operational factors into consideration.

Complex problems such as P1 are usually amenable for solution with tactful simulation modeling and analysis [5]. Obtaining reliable data for such a modeling venture is impossible. However the type of data needed to describe two alternative system configurations (For example, a composite wing versus three monolithic wings) is similar. The data collection methods are similar. This may lead to similar biases in the collected data. The inferences made in comparing these configurations using such similarly biased data are highly reliable.

COMPOSITE WINGS MAINTENANCE SIMULATION

Since the problem P1 is beyond the scope of this project, we consider a more tractable portion of the problem. The problem P2 is to assess the maintenance resource requirements versus the sortie rate per aircraft of a Base Level Aircraft Maintenance (BLAM) facility serving a composite wing. We modeled the problem as a discrete event simulation.

Why Simulation works?

Simulation works because it deals with reality. We simulate models of real systems. We get closer to the system than any other type of modeler. We study the old system, collect data, understand first principles about the system, check out procedures in use before we start modeling, and we test proposed solutions against current operations or baseline designs. We do not force a system into a preconceived normative model. We strive to have our models used and our best alternatives implemented. We stay with a problem until a solution is implemented. We recognize that the model upon which we make our recommendations contains additional information and insights that are useful during implementation [6].

A prototype described below is developed using an object oriented approach and the MODSIM II programming language. It is constructed to test the feasibility of an object oriented simulation approach. The composite wing consists of F-16, F-15, and KC-135 aircraft. An aircraft arrives at the maintenance facility randomly with interarrival time following a prespecified probability density function (e.g., exponential with mean 200 hours). An arriving aircraft is F-16, F-15, or KC-135 with prespecified probabilities (e.g., 0.5, 0.35, and 0.15 respectively).

The maintenance service is offered at the flightline, airframe repair shop (shop 1), electrical shop (shop 2), environmental control shop (shop 3), an reconfiguration shop. Each arriving aircraft gets served in the flightline, a selection of the three intermediary shops, and the reconfiguration shop. This selection of the intermediary shops is made for each type of aircraft using prespecified probabilities. For example, an arriving F-16 needs service at shop 1, shop 2, and shop 3 with probabilities 0.2, 0.4, and 0.1 respectively. These probabilities are 0.5, 0.3, and 0.45 for F-15, and 0.1, 0.35, and 0.5 for KC-135. Thus a given aircraft may get served by none, one, some, or all of the three intermediary shops. The service times at flight line, three intermediary shops, and the reconfiguration shop are all assumed to be independent and randomly sampled from prespecified probability distributions. For example the service time follows a normal distribution truncated at zero. This truncation would assure positive service times.

An arriving aircraft is served on a First Come First Served (FCFS) basis at the flight line. The selection of intermediary shops needed to serve this aircraft is determined. Upon completion of service at the flight line, an aircraft is available to be scheduled simultaneously at its selection of intermediary shops. An intermediary shop would serve the aircraft needing its service on FCFS basis.

Advantages of Object Oriented Simulation

In an object oriented simulation, the system is modeled in terms of communicating objects and messages. Objects are capable of performing some predefined actions in response to requests. A message is a request for an object to carry out one of its operations. Messages specify what operations are desired, but not how those operations should be carried out. The receiver, the object to which the message was sent, must have methods defined for carrying out the requested operations. The method invoked returns an answer to the sending object. The power of object oriented programming lies in two conceptual foundations: encapsulation and inheritance. Encapsulation protects objects from change by restricting the access to the objects to those procedures that were put there to control access. Inheritance helps developers describe complex systems quickly and consistently by starting with generic descriptions and specializing them.

The Selection of MODSIM II

The MODSIM II programming language is selected for prototyping for two reasons. First, it is an object oriented simulation language. Modularity in MODSIM II improves reliability and reusability. Objects performing related functions can be grouped into modules. These can be put into libraries for reuse by other programs. Modules permit step-wise development, particularly by separating the definition module from the implementation module. It is a well supported language and is continually growing with the incorporation of several desirable simulation features such as parallel processing and dynamic graphics. Second, TASC is developing an user friendly version of MODSIM II for use in Air Force simulations under a contract, Integrated Model Development Environment (IMDE) from our focal point, i.e., the Logistics Research Division of the Armstrong Laboratory (AL/HRG) located at the Wright Patterson Air Force Base. We may in the future be able to make a smooth transition to using IMDE for the development of a full scale composite wing simulation.

CONCLUSION

In this report, we pose a decision problem concerning the establishment of composite wings of aircraft. The overall problem to determine the locations of composite wings, and prescribe their size, time of establishment, and mix of aircraft. The operational benefits versus costs involved have to be systematically weighed in making these determinations. The problem is dynamic and sensitive to the technological, political, military, and economic changes.

We focus on a portion of this overall decision problem. It involves the assessment of the operational characteristics of a base level maintenance organization serving a composite wing of aircraft. We model this problem as an object oriented discrete event simulation. A prototype simulation is designed and coded using MODSIM II on a SUN 4/ SPARC Station. The listings and a description of this program is attached in the appendix. This prototype has demonstrated the proof of concept and made a strong case for developing a full scale simulation. Such a simulation would be helpful in comparing both sorties per aircraft and maintenance cost for operating composite versus monolithic wings. It can be designed to analyze the impact of various levels of maintenance and the extent of maintenance skill cross training.

FUTURE DIRECTIONS OF RESEARCH

The natural extension of the prototype simulation described here is to build a working maintenance simulation model to assess the cost and maintenance implications of a composite versus monolithic wings under various levels of skill cross training and different allocations of maintenance tasks to a base level maintenance facility. TASC is developing IMDE, an user friendly simulation modeling environment using object oriented design. Since its simulation elements are written in MODSIM II, a smooth transition can be made in coding the simulation model in MODSIM II to coding in IMDE. IMDE's features would improve the simulationist's productivity.

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APPENDIX

A PROTOTYPE BASE LEVEL AIRCRAFT MAINTENANCE SIMULATION: MODSIM II PROGRAM LISTINGS AND A DESCRIPTION

```
MAIN MODULE Wing;

{ AUTHOR : Jacqueline C. Schnepp
           Summer Research Associate
           July, 1991.
   This complete program is a prototype simulation of an airbase maintenance
   facility capable of maintaining a composite wing.  Actual data is not used
   in this prototype.}

FROM  SimMod IMPORT SimTime, StartSimulation,ResetSimTime;
FROM Controller IMPORT ModelInit,ControllerObj;

VAR
  ProgramBegin : ControllerObj;

BEGIN  {main code -- Time Base of this model is in minutes}

NEW(ProgramBegin);
ModelInit;
TELL ProgramBegin TO Control;
StartSimulation;

END MODULE.
```

```
DEFINITION MODULE Controller;

{AUTHOR : Jacqueline C. Schnepp, July 1991.}

FROM MaintShops IMPORT ShopObj;
FROM RandMod IMPORT RandomObj;
FROM Aircraft IMPORT AirType;

VAR
   plane : AirType;
   Stream1, Stream2, Stream3 : RandomObj; {used for random number generation}

TYPE

 ControllerObj = OBJECT { Controls the flow of the aircraft instances.}
   TELL METHOD Control;
 END OBJECT;


PROCEDURE ModelInit;
  VAR
       F16,F15,KC : AirType;
       shop : ShopObj;
       StopTime : REAL;

END MODULE.
```

```
IMPLEMENTATION MODULE Controller;

{AUTHOR : Jacqueline C.Schnapp, July 1991.}

FROM MaintShops IMPORT ShopObj,StartShops;
FROM RandMod IMPORT RandomObj, FetchSeed;
FROM Aircraft IMPORT AirType,CraftInit;
FROM SimMod IMPORT SimTime;

{------------------------------------------------------------}

PROCEDURE ModelInit;

{ Initializes the model.}

BEGIN

  NEW(plane);
  NEW(shop);
  StartShops; { Initializes the shops involved.}
  CraftInit;  { Initializes the aircraft types.}
  StopTime := 20000.0;  { Length of simulation run.}

END PROCEDURE;

{------------------------------------------------------------}

OBJECT ControllerObj;

{------------------------------------------------------------}

TELL METHOD Control;

{ Controls the flow of the system and keeps it running until the simulation
  time reaches the given StopTime. }

VAR
  WaitBetween : REAL;

BEGIN

  NEW(Stream1);  { random number stream used for arrival rates.}
  NEW(Stream2);  { random number stream used for the draw for comparison.}
  NEW(Stream3);  { random number stream used for the repair times. }
   ASK Stream2 TO SetSeed(FetchSeed(2)); {sets different seeds for each stream}
   ASK Stream3 TO SetSeed(FetchSeed(3));
   WHILE SimTime() < StopTime
     NEW(plane);
     TELL plane TO Arrive;
     WaitBetween := ASK Stream1 Exponential(200.0); { wait time between each
                                                      arrival}
     WAIT DURATION WaitBetween
     END WAIT;
   END WHILE;

END METHOD;

{------------------------------------------------------------}
END OBJECT;
END MODULE.
```

```
DEFINITION MODULE Aircraft;

{AUTHOR : Jacqueline C. Schnepp, July 1991.}

FROM GrpMod IMPORT StatQueueObj;
FROM MaintShops IMPORT BeginShop,EndShop,ShopObj,GrpShops;

TYPE

 WaitGrp = OBJECT(StatQueueObj) {Statisitical group which will hold aircraft
                                  waiting for a particualr shop to free up
 END OBJECT;                        resources.}

 AirType = OBJECT
        ShopsToVisit : GrpShops; { A group of shops which is determined
                                   dynamically for each aircraft instance to
                                   visit.}

        ASK METHOD FindShops(IN craft : AirType);
        TELL METHOD Arrive;
        TELL METHOD Depart;
        TELL METHOD VisitShops(IN craft : AirType; IN STV : StatQueueObj);
        TELL METHOD CheckLine(IN name : STRING; IN Wait: WaitGrp);

CLASS
        EntryProb : ARRAY INTEGER OF REAL; { An array for each aircraft type
                                              of the probabilities it will enter
                                              each shop in the system}
        ASK METHOD ArrayInit(IN sh1,sh2,sh3 : REAL);

END OBJECT;

VAR
  WaitLine : WaitGrp;  {Variable named used for the queue group}
  F16, F15, KC, plane : AirType; {The three types of aircraft used in the
                                  prototype.}

PROCEDURE CraftInit;

END MODULE.
```

```
IMPLEMENTATION MODULE Aircraft;

{AUTHOR : Jacqueline C. Schnepp, July 1991.}

FROM MaintShops IMPORT ShopObj, StartShops, BeginShop, EndShop, GrpShops, Maintenance;
FROM SimMod IMPORT SimTime;
FROM Controller IMPORT StopTime,Stream1,Stream2,Stream3;
FROM GrpMod IMPORT StatQueueObj;

{------------------------------------------------------------------}

PROCEDURE CraftInit;

{ Initializes the probabilities used for each type of aircraft to enter each shop.}

BEGIN
  NEW(WaitLine);
  NEW(F16);
  NEW(F15);
  NEW(RC);

  { Each aircraft type has its own array labelled as EntryProb.}

   ASK F16 TO ArrayInit(0.20,0.40,0.10);
   ASK F15 TO ArrayInit(0.50,0.30,0.45);
   ASK RC TO ArrayInit(0.10,0.35,0.50);

END PROCEDURE;

{------------------------------------------------------------------}

VAR
  RepairShops : GrpShops;
  rtime : REAL;               {repairtime}
  shop, line, visit : ShopObj;
  visname,shname : STRING;
  crew,avail : INTEGER;

OBJECT AirType;
{------------------------------------------------------------------}

ASK METHOD ArrayInit(IN sh1,sh2,sh3 : REAL);

{ Invoked by the CraftInit Procedure, this method allocates the EntryProb
  array with the given data for each aircraft type.}

 BEGIN
  NEW(EntryProb, 1..3);
  EntryProb[1] := sh1;
  EntryProb[2] := sh2;
  EntryProb[3] := sh3;

END METHOD;

{------------------------------------------------------------------}

TELL METHOD Arrive;

{ Simulates the arrival of an aircraft instance into the Maintenance Shop
  system. Through a discrete distribution setup, the type of aircraft
  entering the system is decided.}
```

```
VAR
  PlaneType : REAL;

BEGIN

  PlaneType := ASK Stream2 UniformReal(0.0,1.0);
  IF PlaneType < 0.50
    NEW(F16);
    ASK F16 TO FindShops(F16);
  ELSIF PlaneType < 0.85
    NEW(F15);
    ASK F15 TO FindShops(F15);
  ELSE
    NEW(RC);
    ASK RC TO FindShops(RC);
  END IF;

END METHOD;

{------------------------------------------------------------}

ASK METHOD FindShops(IN craft : AirType);

{ Selects which shops the aircraft instance must visit in the system and places
  a copy of the Shop into the statistical group ShopsToVisit which is specific
  to each instance.}

VAR
  draw : REAL;
  postflight,shop : ShopObj;
  i : INTEGER;

BEGIN

  postflight := BeginShop;              {All aircraft instances must go through
                                         the first shop, Postflight.}
  rtime := ASK Stream3 Normal(250.0,20.0);
  TELL postflight TO RepairCraft(2,rtime,BeginShop);
  NEW(ShopsToVisit);
  shop := ASK Maintenance First();
  WHILE shop <> NILOBJ
   FOR i := 1 TO 3
    draw := ASK Stream2 UniformReal(0.0,1.0);
   IF draw < EntryProb[i]
     ASK ShopsToVisit TO Add(shop);
  END IF;
    shop := ASK Maintenance Next(shop);
   END FOR;
  END WHILE;
  IF ShopsToVisit <> NILOBJ
   TELL craft TO VisitShops(craft,ShopsToVisit);
  ELSE
   TELL craft TO Depart;
  END IF;

END METHOD;

{------------------------------------------------------------}

TELL METHOD VisitShops(IN craft : AirType; IN STV : StatQueueObj);

{ The process of finding which shops in the instance's ShopsToVisit group have
  available resources to work on the aircraft.}
```

```
BEGIN

  RepairShops := Maintenance;
  visit := ASK ShopsToVisit First();

                                             { Locate a match of the Shopnames in the
                                              instances group against those in the
                                              Shop group.}
  WHILE visit <> NILOBJ
    shop := ASK RepairShops First();
    WHILE shop <> NILOBJ
      visname := ASK visit ShopName;
      shname := ASK shop ShopName;
      IF visname = shname
        crew := ASK shop CrewNo; { Check that there is enough available crew.}
        avail := ASK shop TO ReportAvailability();
        IF crew < avail
          rtime := ASK Stream3 Normal(400.0,35.5);
          TELL shop TO RepairCraft(crew,rtime,shop);
          shop := NILOBJ;
          IF WaitLine <> NILOBJ
            TELL craft TO CheckLine(visname,WaitLine);
   { Check if an instance in the queue could use the recently freed resources.}

          END IF;
        ELSE
          ASK WaitLine TO Add(visit);
   { Put the instance in the queue if the shop is unavailable.}

        END IF;
      ELSE
        shop := ASK RepairShops Next(shop);
      END IF;
    END WHILE;
      visit := ASK ShopsToVisit Next(visit);
  END WHILE;

  TELL craft TO Depart;
  { Instance goes to final shop after all ShopsToVisit have been visited.}

END METHOD;

{----------------------------------------------------------------------}

TELL METHOD CheckLine(IN name: STRING; IN Wait: WaitGrp);

{ Invoked by a recently released shop in VisitShops. Searches through all
  the craft instances waiting for a particular shop to see if the
  recently released shop will meet its needs.}

BEGIN

  visname := name;
  WaitLine := Wait;
  line := ASK WaitLine First();
  WHILE line <> NILOBJ
    shname := ASK line ShopName;
    IF visname = shname
      crew := ASK line CrewNo;
      avail := ASK shop TO ReportAvailability();
```

```
      IF crew < avail
        rtime := ASK Stream3 Normal(400.0,35.5);
        TELL line TO  RepairCraft(crew,rtime,shop);
        ASK WaitLine TO RemoveThis(line);
      END IF;
    ELSE
      line := ASK WaitLine Next(line);
    END IF;
  END WHILE;

END METHOD;

{------------------------------------------------------------------}

TELL METHOD Depart;

{ All aircraft instances must go through the final shop, Preflight.}

VAR
  preflight : ShopObj;

BEGIN

  preflight := EndShop;
  rtime := ASK Stream3 Normal(300.0,30.0);
  TELL preflight TO RepairCraft(2,rtime,EndShop);

END METHOD;

{------------------------------------------------------------------}

END OBJECT;

END MODULE.
```

```
DEFINITION MODULE MaintShops;

{ AUTHOR : Jacqueline C. Schnapp, July 1991.}

FROM ResMod IMPORT ResourceObj;
FROM GrpMod IMPORT StatQueueObj;

TYPE
 ShopObj = OBJECT(ResourceObj)
  CrewNo, DayShift, NightShift : INTEGER;
  ShopName : STRING;

  TELL METHOD RepairCraft(IN cr : INTEGER; IN rt:REAL; IN sh:ShopObj));
  ASK METHOD Init(IN crew,ds,ns:INTEGER;IN name:STRING;
                               IN number: ShopObj));
 END OBJECT;

 GrpShops = OBJECT(StatQueueObj)); { Statistical group of all the shops used
                                    in the prototype.}
  ASK METHOD ChangeShift;
 END OBJECT;


PROCEDURE StartShops;

 VAR

  BeginShop,EndShop,Shop1,Shop2,Shop3 : ShopObj; {The five shops used }
  Shop,Change : ShopObj;
  Maintenance : GrpShops;

END MODULE.
```

```
IMPLEMENTATION MODULE MaintShops;

{ AUTHOR : Jacqueline C. Schnepp, July 1991.}

FROM SimMod IMPORT SimTime;
FROM GrpMod IMPORT StatQueueObj;
FROM RandMod IMPORT RandomObj;
{--------------------------------------------------------------------}

PROCEDURE StartShops;

{ Initializes the shops and their attributes which will remain static
  throughout the simulation. }

BEGIN

 NEW(Maintenance);
 NEW(BeginShop);
 NEW(EndShop);
 NEW(Shop1);
 NEW(Shop2);
 NEW(Shop3);
  ASK BeginShop TO Init(2,6,3,"Flightline",BeginShop);
  ASK EndShop TO Init(2,6,3,"Reconfigure",EndShop);
  ASK Shop1 TO Init(2,4,2,"Airframe Repair",Shop1);
  ASK Shop2 TO Init(1,6,3,"Electrical",Shop2);
  ASK Shop3 TO Init(1,3,1,"Environ Control",Shop3);

 { Puts the intermediary shops into a common group to ease manipulation.}

  ASK Maintenance TO Add(Shop1);
  ASK Maintenance TO Add(Shop2);
  ASK Maintenance TO Add(Shop3);

END PROCEDURE;

{--------------------------------------------------------------------}
OBJECT ShopObj;
{--------------------------------------------------------------------}

ASK METHOD Init(IN crew,ds,ns : INTEGER; IN name : STRING;
                IN number : ShopObj);

{ Invoked by tthe StartShops procedure, assigns the inputed attributes to
  common variables. }


VAR
  Shop : ShopObj;

BEGIN

  Shop := number;
  ASK Shop TO Create(ds);           {creates ds number of resourcesfor each shop}
  ASK Shop TO SetAllocationStats(TRUE); {collects statistics for each shop}
  ShopName := name;
  DayShift := ds;          {number of resources on the day shift}
  NightShift :=ns;         {number of resources on the night shift}
  CrewNo := crew;          {number of resources needed to work on one job on
                            an aircraft}

END METHOD;
```

```
{------------------------------------------------------------}
TELL METHOD RepairCraft(IN cr:INTEGER; IN rt:REAL; IN sh:ShopObj);

{The craft instance is delayed by the rtime and using cr resources of thr
 shop thus simulating the repairing of an aircraft.}

BEGIN

 Shop := sh;
 WAIT FOR Shop TO Give(SELF,cr) END WAIT;
 WAIT DURATION rt END WAIT;
 ASK Shop TO TakeBack(SELF,cr);

END METHOD;

END OBJECT;
{------------------------------------------------------------}
OBJECT GrpShops;
{------------------------------------------------------------}

ASK METHOD ChangeShift;

{ At every twelve hour interval the shifts in the Maintenance Shops change
  from day to night or night to day.  The resources allocated to each shop are
  incremented or decremented accordingly. INitially the system starts on the
  day shift.}

 VAR
   a,c,x,z  : REAL;
   b,shift,r,s,w,y :INTEGER;

BEGIN

   x := SimTime()/720.0; { Checks if twelve hours have passed.}
   y := TRUNC(x);
   z := FLOAT(y);
   IF x = z
     a := SimTime()/1440.0; {Checks if twenty-four hours have passed.}
     b := TRUNC(a);
     c := FLOAT(b);
       IF a =c
         shift := 2;  {presently day shift}
       ELSE
         shift := 1;  {presently night shift}
       END IF;
    Change := ASK Maintenance First();
    WHILE Change <> NILOBJ
     r := ASK Change DayShift;
     s := ASK Change NightShift;
     w := (r-s);
      IF shift = 1
        ASK Change TO IncrementResourcesBy(w);
      ELSE
        TELL Change TO DecrementResourcesBy(w);
      END IF;
      Change := ASK Maintenance Next(Change);
    END WHILE;
  END IF;

END METHOD;
```

```
  END OBJECT;
END MODULE.
```

Composite Wing Prototype Using MODSIM II

What It Is

This prototype is a discrete event generic object-oriented simulation model of an airbase maintenance department consisting of many specialized shops which have the capabilities of maintaining and repairing more than one type of aircraft.

When an generic aircraft arrives in the system a discrete probability function decides what aircraft type the instance will be assigned. Each arriving aircraft must initially enter the Postflight Shop for repairs. Upon completion the aircraft will then visit a selection of intermediary shops. This selection is dynamically decided upon by each aircraft instance using wayward probabilities specific to the type of aircraft. The instance has the chance of visiting none, one, some or all of the intermediary shops. All aircraft must finally visit the Preflight shop for inspection. The service or repair times for each shop are independent and sampled from a normal distribution.

When a maintenance shop is unable to allocate the resources to repair an aircraft in need of its services, the aircraft instance is put into a queue to wait for the shop to be released by other aircraft. It will be served on a first come first serve basis. If the aircraft has other shops to visit it will check their availability while it is waiting for the unavailable shop. Therefore shops can simultaneously work on one aircraft.

Assumptions Made

1. All the maintenance shops and their crews have the capability of handling any type of aircraft.
2. Any shop can work simultaneously with any other shop in the Maintenance Department.
3. All aircraft instances must go through the Postflight Shop before any other Maintenance shop first and go to the Whereat Shop last.
4. Each aircraft type has an exponential interarrival time.
5. There is no limitation to the number of aircraft instances or aircraft type that can enter the system during the simulation run.
6. Each intermediary shop has the same normal distribution parameters for the repair time.
7. Specific to this model:
   - There are only five Maintenance Shops, three intermediary, Postflight and Whereat.
   - Only three types of aircraft can enter the system, F16, F15, KC-135.

Program Specifics

A. Modules

1) MWing.mod - Main Module
2) DAircraft.mod, IAircraft.mod - Aircraft Library Module
3) DController.mod IController.mod - Controller Library Module
4) DMaintShops.mod, IMaintShops.mod - Maintenance Shop Library Module

B. Objects

1) AirType - OBJECT
Located in the Aircraft Library

Attribute:
ShopsToVisit(StatQueueObj) - each instance stores the selected intermediary shops in this group object.

Methods:
FindShops - allocates an aircraft instance's selected intermediary shops to its ShopsToVisit variable.
Arrive - simulates the arrival of an aircraft instance into the Maintenance Shop system. It picks the aircraft type that is arriving through a discrete distribution.
VisitShops - takes the instance through the shops specified in its ShopsToVisit group and the initial Postflight.
CheckLine - searches through all the craft instances waiting for a particular shop to see if a recently released shop will meet any instances' needs.
Depart - sends each instance through the final, Preflight Shop.

Class Attribute:
EntryProb - an array of probabilities to enter each intermediary shop for each aircraft type.

Class Method:
ArrayInit - initializes the EntryProb array for each aircraft type.

Variable:
WaitGrp(StatQueueObj) - the group which stores the aircraft instances waiting for a specific available shop.

2) ControllerObj - OBJECT
Located in the Controller Library

Method:
Control - controls the flow of the aircraft instances.

3) ShopObj - ResourceObj
Located in the MaintShops Library

Attributes:
DayShift - number of crew on the day shift.
NightShift - number of crew on the night shift.
Crew - number of crew required to work in a specific job.
ShopName - the name of the shop.

Methods:
Init - assigns the numbers inputted to the ShopObj attributes for each shop.
RepairCraft - the aircraft instance is delayed by a random repair time utilizing a certain number of crew from the shop.

C. Procedures

1) ModelInit - located in the Controller Library Module
This procedure starts the initialization of the Maintenance Shop system and the aircraft that will visit it.
2) StartShops - located in the MaintShops Library Module
This procedure initializes the shops and their attributes at the beginning of the simulation run.
3) CraftInit - located in the Aircraft Library Module
This procedure initializes the probabilities used for each type of aircraft to enter each Maintenance Shop.

When Actual Data is Available

1. Arrival Rate
   The prototype uses a generic arrival rate for all aircraft, with the type being decided after the aircraft instance has arrived. This can be updated to having each aircraft type with its own specific arrival rate.

2. Repair Times
   The prototype assumes a normal distribution for repair times and generates for each aircraft instance at the time it seizes the crew from a shop. The intermediary shops have the same parameters. To change to more realistic the distributions are located in the following modules:

   Aircraft.VisitShops : Postflight Shop
   Aircraft.Depart : Preflight Shop
   Aircraft.VisitShops & Aircraft.WaitLine : Intermediary Shops

3. Maintenance Shop Information
   The attributes of each shop are initialized in the StartShops procedure located in the MaintShops Module. To change the values or add a new shop, the initialization must be put in this procedure and the shop name must be defined in the MaintShops Definition Module.

4. Entry Probabilities
   In this prototype each aircraft type has a certain probability attached to each shop that it will need repair in that shop. The EntryProb variable is an array for each type of aircraft and is initialized in the CraftInit Procedure and put into an array in the ArrayInit procedure, both located in the Aircraft Library Module.

5. Statistics Collection
   To collect statistics on a simulation run more program code must be added to the modules. MODSIM II does not have any standardized output form and therefore it is left up to the user as to what format should be used. The MODSIM II Reference Manual has an Appendix listing the different object types and the built in statistical functions they have. The objects in the prototype which can collect statistics are the ShopObj which is a ResourceObj. The queues for the Preflight and Postflight shops can collect statistics but the intermediary shops' queues were overridden and put into the WaitLine which itself is a StatQueueObj.

ACQUISITION MANAGEMENT OF HAZARDOUS MATERIALS -- A DESIGN ADVISOR

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Abstract

A design advisor concept is presented to show how and where the several databases which are available relating to hazardous materials could be used to anticipate and hopefully avoid being surprised by hazardous materials issues on future systems. A review of the very complicated problem facing the designer of minimizing hazards for humans and the environment is presented which shows that different databases would be of interest at the various design stages. The design advisor would involve accessing about 100 different databases which could provide partial information on hazardous materials identification and alternative evaluation. A strategy and software tool concept for identification of hazardous materials is presented. The significance of such a software tool would lie in the ability of the designer to obtain appropriate information in a timely manner.

1. Introduction

Protecting the environment is not only a common sense social goal but also a legitimate national defense role. The present environmental situation was eloquently described by Major Thomas Morehouse in a recent article in the Air Force Journal of Logistics[1]. Morehouse suggests that the Air Force must respond to the environmental concerns in visible and substantive ways for several reasons. A) The U.S. has signed a treaty with about 90 countries in 1987 requiring reductions in chemicals believed to deplete the earth's ozone layer. A complete ban on the use of certain chemicals such as Halon 1301 fire fighting gas is called for by the year 2000. B) The House and Senate recently passed similar versions of a new Clean Air Act legislating a cleaner environment. C) Secretary of Defense Cheney has clearly stated the legitimacy of environmental concerns as a national defense role, "I want the Department of Defense to be the Federal leader in environmental compliance and protection." D) General Henry Viccellio, Jr., Deputy Chief of Staff, Logistics and Engineering, Headquarters, USAF, called for protecting and enhancing the environment needs to become part of the definition of excellence. E) Congressman Richard Ray of the House Armed Services Committee stated "Next to outright conflict itself, this (base cleanup) is probably the No. 1 priority the Department of Defense has to face."

Morehouse also points out that attention to the environment is a method for retaining funding in a deficit budget climate. His strategy is to combine mission requirements with Congressional demands for environmentally responsible action. He mentions that one of the reasons that hazardous waste cleanup is so backlogged today is that the cost of managing the hazardous waste stream was never factored into the cost of doing business. He cites a recent Army study that shows that for every dollar spent to procure a hazardous material, $8 to $10 are required for handling and disposal. The challenge is also clearly stated in DoD Directive 4210.15, July 27, 1989 "it is DoD Policy that hazardous materials shall be selected, used, and managed over its life cycle so that the Department of Defense incurs the lowest cost required to protect human health and the environment." Morehouse also suggests that we must identify, track, and centrally control all hazardous materials from cradle to grave.

Acquisition management of hazardous materials is an important area of broad national concern. The life cycle of a weapon system starts from a conceptual design requirement and ends with the disposition of the system. There are several key points in the life cycle at which acquisition logistics could provide directions which should prevent most if not all environmental concerns. At the design stage when a tentative list of components is determined and their materials specified, one could identify the materials for possible hazardous effects and evaluate alternatives. The identification should consider not only the component materials but also any other materials needed to support the system such as fuel, cleaning materials, etc. and any possible compounds that may be generated. This is of course a burdensome task at least without some design aids. Several computer databases exist which could be used for such a test; however, a clear procedure needs to be developed which will show which databases to use, the expected outcomes and the limitations of the procedures. If a hazardous material must be used because of mission requirements, a thorough search for alternative materials which will still satisfy the requirements should also be made. Again, with the many databases available, it may be possible that a clear procedure could be developed to search for these alternatives. Of course, one must also specify how to choose between the alternatives and evaluate the best or at least an acceptable solution. Again, if the hazardous material is the best alternative, then an entry into a tracking database is needed so that future direction may be provided. At this stage it is also desirable to plan for material management and estimate costs of the use of the hazardous material. Again, a computer tool to assist with these tasks is very desirable. Finally, a life cycle plan can be developed. However, how does one determine if the plan is acceptable? If the plan is acceptable, one can proceed with the acquisition with the knowledge that all reasonable alternatives have been investigated. During the process of system development and use of the system, the database of hazardous materials should be continuously updated. However, the material collection and disposition may still be a major concern. The method for disposition and location of sites for storage must still be addressed. Constant attention perhaps over decades is required to ensure safe usage to humans and the environment.

As discussed in Major Brian McCarty's notes, [2] both information and material handling are topics that require more research in the hazardous materials context. The first task should be directed toward the information handling. Databases are available which may be used for material identification, selection and evaluation of alternatives. Mavis, et al. in their MITRE Corp. Working Paper [3] indicates 95 online sources of primary and secondary hazardous materials (HAZMAT) data. Childress [4] also indicates available databases.

The purpose of this report is to provide an information aid for designers by introducing the available data bases for identifying hazardous materials and substances, the procedures available in the Logistic Support Analysis for identifying hazardous materials, and methods for tracking hazardous materials throughout the life cycle. The considerations for hazardous materials must start at the pre-concept stage of a system design. Identification not only of hazardous materials which may be used directly in the system but also of hazardous waste products that may be generated in the operation or maintenance of the system should be made. Through use of resources such as the published literature and online data bases, the designer may become aware of potential future problems at a stage in which they may be avoided.

An introduction to hazardous materials definitions will first be given in Section 2. In Section 3, a literature review is presented for some past hazardous materials studies that demonstrate some of the primary issues and concerns. A design advisor is presented in Section 4. Conclusions and recommendations for further research are described in Section 5.

2. Why Should Designers be Concerned about Hazardous Materials?

It may be argued that designers should not be concerned with the use of hazardous materials or the generation of hazardous waste since they may not be qualified as environmental engineers, lawyers, or physicians. A little knowledge may be a dangerous thing. However, the other side of this double edged sword is that ignorance of the law is no excuse for wrong doing. Failure to comply with federal, state or local laws or regulations is possible with such complex issues as hazardous materials. Also, loss or damage to property or persons caused by negligence or willful acts of omissions are easily possible. The Air Force Acquisition Management of Hazardous Materials (AMHM) Task Force is a team approach which provides the opportunity to anticipate and avoid future hazardous materials problems several years before the material is to be used. In this approach proper consideration can be given to materials selection and alternatives during the early stage of a system life cycle. As originators of technical information, the designers have the initial opportunity to identify a possible hazardous material use and initiate a risk assessment.

Engineers have traditionally been concerned with safety and health issues in design and in the workplace(ReVelle [5]). The workplace environment can be kept safe through the use of protective equipment, engineering controls, and administrative controls or a combination of these approaches. Protective clothing such as gloves, glasses, face masks, etc. should be tailored to the materials and task. Engineering controls must eliminate the hazard at the source without relying on the workers effectiveness and often offer the best and most reliable means for safeguarding against accidents or eliminating hazards. Administrative controls such as safety procedures, safety awareness training, special markings, etc. can also contribute to maintaining a safe working environment especially when management provides high quality leadership. The Acquisition Management of Hazardous Materials Program may be considered as a form of administrative control at the early stage of a system design which is the ideal time to anticipate and avoid future problems.

2.1 Definitions of Hazardous and Toxic Materials

Although everyone has some concept of some materials that are hazardous, there are several common and specific definitions in use. The dictionary definitions of hazardous and toxic materials are a good place to start. The **Condensed Chemical Dictionary** [6,21] provides the following.

A hazardous material is " any material or substance which, if improperly handled, can be damaging to the health and well-being of man. Such materials cover a broad range of types which may be classified as follows.

(1) Poisons or toxic agents, including drugs, chemicals and natural or synthetic products that are in any way harmful, ranging from those that cause death to skin irritants and allergens.

(2) Corrosive chemicals that burn or otherwise damage the skin and mucous membranes on external contact or inhalation.

(3) Flammable materials including (a) organic solvents, (b) finely divided metals or powders, (c) some classes of fibers, textiles, or plastics, and (d) chemicals that either evolve or absorb oxygen during storage, thus constituting a fire risk when in contact with organic materials.

(4) Explosives and strong oxidizing agents such as peroxides and nitrates.

(5) Materials in which dangerous heat build-up occurs during storage, either by oxidation or micro-biological action.

(6) Radioactive chemicals that emit ionizing radiation."

Toxicity is defined in the same dictionary as:

"The ability of a substance to cause damage to living tissue, impairment of the central nervous system, severe illness, or, in extreme cases, death when ingested, inhaled, or absorbed by the skin. The amounts required to produce these results vary widely with the nature of the substance and the time of exposure to it. 'Acute' toxicity refers to exposure of short duration, i.e., a single brief exposure; 'chronic' toxicity refers to exposure of long duration, i.e., repeated or prolonged exposures.

The toxic hazard of a material may depend on its physical state and on its solubility in water and acids. Some metals that are harmless in solid or bulk form are quite toxic as fumes, power, or dust. Many substances that are intensely poisonous are actually beneficial when administered in micro amounts, as in prescription drugs."

Also, harmless materials which react when combined must also be considered. "Reactive materials are those which can enter into a chemical reaction with other stable or unstable materials. Some materials are capable of rapid release of energy by themselves, as by self-reaction or polymerization, or can undergo violent eruptive or explosive reaction upon contact with water or other extinguishing agents or within certain other materials." (NFPA [7])

Another variation of the definitions is used by the Defense Reutilization and Marketing Service (Kim [8]). DRMS terminology refers to "hazardous materials" as those classified as hazardous by the Department of Transportation and "hazardous waste" as those classified as hazardous by the EPA.

In 1989, the Air Force created the Acquisition Management of Hazardous Materials (AMHM) Program to institutionalize consideration of hazardous materials issues in the weapon system acquisition process with the aim of minimizing hazardous materials use and hazardous waste generation throughout the weapon system life cycle. As part of their effort, the MITRE Corporation, as an unbiased third party, has developed a systematic process for the identification and evaluation of hazardous materials. To clarify the definitions as they pertain to the AMHM program and to Air Force concerns, they have developed two additional definitions (Roberts [9]). The first is an administrative definition which reflects the scope of the AMHM program:

"A hazardous material of concern under the Acquisition Management of Hazardous Materials Program is any material which is mission-critical to weapon systems acquired by the Air Force and because of the material's physical, chemical, or biological characteristics; quality; or concentration may

(a) Cause or contribute to adverse effects in organisms or offspring

(b) Pose a substantial present of future danger to the environment

(c) Result in damage to or loss of equipment or property

during the system's life cycle (development, testing, manufacture, operation, maintenance, modification, and disposal)."

The mission-critical elements are considered essential to perform the mission of the weapon system. Non-mission-critical agents, nonmaterials such as noise, biological agents, and radioactive materials are currently excluded from consideration under AMHM.

Roberts [9] also presented a second working definition to aid in their identification and evaluation. The "working" definition is as follows.

"A mission-critical material is considered hazardous in the context of AMHM if available information

(a) States or suggests that the material itself, or any of its ingredients, pose a significant potential hazard in any of the following seven categories:

Acute health
Chronic health (non-cancer)
Cancer
Contact
Flammability
Reactivity
Environmental

or is insufficient to determine that a significant potential hazard does not exist in any of these categories and

(b) The material is used in sufficient quantity to allow that potential hazard to be realized."

A recent note indicated that "ignitability" was also added to the categories. These definitions aid in reducing the scope and permitting evaluation of selected hazardous materials for the AMHM Program.

2.2 Responsibility for Hazardous Materials

The System Program Office (SPO) prime contractor and associated subcontractors have primary responsibility for identifying hazardous materials proposed for use and for evaluating the health and safety aspects associated with their use. This may require special expertise in toxicology, environmental engineering, analytical chemistry, etc. The SPO System Safety Manager may not have a formal mechanism in place to provide such assistance in a timely manner. However, a Logistic Support Analysis (LSA) provides a structured procedure.

Since the issues involved in the potential use of hazardous materials are complex, one should expect some difficulty in answering apparently simple questions. To determine the definitive answer may require special expertise in environmental engineering, safety engineering, analytical chemistry, medicine or law. This expertise is unlikely to be available in the SPO but can be obtained. An acquisitions management of hazardous materials study may be used to identify sources and make them available to the SPO in a timely manner (Roberts, pp xi [9]). A life cycle cost estimation tool is being developed by TASC (Hilton [10])

2.3 Strategy for Environmental Concerns

Hazardous materials questions are complex for several reasons. There are over five million known and patented substances which are identified with more than seven million names. The lists of a few thousand of these materials that have been designated as extremely hazardous may not be complete. Many thousands or tens or hundreds of thousands of hazardous waste materials may be generated from the use of these hazardous substances. Many of the mixture hazardous materials have not been thoroughly studied. The generation of hazardous waste materials may occur in an innocent appearing process such as using a fire extinguisher, stripping paint or cleaning a surface. A lack of training of personnel should be expected since the field is very broad and based on both social and physical sciences.

Effective hazardous materials management must be a functional and flexible approach which is able not only to address existing concerns but also to lead to new discoveries of potential hazards or improved procedures. This requires the collection of appropriate technical data on materials and processes, decision making, evaluation, and reporting. This procedure provides a basis for material selection, evaluation of alternatives, and good system design decisions throughout the acquisition process.

A strategy is needed for environmental concerns during the life cycle of a system. The acquisition stage is the time at which new concepts, feasibility studies, design alternatives, and experimental studies are of primary concern. It is also the time that changes are easiest to accomplish. Therefore, major effort should be devoted during this stage to reducing hazardous materials usage, seeking safe alternatives, and initiating any required data base to record and track usage of hazardous materials throughout the life cycle.

During the operation of a system, constant attention is given to safety. However, emergencies, accidents, and disasters have happened in the past such as those at Three Mile Island, Bhopal, and Chernobal. Minimizing hazardous materials usage should reduce the risk of such occurrences.

For a retired system, the problem of hazardous waste management is substantial. However, with proper material identification and management, the hand off from hazardous material to hazardous waste can be done in an orderly and controlled manner. Hazardous waste testing for ignitable, corrosive, reactive or toxic characteristics is much easier if the material is identified and controlled. Similarly, recycling of waste is easier if the waste is known and controlled. Finally, appropriate disposition of hazardous waste is also easier if the original source and process is known.

The successful management of a system in terms of hazardous materials requires both information and materials management. The need for both information and material management varies throughout a system's life cycle. The need for information management starts at the pre-concept stage of a system and is continuous throughout the life cycle. The need for material management is significant during system operation and maintenance and perhaps greatest at system retirement and post-retirement. Only when information and materials flow are coordinated can efficient system operation and control be expected. Currently, it appears that such control is being lost at one or more points in the life cycle.

Answering the question: is this material hazardous? is not easy. Since the number of materials is large and increasing with new materials and compounds discovered daily, it is possible that a new hazardous material or a new hazard from an existing material could be discovered at any time. Of those known materials, several knowledge bases are available such as the Chemical Abstract Library which publishes more than 60,000 basic patents per year. (Skolnik, pp. vii [11]) Skolnik describes the Chemical Abstracts Service (CAS) and its chemical registry system. In this system a number is assigned to each unique substance. The foundation of the system is an algorithm that generates a unique description of each molecular structure in terms of atoms, bonds, spatial arrangement, etc. Over 5 million unique structures have been assigned CAS numbers and new structures are reported at the rate of about 350,000 per year. Skolnik also reports that for the 5 million registered substances there are 7.7 million names. For example, polyethylene has 945 names. Even conducting a literature search is complicated by the variety of names and applications.

The number of hazardous materials is also difficult to determine and may change since problems with new materials may be discovered which may prompt new laws. For example, one list from the Clean Water Act contains 366 hazardous substances [13]. Historically, when the EPA list of extremely hazardous substances went into law, 406 chemicals were listed. Forty of these were deleted by Feb. 1988. Another list which is related to the transportation of hazardous materials is contained in Title 49 of the Code of Federal Regulations and contains about 740 radionuclides and about 1500 other chemicals [14]. The CHEMTOX data base contains over 6000 hazardous substances [15]. Since new substances are constantly being synthesized, the new additions to the list are published in the Code of Federal Regulations as described in 40 CFR 261.30 [16].

Not all materials known to man are used in the U.S.; however, the U.S. "right to know" laws require those who manufacture or use hazardous materials in sufficient quantities must provide Material Safety Data Sheets (MSDS). The Material Safety Data Sheet (MSDS) contains information on: physical data; fire and explosion data; transportation data; toxicity; health effects and first aid; storage and disposal; conditions to avoid; spill and leak procedures; and protective equipment. The entire set of MSDS's from U.S. manufacturers and users may be thought of as a large and important data base. Unfortunately, this data has not been collected into a single database. For materials purchased by the U.S. Government, MSDS are required to be submitted to DoD. These have been used to form a computerized database called the Hazardous Materials Information System (HMIS). The Hazardous Materials Information System (HMIS) data elements by major category include: hazardous item description; hazardous components; transportation data; health and physical properties data; safety storage handling and fire fighting procedures; spill and leak procedures; and disposal information. The Hazardous Materials Information System (HMIS) provides useful information on over 30,000 hazardous records on products supplied to the Department of Defense. However, if an item is not in HMIS, one cannot assume that the item is nonhazardous. Additional research is required.

An important step in any research undertaking is the searching of relevant indexes and databases to identify the existing literature on the topic of research. No one single database exists which lists all the literature and knowledge of hazardous materials effects; however, a number of data bases are available which offer wide coverage of the field. The serious designer/researcher would want to take advantage of all the data bases to which he or she has access or can obtain access with the resources available.

In addition to the existing databases, the Logistics System Analysis Report (LSAR), provides a procedure for producing a data base for major systems as part of the Logistics Systems Analysis [17,18]. This may be used to provide a database of hazardous materials used or associated with the system throughout its life cycle.

3. Literature Review

3.1 Logistic Support Analysis and Logistic Support Analysis Record

The Logistic Support Analysis (LSA)[17] is an iterative and interactive analytical process within systems engineering. The design engineer is provides with two major tools for acquisition management of hazardous materials. First is an identification which is contained in the considerations for System Safety and Hazardous Materials (pp. 7-13, 7-14). Secondly is the provision for a database record which may be used for tracking and reporting the use of hazardous materials throughout the system life cycle (pp. 7-3).

The Logistics System Analysis is a procedure used to evaluate an emerging system design to determine if it is adequate to accommodate operating and maintenance tasks, quickly, easily, with minimal skill levels and minimal special tools. The LSA is the procedure for following the recommendations given in MIL-STD-1388-1A[19] including the generation of a Logistic System Analysis Record (LSAR) data base. The LSAR is the primary source of logistics data for many elements such as maintenance planning, design, interfaces, reliability, maintainability, safety, survivability and hazardous materials.

3.2 Related Reports

A literature search of the DTIC Technical Report Database was conducted to determine related past work. Selected reports will now be briefly described.

3.2.1 An Analysis of Army Hazardous Waste Disposal Cost Analysis [8].

This recent study is reported as the Army's first effort to compile and analyze representative hazardous waste disposal cost data. Disposal quantities, unit costs, and total costs were calculated and analyzed from data provided by the Defense Reutilization and Marketing Service (DRMS) from installations within the continental United States (CONUS) for FY 88. The DRMS database contains Contractor Line Item Numbers (CLIN) which categorize waste on the basis of type, amount, container, and other factors. The Master CLIN list provides a further breakdown of each category.

An important concept mentioned in this report is that by studying disposal data, it may be possible to trace hazardous waste to its source of generation. This would undoubtedly reveal a number of potential opportunities for reduction of hazardous waste generation. This may also be observed by study of the top 20 most costly CLIN's. The item with the highest total disposal cost was lithium - sulfur dioxide batteries. This was followed with contaminated containers, PCP wood or debris, spill residues with RCRA contaminants, oil sludge, containers, paint wastes, decontaminant agents, compressed gas cylinders, sludge, paint removers, toxins, solvents, asbestos, PCB's, and medical waste.

Several important recommendations are also made in this report. One was that hazardous waste management data covering a longer period of time be analyzed to provide a more accurate picture of disposal costs and the opportunity to trace data back to its source. Several recommendations for improving the DRMS HW database such as linking CLIN to EPA hazardous waste codes and to National Stock Numbers to provide some link between hazardous waste data and material data. It was also recommended that the Army conduct research on how to reduce the quantities and disposal costs of each specific waste stream item of high disposal cost.

3.2.2 An Expert System for the Management of Hazardous Materials at a Naval Supply Center [21]

This thesis analyzes, designs and implements an expert system for the management of hazardous materials at a Navy Supply Center (NSC). This system is part of a series of expert systems built by the Naval Postgraduate School to assist the Naval Supply Systems Command in automating its inventory management system at NSCs. Selecting the proper storage conditions and locations for newly received hazardous materials requires the NSC's expert in such matters, the safety and health manager, to research the primary data base, the Hazardous Materials Information System (HMIS), and any other relevant information sources, and extract the pertinent information. He determines the best storage conditions for the material and passes this information to the warehouse worker. The Hazardous Materials Expert System (HASMAT ES) will facilitate making the storage decision and will allow a warehouse worker to safely store hazardous materials without the assistance of the safety and health manager. In addition, it can provide information on an item's flash point, reactivity, and disposal requirements.

3.2.3 Computer Generation of Hazardous Analyses[22]

This report identifies an automated process to develop a preliminary hazard analysis (PHA) for a standard operating procedure (SOP). The automation is done by an integrated data base management and interactive program. Engineering and clerical personnel can save much time automating the PHA generation. When automating a hazard analysis, it is important not to sacrifice the quality of the analysis for time and cost savings. The automation process presented requires input from a safety engineer following a review of the draft SOP.

3.2.4 Hazard Response Modeling Uncertainty[23]

There are currently available many microcomputer-based models for calculating concentrations of hazardous chemicals in the atmosphere. The uncertainties associated with these models are not well-known and they have not been adequately evaluated and compared using statistical procedures where confidence limits are determined. The U.S. Air Force has a need for an objective method for evaluating these models, and this project provides a framework for performing these analyses and estimating the model uncertainties. As part of this research, available models and data sets were collected, methods for estimating uncertainties due to data input errors and stochastic effects were developed, a framework for model evaluation was put together, and preliminary applications using test data sets took place.

3.2.5 The 'Hazard Expertise' (HAZE) Knowledge Based System[24]

The 'Hazard Expertise' (HASE) program is a knowledge based system for military installation personnel working with hazardous materials/waste management. HASE is an easy, informal way to share problems, ideas for solutions, and information on the latest technologies and environmental management strategies. The system allows self contained updating, systematic analysis of alternatives, and selection of optimal technologies. The system provides a list of courses, meeting announcements, a personnel directory, a listing of pertinent literature and other special services. Example sessions demonstrate use of the commands.

3.2.6 Technology Assessment of Hazardous Waste Minimization Process Changes[25]

The objective of this study was to technically evaluate selected industrial process changes for application to Air Logistic Centers for hazardous waste minimization. Those processes evaluated were as follows: (a) Ion vapor deposition of aluminum as a replacement for cadmium electroplating, (b) Non-cyanide strippers to replace cyanide strippers, (c) Plasma spray of chromium to replace chromium electroplating, and (d) Nickel boron as a replacement for chromium electroplating. The study resulted in the recommendation to develop databases, test plans, pilot studies, and demonstrations of the effectiveness of processes (a) and (b), above, in minimizing hazardous waste generation. Processes (c) and (d) showed minimal potential for hazardous waste minimization, and were not recommended for further study.

3.2.7 Geotox Multimedia Compartment Model User's Guide[26]

This report describes how to use the GEOTOX programs. GEOTOX is a set of programs designed to calculate time-varying chemical concentrations in multiple environmental media and to estimate potential human exposures. The report provides a description of the partitioned environment that is modeled by GEOTOX, discusses the theoretical basis for compartment models, and presents the design criteria against which the model is judged. This is followed by a description of what the user must do to run the GEOTOX on a particular system. A step-by-step tutorial for running GEOTOX programs is provided. A discussion of the functions of the GEOTOX models is given.

Finally, a discussion of model inputs and outputs is provided.

3.2.8 Evaluation/Selection of Innovative Technologies for Testing with Basin F Materials[27]

A study was conducted to determine promising hazardous materials treatment technologies for the Rocky Mountain Arsenal. Three technologies were selected for laboratory/pilot scale tests. These were: glassification; fluidized/circulating bed combustion; and soil washing. In actuality, these three technologies offer one the opportunity to evaluate a spectrum of processes, each offering potentially distinct advantages. Glassification destroys organics and fixes metals under controlled conditions whereby further treatment of residuals may be eliminated; circulating bed combustion destroys organics and offers in-situ acid gas removal, thereby eliminating wet scrubbing; and soil washing offers the possibility of removing organics from soil without having to heat considerable quantities of soil to very high temperatures.

3.2.9 A Health and Environmental Effects Data Base Assessment of U.S. Army Waste Material[28]

Substances used by the U.S. Army on a regular basis in accomplishing their missions of training, defense, and weapons development have a wide range of uses, storage and disposal methods. Humans and the environment may be exposed to them in varying amounts. Proper research planning requires knowledge of gaps in health and environmental data on those compounds. CARLTECH was contracted to develop a data base on health and environmental effects of commonly encountered materials. A comparison data base of sixty hazardous materials is presented.

3.2.10 Extremely Hazardous Substances: Superfund Chemical Profiles [29].

The Extremely Hazardous Substances list[29] contains the data profiles on 366 hazardous substances as listed in Feb. 1988 as extremely hazardous. Profiles are presented alphabetically with Chemical Abstract Service (CAS) numbers and other information. The CAS number was used to search the Toxicology Data Base (TDB) and Hazardous Substance Data Base (HSDB) from the National Library of Medicine. Approximately 65 % of the 366 chemicals were found listed in the TDB/HMDB files. For the others, standard references were used to construct profiles. The profile contains the chemical identity, CAS number, synonyms, chemical formula and molecular weight, regulatory information, physical chemical characteristics, health hazard data, fire and explosion hazard data, reactivity data, use information, precautions for safe handling and use, protective equipment for emergency situations, emergency treatment information and comments.

3.2.11 J. K. Webster, **Toxic and Hazardous Materials**, Greenwood Press, Westport, CT 1987.

The Toxic and Hazardous Materials book[30] is an excellent general guide to information sources on toxic and hazardous materials. The fields covered include monitoring, disposal, effects on humans, air, land and water and more specific areas such as oil spills, acid rain and radiation.

Books, monographs, periodicals, reports and documents, proceedings, reviews, indexes and abstracts, data bases, audiovisual materials, dissertations, government organizations, research centers, and industrial laboratories, libraries, information centers, and associations and societies are listed.

3.2.13. The Installation Restoration Program (IRP) Toxicology Guide[31]

This excellent guide provides detailed health and environmental information for 70 potential contaminants of drinking water supplies associated with USAF installations. For each chemical in the IRP Toxicology Guide, the environmental fate, exposure pathways, toxicity, sampling and analyzed methods and state and federal regulatory status are outlined. The 70 chemicals are described in four volumes. An additional volume on metals is also available.

4. Design Advisor

At least four options can be considered at the design stage for the control of pollutants: eliminate the source, eliminate the waste, treat the waste to reduce the deleterious load, or augment the environmental capacity to assimilate the waste. All of the above options may be required; however, at the acquisition design stages the first option is of primary concern. What tool could be developed to guide the designer through the appropriate knowledge bases at each stage of design? An overview of the design advisor strategy is shown in Table 1. At each stage of design, certain key decisions must be made. Several databases are available which can aid in this decision making process. Also, some output could be expected at each stage from querying the database. At the pre-concept stage, one may consider a mapping from concept to a previous system to problems encountered.

Concept -- Previous system -- Problems

For example, one may consider a fighter aircraft, look up the F - 16, and find hydrazine used for the emergency power unit.

At the concept exploration stage, the important mapping from compounds to component chemicals may be most important.

Compounds -- Component chemicals
Chemicals -- MSDS
Chemical -- DOD Usage

Chemical -- Regulations

For example, one may consider a composite material, and need to determine the chemicals used in the bonding. Once the components are known, the MSDS information could be determined.

Table 1. Design Advisor

Design Stage	Databases	Output
Pre-concept	Lessons Learned	Previous problems
	Legal	
	LEXIS	
	WESTLAW	
Concept exploration	Identification	
	CAS	Synonyms
	OHS	MSDS
	HMIS	DOD Usage
	REGMAT	Regulated
Design analysis	Consequences	
	HMIS	Hazards
		Reactivity
		Protection
		Warnings
		Transportation
Concept	Procedures	
	LSAR	Tracking of hazardous materials
	CLIN	Tracking of hazardous wastes

At the design exploration stage, the mapping from materials to hazards and from hazards to actions may be most important.

Material -- Hazards
Hazards -- Protective Clothing
Hazards -- Toxicity

Hazards -- Procedures

For example, if hydrazine is the material, the hazards and protective clothing required to handle this toxic substance could be determined.

Finally, at the concept stage, tracking the hazardous materials and wastes may be the prime concern.

Materials -- How much, where
Waste -- How much, where

For example, the amount and location of hazardous materials and the generation of hazardous waste would be of prime concern.

4.1 Pre-concept Stage - Lessons Learned and Legal Databases

The designer's options are greatest at the pre-concept and concept exploration stages of a project. At the pre-concept stage, a entire system such as a helicopter or fighter is being considered. This might be the easiest time for the designer to examine past lessons as well as explore legal problems on similar systems.

(a) The designer could examine the "Lessons Learned" data base to determine if problems had arisen with similar concepts and designs in the past.

(b) Legal issues could be explored through examination of such databases as LAWS, LEXIS or WESTLAW or the legal office to determine if past legal issues had been raised over a related system.

4.2 Concept Stage - Identification and Selection Databases

At the concept exploration stage of design, the main sub-systems would be defined. For example, the power plant, engine and airframe components of a helicopter would be considered. At some point a tentative bill of materials would be defined. At this point the designer could request MSDS for the items on the list from the HMIS or other database. A properly completed MSDS provides a wealth of information.

If any hazardous materials are identified, a list of alternatives could be established and the HMTF requested to assist with the evaluation of the alternatives.

With a material list available, the identification search could begin.

1. For each material selected, an identification search could be made to determine:
    (a) Is the material hazardous? (To what extent?)
    e.g. halon

(b) Does the manufacturing process use hazardous materials or produce hazardous wastes?
e.g. electroplating

(c) Does the maintenance require hazardous materials?
e.g. composite material repair, stripping

2. During design analysis:

(a) What interactions in the design may produce hazardous materials?

(b) Could new compounds or mixtures be formed?

(c) What alternatives could be considered?

It appears that a hazardous materials module could be created for computer aided design (CAD). Questions of what the designer needs to know and when he needs hazardous materials information could be answered by an expert system which could provide guidance to the designer. Information would be provided to the designer on the implications of the use of hazardous materials on a real time basis through the use of appropriate online data bases and expert systems. It would also be possible to track a design effort to determine when, where, how, who, what and possibly why hazardous materials were/are considered for use and document the alternatives which were considered.

4.3 Software Tool

Since several different databases are of interest at the various design stages, a software tool that could access these databases would be useful for the designer. Such a tool could save designer's time by permitting a directed search that could provide important information for identification and evaluation of hazardous materials at the earliest design stage.

The software tool could be in the form of a menu driven communications tool similar to GRATEFUL MED [32] which may be used to search the National Library of Medicine databases. It could contain the following features.

1. Input screens to prompt the user with key words for developing a search strategy before connecting to the online databases.

2. Access to online databases with automatic dialing.

3. Automatic login.

4. Ability to conduct the online search and automatically download the results of the search.

5. Search up to 100 different databases.

6. Have an expert search mode for frequent users.

7. Help capability to explain key words.

8. Have a computer based training capability.

To use such a tool, accounts and passwords for all the component databases would need to be established. Also, some amount of training may be required.

A communications program such as PROCOM could be used to log in and download information from any of the individual databases; however, a specific tool for designers would have several advantages in terms of ease of use. The computer tool could also save computer charges by permitting the search strategy to be formulated before logging in and automatically downloading the search results. A menu of the various databases categorized into appropriate categories such as lessons learned, legal, identification and evaluation, and archival would also reduce the search time. Each of these categories could be further subdivided into logical categories then into specific database acronyms with a help feature which describes each database.

The rates for online service include a subscription fee which varies from $25 to $300 plus an hourly connection fee that varies from $17 to $90 per hour. The online service has the advantage of charging in proportion to usage.

A PC based system may cost as little as a few hundred dollars; however, one must be certain of the specific database which would be used. Several CD ROM systems are also available at costs around several thousand dollars. Again, a relatively high usage would be needed to make this type of system cost effective.

The significance of such a software tool would lie in the ability of the designer to obtain appropriate information in a timely manner. This should permit correct logical decisions about future uses of hazardous materials. By increasing the ease of obtaining information about hazardous materials, the designer would have a greater chance of obtaining the right information at the right time in order to satisfy mission requirements and minimize hazards for humans and the environment.

5. Conclusions and Recommendations for Future Work

The purpose of this study was to determine which hazardous materials data bases would be useful to a designer and permit the minimization of the use of hazardous materials by identifying and evaluating alternatives in the early design stage. Previous studies concerning hazardous materials and related programs were examined to understand the current situation. A variety of online databases are available; howev=r, these do not appear to be currently used by designers. One reason is the complexity of the hazardous materials field. Another may be the cost. However, at least two of the most important data bases for the Air Force, the Lessons Learned and HMIS are free to use for Air Force purposes. Several high quality commercial databases are available in either online, PC or CD ROM formats. It appears that further training in the importance of environmental concerns and more tools for designers are needed.

The design advisor concept described in section 4 shows where the databases could be used to anticipate and hopefully avoid being surprised by hazardous materials issues on future systems, by addressing these issues at the pre-concept phase of a system design. Future work could include a prototype design advisor, or simply a tool similar to GRATEFUL MED which would provide rapid access to several different HAZMAT databases.

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What's in a rule?:

A structural model of inductive reasoning

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Running head: STRUCTURE AND INDUCTIVE REASONING

Abstract

The purpose of the current research was to systematically identify structural components of inductive reasoning tasks which were sensitive to individual differences in performance. Structural components were defined as basic patterns of attribute predictability within and between individual stimuli in a classic 3x3 matrix task of inductive reasoning, the Raven's Advanced Progressive Matrices (APM; Raven, 1962). The relationship between structure and both individual differences in performance and item difficulty was tested. Two pilot studies were conducted. The first study tested how well structural parameters predicted item difficulty on the APM and contrasted that work with predictions from a more traditional rule based model. In the second study an experimental matrix test was constructed based on structural parameters identified in the first study. The strength of using structural principles to identify components of inductive reasoning tasks which make them excellent predictors of intelligence was discussed.

Introduction

Inductive reasoning tests have consistently been recognized as the best single predictors of general ability or Spearman's quantitative index of 'g' (e.g., Paul, 1985; Jensen, 1987; Snow, Kyllonen, & Marshalek, 1984). In fact, inductive reasoning tasks have been described as the cornerstone of intelligence in many current theories of intelligence (e.g., Pellegrino, 1985; Sternberg & Garner, 1982). But the nature of inductive reasoning tests and the reason for their high 'g' loadedness remains a mystery.

In a recent study investigating the relationship between reasoning and working memory factors, Kyllonen and Christal (1990) produced correlations between working memory and reasoning ranging between .80 and .88. Estimates were robust, and were as high as intercorrelations between measures of reasoning and test-retest reliabilities for reasoning tasks. But specific components of working memory responsible for the high correlations were not identified. In fact, the authors suggested that it cannot be determined from their analyses whether working memory accounts for performance on reasoning tasks or whether reasoning accounts for performance on working memory tasks. While the research succeeded in linking the concepts of reasoning and working memory in terms of Spearman's quantitative index of 'g', the identification of specific component processes in reasoning/working memory tasks responsible for the high intercorrelations was not addressed by this study.

The process of reasoning has generally been defined in terms transformational rules (e.g., Carpenter, Just, & Shell, 1990; Evans, 1968; Jacobs & Vandeventer, 1972; Mulholland, Pelligrino, & Glaser, 1980; Raven, 1948; Sternberg, 1977). On the most basic level, these rules can be thought of as a series of similarity judgements based on the number of shared dimensions between stimuli in multi-dimensional space (e.g., Holyoak, 1984; Royer, 1978; Rumelhardt & Abrahamson, 1973; Smith, 1989; Whitman & Garner, 1962).

The description of transformational rules in terms of dimensional relationships provides a logical transition between perceptual and conceptual structure. Individual differences in the ability to perceive simple dimensional relationships is a fundamental process which has been studied by many authors in the areas of attention, perception, and cognition (e.g., Gibson, 1969; House, 1979; Tighe & Tighe, 1979; Tversky, 1977; Zeaman, 1978). In fact, the ability to recognize and use simple dimensional relationships is often cited as the primary building block for concept formation, categorization, and reasoning (e.g., Medin, 1983; Offenbach, 1983; Smith, 1989; Rumelhardt, 1989).

Only one measure designed to quantify dimensional relationships among objects has gone beyond simplistic distance or same-different measures, however. This measure is based on the pattern of predictability among dimensions, i.e., the number of dimensions related in a simple contingent manner. Using an index of correlation among dimensions or 'correlational structure', it is possible to measure the form or redundancy of structure between stimuli while controlling the information load or amount of structure within individual stimuli. This correlational index of similarity was originally developed by Whitman and Garner (1962) to quantify the dimensional structure between two or more multidimensional stimuli and has subsequently been applied by Royer (1978) in the prediction of individual differences in performance on an inductive reasoning task with great success.

It is important to note that the description of transformational rules in terms of relationships between attributes does not argue for or against the presence of rules. Rather it allows the investigation of rule difficulty at a more basic level, enabling the identification of specific components of rules which make them easy or more difficult. It also provides a general framework for understanding inconsistencies in rule based models, i.e., the assignment of multiple rules to the same problem solution. The power of using a structural index for identifying the reasoning components which are sensitive to individual differences is enormous. Structural indices enable performance on reasoning tasks to be explained in a general theoretical framework allows the independent testing of reasoning components. Identification of basic structural components which comprise reasoning tasks will enable the relationship between constructs of reasoning and working memory to be systematically tested and understood.

Past Research

In past research, I adapted the structural model of inductive reasoning first proposed by Royer (1978) to identify and test components of inductive reasoning tasks (Andrist & Detterman, 1990; Andrist, 1991). Using a structural model of inductive reasoning, two computerized matrix tasks were constructed and tested in two successive studies. The first study was conducted at Lackland Air Force Base with 220 Air Force recruits. The second study was conducted with 100 college undergraduates.

The first computerized task tested the role of dimensional structure by systematically increasing the difficulty of dimensional relationships between stimuli in a 3x3 matrix task. The second task further refined the initial matrix task by defining two individual components of dimensional structure: amount and form. Amount was the quantitative component of interstimulus structure; form was the relational component. Amount was a measure of the number of attributes in the matrix. Form which has generally been defined in terms of transformational rules was defined in terms of patterns of same-different dimensional relationships. Form reflected the level of predictability among the attribute dimensions. Amount and form roughly correspond to number and difficulty level of rule tokens, respectively.

The two studies attempted to bridge the gap between 'perceptual' and 'conceptual' processing by operationally defining processes on an inductive reasoning task in terms of relationships between dimensions in the matrix. Results indicated that changing dimensional relationships between stimuli were important predictors of individual differences in general cognitive ability. Performance on tasks measuring stimulus encoding and discrimination were highly related to both quantitative experimental measures: individual stimulus (information load) and matrix (number of attributes). Form was the best single predictor of reasoning ability.

Changes in task performance related to the increased number of attributes in a problem have been linked to increased 'working memory' load and number of sub-goal generations (e.g., Mulholland et al., 1980; Carpenter et al., 1990). If increased memory load predicts individual differences in performance on reasoning tasks, then it seems logical that memory for position should be related to increased amount. Memory for position was tested in the second study (Andrist, 1991). Surprisingly, memory for position was not related to the number of attributes in the matrix (amount). Instead, memory for position was related to decreases in form, i.e., the relationship between attributes. Results seem to indicate that increasing the number of attributes (increased amount) in a reasoning task does not directly affect performance by increasing the memory load per se. Rather, the association between working memory and performance on inductive reasoning tasks seems to be directly related to the increased difficulty of identifying relationships between attributes (uncorrelated form) as the number of attributes in the problem increases.

Summer Research

The overall purpose of the summer research project was to construct and test a matrix task based on a general structural model of inductive reasoning derived from the problem characteristics of the APM. Research was based on the two previous studies listed above investigating the importance of dimensional structure in the prediction of performance on inductive reasoning tasks (Andrist & Detterman, 1990; Andrist, 1991), the Carpenter, Just, and Shell (1990) production model of inductive reasoning, and a study by Jacobs and Vandeventer (1972) which identified 12 rules of spatial inductive reasoning problems. Specific objectives of the current research were: 1) to generate a basic structural model derived from problem characteristics of the APM rather than from parameters of information load as in the two previously cited studies done by the author, 2) to examine the relationship between the Carpenter, Just, and Shell model, the 12 Jacobs and Vandeventer rules, and the adapted structural model of inductive reasoning, and 3) to develop and test an experimental matrix task based on the adapted structural model based on characteristics of the APM problems.

Model

Initial weeks of the summer were spent adapting the structural model of inductive reasoning designed above to the APM. The first step in this process was to identify and classify general characteristics of the 36 APM problems. This was accomplished by systematically identifying characteristics of the problems related to both individual attributes in each of the nine matrix entries and patterns of shared attributes between the nine entries. The model was compared to both the Carpenter et al. model (1990) and the 12 general inductive rules identified by Jacobs and Vandeventer (1972).

Individual Matrix Entries

Characteristics of individual matrix entries were divided into four broad classifications: type of elements, and number of elements, type of attributes, number of attributes.

Type of Elements. An element was a feature of a matrix entry which was either present or absent. This distinction was important since some elements had more than one attribute, i.e., a line could vary in both orientation and shape. Initially, four element types were identified: enclosed figures, open figures, lines, and dots. Problems arose with the distinction between open figures and lines. In some problems, the attribute change, i.e., shape or pattern, would correspond to only one line of the open figure rather than the entire figure as such. In order to systematically code the matrix entries and changes associated with each entry, open figures were coded as individual lines. A contrast between discrete elements and open figures which could be coded as either figures of individual line elements is provided in Figures 1 and 2, respectively.

Insert Figures 1 & 2 about here

Number of Elements. Number of elements was the total number of features in the matrix. Although the number of elements which varied in any given matrix problem should have been a very straight forward thing to determine, it was confounded by the fact that one 'type' of attribute that varied in the matrix problems was the attribute of number itself. It became clear that the number of elements (lines or dots) in any given matrix problem could be counted in two ways (see below).

Type of Attributes. An attribute was a characteristic of an element in a matrix entry which had multiple levels or dimensions. Six attributes were identified and coded in the APM problems: size/length, shape, orientation (rotation around center), position (distance from center), pattern (solid, stripped, dotted, etc.), and number. Due to confounds with the distinction between number of elements (see below) and the attribute of number, only five attributes were coded as such in the final model. The sixth attribute, number, was coded under number of elements rather than as an attribute.

Number of Attributes. Number of attributes was simply the number of different attributes which varied in the matrix, i.e., size, shape, pattern. Attributes which remained constant across the entire matrix problem were not coded.

Finding Correspondences

It became very clear as the matrix problems were coded, that the identification of attributes and elements was interrelated to both the type and number of elements/attributes and the relationships between those attributes in the matrix.

Confounds with Type. An inability to 'find correspondences' between attributes and elements seemed to be confounded by factors associated with repeated attributes and/or elements, i.e., the same attribute or element type repeated more than once in the matrix. The inability to find correspondences was also related to the discreteness of the elements, i.e., elements which were not obviously separate parts of the whole were not easily identified as elements. See for example the contrast between matrix entries in Figures 1 & 2. Problems in Figure 1 have discrete elements which are easily identified as such. Problems in Figure 2, on the other hand, have both repeated and fused elements which are not easily identified as individual elements per se. In problems of this nature, the difficulty level of the rule seemed to interact with the finding of correspondences.

The identification of individual elements and patterns of correspondences between attributes did not seem to be an important factor if the attributes were correlated, i.e., the elements/attributes changed together. Again the reader is referred to Figure 2, specifically to the matrix problems on the left hand side of the page. In these problems, the attributes/elements acted as a 'whole' and the inability to identify discrete attributes/elements was irrelevant or actually a benefit to the problem solver. An example of 'correlated' attributes in unique (discrete) and repeated/fused problems can be seen on the left hand side of Figures 1 and 2, respectively. If identification of the 'rule token', i.e., pattern of change was dependent on the identification of individual attributes/elements in the matrix as the case of uncorrelated attributes, however, then when attributes/elements were repeated and/or fused, it became very difficult to determine which attribute corresponded to which element. See for example matrix entries on the right hand side of Figure 2. In the case of uncorrelated elements, more difficult rule tokens were associated with more difficulty in finding correspondences if the elements were repeated and/or fused. For example, if more than one set of lines was present (repeated elements) and more than one attribute was changing, it was not clear which attribute corresponded to which line. Again the reader is referred to Figures 1 and 2 for a contrast of difficulty in 'correspondence finding'. An example of 'uncorrelated' attributes for unique and repeated/fused elements appears on the right-hand side of Figures 1 and 2, respectively.

In order to operationalize 'correspondence finding', matrix problems were coded on two separate dimensions of attribute/element type: unique/repeated and discrete/fused. Three types of matrix problems were identified: unique-discrete, repeated - discrete, and repeated - fused. There were no unique-fused problems in this design.

Confounds with Number. During initial attempts to code number of elements, some very important aspects of number as an attribute were identified. If the distribution of number was constant on either a column or a row and/or the same element type, i.e., lines or dots, was not repeated as a separate element in the matrix, it was easy to identify number as an attribute. But if the same element type was repeated and/or number was not constant on either the column or the row, it was impossible to determine whether number was an attribute as such or if the number of elements in the matrix were changing as a function of null values in some entries.

Relationships between Matrix Entries or 'Rule Tokens'

Relationships between matrix entries included: pattern of shared attributes (correlations between attributes) and pattern of attributes in relationship to the x- and y-axis of the matrix (type of distribution in the matrix).

Correlations between Attributes. The pattern of shared attributes refers to the level of correlational structure between attributes, i.e., the number of attributes that are related to each other in a simple contingent manner. For example, if levels of two attributes such as color (red, blue) and size (small, large) were correlated, whenever an object was red it would be small and whenever an object was blue it would be large, i.e., the size could be predicted from the color. If, on the other hand, attributes are independent of each other they are 'uncorrelated'. The distinction between levels of attribute correlation has been shown to be an important factor in the identification of factors contributing to the difficulty of matrix problems and increased memory loads (Royer, 1981; Whitman & Garner, 1962)

Attribute Distribution in the Matrix. The distribution pattern of attributes in the matrix can be thought of as the number of x- and y-axis correlations in the matrix. Attribute correlation with the x- and y-axis refers to the number of attributes predicted by row position (constant in a row), column position (constant in a row), or distributed over the row and/or column, i.e., Latin square arrangement (one level of each attribute present on each column and each row).

Structural Equivalents to Rule Tokens

Comparisons were made between rule based and structural models. As indicated in Table 1, the proposed structural model was more general and encompassed both the Carpenter et al. (1990) and the 12 general rules identified by Jacobs and Vandeventer (1972).

Insert Table 1 about here

The five rule tokens from the Carpenter et al. model (1990) were rewritten in terms of more general structural principles. This gave a theoretical structure to the hierarchy of rule difficulty, rather than just an empirical base and broke the rules down into more basic units of difficulty, rather than just an empirical base and broke the rules down into more basic units of structure. In forming a structural hierarchy based on attribute relationships, the five rules identified by Carpenter et al. (1990) can be conceived as increasing in difficulty due to a systematic increase in the number of degrees of freedom present in the matrix, consequently making it less predictable and therefore more difficult to solve.

In comparing the five rule tokens from the Carpenter et al. study with their basic structural counterparts, several things are important to note:

1) The basic components of the constant and pairwise rules were identical except that one had an attribute constant on the row and the other had an attribute constant on the column. Accordingly, the bias towards each of these rules should vary according to cultural training (reading across or down), a testable hypothesis.

2) Components of the constant/pairwise and distribution-of-three rules differed only in the addition of a degree of freedom added to either the column or the row, i.e., attributes for both constant and pairwise rules were constant on one axis and distributed on the other in a Latin square arrangement; attributes for the distribution-of-three rules were distributed on both axis.

3) The addition/subtraction and distribution-of-two values both dealt with null values. The main difference between the rules was that the addition/subtraction 'rule tokens' were constant patterns on the column or row and distribution-of-two values was completed distributed.

The 12 rules from Jacobs and Vandeventer were also compared to their structural equivalents. The strength of a structural approach versus Jacobs and Vandeventer approach was that the structural model provided a clear separation between the identification of the individual type of attribute which is changing versus the 'rules' or pattern of attribute change, i.e., shape or size can be distributed in a matrix or be constant on a row or column. The structural model also provided a hierarchical framework for the ordering of identified rule tokens from both studies.

Preliminary data comparing rule based versus basic structural components in the prediction of item difficulty on the APM were gathered in Study 1. Individual matrix problems were further coded according to both the Carpenter et al. 'rule tokens' (number and type) and a structural model and used to predict item difficulty on the APM.

Pilot Study 1

The purpose of Study 1 was twofold: 1) to test the predictability of the structural model outlined above against the Carpenter et al. (1990) parameters of number and type of rule tokens in difficulty, rather than just an empirical base and broke the rules down into more basic units of structure. In forming a structural hierarchy based on attribute relationships, the five rules identified by Carpenter et al. (1990) can be conceived as increasing in difficulty due to a systematic increase in the number of degrees of freedom present in the matrix, consequently making it less predictable and therefore more difficult to solve.

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Pilot Study 1

The purpose of Study 1 was twofold: 1) to test the predictability of the structural model outlined above against the Carpenter et al. (1990) parameters of number and type of rule tokens in the prediction of item difficulty on the APM and 2) to test the additional predictability of 'finding correspondences' as defined above in terms of attribute type on attributes of uniqueness (unique-repeated) and discreteness (discrete-fused) and the presence or absence of null values.

Method

Items

All 36 APM problems were coded under the structural model; only 25 of the 36 APM problems were coded for the Carpenter et al. model. Limits were due to the fact that 11 problems were not coded for rule token type and number (Carpenter et al.,1990; Appendix A).

Coding scheme

A dichotomous coding scheme was devised in order to systematically code each factor identified in the both the structural and rule based models outlined above. All parameters representing attribute type, element type, and rule type as presented in Table 1 above were coded for both presence/absence (1/0) and frequency. Type B attributes/elements were coded separately in the structural model. These attributes/elements were the ones hypothesized to affect 'correspondence finding' and were therefore coded separately. Although Carpenter et al. discuss the role of 'correspondence finding' at various points in their paper, no clear operational definition was provided. However, the authors did specifically state that increased 'correspondence finding' in Betteraven was related to the ability to deal with null values and consequently to be able to solve the distribution-of-two rule. A specific 'correspondence finding' variable was not coded for the Carpenter et al. model.

After coding was complete, computed summary scores were obtained for number and type of: attributes, elements, correlations between attributes, correlations with the x- & y- axis, and rule tokens identified in the structural model (including the overall constant rule).

Results

Exploratory correlation and multiple regression analyses were conducted to contrast predictions of item difficulty on the APM (as indicated by item number) from coded factors in the rule-based and structural models above. Correlational analyses indicated that parameters reflecting individual item difficulty (number of null, discrete, & repeated attributes), frequency of attributes, and distribution of attributes were all significant predictors of item difficulty with correlations ranging between .49 to .78.

Multiple regression analyses for the rule-based and structural models were comparable with parameters from each model accounting for 62 and 67 percent of the variance, respectively. Variables in the rule-based model represented the presence and total frequency of rule tokens. Results indicated that parameters representing basic structural characteristics of attribute patterns are comparable to predictions of item difficulty from rule-based models.

Discussion

So what does a structural approach add to our understanding of the reasoning process? By having a model to look at the basic components of rules in terms of patterns of correlations between attributes rather than the 'rules' per se, we can construct a general theoretical model of inductive reasoning enabling us to better understand what makes a rule into a rule. A model could also help explain both the rule order and the inconsistencies found in empirical data. For example, the structural framework proposed can to used to understand exactly how subjects could use different 'rules' for the same problem depending on which relationships are more salient to them. According to a general structural model, rules are really names for predictable patterns of how the attributes in the matrix change. The proposed model is also more parsimonious because rules can be explained and investigated at a more basic level. Through the use of a more basic model, the relationship between individual differences in reasoning and working memory tasks can be investigated in terms of shared task components.

Another important aspect of a structural model is in terms of quantifying individual item difficulty. This is crucial for the study and control of 'finding correspondences' independent of rule difficulty. It was not clear beyond the increased capacity of the Betteraven model to deal with null values, exactly what determined the difficulty of the correspondence finding in the APM problems studied by Carpenter et al.. Many unanswered questions were left concerning the role of correspondence finding in determining the difficulty level of matrix problems. Is the difficulty related to null values per se as Carpenter et al. suggest, or as is the difficulty related to a more general problem definition and representation of problem space which is determined by the structure or predictability among problem attributes as the pilot work suggests.

Pilot Study 2

The purpose of Study 2 was to isolate and test structural properties of matrix tasks which make them important predictors of individual differences in intelligence. This purpose was accomplished through the design and administration of a paper-pencil matrix task based on identified structural principles.

Preliminary Work

Initial design of the experimental matrix task

After initial studies which identified structural properties important to the prediction of item difficulty, a preliminary test was designed according to the identified structural principles. The test consisted of 24 items constructed as follows: 2 (rule type) x 2 (number of rules) x 2 (correlational structure) x 3 (element type). Rule difficulty was either constant on the x- & y-axis or distributed, representing a structural variation between matrix items. Number of rule tokens varied between two and three, representing the number of attributes which changed in the matrix. The correlational structure of individual matrix items or the number of attributes which were related to each other in a simple contingent manner varied on two levels. The last factor, element type was manipulated on three levels: unique elements, repeated elements (lines) - separated, repeated elements (lines) - joined. Examples of unique and repeated - joined elements can be found in Figures 1 and 2, respectively.

Pilot data collection

To get feedback on approximate item times and difficulty levels, generated items were administered informally to a combination of 50 students and recruits in counterbalanced order. Pilot testing consistently confirmed the importance of structural parameters in determining item difficulty. Unique items were subjectively judged to be easier than repeated elements (40 out of 50 tested thought unique element problems were easier; 5 thought problems with repeated elements - separated were easier, 5 thought there was no difference in the sets). All subjects thought correlated items were easier when they were distributed (hard rule tokens); only 62% thought correlated items were easier when they were constant on either the x- or y-axis (easy rule tokens). Since distributed versus constant structure (difficulty level of rule tokens) has been clearly established as determining matrix problem difficulty. The focus of this pilot testing was to gather data on the importance of manipulations associated with element type and level of correlation.

Final design of the paper-pencil matrix test

The expanded paper-pencil version of the experimental matrix test was modeled after the 24-item test, but was lengthened to include null values and a third element-type. The final version of the test included 64 items distributed as follows: 4 (element type) x 2 (null values) x 2 (rule type) x 2 (number of rules) x 2 (level of correlation). In the 64-item test, element type was manipulated on four rather than three levels. The added condition included repeated elements (lines) - crossed. In this condition, the lines were discrete, but not separated from the rest of the figure as in the repeated elements (lines) - joined condition. Manipulations of rule type, rule number, and correlation level between attributes were identical to the 24-item version.

Method

Subjects

Subjects included forty-four Air Force Recruits tested on the paper-pencil version of the experimental matrix test. Participation was coordinated by the Air Force Human Resources Laboratory at Brooks Air Force Base as an optional part of basic training. The sample was predominantly Caucasian (88.6%) and male (84.1%). The age of the sample ranged from 17 to 26 years with a mean of 18.5 (SD = 2.15). The recruits were part of a larger group of 180.

Materials & Procedure

An adapted version of the Raven's Advanced Progressive Matrices, Set II (APM; Raven, 1962) and the expanded 64-item paper-pencil version of the experimental matrices test were administered in group format in a classroom setting. The APM is a standardized 36-item inductive reasoning test consisting of 3x3 matrices with the bottom right hand corner piece missing. The experimental matrix task measured inductive reasoning as a function of a general structural model in a series of progressive matrices as described above. Format for the experimental matrices was identical to the format of the APM. The APM and experimental matrix problems were randomized together with each subject receiving all matrix problems in a unique random order. Answers for all matrix problems were drawn-in rather than chosen from a field of eight multiple choice options (the standard format for the APM is multiple choice). Recruits were given unlimited time to complete the test. Recruits recorded completion time for each problem from a second-clock centered on a computer monitor in the front of the room. Recruits were instructed to take as long as they needed for each problem. The experimental nature of the tests and the importance of being accurate was stressed. Recruits were encouraged to take a break at any time. Mean administration time for the two matrix tasks was approximately 2 hours.

Results

Descriptive statistics

Means and standard deviations for solution time were computed across difficulty levels of the experimental inductive reasoning task. Patterns of performance reflected a systematic increase in difficulty across levels of matrix structure with solution time slower as matrix structure decreased. Means (SD) across difficulty levels of the experimental inductive reasoning task are shown in Table 2.

Insert Table 2 about here

Analyses of Variance

A 2 (constant, distributed) x 2 (correlated, uncorrelated) x 2 (null, no null) repeated measures analysis of variance was conducted. Subjects with missing items were excluded from the analysis. Main effects were identified for type of structure, level of correlation between attributes, and presence of null values, all F's $(1,35) > 18.97$, all p's $< .001$. Significant interactions were noted between structure and level of attribute correlation and between correlational level of attributes and presence of null values, both F's $(1,35) > 5.02$, both p's $< .05$. Results indicate that correlational level interacted with both rule difficulty and the presence of null values, with uncorrelated attributes making problems substantially more difficult when attributes were distributed or when matrix problems contained null values.

Correlations

Correlations between solution time on the APM and the experimental task were computed. Results indicated that correlations between matrix items which had uncorrelated attributes were higher on average than matrix items with correlated attributes, mean $r = .53$ versus $r = .09$, respectively. Results also indicate that correlations between the APM and repeated - joined attributes are higher than other types of attributes even though no mean differences were observed, $r = .75$. Results indicate a relationship between decreasing degrees of interstimulus structure and performance on the APM. Results must be interpreted with caution, however, since correlations are based on small n's and therefore highly unstable.

Discussion

A relationship between structural components and performance on the APM was established. A significant relationship was found between the experimental matrix task and the APM tasks with the relationship increasing across decreasing levels of structure. It was hypothesized that dimensional redundancy mediated the relationship between the experimental matrix task and measures of higher order or complex mental processing such as performance on inductive reasoning tasks (APM). Preliminary investigations supported this hypothesis.

General Discussion

Although problems are evident due to the preliminary nature of these investigations, some important ~~very crucial~~ things emerged concerning the relationship between more traditional rule based approaches to inductive reasoning and a more general structural approach. The outline of general structural model is a way to think about inductive reasoning so that number and difficulty of rule tokens can be separated and studied independently. It also provides a mechanism to study identify individual item characteristics which contribute to problem difficulty so that they can be isolated and controlled.

In sum, the identification of individual components of reasoning would allow a more precise study of the relationship between reasoning and working memory. Components of rule tokens can more easily be identified and studied through the proposed structural model. Using this framework, we can more clearly begin to understand what's in a rule and how components of rules are related to the construct of working memory.

The study only represents the beginning of the formulation of a general structural model. Although initial studies show promise in providing a mechanism for understanding reasoning in terms of basic component processes, problems with the paper-pencil tasks are evident. Still, the basic model outlined has enormous potential for untangling the relationship between reasoning and working. The computerized version of the matrix task is in it's final stages, and I look forward to pursuing this project to it's completion.

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Table 1: Structural Equivalents to Rule Tokens

	Rule Token	Structural Equivalent
Individual Attributes		
Type A:	shape (J&V)	shape
	shading (J&V)	pattern
	size (J&V)	size
	movement in a plane (J&V)	position
	flip-over (J&V)	orientation
	number series (J&V)	number
Type B: (related to 'correspondence finding')		unique repeated
Individual Elements		
Type A:		figures lines dots
Type B:	added element (J&V)	unique-discrete repeated-discrete repeated-fused null
Relationships between attributes (rule tokens)		
Inter-attribute correlation		
		correlated
	reversal (J&V)	distributed
Attribute correlation with x- & y-axis		
	constant (rC,J,&S) identity (J&V)	correlated (row/column)
	constant in a row (C,J,&S)	correlated (row); distributed(column)
	quantitative pairwise	correlated (column); distributed (row)
	progression (C,J,&S)	
	dist.of 3 values (J,C,&S) elements in set (J&V)	distributed (row/column)
	addition/ subtraction(J,C,&S)	correlated (row/column); null values
	addition (J&V)	
	distribution-of-two-values unique addition (J&V)	distribution (row/column); null values

Table 2: Means (SD) for Solution Times on the Experimental Task.

	No Null Attributes	Null Attributes
Constant on x-, y-axis		
Correlated	16.45 (14.34)	18.32 (9.62)
Uncorrelated	23.88 (18.20)	35.33 (31.60)
Distributed		
Correlated	27.16 (11.91)	19.23 (11.62)
Uncorrelated	33.01 (19.67)	57.45 (29.21)

Figure 1: Sample matrix problems with unique-discrete elements.

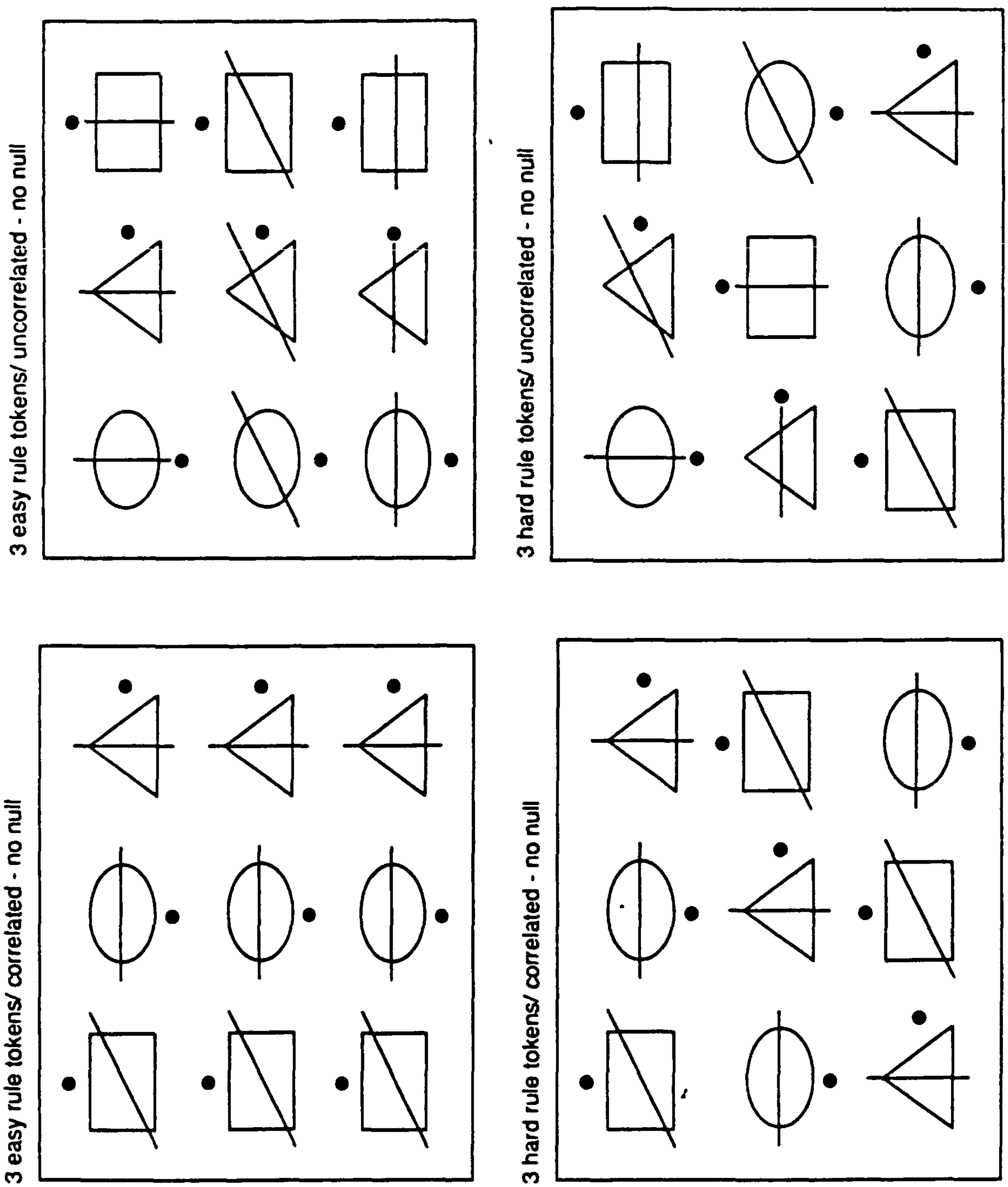
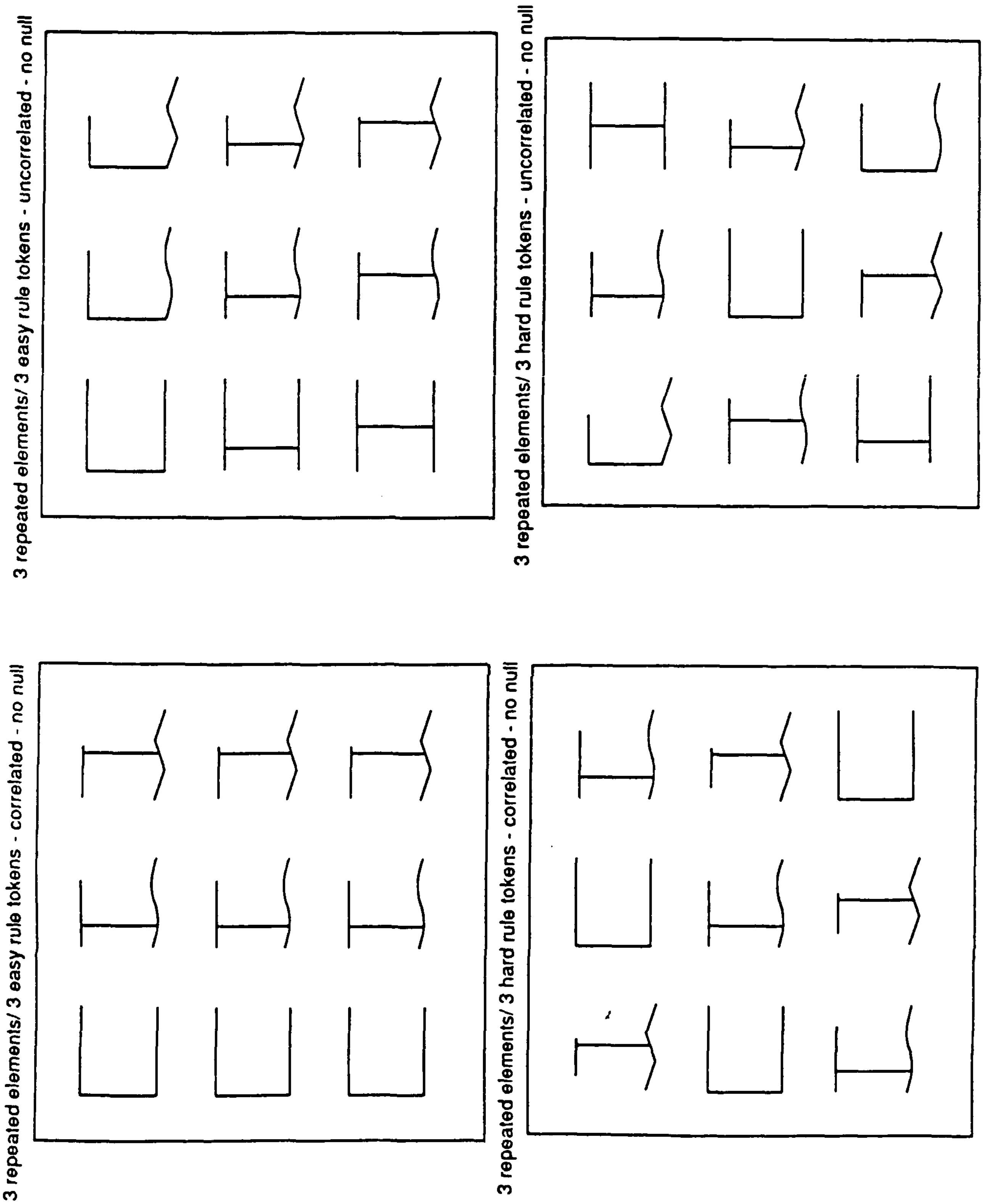


Figure 2: Sample matrix problems with repeated-fused elements.



Integrating the Affective Domain into the Instructional Design Process

Robert G. Main, Ph.D.

ABSTRACT

Educational psychologists, instructional theorists and practitioners generally agree that student attitude and motivation are critical components of the learning process. Historically, more workers are discharged because of behavioral problems than because of their inability to perform job tasks. Achievement scores in public schools continue to decline and the dropout rate in some high schools exceeds 50 percent. A major study shows student interest in learning declines as a function of the length of schooling.

Despite these indicators of the need to address the affective component in curriculum development, instructional design models focus almost exclusively on the cognitive domain. Research in strategies, tools and techniques for instructional developers related to student interest and motivation to learn is virtually ignored.

This study develops an integrated model of instructional design that incorporates the affective domain as an integral component. The model combines the ARCS model of motivation for learning developed by Keller with the traditional five phased military ISD model. The proposed ISD model provides a framework for organizing instructional principles, strategies and techniques concerning the affective domain and furnishes a theoretical base to aid in formulating research hypothesis and collecting empirical data.

The study concludes with recommendations for additional elaborations and research needed to operationalize the model to make it a practical tool for use by instructional designer/developers. Attention to the affective domain is particularly important for technology based instruction that removes the teacher/student interaction from the lesson delivery. This model should be helpful because it provides the <u>systematic</u> consideration of the affective domain in every aspect of the instructional design process.

Integrating the Affective Domain into the Instructional Design Process

Robert G. Main, Ph.D.

INTRODUCTION

"Historically, it is well known that more workers are discharged because of behavioral problems than because of their inability to perform job tasks" (Daggett and Marrazo, 1983). In discussing the effects of government regulations on productivity and competitiveness in the world economy, The president of General Motors is quoted as telling Congress that regulations didn't bother him as much as worker productivity. What he really needed was help in motivating his workers to be productive--even to show up for work (Walgren, 1991). A recent study at the Defense Information School indicated that three out every four failures in the basic broadcasting and military journalist courses were due to a lack of interest or enthusiasm rather than inability to master the subject matter.

It follows then that teaching in the affective domain is at least as important as instruction in the cognitive and psychomotor domains. Yet, instructional design models and practices have focused primarily on the acquisition of knowledge and psychomotor skills. Concern for the affective component has been largely confined to such things as the "user friendliness" of the computer based instruction or ways to overcome computer phobia among teachers and students.

The purpose of this research is to investigate how the affective domain can be addressed systematically in the instructional design process. The goal is to produce an integrated model of instructional design that includes the affective domain as an essential component. The model must include sufficient rationale and elaborations that it will serve as a framework for organizing instructional principles, strategies and techniques concerning the affective domain and provide a theoretical base to aid in formulating research hypotheses and collecting empirical data.

DISCUSSION OF THE PROBLEM

Defining the Affective Domain. The separation of learning objectives into separate domains has been largely accepted by educators since the landmark effort by Bloom and his group (1956) established the three categories of affective, cognitive, and psychomotor categories of educational objectives. The cognitive (thinking) and psychomotor (physical) domains are fairly well bounded in theory and research. The affective domain has been much more difficult to pin down. It is generally agreed to encompass those human behaviors associated with emotion and feelings, but these are very fuzzy areas. Ringness (1975) says the domain is so difficult to define because it is both ambiguous and controversial.

The literature of the affective domain in instruction spans the gamut from those who feel it is subsumed into the cognitive domain (i.e., achievement of cognitive and/or psychomotor objectives generates affective behavior) to those with the belief that "what you imagine, what you believe in, you can do." The latter group believe that developing one's own positive mind set is the most important factor for success.

Martin and Briggs (1986) claim the domain is so broad and unfocused that all behaviors not clearly cognitive or psychomotor are simply lumped together as affective. They cite self-concept, motivation, interests, attitudes, beliefs, values, self-esteem, morality, ego development, feelings, need achievement, locus of control, curiosity, creativity, independence, mental health, personal growth, group dynamics, mental imagery, and personality as being associated with the affective domain in the literature.
They contend "...that the lack of definition and focus has made measurement and research in the domain difficult; and it has made translation of affective behaviors into classroom practices inadequate" (p. 13). Bills (1976) states: "We are not close to an agreement about what affect is or what to call it....I have concluded that unless we can achieve a better concept of affect, we will never be able to deal with it in our classrooms or in our research" (p. 10).

Bloom (1956) describes learning objectives in the affective domain as those involved in interest, attitudes and values. Krathwohl (1964) says affective objectives are those which emphasize a "feeling tone, an emotion, or a degree of acceptance or rejection" (p. 7). Mager (1984a) defines attitude as a tendency to behave in one way or another. Ever the behaviorist, he says positive attitudes are determined by approach behaviors and negative attitudes by avoidance behaviors.

Gagne (1988a) refers to attitudes as a class of learned capabilities that predispose an individual to have a positive or negative reaction toward some person, thing or situation. Gephart and Ingle (1976) separate the affective domain into physiological (perspiration, heart rate, respiration, and visceral responses) and psycho-social behaviors and responses (attitudes, beliefs, values, emotions, and perceptions).

Gagne (1985) discusses motivation as a condition of learning and provides three ways of harnessing motivations to accomplish educational goals. These are incentive motivation, task motivation and achievement motivation. Keller (1983) defines motivation as the direction and magnitude of behavior.

Snow (1989) talks of goals, motives and values as broadly defining the affective domain. Krathwohl (1964) offers a classification system that establishes a continuum for affective behaviors based upon the degree to which an attitude, value or interest is internalized or incorporated into the personality of the learner. His categories go from <u>receiving</u> (merely being aware) through <u>responding</u>, <u>valuing</u>, <u>organization</u> and <u>characterization</u> (i.e., a value complex becoming a basic outlook on life). Anderson (1981) cited seven central student affective characteristics:

1) values;
2) academic self-esteem;
3) anxiety;
4) interests;
5) locus of control;
6) attitudes; and
7) preferences.

Sinclair (1985) refers to "affect" as describing the feeling or emotional aspect of experience. He says it is concerned with:

- -The motivation of behavior.
- -The maintenance and enhancement of self-esteem.
- -Anxiety and achievement motivation.
- -Development of curiosity, exploratory behavior, and a need-to-know and understand.
- -Social motives, such as a need for praise, recognition and attention.

Romiszowski (1989) makes a distinction between attitude and affect. He proposes to view skilled behavior as covering four domains: <u>Cognitive</u> (thinking), <u>psychomotor</u> (physical), <u>interactive</u> (interpersonal), and <u>reactive</u> (the skills component of the affective domain). In Romiszowski's scheme, the reactive domain deals with personal control and conditioned habits. In terms of instruction, it would include listening habits, study skills, etc. as well as development of a "mental set" or value system related to learning. The interactive domain includes social habits, e.g., good manners and interpersonal control skills such as leadership, salesmanship and supervision.

Romiszowski further postulates that the skills involved in the reactive and interactive domains are as amenable to the general principles of instruction as are cognitive skills and psychomotor skills. He also sees a parallel between the automation of affective domain skills (i.e., reflexive, conditioned activity vs. behavior resulting from a planned strategy of action for a specific situation) and the automation of cognitive and psychomotor behaviors.

The most comprehensive attempt to provide a taxonomy of the affective domain is provided by Martin and Briggs (1986). They provide 132 conditions related to the affective domain that range from morals and ethics to self-development and group dynamics. They believe the most relevant for training, however, to be attitudes and values.

For purposes of this paper, the affective domain is characterized in terms of motivation as it affects the direction and intensity of behavior. This is not meant to be restrictive of the factors involved in establishing motivation, but rather as a convenience in bundling the many components and how they are considered in relation to including the affective domain in instructional design. This definition reflects Gagne's concept of attitudes and Keller's concept of motivation in developing instructional plans and activities designed to influence the learner's effort to achieve a desired performance. It does not preclude the consideration of aptitude (Snow, 1989) and trait (Kyllonen and Shute, 1989) interactions as determinants of learner performance, but they would be considered only in terms of their contribution to motivating the learner's behavior.

Importance of the Affective Domain to Learning. Gagne states, "It is a truism that in order for learning to occur, one must have a motivated individual" (1988a, p. 25). He recognizes the importance of the affective domain to the instructional design process. "...[P]lanning for the activation of an appropriate motivational state must be an early step in instructional planning. Motivation must be activated (or at least have an identified occurrence) before learning begins and during the time it is taking place. Even the events after learning...have a significant effect on motivation for subsequent occasions of learning (p. 64). Schunk (1991) is just as emphatic about the importance of the affective domain in instruction.

> Although one can learn without being motivated, motivation plays an important role in learning. Students who are motivated to learn attend to instruction and engage in such activities as rehearsing information, relating it to previously acquired knowledge and asking questions. Rather than quit when they encounter difficult material, motivated students expend greater effort to learn. They choose to work on tasks when they are not required to do so; in their spare time they read books on topics of interest, solve problems and puzzles, and work on

special projects. In short, motivation leads students to engage in activities facilitating learning (p. 229).

Kozma (1991) and Salomon (1979) present an image of learning as an active, constructive process where the learner manages the available information resources to create new knowledge by taking external information and integrating it with information already stored in memory. This model presents the learner as having major responsibility in the instructional process. If the model is accurate, then the importance of motivating the student to be a willing and eager participant seems paramount--indeed axiomatic. "Motivation initiates, maintains, and controls the extent and direction of behavior" (Ringness, 1975).

<u>Neglect of the Affective Domain</u>. Motivation is the neglected "heart" of our understanding of how to design instruction, according to Keller (1979). "Historically, instructional science has benefitted from the work of behavioral psychology and cognitive-learning psychology, but this has given us only partial knowledge of how people learn, and almost no knowledge of <u>why</u> they learn" (p. 390). According to Beane (1985/86) "...the form or substance of affective education represents perhaps the most problematic of all school issues" (p. 27).

Even a cursory review of the literature indicates there is a much greater emphasis on the cognitive domain in instructional research than there is devoted to the affective domain. This neglect of the affective component in instruction has not always been true. Krathwohl (1964) studied the history of major courses in general education (liberal studies) at the college level. He found that, "...in the original statement of objectives there was frequently as much emphasis given to affective objectives as to cognitive objectives. However, as we followed some of these courses over a period of ten to twenty years, we found a rather rapid dropping of the affective objectives from the statements about the course and an almost complete disappearance of efforts at appraisal of student growth in this domain" (p. 16).

Snow (1989) suggests cognitive psychology has hardly considered the cognitive-motivation interface at all. He recommends research on problem-solving, cognition-motivation interaction be emphasized.

Although instructional designers and developers have largely ignored the affective domain in instructional design models, the practice of affective instruction has been kept alive by teachers in their classrooms. It is usually the mastery of affective techniques that differentiate the master teacher from the mediocre. The ability to capture the student's attention and structure the presentation to engage the student with the subject matter is an art form. Good teachers commonsensically or intuitively control the learning environment using their experience tested techniques and the technology available to maintain interest and motivate the learner.

Anecdotal accounts of the import of attention to the affective domain to student achievement are supported by Laminack and Long (1985) in an extensive study of teacher effectiveness. They found that undergraduates' recollections of their favorite elementary teacher are characterized by a variety of affective\ factors. In general, however, empirical evidence supporting the affective domain as either dependent or independent variables is sparse.

It is reasonable to question why so little effort has been placed in exploring the affective component of the learning process if it seems to be so widely recognized as a major factor in learning acquisition. Krathwohl (1964) postulated the erosion of affective objectives in college curricula could be due to the hesitancy of teachers to assign student grades in terms of their interest, attitude, or character development. To be sure, extreme behaviors are recognized and discipline exercised. Or, at the other extreme, awards and honors presented. It is interesting to note that, for the most part, the imposition of discipline and honors recognition are assumed as administrative functions and performed external to the classroom except in the primary grades. Krathwohl believed the hesitation to use affective measures for assigning grades was mostly due to the inadequacy of the appraisal techniques and the ease with which students could exploit their ability to detect responses to be rewarded or penalized.

He felt cognitive performance could be measured more objectively than affective behavior. It was fairly straightforward to determine competence in meeting cognitive objectives. In contrast, we might not trust the professed evidence of an interest or attitude because of the difficulty in determining whether a response was sincere.

A more serious reason advanced by Krathwohl for eliminating affective objectives from the curriculum is the philosophical basis of personal privacy, cultural diversity and individualism. The concepts of free choice and individual decision are central in a democratic society. The imposition of affective behaviors blurs the distinction between education and indoctrination.

Another reason identified by Krathwohl for the erosion in affective objectives in education has to do with the immediacy of results. Particular items of information or a specific skill is learned relatively quickly and results of instruction are readily observed. In contrast, affective objectives dealing with values and attitudes may be achieved only over considerable time, perhaps even years before affective based behaviors can be appraised. Topics such as honesty, organizational loyalty or drug abuse prevention are difficult to assess from immediate performance measurements.

Martin and Briggs (1986) searched the literature for clues as to why the affective domain has not been addressed more vigorously in instructional design theory and practice. They identified six problems they feel have contributed to the neglect of the affective domain in instructional design in addition to the difficulty of definition and measurement.

- The belief that affective goals are so long range and intangible that the time restrictions of instructional programs prevent development and measurement of affective outcomes.
- A fear that discussion of values, attitudes, morals, and other aspects of the domain may be seen as indoctrination or brainwashing.
- A recognition that the absence of behaviors may often be as important in the affective domain as the presence of behaviors.
- The inability to identify and specify affective behaviors because of the imprecision of natural language.
- An uneasiness about some of the persuasive communication methods associated with attitude change.
- Disagreement and confusion about whether affective behaviors are ends (outcomes) or means to ends.

The rationale presented by Krathwohl and others for the decline of affective objectives in education seem reasonable and it seems probable their effects are still operant today. Still unexplained, however, is the neglect the affective domain has suffered in instructional design theory for military and industry training. Here, technology itself may have been a contributing factor.

Computer based training (CBT) has been the leading edge for instructional technology for almost three decades. It is an expensive technology and education and training administrators are sold on innovation by cost/benefit analysis. Consequently, the pressure for research has been to determine how much and how fast knowledge could be acquired and skills attained using CBT. Besides there is something Orwellian about having a computer teaching attitudes and values--especially in the public schools. Not surprisingly, the achievement of cognitive objectives by new technology delivery methods is invariably compared with traditional instructional methods (Stephenson, 1990). Keller (1983) reinforces this notion when he states, "... we often read that the goal of instructional technology is to design effective and efficient instruction. Unfortunately, these criteria make it easy to exclude a specific concern for motivation, or the appeal of instruction" (p. 388).

Experience with the school system tells us that small children are generally eager and excited about going to school, but as they grow older they are likely to have negative feelings about school and school tasks (Ringness, 1975). Krathwohl, Mager, Keller and others have pointed out that this curiosity, interest and motivation to learn seems to be extinguished at least for a great number of the students by the very procedures of instruction used in the classroom (from Romiszowski, 1989). This change in attitude cannot be attributed entirely to the schools, but it does indicate a condition that needs to be addressed.

RESULTS

The Integrated Instructional Design Model. Affective domain instruction can be divided into two areas. One of these deals with instruction where the subject matter itself is principally concerned with changing student values, beliefs and attitudes. Courses in race relations, ethics and drug abuse prevention fall into this category as do military classes in the history and tradition of the service that are primarily concerned with generating a sense of loyalty and pride in belonging to an organization dedicated to the service of the nation and defense of freedom.

The second area of affective domain instruction addresses how the learner feels about the subject being learned. The goal is simply to motivate the learner to want to master the knowledge and skills being taught. We need to spend as much effort in motivating the student to learn in the design and delivery of instruction as we do with the cognitive and psychomotor needs. Perhaps we should spend more time and attention since it has such a powerful impact on achievement.

It is evident from the literature that the affective domain is an important area in education and training--both in terms of achieving affective behaviors and the facilitation of cognitive and psychomotor objectives. The development of clearly defined instructional activities and strategies for the affective domain has lagged those of the psychomotor and, particularly, the cognitive domains. Current instructional system design models have been developed principally for use in developing instruction for cognitive objectives.

To correct this problem and insure that affective domain objectives are addressed in every instructional lesson, the affective component of instruction must be embedded within the instructional system design model. This paper presents an instructional design model that integrates the work of Keller in his model for motivating the learner with the five phase military ISD model. The model proposed will make sure the affective domain is considered in a systematic and routine fashion from curriculum planning and design through lesson development, delivery and evaluation of learning outcomes.

The A R C S Model. Keller (1983) has developed a general model integrating the various sources of motivation for learning. He refers to it as the ARCS model; an acronym for the four sets of conditions that must be met in order to have a motivated learner:

A for attention;
R for relevance;
C for confidence; and
S for satisfaction.

Attention involves grabbing the learner's interest at the beginning of instruction and maintaining that interest throughout the lesson and the course. Attention sustaining events arouse the learner's curiosity. Relevance is the personal significance and value to the learner of mastering the learning objectives. The most straightforward tactic, according to Keller, is to inform the learner of the importance of the learning outcome to some desired state or goal, i.e., completing a technical course will provide eligibility for a promotion. The point is that the goal is desirable from the learner's perspective--not the lesson developer. Confidence relates to the learner's expectancy of success. Keller maintains that personal expectancy for success is influenced by past experiences (success or failure at the given task) and locus of control and personal causation (personal control and competence). Difficulty of tasks are also a factor. Success at simple tasks may not generate confidence. Satisfaction is derived from achieving performance goals. The gratification of goal achievement is confounded to some degree by whether the evaluation of learning outcomes are externally based or made by the learner internally. Keller speculates that because heavy doses of performance evaluation characterize instructional design, it is not difficult to see that as part of the reason for the erosion of the intrinsic interest of children in the school process.

Keller makes a point to distinguish between effort and performance as factors in motivation. He sees effort as the primary dependent variable of motivation while performance is influenced by ability (individual characteristics) and opportunity (learning design and management) and only indirectly related to motivation. A further distinction is made between performance and consequences. Consequences include affective responses, social rewards and material objects.

Consequences combine with cognitive evaluation to influence changes in personal values or motives. Affective behavior is considered to be a function of both person and environmental factors.

The Military Instructional Design Model. The instructional system design (ISD) model used for this paper is a modification of the five phased model used by the military services (NAVEDTRA 110A, 1981). The military ISD model is based on the foundations of learning principles and standard system theory (Tennyson, 1989). There has been a movement in instructional theories over the past two decades from the behavioral paradigm to cognitive science (Merrill, 1990). This interest in organization of information (knowledge base), information acquisition (pedagogy base), and knowledge representation is greatly influenced by developments in artificial intelligence and expert systems architectures.

The military instructional system design model is divided into five categories of activities or phases. The name of each phase is descriptive of the activities involved. The ANALYSIS phase has two major tasks--analyzing the performance problem and assessing the instructional need. The product of the ANALYSIS phase is a needs assessment document that answers five basic questions about the need for instruction:

- Why is the instruction needed?
- Who is it that needs the instruction?
- What is it they need to know or do or feel?
- Where will the instruction take place?
- When is the instruction to be conducted?

The DESIGN phase is where the "how" of the instruction is answered. Here, a task analysis is performed and the instructional objectives developed, admission requirements prescribed and the criteria specifying the competency level required of the learner. Instructional strategies are selected and the instructional mode and method determined. Existing learning materials may be identified and reviewed for use in the lesson.

In the DEVELOPMENT phase, the lesson plans are developed and the lessons are prepared and learning activities are sequenced and scheduled. Learning materials are selected or new ones produced e.g. workbooks, videos, computer programs, etc. Exams are prepared and the completed lessons pilot tested.

The IMPLEMENTATION phase is the administration of the training to the students. It involves both teaching and management of the instructional process. Learner progress is assessed and learning activities adjusted appropriately.

The CONTROL phase involves summative evaluation of the lesson and feedback for maintenance and improvement of the instruction.

The Integrated Affective Domain/ISD Model. A conception of how Keller's A R C S model can be integrated with a modified version of the military ISD model to create a matrix of the design process is shown in Figure 1.

INSTRUCTIONAL DESIGN PHASES

Affective Domain	Analysis	Design	Development	Implementation	Evaluation
Attention					
Relevance					
Confidence					
Satisfaction					
	Validation/Feedback				

Figure 1. ISD Model Integrating Affective Domain

Across the top of the model are the five phases of the military ISD model: Analysis, Design, Development, Implementation, and Evaluation (this is the control phase in the military ISD model). Down the left side of the figure are the four categories defined by Keller as components of motivation: Attention, Relevance, Confidence, and Satisfaction. Along the bottom of the model is a rectangular cell labelled Validation/Feedback to depict the formative evaluation which occurs throughout the instructional design process and serves to validate that the tasks in each phase have been completed and reviewed. The arrows indicate the two-way flow of information between the phases that provide feedback for improvement and maintenance of the system. It also shows the process is ongoing and not necessarily linear. Kemp (1985), for example, has developed an instructional design model that is circular to illustrate that instructional development is a dynamic process where evaluation data provides input for improving the instruction for the next class.

Following are a list of the tasks that are to be performed in each phase. These tasks apply for cognitive, psychomotor and affective domains.

Analysis Phase
1. Determine why the instruction is needed (establish the purpose and goals of the instruction).
2. Describe who needs the instruction (determine learner characteristics and attributes).
3. Establish the content of the instruction (determine the knowledge domain).
4. Determine where and when the instruction will take place (establish the location and schedule for the instruction).

Product: Needs assessment documentation.

Design Phase
1. Specify performance objectives (behavior desired, standard and conditions of performance described).
2. Establish how performance will be measured (evaluation criteria).
3. Determine instructional strategies to be used.
4. Sequence learning activities.
5. Design the delivery system.
6. Select presentation media.

Product: The instructional system design blueprint.

Development Phase
1. Produce or select learning materials (text, work books, graphics, visuals, training aids).
2. Develop delivery system hardware.
3. Generate software for system operation.
4. Create courseware.
5. Test and validate instructor/student/system interaction (interface).

Product: The instructional lesson and delivery system.

Implementation
1. Enroll students (insure students meet selection criteria).
2. Schedule instruction (assign classroom and structure learning activities).
3. Deliver instruction to the student.
4. Maintain the learning environment (insure facilities, learning materials, instructional equipment are available and operating and classroom decorum is maintained).

5. Monitor instructional progress (diagnose learning problems and schedule alternative presentation or remediation).
   Product: Desired student performance behavior.

Evaluation
1. Measure achievement in performing learning objectives.
2. Evaluate instructor performance.
3. Assess the instructional system performance (course materials, mode and methods of instruction, and hardware software operation.

Product: Certification of student achievement and a system evaluation report.

Validation/feedback
1. Conduct formative evaluation of the instructional design process.
2. Validate performance measures through external criteria and follow-up evaluations of related job performance.
3. Provide feedback for system maintenance and improvement.

Product: Feedback for system maintenance and improvement.

The A R C S model provides a framework for affective considerations in each of the five phases. Attention in the ANALYSIS phase includes determining the learners' interest in the subject matter and what the instructional needs are to arouse the students' curiosity. Factors involved include why the student is enrolled in the course (is it prescribed or voluntary), the nature of the subject matter (does it have inherent interest) and knowledge of generic interests for the student demographic profile.

Relevance includes analysis of the relationship of the instruction to the personal and professional goals of the learner and what needs to be included in the instruction to emphasize this relationship.

Confidence involves analysis of the learners' past experience of success or failure in similar learning situations and what needs to be included to raise the students' expectancy of success. Expectancy varies greatly between individuals, but the belief that it can be taught provides much of the basis for the long standing Dale Carnegie success workshops, EST training and other self-improvement programs.

Satisfaction requires the analysis of learners' needs for achievement and whether those needs are better served by extrinsic or intrinsic rewards. The students' locus of control orientation is an important consideration for determining the needs for establishing competence evaluation during the instruction.

In the DESIGN phase the tasks are to generate performance objectives that meet the affective needs identified during the needs analysis phase and select the appropriate strategies, learning activities and media that will best insure achievement of those objectives by the learner.

Even when the student has no choice in attending the instruction, it is important to include attention gaining strategies and activities early in the instruction and throughout the curriculum to refresh the students' interest frequently.

Strategies and activities to meet relevance instructional objectives should also be considered early in the course and reinforced at every opportunity throughout the instruction. Instructional content relating success in the classroom to personal and professional goals may range well beyond the subject matter needed for achieving cognitive and psychomotor objectives.

Confidence performance objectives relating to expectations of success may be best served by concentrating on the students' past successes. Having students identify selection for the course (if it is competitive or has entrance requirements) may encourage self-assurance. Determination is sometimes strengthened by emphasizing the difficulty of the course imparting a sense of elitism in performance.

Satisfaction is derived primarily from achievement, but it is generally considered more motivating if success is determined by self-evaluation than by external assessment. Rewards inherent to the learning task have been found to be less satisfying than those not directly tied to a specific performance criteria.

The difficulty in selecting affective domain instructional strategies, activities and media is that there are so many confounding and interacting variables that rules and principles are almost impossible to generalize and must be burdened with situational qualifiers. Variations in learner characteristics and traits compound the selection algorithm even more. That is why a carefully conducted analysis of the instructional requirement and needs assessment is so critical for proper affective domain instructional design.

Compared with the tasks of the ANALYSIS and DESIGN phases, the DEVELOPMENT phase is relatively straight forward. The biggest problems are generally related to costs. Compromises are often necessary between what is the most desirable method and mode of instructional delivery and what is within the budget.

Attention of the learner is gained through a variety of techniques used in the media arts. Interest is generated by visuals, auditory messages, motion and color. Animation, sound effects, signals, layout and literary devices such as dramatizations and story telling may all be useful in maintaining student involvement in the lesson.

Relevance can be addressed in the lesson by use of testimonials, illustrative stories and the use of simulations or exercises with actual equipment. The nearer the instruction approaches reality, the easier it is for the student to relate classroom activities to useful application. Generalizing specific skills and knowledge to applications beyond the immediate task in time and location is also helpful.

Expectations for success can be increased by modeling successful behavior and anecdotes of individuals who have overcome fears, obstacles and handicaps. Confidence may also be built up by a series of increasingly difficult challenges that can be met successfully. The technique, as with many dealing with the affective domain, requires a fine touch. If the exercises are too easy expectations may be lowered and if they are too difficult the learner may fail. Help or second trials may be used but care must be used that these do not generate undesirable dependency behaviors.

Rewards may be built into the lesson that address learner gratifications. Satisfaction may also be generated by competition, peer recognition and self-evaluation methods. Maslow's needs hierarchy may be useful as a guide to the lesson development in this aspect of affective objectives (1954).

IMPLEMENTATION is the phase in which the affective domain has been traditionally addressed--not by the designer, but by the instructor. Techniques for gaining attention, maintaining classroom decorum and sparking student enthusiasm are affective objectives that are routinely practiced by even the most inexperienced teacher, but are rarely addressed by the instructional designers and developers. As more and more instruction is delivered through a mediated process administered (and sometimes controlled) by computer programs, the greater the need becomes for the affective domain to be considered in the instructional design. Good instructors can overcome poorly designed curricula and instructional materials. But, even the most sophisticated intelligent computer system cannot unless the affective objectives have been included in the lesson design. It is during the instructional delivery through personal interactions between instructor and student that individual characteristics, aptitudes and traits can best be considered and the presentation modified to achieve affective objectives. If that behavior is to be included in automated instruction, student performance must be monitored and compared with some standard for behavior during the learning process.

The EVALUATION phase requires a great deal of attention for the affective objectives. As noted in the literature, the difficulty of measuring affective goals is cited as one of the major reasons for the neglect of the affective domain in the instructional design models. One of the problems is the relatively short duration for most instruction and the relatively long period required for building complex affective behaviors.

Some affective domain goals may be very difficult to achieve. Development of a value system may require instruction over a considerable time period. It may require inclusion in lessons throughout a curriculum or training program in a variety of message formats--much like an advertising or public relations campaign. Even lower level affective objectives such as learner attention will need reinforcing and refreshing periodically. On the other hand, once a value system has been learned, it is very persistent. It tends to become self-reinforcing as individuals attend more closely to information supporting an existing belief system and tend to avoid or discredit information contrary to their values. For example, the Marine Corps exerts a powerful and carefully orchestrated campaign to instil the concept semper fidelis as an affective behavior. However, once adopted, it remains a behavior often for life. Hence, the expression, "Once a Marine, always a Marine."

Research is needed, but I am firmly convinced measures can be adopted that are sufficiently accurate to determine if affective learning objectives are met. Certainly attitudes toward the subject domain, the instructional process and the eagerness to use the newly acquired knowledge and skills can be assessed. Attention measurement can include interest shown in continuing to learn about the subject after course is completed. Relevance can be assesed by questioning how the learner perceived she/he would be able to use the knowledge and skills attained in their job and beyond. Self-evaluation of competence in solving problems and performing tasks within the subject domain without assistance will give an indication of the Confidence level attained. Satisfaction with the instruction and knowledge and skills learned can be deduced from the successful completion of the course and verified by a questionnaire. The most effective measurement of the successful achievement of affective goals is a follow-up questionnaire of the graduate and his/her supervisor six months or longer after completing the course. But, that is generally true for cognitive domain goals as well.

CONCLUSIONS

This paper is an attempt to provide a first tentative step in addressing affective components within the instructional design process. To become a useful tool for instructional designers and lesson developers, the model must be fleshed out with task lists and taxonomies of strategies for each cell.

The theories of instruction and models of instructional design focus by and large on the cognitive and psychomotor domains. The affective domain is recognized by most in the literature, but in practice is largely ignored as an area of scientific research in the instructional technology field. An examination of military manuals regarding instructional design and development shows just how little attention is devoted to affective objectives. The Office of Naval Education and Training has published a summary of research findings with implications for Navy instruction and learning (What Works, 1988) with 60 pages of practical tips on instructional practices found to be effective in schooling. The book "...represents a synthesis of the best available information about instruction available from decades of research studies and teaching experience" (preface). There is only one page devoted to motivating students to learn.

The Air Force Handbook for Designers of Instructional Systems (1978) mentions the affective domain only twice, and that is in the overview section of the manual. It defines ISD as "a deliberate and orderly process for planning and developing instructional programs which ensure that personnel are taught the knowledge, skills, and attitudes essential for successful job performance" (p. 1-3). The manual goes on to state that the analysis phase of the ISD process results in a statement of all human activities (skills, knowledge, and attitudes) required for successful performance. No further references are made regarding attitudes, motivation or other aspects of the affective domain in the application of the model to Air Force lesson development.

How should we approach the task? We need to first recognize there are two distinct categories of affective domain requirements in instructional design. One of these is the design and development of curriculum whose primary goal is to change behavior in the affective domain, e.g. ethics, race relations. The other category is the design and development of lessons that include activities that motivate the student so that he/she wants to acquire the knowledge and skills needed to accomplish a task or solve a problem. In this case the affective component supports the cognitive and psychomotor objectives.

A great deal has been written about the changing role of teachers in computer based instruction. They are to become more managers of instruction than the presenters of instruction and the instructor/student ratio increases in the computer based training environment (Kearsley, 1983). As that occurs, the role shifts more and more to manager/technician as the principal duty becomes keeping the technology on line and managing the instructional environment. In this scenario, the affective domain receives less and less attention unless the art of teaching is incorporated into the CBT lessons.

The way to insure the affective domain is given consideration and treated systematically in all instructional environments is to have it embedded within the instructional system design model. Bear (1984) in a discussion of microcomputers in schools concluded that "... future research will find CAI (computer assisted instruction) to be effective in those classrooms that are characterized by the same elements of instruction that previously research has shown to be associated with effective teachers" (p. 12). It seems important, then, to research the pedagogy of traditional instruction to determine the affective domain principles so they can be incorporated within the CBT system design and lesson development.

The lack of explicit depiction of the affective domain in contemporary instructional system design models does not necessarily mean that instructional developers do not include affective considerations in their lessons. It is well established in the literature that the affective-cognitive-psychomotor classification is an arbitrary abstraction of human learning and behavior (Krathwohl, 1964). The division among the domains is largely a convenience created by psychologists and educators to distinguish the fact there are differences in educational goals and learning behaviors. But, the categories are neither natural nor discreet and cannot be separated except in an artificially contrived classification scheme.

It is simply not possible to design either cognitive or psychomotor instruction without including some affective component. The very act of establishing an instructional goal implies some value to the person, organization or society in its achievement. The selection of content to be included or excluded in the lesson requires the exercise of judgment as to the importance or worth of the knowledge and skills to be taught. Hence, the current debate raging in higher education (and spilling over into the public discourse) over the emphasis on Western culture in the general education curriculum. Similarly, it is impossible to teach a motor skill such as swimming, playing the piano or shooting a basketball without some emphasis placed on the value of acquiring dexterity. The motivation to learn may be already present in the student (it may even be a prerequisite) prior to instruction, or it may need to be generated or enhanced by the instructional program.

It is precisely because the affective is so entwined with cognitive and psychomotor learning achievements that it needs careful and conscious attention during the design and development of instruction. That is why this model should be helpful. It provides that the systematic consideration of affective objectives be integrated into every aspect of the instructional design process.

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Air Force Productivity Issues

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Abstract

The purposes of the current report are to (1) critically examine the evidence relating to the efficacy of Total Quality Management (TQM) interventions, particularly within operational Air Force organizations; and (2) to explore the literature examining the relationship between individual characteristics and group or unit performance. The first objective of this report focuses on an effort which blends the Method for Generating Effectiveness and Efficiency Measures, or MGEEM (Tuttle, Wilkinson, & Matthews, 1984), with the suggestions of Deming (1986) in implementing TQM programs. The focus of the latter objective is on operational military work groups. Efforts will be made to identify areas of research within the context of these issue which may ultimately produce results that may enhance unit productivity of Air Force organizations. Thus, both objectives of the current paper focus on issues pertaining to unit productivity.

BACKGROUND AND DISCUSSION OF PROBLEM

Total Quality Management (TQM) refers to a variety of methods, based on the work of Deming (1986) and others, whose aim is to enhance the productivty of work organizations through "satisfying customer requirements at low cost by involving everyone's daily commitment" to the mission of the organization (Metcalfe, 1991). The emphasis is primarily on improving quality, as Deming sees quality as a necessary condition that must first be met before meaningful and lasting improvements in productivity may occur. This approach assumes that workers want to be productive and to produce quality work and it is the role of management to set the occasion for productive work by removing organizational constraints that interfere with this basic motive.

A number of different TQM approaches exist (e.g., Crosby, 1984; Deming, 1986, Juran, 1988; Peters, 1987). These interventions have in common an emphasis on changing the philosophy of management. They emphasize the role of the system, rather than the worker, in causing production/quality deficits. Because the thrust of Armstrong Laboratory's TQM efforts have focused on the work of Deming, his approach will be emphasized in this report. A thorough review of Deming's philosophy is beyond the scope of the current discussion, but an excellent description is offered by Walton (1986).

At the current time, TQM is actively being implemented in a number of Air Force and other Department of Defense organizations. This is in response to official Department of Defense endorsement of TQM (Secretary of Defense, 1988). The chief approach being used in the Air Force is based on work sponsored by the Air Force's Armstrong Laboratory's Human Resources Directorate (Weaver & Looper, 1989). This particular approach to TQM represents a blending of Deming's approach with a unit level productivity measurement procedure, called the Method for Generating Efficiency and Effectiveness Measures (MGEEM). The MGEEM utilizes the nominal group technique to identify critical mission elements (referred to Key Result Areas, or KRAs) and measures of output for each KRA, referred to as indicators. A field test of an early MGEEM implementation showed considerable support and favorable reaction to MGEEM by the commanders and supersivors of three operational Air Force Squadrons: Weather, Propulsion, and Administration (Tuttle, Wilkinson, & Matthews, 1985). This study, however, did not explore any organizational consequences of the MGEEM intervenion, such as improvements in morale, increases in the quality of work, etc.

Work has continued on refining the MGEEM (Tuttle & Weaver, 1986; Weaver & Looper, 1989). The main thrusts of these improvements involve ways to standardize and weight productivity indicators. The output of an organization on various indicators is placed on a common scale to allow direct comparisons of productivity. Next, "mission effectiveness charts" (MECs) are developed. These require judgments about what level of output constitutes poor performance, average performance, and ceiling performance. These indicators may be aggregated, on a weighted metric, across a unit to provide a single omnibus measure of that unit's productivity. It is important to emphasize that these MECs are weighted to assess the relative contribution of individual indicators toward accomplishment of the unit's overall mission. Moreover, it is also important to note that these measures are created by worker level input, and are used to create statistical bounderies of production/performance, not as feedback to individuals. Thus, they represent what Deming (1986) calls "Statistical Quality Control," a key feature of TQM. A detailed description of this process is provided by Weaver and Looper (1989).

Despite the large number of TQM/MGEEM interventions that have been conducted in Air Force organizations, little information exists which evaluates in a controlled and systematic manner the efficacy of these implementations in terms of effects on various aspects of productivity. Clark (1991) reports that TQM/MGEEM was implemented in the Air Force Human Resources Laboratory (AFHRL). The implementation at AFHRL met with mixed results. According to Clark (p. 31) "many managers and workers did not support the programme. They viewed MGEEM as a paperwork exercise unrelated to TQM." This weak support for the MGEEM/TQM persisted for 20 months after the initiation of the intervention, despite nominal support from the organization's managers. Only 20 percent of respondents to a follow-up survey indicated they believed the intervention was of any value. However, it might be noted that less than 25 percent of the 380 people assigned to the laboratory turned in a useable questionnaire. Thus, response bias could have influenced the results obtained. It might also be mentioned that the majority of workers assigned to AFHRL are professional or technical workers, used to working independently on complex tasks. They are not representative of workers assigned to operational Air Force units.

It is interesting to note that, despite the widespread popularity of TQM among civilian organizations, relatively few controlled studies investigating its efficacy have been reported. The journal Total Quality Management is devoted almost exlusively to position papers, reviews, and "how to" descriptions of TQM programs. Two recent issues, which contain a total of 25 articles, had no empirical assessments of TQM. No empirical studies of TQM or MGEEM, except for those described above, have been reported. Walton (1986) and Deming (1986) describe in detail several interventions, all of which appear to be successful. However, the support was anecdotal. Moreover, not all anecdotal evidence is supportive of TQM. Main (1991) reports that Florida Power & Light, to date the only American company which has been awarded the Deming prize (an award, based on the management philosophy of Deming, highly valued among Japanese companies) did not show consistent increases in quality following its TQM implementation. The process was reportedly met with "widespread resentment." There are even reports of less than enthusiastic reception of TQM in DoD organizations (Boyd, 1991). Additionally, the Deming approach has received little or no attention in academic reviews of industrial/organizational psychology. Landy (1989), for instance, in his comprehensive review of the field, does not cite Deming or refer to TQM. In short, a scientific analysis is lacking.

Another area of concern with respect to the productivity of Air Force organizations involves the relationship between individual characteristics and unit productivity. There is a large literature dealing with the relationship between individual characteristics and group performance. The majority of these studies involve laboratory based experiments, employ experimental subjects who have not worked together as a group previously and often do not know each other prior to the experiment, utilize a somewhat homogeneous subject pool (college sophomores), and remain together as a group for short periods of time (usually no more than a few hours). Moreover, these studies focus on a limited range of dependent variables, most often learning, concept formation, brainstorming, and problem solving. These variables are relatively easy to operationally define, can be readily measured, and solutions can be obtained within the time constraints of the typical laboratory experiment. Excellent reviews of these studies are offered by Lorge, Fox, Davitz, & Brenner (1958) and more recently by Hill (1982).

As Campbell and Stanley (1963) point out, while experiments allow inference of causation and may show substantial internal validity, the degree to which the results of basic experimentation may be generalized to the "real world" may be questioned. Operational Air Force units, for example, are quite different from the groups studied in laboratories. In contrast to experimental groups, Air Force units are more heterogeneous, being comprised of individuals of different ages, races, length of experience. Also, most units now have both sexes assigned to them. Additionally, the members of Air Force units may have been together for periods up to several years, and individual members may bring years of experience of working within similar units to their current unit. The aptitude mix of Air Force units is limited only by the minimum ASVAB cutoff for a particular career field and by the size and quality of the recruiting pool. Finally, the relevant index of the productivity of operational units is more difficult to define than the dependent measures usually examined in experiments. It may or may not be measurable by "hard data," and likely involves processes in addition to cognition.

Relatively few studies have been reported which focus on operational military units or groups that are similar to these units. A review of such relevant literature was reported recently by Kahan, Webb, Shavelson, & Stolzenberg (1985). They focused on studies of military units and one aspect of the civilian literature - team sports. The focus of their review was on factors that predicted group performance/productivity. Five major areas of predictors were identified and reviewed - these included individual characteristics (ability/aptitude, task proficiency, personality and motivation), leadership, group structure, group processes, and training techniques. According to this review, the most consistent predictor of unit performance was the ability/aptitude of individuals in the unit, but this effect was moderated by several variables such as type of task. Training techniques were also related to group performance, with a combination of individuual and group feedback leading to the best overall unit performance. It was concluded that personality measures were not predictive of unit performance, nor could leadership variables be consistently related to this criterion.

Little has been done with respect to the role that vocational interests play play in unit performance. Alley and Matthews (1982) report the development and validation of an interest battery explicitly designed to predict job satisfaction and other important occupational outcomes among Air Force enlisted personnel. This battery, known as the Vocational Interest Career Examination (VOICE), has been shown to be predictive of first term attrition (Matthews & Berry, 1982), and Air Force and technical school attrition (Matthews & Ballentine, 1984). VOICE scores have also been shown to be quite stable, with test-retest reliability of .90 or higher (Matthews & Watson, 1984). Moreover, recruits assigned to Air Force careers which are similar to their measured interests are more likely to reenlist and less likely to leave the Air Force prematurely than persons assigned to career fields with a large disparity between their measured interests and interest for the assigned career (Matthews & Weaver, 1987). It would seem that groups composed of members who showed strong interest in their occupation would be more productive than those composed of members disinterested in their jobs. Moreover, the presence of a single highly interested/motivated member might positively influence the behavior of the group toward better productivity.

The studies reviewed by Kahan et al. (1985) attempted to define leader characteritics in terms of ability and personality. Perhaps in an empirical investigation of leader characteristics on group performance within military units, it would be useful to restrict leadership variables to ones that can be defined in terms relevant to the military. For instance, rank of the leader, time in grade, time in current duty assignment, age of leader, ASVAB or AFOQT scores of leader could be used as a set of predictor variables in predicting unit performance.

As Kahan et al. (1985) suggest, there are several questions within the domain of individual measures and their relationship to unit productivity that have not been investigated. For example, the majority of military work in this domain has utilized tank crews, which consist of three to four members, as its subject population. During training exercises, in particular, this population has proved valuable in terms of the flexibility with which members may be assigned to crews, data gathered on their individual characteristics, and objective measures of performance collected for tank crews. However, one may question the extent to which tank crews are representative of military units in general and of Air Force units in particular. Moreover, these studies have not used the individual measures of _each_ member of the crew to predict crew performance. Rather, they have used highest ability/aptitude member, lowest ability/aptitude member, and the mean level of ability/aptitude of the group. Studies which assess the aptitude of each member of a unit and then use that information to predict unit performance are needed.

Other variables which may interact with individual measures to influence unit productivity have not been examined. For example, the work demand for the unit may vary with time and conditions. In flying squadrons, the sortie rate may fluctuate with user needs, training demands, and operational considerations. Similarly, some constraints upon unit productivity come from logistics, supply, and coordination and cooperation among other units. Factors pulling unit members away from the job such as illness, pregnancy, TDY, and so forth may have temporary effects on unit productivity.

It would appear that what is lacking in the current research on individual measures and unit productivity is a large scale field-based study, comprehensive in nature, that looks at a variety of predictors and moderating variables within the context of an operational Air Force organization. One could specify and define a number of sets of vectors to predict unit productivity. For example, one set of variables could encompass individual measures. These would include aptitude/ability, skill level, training, experience, and vocational interests. The mean and standard deviation of aptitude of members assigned to the unit might also predict unit peformance. Similarly, the degree to which an organization's members exceed minimum aptitude requirements could be determined. These could be regressed against a unit productivity criterion and their influence on unit productivity both individually and as a set could be assessed. A second set of variables could focus on intraorganizational factors, including organizational climate and mission type. A third set might include extraorganizational factors such as demand for the unit's product, availability of supplies, and logistics. Yet another set of variables pertaining to leadership could be defined. This could include leader characteristics of individual unit's supervisor, as well as characteristics of individuals in the chain of command within the larger organization.

Such a design would allow a more complete explanation/description of what influences unit productivity in an operational organization. In some organizations, it might be found that factors besides individual characteristics would account for the majority of the variance in unit performance. Regardless of the ability of maintenance workers, productivity will be low if supplies are in short supply or are slow in delivery.

A limitation to this sort of study involves developing a sensitive and psychometrically sound measure of unit productivity. However, the MGEEM was explicitly designed to produce such a measure, even in organizations where "hard measures" either do not exist or are difficult to obtain (Tuttle et al., 1985). As discussed earlier, recent refinements of the MGEEM allow a unit to aggregate individual measures of productivity onto a common scale, and to produce a single overall measure of unit productivity.

Because the MGEEM is being implemented in several operational Air Force organizations, it would seem plausible to utilize units within such organizations to carry out a study of the type described above. Such an effort would pull together current Air Force productivity research and development programs and perhaps further facilitate/enhance the productivity of the target organization while at the same time provide valuable information on the relationship between individual measures and unit productivity.

RESULTS

There are several questions raised by the current review that could be addressed by research. Each of these questions pertain to some extent to the TQM/MGEEM.

First, a systematic and controlled evaluation of the effectiveness of the TQM/MGEEM in an operational Air Force organization needs to be undertaken. This will be the subject for the Research Initiation Proposal (RIP) that will be developed from the author's Summer Research Faculty Fellowship. Briefly, the proposed study will compare Charleston AFB, which is undergoing a TQM/MGEEM intervention, with McGuire AFB, which has a similar mission to Charleston but is not receiving an intervention of this type. The bases will be compared with respect to a number of hard and soft criteria, including organizational climate, attrition and retention, measures of productivity and, for Charleston, reaction to the TQM/MGEEM.

It is also suggested that additional research be conducted at Charleston AFB. The reliability and validity of TQM/MGEEM generated productivity measures needs to be determined. Given the massive scale of this intervention and the apparent receptiveness of the command of this base to the intervention, data bearing on this should be readily obtainable at this location.

Given the information that exists and will be generated by the TQM/MGEEM at Charleston AFB, the opportunity to explore the relationship between individual characteristics and unit work performance is unparalled. The external validity of research findings resulting from laboratory studies may be established by studying the operation of independent variables in an operational setting. With the downsizing of the force and decreasing pool of eligible applicants for the military, this is potentially a very critical area for future research.

CONCLUSIONS

As in private industry, productivity is rapidly becoming a focus of Air Force organizations. "Doing more with less," given the prospects of decreasing defense budgets and more competition for recent high school graduates, becomes imperative.

The research projects suggested in the current review are critical to this end. TQM/MGEEM has already been implemented in a large number of Air Force organizations, with requests for implementations coming in regularly from other organizations. Given the organizational resources that must be committed to TQM/MGEEM, it is important not to be satisfied with anecdotal support but rather to objectively evaluate its effectiveness.

Manpower assignment procedures currently only require that enlistees meet minimum cutoff scores for entry into a career field. Once trained, personnel are assigned to a particular job, unit, and base based on preference and requirements of the Air Force. However, this may not be the opitimal assignment strategy. Research into the role of individual characteristics on unit performance may suggest that taking into account the characteristics of existing group members may also be important in determining unit performance. For instance, there may be some tasks for which a single high aptitude unit member could raise the group's performance significantly. This might allow a more efficient utilization of highly able personnel, and allow for less impact of low ability personnel. Thus, it may be concluded that the areas identified for future research are important for maintaining an effective fighting force into the next century.

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Individual Differences (Impulsivity) and Personnel Selection

Final Report

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Siem, Carretta, & Mercante (AFHRL-TP-87-62, 1988) found a relationship between performance on the Self Crediting Word Knowledge (SCWK) test portion of the BAT and pilot performance in Undergraduate Pilot Training (UPT). SCWK correlated 0.14 ($p < 0.01$) with pass/fail criteria for UPT candidates. One way to interpret these data is to note that subjects who passed UPT : took longer to answer on SCWK, had fewer total correct responses, and bet fewer points on the responses they did make. Even when overall verbal ability was statistically controlled there were smaller but robust differences in time to answer between successful and unsuccessful candidates. Those candidates who completed UPT tended to take longer for their responses. The authors interpreted this finding as a manifestation of a more cautious decision-making style exhibited by successful UPT candidates.

Siem (1991) tested 302 UPT candidates using various tests (BAT) including the SCWK test and the Activities Interest Inventory (AII). Siem found: 1) that response latency measures were related more closely to self-report personality measures than to cognitive response times, 2) that the risk-taking score was associated with a self-report measure of thrill seeking, and 3) that the performance-based self-confidence score was correlated with verbal aptitude but not with a self-report measure of self-confidence. A confirmatory factor analysis performed to examine the data structure provided a three factor model: 1) verbal self-confidence, 2) cautiousness, and 3) thrill-seeking.

What does all this mean mean? We know: 1) pilots need adequate levels of thrill-seeking or they won't fly jets, 2) cautious decision makers do better in UPT, 3) thrill seeking and cautious decision making (the opposite of impulsivity) are components of what purveyors of the "Big 5" call Surgency, or that Eysenck calls Extraversion, and 4) Surgency, by itself, is not strongly associated with pilot characteristics (Ashman & Telfer, 1983).

What would we like to know: 1) will a composite score incorporating high thrill-seeking and low impulsivity, essentially a decomposition of surgency, predict pilot training success, 2) if such a situation occurs what is the magnitude of the relationship, and 3) are there particular "impulsivity factors" associated with poor training performance?

Method

Subjects:

One hundred fifty-three AFROTC Flight Screening Program (FSP) candidates tested during the summer of 1991. One hundred forty-four subjects yielded usable data.

Procedure:

- -The FSP candidates were tested on the BAT.
- -Substituted for the Automated Aircrew Personality Profiler were 169 items from:
  - -Barratt & Patton Impulsivity Scale items (impulsivity)
  - -Gerbing, Ahadi, Patton Items - 12 Factor (impulsivity)
  - -16PF Scales
    - -Surgency (Extraversion)
    - -Ego Strength (Impulse control)
    - -Superego Strength (Environmental Conformity)
    - -Premsia (Tendermindedness/Dependency)
    - -Protension (Anger, Introverted Suspiciousness)
    - -Autia (Unconventional Behavior/Imaginativeness)
    - -Q3 Self-sentiment Strength (Sense of Identity)
    - -Q4 Ergic Tension (Undischarged Instinctual Energy)
  - -GZTS Restraint Scale
  - -MMPI Impulsivity Items

- -The FSP candidates then completed the regular pilot screening program in prop-driven aircraft.
  - -Criterion variables include:
    - -Pass/Fail
    - -Academic Average Score
    - -Check Ride Scores
    - -5 Point Likert Scale overall rating of Pilot Competency by AF Pilot Instructors

Results

One hundred fifty-three subjects were tested during the BAT portion of the study. One hundred forty-four subjects completed all the testing and comprise the subject pool. As of September 27, 1991 the data from these subjects is in the custody of OAO Corporation (Air Force contractor in charge of BAT testing) employees at Brooks AFB, Texas. SAS programs for analyzing these data were written at Brooks by Dr. Patton and Ms. Brady. These programs are now resident on the Baylor University VAX mainframe computer. When OAO provides the data files to Dr. Patton they will be uploaded onto the Baylor VAX and analyzed.

Dr. Patton gave an "Exit Lecture" on August 28, 1991 at Armstrong Laboratory, HRD, HRMA, Brooks AFB, Texas. When these data are analyzed Dr. Patton has agreed to return to Brooks to provide a briefing on the results and their meaning.

A COMPUTER MODEL OF MULTIRAD (Multiship Research and Development)

Arthur W. Draut

Abstract

This report describes a first attempt at modelling the aircraft simulator network at the Armstrong Laboratory, Aircrew Training Division, Williams AFB, AZ. The laboratory uses a modification of SIMNET (Simulation Network) as the network connecting the simulators. The modelling tool used was a free trial version of Network II.5, produced by CACI Products Co. This report includes descriptions of MULTIRAD, SIMNET and Network II.5. Most of the author's ten-week tenure was spent understanding the configuration of the system as it exists. Simple models of simulation networks were built on Network II.5 as a means of learning to use the software. The author recommends buying the Network II.5 software. The building of detailed models of existing and proposed networks is proposed as continuing research.

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ACRONYMS

DARPA Defense Advance Research Projects Agency

DIS Distributed Interactive Simulation

GCI Ground Controlled Intercept

LAN Local Area Network

NIU Network Interface Unit

OSI Open Systems Interconnection

RVA Remote Vehicle Approximation

SAM Surface to Air Missile

SIMNET Simulation Network

The MULTIRAD configuration at Armstrong Laboratory, Williams AFB, AZ.

The system consists of four aircraft simulators, computer generated threats (RADARs, SAMs, etc.), a GCI site, and an operator's station. It is intended to allow pilots to fly simulators in a battle scenario to achieve realistic training in environments that cannot be offered in peacetime, stateside training. For example, we cannot fire real missiles at pilots flying real aircraft for the purpose of teaching the pilots to defeat the missiles, but such training can be accomplished in simulators. Another scenario we can fly in the simulators is that of flying several pilots in a coordinated attack against enemy targets. The computers can generate realistic images of the terrain and defenses in enemy territory. Thus the pilots can practice flying over enemy territory before going into battle.

The aircraft simulators are linked together so that the display in one simulator correctly displays the actions of the other aircraft, as flown by pilots in the other simulators. The SIMNET network was chosen for this link between the simulators.

SIMNET was proposed by DARPA and developed by the Army to link tank simulators together. It has been very successful in training Army tank personnel to execute coordinated attacks against various enemy defenses. It has been credited with being a small part of the reason for our success in the war in Iraq. SIMNET has been expanded to include helicopter simulators and A-10 simulators and also long haul links between two local area networks.

Armstrong Laboratory has modified SIMNET to link F-16 and F-15 simulators. The F-16 and F-15 simulators were already being used in aircrew training research. The simulators consist of actual cockpits, various types of wide field of view displays, and various computer equipment for linking the cockpits and displays and for image generation. These existing simulators are herein called host simulators. An Ethernet network was installed and Network Interface Units (NIU) were built to link the host simulators to the Ethernet. The NIUs were built to conform to SIMNET protocols.

The primary purpose of the NIU is to transform data formats as they exist in the host simulators into formats prescribed by SIMNET. SIMNET protocol uses sixteen different types of data packets, such as "vehicle appearance" and "radiate", used respectively to transmit data about the position, attitude, and configuration of the vehicle and to transmit data about RADAR activity[1]. These data packets are about 200 bytes in length and are appropriate for use on an Ethernet LAN.

One of the features of SIMNET that reduces the amount of traffic on the network is the Remote Vehicle Approximation (RVA). The RVAs are performed in the NIUs. Each NIU performs an RVA on its own host and also for each of the other simulators on the network. The RVA predicts the position (latitude, longitude, and altitude) of its associated aircraft and passes this position to the image generation computers. Each NIU monitors the position of its host simulator and compares it to the host RVA, which it continuously computes. Whenever the position predicted by the host RVA and the position of the host simulator deviate beyond a prescribed threshold, the RVA updates itself to reflect the correct position. Then this new position is sent across the network to all the NIU's so that the appropriate RVA can be updated in each NIU and also the appropriate aircraft position can be updated in the image generation computers of each host.

Without the use of RVAs, the position of each aircraft would have to be sent from its host simulator to every other host simulator for every image frame generated. This would generate an excessive amount of traffic on the network.

The author feels that in the present software, the computation of the RVAs in the NIUs is inappropriate and has expressed this concern to the Armstrong Laboratory personnel. These computations are not cleanly separated from other functions and therefore violate the principles of layered protocols and modular software. Others have expressed the same concern. There is work underway to create a new simulation network protocol which would be more in line with the OSI model of layered protocols.* This new network protocol is called Distributed Interactive Simulation (DIS) and may replace SIMNET.

* The OSI model of layered protocols is described in several textbooks. One is Spragins[2].

The author noted what he considers to be a deficiencies in his study of the NIU software. Inquiries were made and the same deficiency appears to exist elsewhere. The software was not developed according to the DOD standard 2167A[3]. There appears to be no software documentation standards and no software configuration management standards. The design document[4] did not present a useful picture of the software. This lab is a research facility and software modifications need to be made for different studies and these modifications are not permanent. Therefore, one can argue that production software standards are not appropriate. But the author believes that this software is so extensive and complex that modifications are highly error prone because of the lack of proper software standards. For example, during a modification, a bug may be created in the software but not be noticed. Several configurations later the bug may become apparent, but it will not be obvious which configuration created the bug. At present there are no requirements to document and save the various configurations.

The purpose of modelling the network is to be able to predict the speed and size problems that will arise when larger networks and long haul networks are built. Thus there is a need for exact values of speed and size parameters in the current network. These parameters are critical inputs to the modelling process. In order to perform network analysis, Armstrong Laboratory has two devices, a Data Logger, and a LAN Analyzer. These provide information about data in the data packets and about relative times (as seen at the LAN analyzer). However, devices are needed to capture dumps of the raw data packets (including headers) and to measure absolute sizes of data packets and times of transmittals at various places in the network relative to one master clock. The author recommends that such devices be built.

The Network II.5 modelling software

Network II.5 is a software product produced by CACI Products Company, La Jolla, California. Its cost is approximately between $15,000 and $25,000, depending on which type of computer it is run. It can be run on mainframe computers, work stations, and desktop (personal) computers. For creating models it provides both text and graphical (mouse) user interfaces. For output, the user is provided with statistical data on various parameters and with textual descriptions or graphical animation descriptions of the network performance. The graphical animation shows a diagram of the network and the movement of data through the network. Statistical information of many types of parameters is available including percent of use of the network and counts of data packets among others.

This modelling software is very sophisticated and aspects of the network such as buses, processors, memory storage, and most any type of hardware device can be modelled to most any level of detail. Instructions or groups of instructions that are run on a processor can also be modelled to most any level of detail. One feature that should prove very useful is the snapshot. The model can be configured to provide snapshots at regular or prescribed intervals during the run. These snapshots will list the values of various parameters at given instants of time.

During the author's ten week tenure at Armstrong Laboratory, there was not time to analyze other modelling software. This was the author's first exposure to Network II.5, but he is satisfied that he can recommend the purchase of this product. The cost of doing a study of several software modelling packages would be of the order of magnitude of any savings that might be obtained by buying a less expensive product. If the Air Force is going to spend tens of millions of dollars on simulators and networks, it makes sense to spend tens of thousands of dollars on a modelling tool. The author feels that it is more critical to begin the analysis and modelling of the networks than to spend time analyzing modelling software.

Conclusions

Simulator networks are extremely useful to the military services and the analysis and modelling of such networks should proceed in earnestness. Armstrong Laboratory, Aircrew Training Division, should begin to develop skills and experience in the modelling of such networks. These skills and experiences will be useful to any branch of military service involved in the simulation of aerial combat. The primary benefit of modelling is the cost savings achieved by allowing one to do extensive analysis of the simulator network before actually building it.

Additionally, Armstrong Laboratory should consider changing protocols -

DIS instead of SIMNET. This should achieve a cleaner separation of the network functions. Also, it is recommended that devices be built to measure time and data packet size parameters of the network. Lastly, it is recommended that DOD 2167A software development standards be implemented for the network software and, in particular, configuration management procedures be implemented.

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CERTITUDE ESTIMATES AND PROCESSING TIMES MAY FACILITATE STUDENT MODELLING FOR THE ADMINISTRATION OF EFFECTIVE FEEDBACK[1*]

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Abstract

The efficiency of training could be improved if the administration of instructional feedback were based upon the inferred cognitive state associated with each trainee's response. The use of certitude estimates and response times may provide reliable sources for computer generated student models of processing characteristics. In this context, several proposals are made for extending the prevailing model of instructional feedback (Kulhavy & Stock, 1989). These suggestions were explored in an item learning paradigm with 26 subjects responding to 200 semantic knowledge multiple choice questions, studying feedback, and taking posttests on two occasions. This work is placed within a theoretical framework using perceptual control theory (Powers, 1973, 1989), along with aspects of an argument model for confidence in judgements (Read, 1991), and current understandings of knowledge activation (e.g. Anderson, 1983, Anderson, 1989). Also reported are the current plans for more complete experimental studies and for modelling higher level control systems.

Introduction

Problems with Instructional Feedback Research

As the feedback work over the last 30 years has become more cognitively oriented several helpful findings have served to focus the research and provide some clear direction for practical applications, such as in computer based training (CBT). For example, it has been demonstrated that the primary benefit of feedback is in error correction not in reinforcing (Kulhavy, 1977). And it has been demonstrated that regardless of the content of the feedback message, there will be little benefit if the student does not adequately process the information (see Anderson & Kulhavy, 1972; Salomen & Globerson, 1987). These results are encouraging; however, many of the experimental feedback studies in both the behaviorist and the cognitive tradition have tended to produce conflicting or inconclusive results (see Bangert-Drowns, Kulik, Kulik, & Morgan, 1991; Hancock, 1990a; Kulhavy and Stock, 1989).

Part of the problem with much feedback research may be that focus has been on affecting posttest performance by manipulating the instructional environment or the characteristics of the feedback message, while paying only scant attention to the actual mental processes of each learner (c.f. Talyzina, 1981). For example, responses are typically treated as simply right or wrong, when in fact both correct and incorrect responses can be generated from either rich knowledge networks or from random guessing. This is instructionally significant because in each case the cognitive need of the learner is different and the type of feedback that will facilitate learning will likely vary as well.

The view in this paper is that the knowledge, perceptions, and processing characteristics of each student determine the effectiveness of various feedback messages; and that feedback decisions should be rooted in theoretically sound, empirically tested explanations about the cognitive state or model for each student.

Metacognitive Judgements of Knowledge Estimation

The first step in creating such student models may be found in asking more of the learner. Recent work suggests that the metacognitive activities of students should be more explicitly incorporated into instructional environments (e.g. Brown, 1980; Glaser, 1989). The metacognitive activity presented in this paper is similar to other types of knowledge estimation in the experimental literature: feeling of knowing (Metcalfe, 1986); ease of learning estimates (Leonesio & Nelson, 1990); judgements of knowing (Zechmeister & Shaughnessy, 1980); judgments of learning (Nelson & Dunlosky, 1991); and the tip-of-the-tongue phenomenon (Koriat & Lieblich, 1974).

It is proposed here that we ask learners how certain they are of each piece of learning; and that such information be used to make decisions about the knowledge state at each frame or segment of learning, which in turn should determine the type of feedback that should be most effective.

Some of the pertinent findings in the experimental literature indicate that different types of knowledge estimates are somewhat reliably related to the subject's cognitive state: accessed information about the target material (e.g. Blake, 1973); perceptions relevant to the target material (e.g. Schacter & Worling, 1985); degree of prior learning of the target material (e.g. Nelson, Leonesio, Shimamura, Landwehr & Narens, 1982); and latency of recall (e.g. Nelson, Gerler, & Narens, 1984). Also, it has been determined that knowledge estimates can be highly predictive of later performance (e.g. Nelson & Dunlosky, 1991).

Response certitude. The type of knowledge estimation of concern in this work is response certitude (see Hancock, Stock, & Kulhavy, 1991). The experimental paradigm for recent investigations with certitude is item learning--which typically involves a subject in the following activities: (a) reading and responding to a multiple choice question, (b) rating certainty that the response was correct (using a Likert scale), (c) studying feedback information, and (d) responding again to the question at a delayed testing.

The use of certitude ratings and other types of knowledge estimation for improving feedback has remained a largely unexplored field (see Bangert-Drowns et al., 1991). And references to certitude in a CBT context have even been inaccurate (e.g. Steinberg, 1991).

Kulhavy/Stock Model for Instructional Feedback

The second step in facilitating student modelling of knowledge processing characteristics for the intelligent administration of instructional feedback is explored with the Kulhavy/Stock model of instructional feedback (Kulhavy & Stock, 1989), where certitude estimates hold a central place. On the basic level their work has delineated the cycles in instructional feedback sequences, and defined the contents of the feedback message: type, form, load. But perhaps more importantly their work has highlighted that the effectiveness of feedback may vary sensibly and somewhat predictably according to the inferred cognitive state of the learner. They have described a model in which the cognitive processing of the feedback message can be understood as a control process (Powers, 1973, 1978) involving the reduction of cognitive discrepancy.

The cognitive discrepancy measure extends from a minimum value when a learner is certain of a response and is correct, to intermediate values at low certainty, to a maximum discrepancy when one is absolutely certain that a response was correct but in fact it is incorrect. Following this logic, feedback information should be processed to the extent that it is used by the learner to reduce discrepancy. The empirical evidence for the plausibility of discrepancy reduction has been that feedback processing time tends to increase as discrepancy increases (Hancock, 1990b; Kulhavy & Stock, 1989; Kulhavy, Stock, Thornton, Winston, & Behrens, 1990). Though the data are somewhat supportive, they are not particularly convincing, as has been pointed out by Bangert-Drowns et. al. (1991).

Refining the Discrepancy Testing Methodology

Were it demonstrated more conclusively that humans do reduce discrepancy when they process feedback, it would not only affect our theories about human information processing, but it would provide more guidance for instructional prescriptions.

One possible improvement to the methodology for testing discrepancy reduction (another is suggested later), would involve separating the feedback study times according to the posttest correctness. If a learner does not adequately process feedback for some reason (e.g. if conflicting arguments for the incorrect are not attended to and inhibited; or if learning the correct response is not a priority, such as when there is more concern with finishing the entire task), then it is likely that discrepancy will not be significantly reduced. However, if we separate the feedback processing times of those who were first incorrect but later exhibited correct responses, from those who were first incorrect but later fail to correct errors, then we should be able to distinguish successful processing and the discrepancy reduction function should be more evident. The results of exploratory analyses along these lines are reported in this paper, and predictions are partially supported.

Control Theory and Discrepancy

The view in this paper is that a more complete investigation of perceptual control theory (PCT) (Powers, 1973, 1978, 1989, 1991) may prove beneficial for instructional feedback sequences. From the control theory perspective, discrepancy is most fruitfully viewed not as a general construct applying to the whole processing system, but as an aggregate of many error signals occurring at many levels in parallel and interactively. An individual processes information or acts on the environment in order to bring all activated perceptions into line with personal perceptual standards. A pivotal point of control theory is that learners behave in the environment according to the perceptions that are operative in them. When an instructor can specify the various perceptions an individual is trying to control, then that instructor will be able to create a more reliable student model. The point is that to create a student model which provides more precise specification for feedback, the various discrepancies between standards and perceptions need to be specified separately for each individual. Then appropriate feedback could be directed toward specific needs. No one has yet adequately tested models of PCT in this manner at these higher levels of perceptual control, partly because the control theorists typically demand correlations of .95 or above, and the relationships must be demonstrated with individuals, which is often not methodologically desirable. For the present, PCT does provide a context for the concerns in this paper. And plans for more pure control theory modelling are made in the final section of the paper.

A Proposed Theoretical Framework

This section involves hypothesizing about what occurs in the mind of a learner. Parts of this framework are supported by data; other parts have yet to be demonstrated clearly; the whole provides a plausible framework for understanding cognition, in at least one learning paradigm: item learning.

Cognition and control in item learning. It is assumed that when a student answers a multiple choice question, she is using at least three inter-related control systems (Powers, 1973, 1989). These control systems should interact with memory to provide basic item processing predictions. It is assumed that a high level concern for a student is getting a question correct. In control theory terms the individual is controlling for correctness. She 'wants' to see herself get correct answers. (It may be, however, that a particular subject will be controlling more for getting to lunch as soon as possible and would answer questions quickly, perhaps without much search or problem solving.) In the expected case (a cooperative subject, for example), as she perceives the words of a question, knowledge is activated into working memory (Kintsch, 1988). That knowledge which is needed to maintain a sense of meaning does not receive inhibitory activation. Here the learner would be controlling for meaning construction. She wants to perceive meaning. The meaningful knowledge kept active in working memory, would then be transformed by inferential rules into arguments with varying degrees of support (Read, 1991). Here the learner would be controlling either for matches with prior knowledge (Anderson, 1983) and/or for plausible constructions from prior perceptions (Spiro, 1980). When the processing of a response alternative activates some evidence which is judged (by the subject) to be indisputable, then the question processing is completed, and the subject responds. However, those response alternatives that are judged to have some supporting evidence yet short of that individual's standards for a good match, would likely be maintained in active state or at least tagged with a general value of correctness and be relegated to a buffer state. Under this condition, there should be more effort expended to cue some more relevant prior knowledge (i.e. by searching memory); or the question material may be scanned again in hopes of automatically activating more evidence. With each response alternative, the learner should generate one or more arguments supporting or opposing that response.

<u>Exploratory Investigations</u>

<u>Certitude by processing time predictions</u>. If the account given above is correct, higher certitudes should be indicative of arguments that were quite strongly supportive of a particular choice--very possibly being based on a lot of relevant prior knowledge or perhaps being based on one piece of strong evidence (such as a vividly encoded episodic

memory or a perception of the response chosen by the "genius" at the next desk or terminal). In either case any arguments against the correctness of the response should have been deactivated due to overwhelming evidence against them or due to working memory limitations. Thus higher certitude responses should have faster response latencies.

Lower certitudes, on the other hand, should be indicative of arguments that have been generated that do not clearly support a particular choice--perhaps because there is not enough relevant knowledge that has been accessed or because there is perceived evidence for other responses as well. Therefore, they are still active and we might say are competing. That would mean that questions associated with lower certitudes should take longer to process due to competing evidence. The predictions regarding response latencies across certitude values were tested, and are reported in this paper.

Question processing times at each certitude level. A further extension to the feedback paradigm which could be incorporated into student model construction in CBT is to interpret the initial processing times according to their associated posttest results, as was suggested earlier for the improved discrepancy investigations with feedback processing time.

We know that the likelihood of posttest corrects generally increases as initial certitude ratings increase (Hancock, 1990b; Kulhavy, Stock, Hancock, Swindell, & Hammrich, 1989), but at all certitude levels a learner may get an answer correct and then miss it later due to some interfering information or competing evidence. The learner may have initially constructed an argument for an incorrect choice, but it may have dropped from working memory as more evidence was accumulated for the correct choice. At recall, those incorrect arguments may be re-activated and the correct arguments are not activated. Thus, the initially correct response that later becomes an incorrect response, would be generated from a cognitive state with more interfering arguments than for those correct responses that do perseverate. Therefore, the activation of additional unintegrated information should yield longer processing times. These possibilities have been initially explored and were partially supported. The results are reported in this paper.

Other work, of course, has found response latency differences between correct and incorrect responses. But these studies differ in certain important aspects. For example, similar predictions regarding response latencies could be made in terms of positive and negative fan effects (e.g. Anderson, 1987, 1989), but such explanations do not seem to handle the variability found in the judgement literature (e.g. Kahneman, 1991), and do not fit as well with an argument construction explanation. And support for a similar situation has been demonstrated in the feeling-of-knowing literature (e.g. Nelson, Gerler & Narens, 1984): the latency of incorrect recall was greater than that for correct recall, and the latency of correct recognition was less as the feeling-of-knowing increased. In the present case, a correct response that later becomes incorrect, is predicted to have a longer processing time at the time of initial processing! And somewhat similar response time differences between incorrect and correct responding which are associated with amounts of inferred relevant prior knowledge have also been recently reported in a study with Air Force trainees (Kyllonen, Tirre, & Christal, 1991). In that study, the possibility of explaining their data with feeling-of-knowing ratings was mentioned but not tested.

<u>Multiple predictors</u>. And finally, it was hoped that the variables explored above could be combined across test occasions as multiple data sources for instructional decision making. This would make profitable use of the computer's potential to base decisions on data that could be easily recorded at every instructional frame. And if the modelling were valid on an individual basis, individual differences could be more thoroughly defined. The results of such exploratory analyses are reported in this paper.

<u>Summary</u>

It has been argued that most feedback research and CBT feedback administration has not given adequate attention to the cognitive state of the learner. The current proposal is that the understanding of cognition, such as described in the prevailing model of instructional feedback (Kulhavy & Stock, 1989), can be enriched with the following additions: 1. more thoroughly specifying the place of control theory, knowledge activation, and decision making; 2. distinguishing the adequacy of feedback processing (discrepancy reduction) in terms of posttest performances; 3. generating inferences, not only from certitude estimates and feedback study time, but also from initial processing time; 4. modelling mathematically with multiple records of processing time, certitude rating, and correctness values; and 5. determining controlled perceptions by testing control theory models.

Method

Background

The data set from a previous unpublished study by the author (Hancock, 1990a), was reanalyzed in order to explore some of the concerns above. The overview of the method in that original study follows:

Design. The basic design was a 2 x 2 x 5 totally within subjects factorial with two levels of feedback (elaboration vs verification), two posttest occasions (immediate vs one week delay), and five levels of certitude.

Subjects. The subjects were 26 15- to 18-year old students.

Materials. The experimental materials consisted of 200 multiple-choice test items, taken from The College Board Achievement Tests (1986). All test items were presented on IBM PC/XT color monitors and response selections and latencies were collected automatically.

Procedure. The procedure for each subject was generally as follows: first, read a question stem and choose a response alternative by pressing a number key; second, see the certitude rating scale and choose a key 1 to 5 (1 = random guess, 3 = somewhat certain, 5 = absolutely certain); third, see a feedback display and continue to the next question at own speed. There was an immediate posttest and a one week delay posttest.

The analyses. Analyses of variance were conducted and regression lines were fit for all within subjects conditions for the feedback study time on discrepancy scales and for the conditional probability of a posttest correct on the discrepancy scales. (The discrepancy scale extended from a minimum value at certitude 5/correct, to greater values at lower certitude/correct, then to low certitude/incorrect, and finally to a maximum value for certitude 5 yet incorrect (see Kulhavy & Stock, 1989)).

Design for the New Analyses

The basic designs for the new analyses became 1. a two test occasion by five certitude totally within subjects factorial, with feedback study time as the dependent measure and 2. the same design again but with initial question response latencies as the dependent. The reasoning behind these unusual designs was that variations in certitudes and posttest correctness are to be understood as predictors of varying processing times.

For these new analyses, the elaboration feedback condition (response correctness confirmation and a display of the correct response) from the original experiment was chosen as the primary focus since the basic verification feedback is usually not as appropriate in actual instructional environments. In addition, the two types of response states that are the major concern in instruction were analyzed: feedback processing for initial responses that were incorrect, and initial question processing for responses that were correct. The concern in the former case was with how feedback processing relates to error correction, and in the latter case, with what type of question processing relates to the maintenance of correct responses versus changing to incorrect responses.

Additionally, a number of exploratory analyses were conducted. The first was a polytomous logistic regression, using response times and feedback time as covariates, with certitude values (5 levels) and response correctness (right vs wrong) both from two test occasions (initial and immediate posttest). The predicted values were the cross classification of posttest correctness (2 levels) for each certitude value (5 levels). This was a totally within subjects design as well. Also, the same analyses were conducted separately for each subject.

Results

From the Original Analyses

Before reporting on the analyses of present concern, the previous results with this same data set will be summarized (see Hancock, 1990) in order to provide a more complete context for interpretation. There were significant main effects on posttest corrects for type of feedback, test occasion, initial correctness (right or wrong at first testing), and for the following interactions: posttest by feedback, feedback by correctness, and feedback by correctness by posttest. The posttest scores and also the feedback study times fit across levels of discrepancy were significant functions. The effect for level of certitude was also significant, and was best described in a linear relationship with feedback processing time.

From the New Analyses

The following results are from exploratory analyses related to the present theoretical and practical concerns in this paper. At this time more analyses are planned; what follows must serve as a progress report.

The analyses were performed using SAS 6.01 statistical package, using the Proc GLM procedure. When the log base two ($\log_2$) processing time is reported below, it is because residual analysis indicated that this provided the best approximation to meet the assumptions of the analysis of variance.

Feedback processing time by posttest correctness. The initial results of interest were from an adjusted analysis of variance for posttest and certitude (with a subjects factor) and feedback study time (and separately for $\log_2$ feedback study time) as the dependent measure.

For the study time of elaboration feedback (right/wrong confirmation plus the correct displayed) following incorrect responses, the independent effect for certitude on $\log_2$ feedback time was significant, $F(4,172) = 6.05$, $p < .0001$. Also, feedback processing time increased monotonically as certitude increased, with a significant linear component, $F(1,176) = 30.4$, $p = .0001$ and quadratic component, $F(1,176) = 5.8$, $p = .017$. These results are in line with the current predictions that feedback time should vary sensibly across certitude values.

The effect that was of primary interest in this exploratory work was the difference in feedback study time as a function of posttest correctness. In viewing the graphic display of the mean processing times, the expected difference is found at certitude 4 and 5. A t-test performed on the difference at certitude 4 was significant, $t(32) =$

1.77, $p<.05$; and at certitude 5, significance was not obtained, most likely due to one time which had a standardized residual of 4.6. Thus, the mean for certitude 5, posttest incorrect, on the graphic display was calculated without the one deviant score. The adjusted analysis of variance for the posttest effect using the total data set (including deviant scores) not significant, $F(4,172) = .64$, $p = .425$; however, 4 individual data points account for 31% of the error variance.

As a matter of comparison, similar analyses were also conducted for verification feedback (simply informing the learner that the response was incorrect). These did not yield significant differences for the posttest effect. The noteworthy point is that again at certitudes 4 and 5 the differences were most marked (see Figure 2). This trend for verification feedback was opposite to that for elaboration feedback: shorter verification feedback response latencies were associated with later error correction. This was initially surprising, but becomes understandable when seeing that verification feedback did not indicate the correct answer.

Another very interesting trend was found in the analyses of initial incorrect, as well as other analyses of initial corrects. The elaboration feedback study time trends for posttest corrects across certitude were regular (with linear and quadratic fits), but the trends for the initial processing of questions that were incorrect at posttest were quite irregular (e.g. see Figure 1). This again suggests the discriminatory potential of analyzing processing times according to subsequent performances.

Initial question processing time by posttest correctness. The second major area of concern was investigated with a repeated measures analysis of variance with certitude and posttest correctness as the within subjects factors and question processing time of initially correct responses as the dependent measure.

For the initial question processing time in the elaboration feedback condition, the combined question response time curve is fit with a significant linear $F(1,145) = 5.27$, $p = .023$, and quadratic component, $F(1,145) = 6.64$, $p = .011$. In viewing the graphic display of means (see Figure 3), it is evident that correct responses that later turn to incorrect are initially processed longer. And for both posttest corrects and for incorrect, the processing time increases from certitude 1 to 2 or 3, and then drops dramatically to certitude 4 and 5. The effect for posttest correctness on $\log_2$ question response time was nearly statistically significant, $F(1,141) = 3.53$, $p = .06$. These analyses include 4 data points, which alone account for 23.6% of the error variance. These results are generally in line with predictions that initial processing time differs sensibly according to the eventual posttest yield.

Since there was the possibility that varying response times were simply due to the varying length of questions, the relationships were also investigated using response speed, $\log_2$ words per second. The same general patterns were found, as can be seen in Figure 4, which in this case follows responses to the one week delay test. Also, another interesting phenomena to be noticed in Figure 4 is that the variance of responses that later become incorrect was much greater than for the responses that remain correct.

Multiple predictors. In order to test the feasibility of using data from multiple sources as predictors of performance, logistic regression analyses were performed. Certitudes, $\log_2$ response speeds (words per second), and correctness at the first two tests, as well as type of feedback and feedback study time were tested as predictors of the one week delayed posttest correctness and certitude combinations. The Chi-square goodness of fit (actually badness of fit) test was not significant, Chi-square(32) = 28.77, $p = .63$. In other words the model is has predictive utility. The predictors which individually were significant were initial correctness (whether the initial response was correct or incorrect), Chi-square(4) = 10.62, $p = .03$ and certitude, Chi-square(4) = 77.84, $p < .0001$; and type of feedback was nearly significant, Chi-square(4) = 8.87, $p = .06$; and the log feedback time, Chi-square(4) = 6.65, $p = .16$.

A similar analysis was conducted separately for each subject. The model was an adequate fit for 21 of the 26 subjects (alpha .05); the Chi-square goodness of fit statistic getting as low as 1.79 (probability = .94). And it was particularly interesting that the significant predictors varied--the most common being the initial test correctness; but every one of the other seven factors was a significant predictor for at least two of the subjects.

Conclusion

Regarding the Empirical Findings

A few of the proposed steps toward improving our understanding of the functioning of feedback have been explored and the empirical support is somewhat positive.

Certitude estimates. First of all, the predictive power of certitude estimates, has been again confirmed. Not only do certitudes predict posttest performance (e.g. Kulhavy, Stock, Hancock, Swindell, & Hammrich, 1989), but both feedback processing time and initial question processing time are significantly different across certitude levels. The hypothesis that certitude estimates discriminate between cognitive states is supported.

Initial question processing time is the fastest with those responses that are high certitude, 5,--presumably indicative of strongly activated arguments, with no plausible counter arguments (see Figure 3). The longest processing times are at certitudes 2 and 3, which are possibly indicative of plausible arguments constructed both for corrects and for incorrect responses, which take more time to resolve. And at these levels there might be only scant evidence activated. The extreme of such a case would be at certitude 1--with no arguments constructed due to little prior knowledge activation the subject must guess randomly after a general search. In this later case, responding was quicker than where interfering arguments would be considered, but slower than the case where activation quickly converges on strong arguments.

Discrepancy reduction. It appears that the plausibility of discrepancy reduction in the Kulhavy/Stock paradigm, is better understood by separating feedback study times according to posttest correctness. The study time curves are regular when the responses are presumably processed to successfully reduce discrepancy. But for the processing of responses that turn out later to be incorrect, the study time curves were not regular, the variance was much greater, and consequently the linear relationship between study time and hypothesized discrepancy was not as evident. Possibly some of the noise in previous discrepancy analyses (e.g. Hancock, Stock, & Kulhavy, 1991; Kulhavy et al, 1990) was due to those feedback messages that were not processed to facilitate error correction.

At certitudes 4 and 5, the longer feedback times for subsequent posttest correct responses would provide plausible evidence that discrepancy is reduced as processing time increased. A somewhat more detailed explanation of the discrepancy reduction would be that the longer times are indicative of the successful elimination of incorrect arguments as well as the construction of arguments for the correct--which argument construction would involve more processing time than for responses that do not come from sufficient argument construction and are hence not corrected. Future analyses of changes in certitude from initial to posttest will test these hypotheses.

It is possible that at lower certitude levels, the incorrect arguments were not strongly held, would consequently be easier to eliminate, and thus the processing time distinctions are not as evident.

The interesting switch in the processing time when a subject is simply informed that his response was incorrect (see Figure 2) illustrates that it is important to distinguish the content of feedback messages. The longer response latencies at certitudes 4 and 5 for verification feedback, tended to not result in error correction as much as shorter response latencies did. Since the learner had not been informed of the correct response, it is possible that continued activation simply strengthened the incorrect arguments, which would have been the most active in a short term memory state.

In general, all these results are positive, but admittedly much variance is unaccounted for. (One cannot help but wonder if the distinction between feedback processing that is and is not successful may eventually be more specified as each learner's specific reference standards and levels of control are determined.)

Initial question processing time. The second major area of suggestions for improving the work with feedback was to use initial processing times as indicators of a student's cognition. It appears that processing times may be used to distinguish a correct response that is not well learned from one that is well learned, and that this distinction is even independent of the learner's awareness (certitude rating). That is, there was a tendency for outwardly correct responses that were processed relatively longer to later be changed to incorrect responses. This may have been due to incorrect arguments constructed initially that were deactivated in favor of correct arguments, but at posttest the incorrects became mistakenly supported. And regarding the response times at low certitude, 1, it is quite understandable that the difference is not as evident when the subject is randomly guessing; there would possibly be no argument construction for corrects or incorrect (see Figure 3 and 4).

That this phenomena at certitudes 2 to 5 appears to occur without the subject's awareness is significant. This of course should have significant implications--we would have evidence for inadequate learning that is independent of objective correctness and is even independent of the learner's awareness.

Multiple predictors. The third major concern was whether multiple sources of data recorded at each frame of instruction: certitude, response time, and objective correctness, along with types of feedback, could predict the likelihood that particular responses will be correct and responded to confidently at delayed posttests. It appears that the mathematical model does fit. And not only is initial correctness a powerful predictor, but also certitude, and to a lesser extent also feedback type and feedback processing time.

And more importantly, for most of the individual subjects, the model fits as well. Not only is the model adequate for the total sample but also for individuals. This is important because if the relationships described in this paper do not apply to most individuals, then the successful CBT application would be doubtful. The significant predictors that vary from one person to another would possibly become part of the student model for each student's processing characteristics.

Eventually such modelling involving response times will need to be theoretically rooted (see Meyer, Osman, Irwin, Yantis, 1988); at this point, all that can be said is that multiple sources of data, which by themselves can be meaningfully related to cognition, when taken together, do predict performance. And in line with the control theory perspective, those variables that are the most significant differ from one individual to another: each individual is controlling different perceptions during tasks that are outwardly identical.

Regarding Practical Applications

Each of the findings described above could not only help researchers interested in feedback, but could be used in applied settings, such as CBT. For example, two basic concerns in an instructional setting are that correct responses would not change to errors, and that incorrect responses would change to corrects. The findings presented in this paper provide some initial guidance here. An intelligent tutor could be programmed to flag the following two scenarios: a trainee has responded correctly and rates his certainty high, but has taken more time than usual; a trainee has responded incorrectly and has initially rated his certainty high, but has taken less time than usual with the feedback. In both of these cases it would be more likely that the response would be incorrect at a posttest. Other decision making could be based on other response patterns as they become better defined; or decision making could be based on certitude and correctness information alone, which by themselves have appeared to be somewhat indicative of learning success. In addition, mathematical modelling with the variables of certitude, response time, and correctness could help in the decision making process in a probability driven system or by adding one more piece of data to an endorsement based student model (see Murray, 1991).

In all these cases the data sources could conceivably be applied in a similar manner independent of the domain of learning. That is, certain recommendations for using certitude and response times could be established for domain independent expert modelling. As one simple example, it is likely that high certainty, rapid correct responding and greater feedback processing times for high certainty incorrects are both characteristics of expert functioning.

And finally, it is hoped that the response time interactions with certitude will become better understood on a more basic level in terms of knowledge activation, argument construction, and the control of perceptions. This would not only be a benefit for instructional decisions, making them less dependent on intuition or empirical trends, but perhaps more importantly it would contribute to a more coherent understanding of human mental processes. Some researchers (e.g. Anderson, 1987) argue that the potential of understanding human cognition is quite powerful in instructional environments with intelligent tutors; and that promise alone may be sufficient for justifying the work such as described in this paper.

Regarding Research in Progress

The complete picture of the proposals presented in this paper may depend on other work which is in progress. Other analyses are being explored with the data set from above. And a number of other studies have been planned. Patterns like those explored above need to be extended to experiments that yield more data points; measures based on changes in certitude and response time need to be investigated; and response patterns over a number of trials (cf. Bahrick & Hall, 1991) need to be investigated across categories: for example, different categories of cognitive states should be operative when a correct response perseverates over several trials, versus a mixing of corrects and incorrects over several trials, versus a persistence of errors.

In deciding what type of feedback message should be the most appropriate under which circumstances, two approaches should prove fruitful. The first of these involves testing various types of feedback across combinations of certitude, response time, and correctness. The materials described in this paper are being prepared with other types of feedback. Using verification and elaboration feedback types has yielded different response patterns across certitude levels (Hancock, 1990): as one noteworthy instance--for high certitude correct responding, simply informing a learner "correct", appears to be more effective than informing and redisplaying the question along with the correct alternative starred. Thus, describing the parameters for other types of feedback should demonstrate that different types of feedback are effective for different response patterns and inferred cognitive states. And these prescriptions may differ from one learner to another, such as indicated with the logistic regression analyses above, and such as indicated by control theory predictions.

In addition, Dr. Richard Thurman of Armstrong Lab, Aircrew Training Research Division (AL/HRAU), at Williams AFB and I have planned a number of studies. The first of these is concerned with investigating the same variables as above but with three types of feedback, and with other instructional manipulations, such as interstimulus distance variations. In addition, we are using a domain of learning that is generalizable to Air Force training tasks: a computer generated radar recognition drill task. The planning of the methodology is complete and the computer drill tasks are nearly complete.

And finally, in all this work it has been evident that control theory explanations may provide the most power for understanding learning and the administration of feedback. This is particularly true in the realm of CBT, if we are to provide student models with variables whose importance in decision making can be flexibly changed to match each learner's varying perception. In this vein one of several promising approaches that have been devised this summer is the following.

It will be assumed that a student is controlling for meaning. Also, it will be assumed that a Likert certitude rating of 5 (e.g. "I am absolutely certain that I understand") is the reference standard, "RS". And if for each segment of learning the student rates the perceived response in terms of certainty, "PR". Then RS - PR = D, where D = discrepancy. Then the more pure testing of control theory (see Powers, 1978) can be applied, where a processing constant K(O) is defined for each subject. Thus, K(O) = T/D where T is processing time.

I am hoping to apply this modelling procedure to the data set reported above and to the data from future studies, such as with Dr. Thurman. This should account for aspects of the initial learning situation, and it should begin to test the degree to which a student is controlling for meaning. Other similar tests for controlled perceptions could be established. It may be that a CBT system could calculate a K(O) for each student as part of the student model construction.

With the development of such control modelling, it may be that the deviant response patterns, especially, when a learner is not performing as expected, could be diagnosed and treated. If this were the case, feedback could be more effective and some of the precise cognitive correlates of discrepancy could be determined.

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[1] This paper is an end-of-tour progress report for Dr. Hancock's tenure as a faculty research associate at Armstrong Lab, Aircrew Training Research Division, AL/HRAU, at Williams Air Force Base during the summer of 1991.

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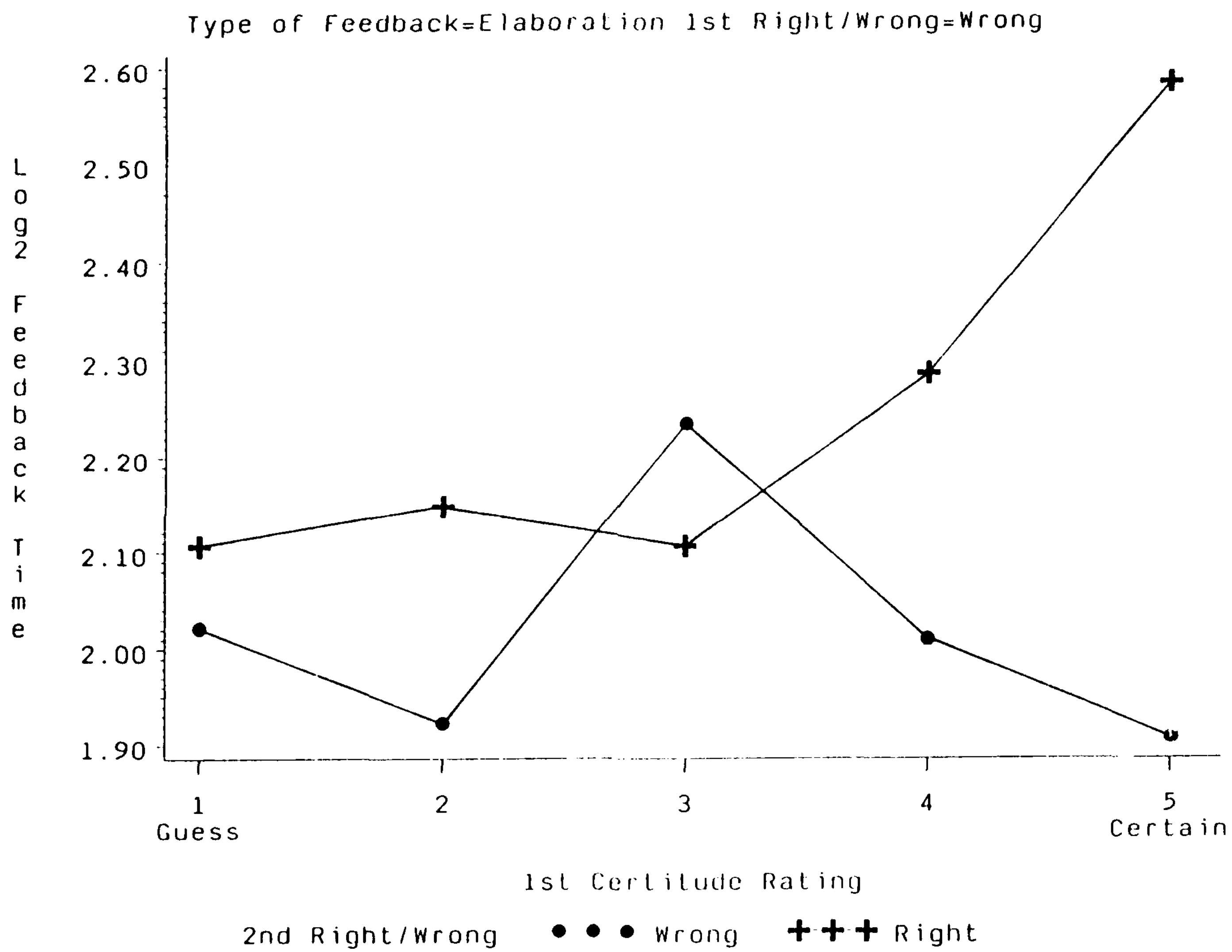

Figure 1: Mean feedback (elaboration) processing time (log 2 seconds) following initial error responses by post-test correctness.

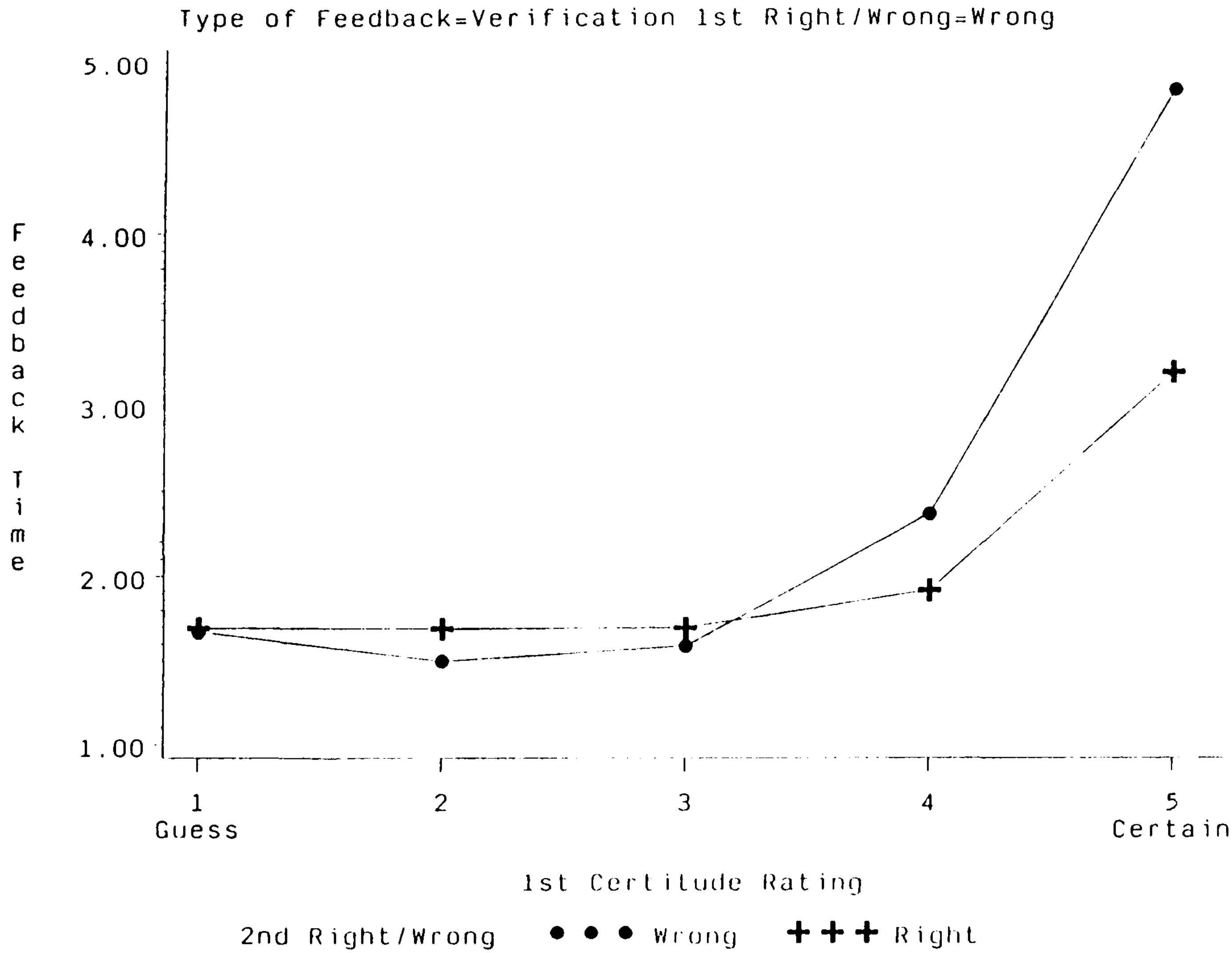

Figure 2: Mean feedback (verification) processing time (log 2 seconds) following initial error responses by post-test correctness.

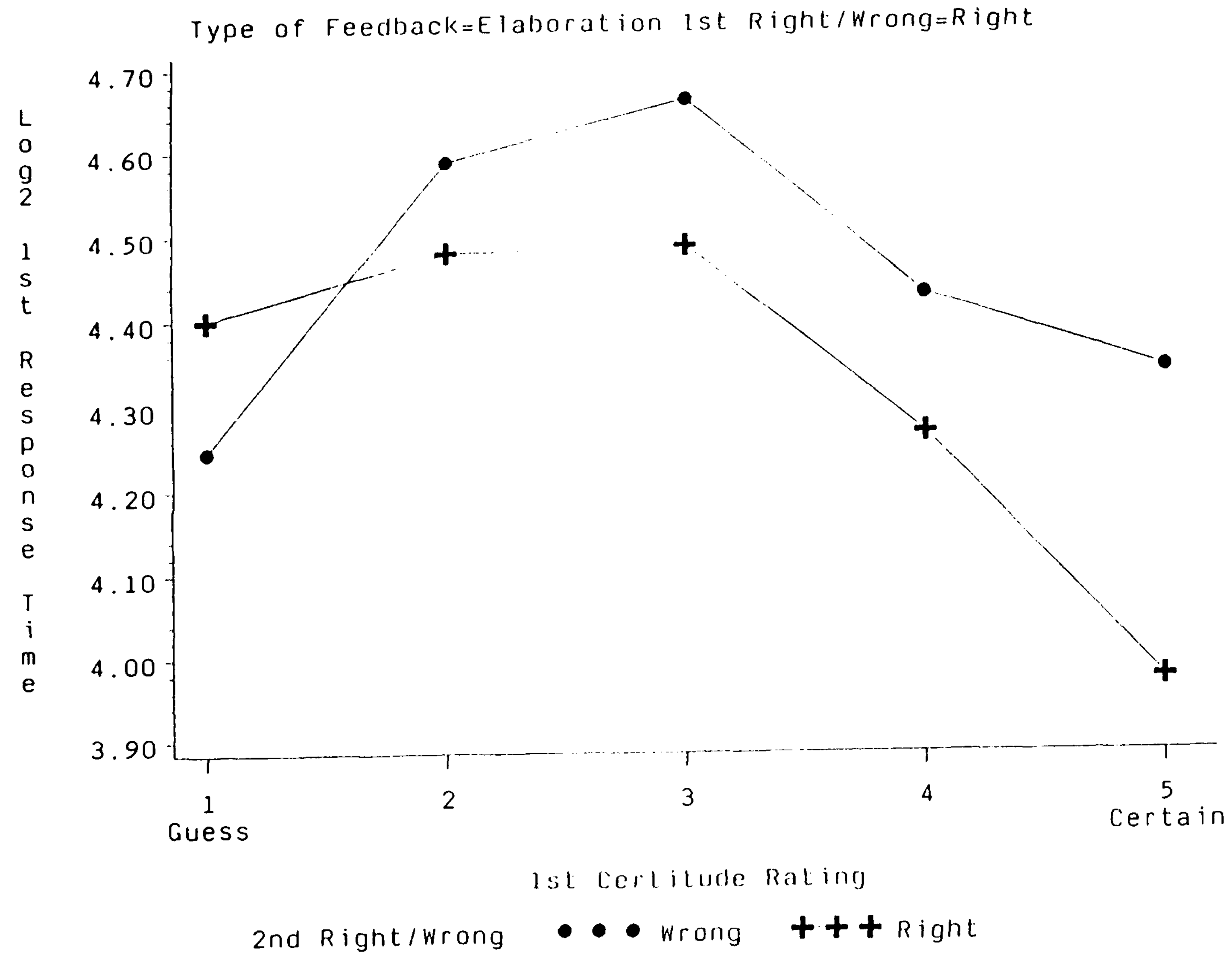

Figure 3: Mean question response time (log 2 seconds) for initially correct responses by post-test correctness (elaboration feedback condition).

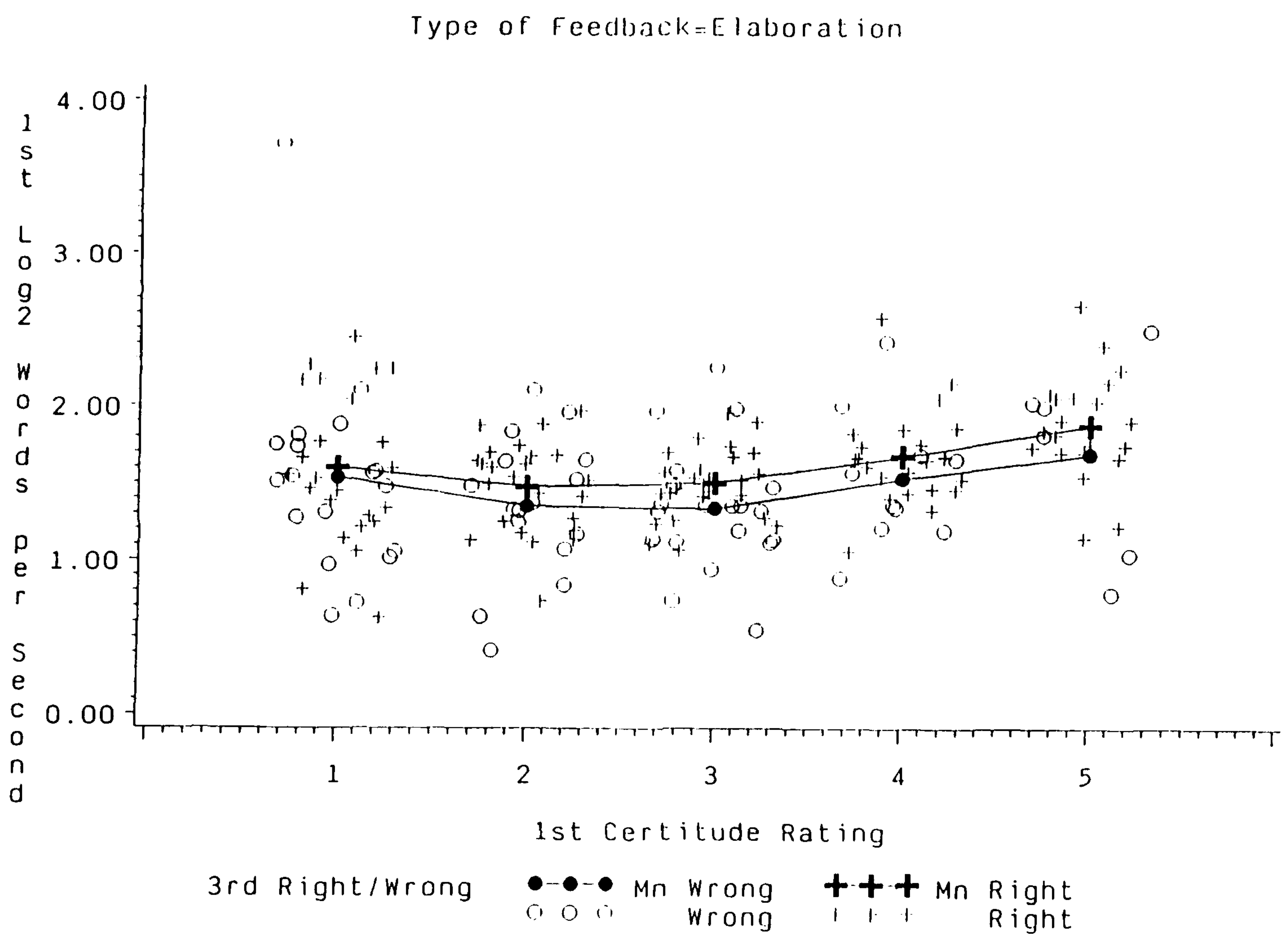

Figure 4: Mean response time (log 2 words per second) for initially correct responses by post-test correctness (elaboration feedback condition). The individual subject mean data points were jittered (adding uniform random error between -1/3 and +1/3).

PRELIMINARY STEPS TOWARD DEVELOPMENT OF RESEARCH PROGRAM

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The general goal of my work this summer was to explore the feasibility of developing acoustical measures of vocally expressed emotion in man and animals. Under appropriate conditions, virtually all sound-emitting organisms acoustically broadcast signs of their biological condition. The ability to acoustically detect emotional changes in the condition of persons and animals would have potential value not only as a research tool, but also in military, medical and civilian applications.

A distinctive feature of acoustical detection is that it can be done remotely. One ramification of this is that non-invasive monitoring is possible, an important consideration in research and medical applications. Furthermore, acoustical signals are easily transduced into electrical energy for transmission, storage, or processing--in either analog or digital form. Sophisticated systems for remote monitoring are now available and, if we are successful in developing reliable acoustical measures of emotionality, they could be readily adapted. A capability to remotely monitor emotionality in voice would be of considerable value in a variety of arenas, e.g., early sensing and identification of dangerous levels of stress or fatigue in radio transmissions of a pilot's voice (or the voices of any individuals working in stressful high risk environments, e.g., divers, astronauts, etc.); detection of excessive levels of emotional fluctuation in critical care patients; monitoring of variations in emotionality and psychological wellbeing of research animals during the course of experiments and in their housing facilities. An acoustical index of emotionality might also make possible a non-invasive approach to the maintenance of psychological wellbeing of laboratory animals. Once the capability has been developed to measure emotionality in the vocalizations of a species, it would be possible to construct recordings of actual or synthesized species-specific vocalizations of low emotional content. Playback of these conspecific vocalizations should act to modulate the levels of arousal, say, in a calming direction. This seems to work for humans. It may also serve as an inexpensive form of environmental enrichment in laboratory animal rooms which, for legal and medical reasons, cannot be made more like an animal's natural environment. This may be very important for primate laboratory animals, both in terms of health and wellbeing of the animals and in terms of the validity of the data we obtain from them.

Whether the interest is in remote detection of distress, monitoring of fatigue and stress during performance of high risk workloads, diagnostics of human and animal medical conditions, or environmental enrichment of research animals, the potential payoffs for an intensive program of research in this area are evident and exciting. It has been a rare privilege for me to have had the opportunity to participate in, and perhaps contribute to, the initial stages of development of a program of research in this area.

The study of sound emission (both vocal and stridulatory) throughout the animal kingdom has been of strong interest to me for many years, but the new possibilities for acoustical analysis created by recent advances in digital signal processing technology have made this area of study even more exciting. Now we can rapidly perform highly sophisticated acoustical analyses that were, just a year or so ago, impractical if not impossible. Much of my work this summer explored some potential applications of this new technology within the framework of on-going research in the Directed Energy Division of the Armstrong Laboratory at Brooks AFB. The originality, quality, and quantity of this work greatly benefited from the tireless and insightful collaboration of Dr. S.C. Baker, also a Faculty Research Fellow, and the generous help of Dr. Michael R. Murphy, our stimulating and supportive sponsor at AL/OEDR. We should like to thank the entire staff of the Division of Directed Energy, in particular Lt. Col. Michael Binion, Lt. Col Andrew Mickley, Dr. Ann Cox, Mr. Ken Hardy and Dr. David Erwin for their good wishes and encouragement which helped to make our stay at the Armstrong Laboratory a productive and worthwhile experience.

Together, we explored many research avenues. Most of these efforts overlapped in time. All were aimed at establishing the science and technology necessary for the measurement of emotionality in the voices of animals and man. Perhaps the most straight forward way to provide an overview of theses efforts is to simply list each with a brief annotation of what was accomplished.

1. Experiment comparing the behavioral and ultrasonic vocal reactions of two groups of Rattus norvegicus, one highly reactive group of Soman-treated animals and one group of normal animals. Behavioral and acoustical responses to an acoustic startle stimulus were recorded and later analyzed on a trial-by-trial basis. The results suggest that, al-

though the Soman-treated group tended to react more vigorously to the startle stimulus than the normal animals, the two groups did not appear to differ in vocal output. While relatively few animals vocalized in this experiment, the intense bouts of vocalizations that were emitted indicate that the rat "22 kHz" call may function as a distress signal. This study was described in detail in Dr. Baker's report.

2. Critical review of the literature on adult rat ultrasonic vocalization. An in-depth search of the published literature was carried out by means through the helpful assistance of personnel in the Strughold Aeromedical Library, and by direct visits to the libraries of Universities in the San Antonio and Austin areas. Dr. S.C. Baker assumed primary responsibility for reviewing publications and writing a major report on rat ultrasonic vocalization. The report will be of value and interest to researchers interested in vocalization in general, especially rodent ultrasonic vocalization. Of particular interest to us was establishing a knowledge base in this area, i.e., vocalization as a sensitive indicator of distress under aversive conditions.

3. Recordings of vocalizations of Rattus norvegicus and Macaca mulatta under a variety of conditions typically found in animal research environments to serve as the beginning of an acoustical data base for studies concerned with detection of emotionality in laboratory animals. Recordings of normal adult rats were made under the following conditions: traversing an elevated maze, exploring an environment, during handling, and during electric shock. Recordings of rhesus macaque vocalizations were made as they operated the Primate Equilibrium Platform (PEP chair); in animal rooms containing individually caged adults and

juveniles, during and after feeding and during and after removal/replacement of an animal from its cage; of individual animals being transported by hand by experienced keepers; and in open-air buildings where animals were housed in social groups.

The many hours of taped records have not yet been analyzed, so we are not in a position at present to comment on findings. We must note, however, our gratitude to the highly skilled animal care personnel of the Air Force and the System Research Laboratories. These dedicated people made every effort to assist and facilitate our work. It is not an overstatement to say that our work simply could not have been accomplished without their support.

4. In line with our interest in environmental enrichment of laboratory-housed animals, we made acoustical assays of noise levels produced by cage washers in two buildings to determine how these major sources of noise might be attenuated, and whether these situations might be good candidates for applications of the new technology of active noise control. The results of our acoustical measurements were sent to an acoustical consulting firm that specializes in active noise reduction. This matter remains under consideration.

5. A major portion of our efforts were directed toward establishment of data bases of scientific literature in the six areas of scientific research. Bibliographic references are provided in each area in a separate appendix to this report. Appendix I includes 73 reports on primate vocalization with emphasis on relevance to macaques (non primate literature was included if pertinent to acoustical analysis); Appendix II lists the 11 major reports that have been published in English on

macaque vocalization; Appendix III is an exhaustive listing of 224 reports concerned with acoustical analyses of voice that are pertinent to the development of an acoustical index of human vocal emotionality; Appendix IV contains only the beginning of a literature search, listing 6 reports concerned with the effects of infra and ultra sonics on humans; Appendix V lists 26 reports which appear to constitute all major reports on the developing technology of active noise control; and Appendix VI lists 124 reports, the complete bibliography that resulted from our review of rat ultrasonic vocalization. All total 464 reports, chapters, and books were searched and selected for these data bases.

APPENDIX I

REPORTS PERTINENT TO THE STUDY OF PRIMATE VOCALIZATION

1. *The Physiological Control of Mammalian Vocalization*, New York:Plenum Press, 1988.

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Appendix IV

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APPENDIX V

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APPENDIX VI

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COGNITIVE CONSIDERATIONS FOR TRAINING "WHERE" AND "WHAT" SPATIAL KNOWLEDGE AS PROPOSITIONS AND RULES

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Abstract

The goal of STAMP is to identify the most effective training method for each knowledge type. Psychologists hypothesize a major distinction between declarative knowledge (knowing that) and procedural knowledge (knowing how). Declarative knowledge is composed of propositions and procedural knowledge is composed of rules. First, evidence is reviewed for the importance of this distinction within the domain of spatial knowledge of large scale spaces. Such "where" knowledge includes both knowing the location of landmarks (propositions) and how to navigate through the space (rules). Second, models about how people store "what" knowledge are reviewed. Third, the importance of the student's learning mode on the training of "what" knowledge is reviewed. It is concluded that early STAMP research should focus on two kinds of spatial knowledge: "where" (large scale spaces) and "what" (classification of instances). Each is central to Air Force mission and can be studied by constructing a common data set, but separately training the information as propositions and rules. Important training variables are discussed with an eye toward the importance of

individual differences.

Introduction

In clinical psychology, research advances on three fronts: 1) refinements in the taxonomy of disorders (DSM-IIIR is a behavioral classification of the discrepancies between clients and ideally adjusted people), 2) refinements in the delivery of interventions, and 3) refinements in the mapping of particular interventions onto particular disorders. Optimal clinical care depends on diagnosing the disorder relative to a functional taxonomy and choosing an established procedure based on that diagnosis. The role of the educator is very similar to the role of the clinician. There is a discrepancy between the knowledge structures of the student and of an expert. The educator must identify that discrepancy and choose an intervention appropriate to that discrepancy. Early clinical treatments were more an art than a science, but current research has greatly improved partially due to formalism in the taxonomy of disorders and in the testing of the effectiveness of intervention based on the taxonomic diagnosis. STAMP brings the same formalism to education. The Knowledge Type axis (proposition, schema, rule, skill, and mental model) provides a taxonomy of how students can differ from experts. The Instructional Environment (rote, didactic, practice, analogy, examples, and discovery) provides a taxonomy of types of interventions. Psychologists in particular have focused on formal studies on the knowledge type axis, but have largely ignored the implications for training. Experts in both human and machine learning have focused on the instructional environment axis. The time is ripe to bring together these two research efforts together to study the mapping between these two axes.

Problem

The question is what evidence the psychological literature provides for the need to customize training for different knowledge types. The main issues of debate in current psychological models of knowledge types and learning can be seen in the early debates between behaviorists and cognitive psychologists. While the tasks studied were artificial, the general skills that they represented were both basic and naturalistic: how do animals know what something is and know where it is. The behaviorists used discrimination learning to study the what question. In order to be reinforced, the animal had to discriminate between two classes of stimuli and execute the correct response. They argued that the animal passively learned associations between specific stimuli as presented and specific motor actions. Cognitive psychologists used concept formation to study the what question. People were shown a set of stimuli and had to discover the rule that determined stimulus membership in the experimenter's concept. They argued that people actively tested hypotheses about these abstract semantic rules. From this point of view, learning involves the abstract stimulus as encoded and response execution is simple. Both behaviorists and cognitive psychologists initially studied the where question with mazes, but their conclusions were different. Behaviorists argued that the animal passively learned a sequence of specific motor responses at maze landmarks. In contrast, cognitive psychologists argued that the animal actively learned an abstract, cognitive map of the landmarks in the maze. Running the maze was considered simple given that a map had been formed.

Three themes from these early studies still guide research today: 1) Should we focus on the actions that the person can execute or should we focus on what s/he understands?, 2) Does the person learn specific instances and episodes or does s/he form an abstract representation that summarizes the specific instances?, and 3) Does the person passively and holistically store experiences or does s/he actively and analytically test hypotheses about the meaning of the experiences? Each of these questions will be considered in turn.

Results

1) Understanding or Action. The general distinction is between "knowing that" (declarative knowledge) and "knowing how" (procedural knowledge). Knowing that whales comprise a subset of mammals and knowing the 12 months in a year are examples of declarative knowledge. Knowing how to change a tire on a car and knowing how to program in a particular computer language are examples of procedural knowledge.

Early cognitive models of memory focused on a subset of declarative knowledge called semantic memory. Semantic memory would contain the meaning of all of the concepts that we know and all of the facts that we know about those concepts. Frequently semantic memory was represented as a propositional network (Collins & Quillian, 1969). For example, "A dog is a four-legged mammal that barks, has long teeth, and has a wet nose" is a list of propositions that could be represented as a netwok in which nodes stand for concepts (DOG, MAMMAL, TEETH, WET, etc.) and links stand for relationships (IS A, HAS A, etc.). In contrast, expert systems are usually based on productions. A production has two parts: a condition list (the IF part) and an action (the THEN part). If the particular condition list is instantiated, then the action associated with it is executed. Such a representation makes it easy to model action.

In the interest of parsimony, some theorists showed that it was possible to model action within a network and to model semantic knowledge witin a production system. Even though each representation is computationally complete, it can be argued that 1) each representation has a subset of knowledge that it more easily models and 2) people use different representations for different tasks.

This position is best evidenced in the literature on the representation of large scale space. Such spatial knowledge appears to be stored in at least two qualitatively different types of representations (Thorndyke & Hayes-Roth, 1982; Sholl, 1987). These two types of representation generally are acquired by different means. The first (route knowledge) is acquired by direct navigation and is procedural. Consequently, it is egocentric: targets in front are faster to localize than targets behind. The second type of knowledge (cognitive map) is based on survey knowledge usually acquired from a map or built from extended navigational experience. This cognitive map is declarative and has imagery characteristics: it has a preferred orientation, would require more time to scan large distances than small distances, and would allow equal availability of all coded locations irrespective of egocentric direction. Simply put, the two types of representations have different learning characteristics and different relative strengths and weaknesses.

In his ACT* model, Anderson (1983) argues that declarative memory is distinct from procedural memory. Anderson further distinguishes between three types of cognitive units in declarative memory: abstract propositional network of concepts (corresponding to the "verbal code" below), spatial images, and strings (ordered lists). The importance of distinguishing between a verbal and a spatial knowledge code has been elegantly demonstrated by Wickens. The importance for training is clear: visual displays and manual responses should be used for task demanding a spatial code, but auditory presentations and speech responses should be used for tasks demanding a verbal code (Wickens, Vidulich, & Sandry-Garza, 1984). Further, the distinction between spatial and verbal codes predicts the interference in dual task situations (e.g., Wickens & Liu, 1988).

In short, propositions are the basic units of declarative knowledge and rules are the basic units of procedural knowledge. They are the most basic types on the STAMP knowledge axis. In turn, propositions are the components of schemata and rules are the components of skills. Schemata and skills are precursors of mental models. While the knowledge types of the ACT* model are theoretically important to psychologists, does these distinctions accurately prescribe optimal training choices? A perfect knowledge type to instructional environment mapping would find that 1) the optimal training decisions made for declarative knowledge are different from the training decisions made for procedural knowledge and 2) the same decisions would be made for any particular content within either declarative or procedural knowledge. The main proviso on this second hypothesis is that the training of spatial knowledge may be different than the training of semantic or temporal knowledge. Initially, this research should attempt to elucidate optimal training decisions for the acquisition of the most basic components of spatial knowledge: propositions and rules. Knowing how to train these basic components will place constraints on the training of more complex knowledge. This should minimize the number of blind alleys searched for optimizing the training of more complex knowledge types.

2) Instances or Generalizations. Early work on concept formation used simple concepts. The exemplars of the concept had to have some combination of defining features such as "Red and Square". In order to learn

such concepts, subjects engaged in hypothesis testing. They actively focused on some features and tested whether those features were necessary for concept membership. They also tested the operator to be applied to the defining features. Conjunction (Red AND Square), disjunction (Red OR Square), and biconditional (Red IF AND ONLY IF Square) are examples of operators. Cognitive psychologists concluded that subjects had learned a single generalization: the abstract proposition relating the features that defined the concept. Medin & Smith (1984) described a major problem in extending the classical work to naturalistic categories: there are usually no defining features that absolutely must be present for all members of naturalistic concepts. A dog that does not bark is still a dog; it is just not a typical dog. They also reviewed two models specifically designed for such naturalistic categories: the probabilistic abstraction and exemplar models.

The probabilistic abstraction model is similar to the classical model in that subjects are assumed to learn abstract feature representations for the concept, but it differs in that the features are probabilistic rather than defining. Features that are common to most members are characteristic features. For some concepts the characteristic features in the abstraction may be independent of each others. Such concepts satisfy the constraint of linear separability (Wattenmaker et al. 1986). Prototypes are instantiations of abstractions satisfying linear separability. The prototype of a class is the average of the exemplars of the class. Since characteristic features are common to most instances, they have high weights and the mean of each characteristic feature is diagnostic of the category. Features that vary widely between instances tend to cancel each other out. To optimize learning of prototypes, subjects should attend to all dimensions of each instance, but the order of instances is irrelevant as long as all subjects eventually see the same set of instances.

The exemplar model posits that subjects remember particular instances. According to this model, subjects remember each animal that has been called a dog in the past. When a new animal is encountered, it is compared to previously encountered animals. The new animal is called a dog to the extent that it is more similar to the person's prior experience with particular instances of dogs than instances of cats. Strong versions of this model assume that no abstraction process is present at either encoding or storage (Hintzman, 1986, 1988). With such a memory representation, the student should pay attention to all of the details of each instance, but encouraging the student to attempt integrating information across instances would be counter-productive. Further the order in which instances are presented should be irrelevant unless additional assumptions are made.

While strong versions of probabilistic abstraction models posit no memory for exemplars and strong versions of exemplar models posit no abstraction process, a number of researchers have found evidence for both types of representations (e.g.; Malt, 1989; Ross, Perkins, & Tenpenny, 1990).

For instance, Medin, Altom, & Murphy (1984) found evidence that subjects learn both exemplars and protoypes for concepts based on geometric shapes. The important aspect of their experiments is that they varied whether or not subjects received the prototypes in the learning set. The addition of prototypes in the learning set both biased the subjects toward a protoype abstraction and facilitated learning rate. Thus the items included in the learning set directly influences the way the knowledge is represented and alters learning efficiency. The use of the abstraction or instances may vary between subjects within a task or may both be used by each subject within the task. As another example, Anderson (Elio & Anderson, 1984) suggests that a given set of exemplars gives rise to multiple generalizations each composed of n-tuple features. Each generalization has a different weight that depends on the frequency of its prior successes for classifying instances of the concept. Its weight also determines the probability that it will be accessed in the future. As with the prototype model subjects should attend to all aspects of each instance, but the order in which the instances are encountered will produce major effects in terms of the generalizations formed and their weights. This directly alters the adequacy of the generalizations formed.

3) Analytic and Holistic Strategies. If the subject can choose a particular learning strategy, then the optimal training sequence should be matched to that strategy. This was most elegantly demonstrated by Elio &

Anderson (1984). They had subjects categorize verbal descriptions of instances into one of two categories. Each instance was a "person" that could vary on five four-valued dimensions. Dimensions include job (unemployed, self-employed, government, and private firm) and hobby (tennis, chess, golf, and bowling). These instances were constructed as variants of multiple prototypes for each category. While all subjects were given the same set of instances, the order was varied between groups. One order (centered) began with a low variance sample and subsequently less typical instances were introduced. Another order (representative) started with a high variance sample. When subjects were asked to state the rules that determined category membership, the representative order was better than the centered. In contrast, the centered order was better when subjects did not expect specific rules to determine category membership. Elio & Anderson suggest that asking subjects to state a rule leads to an analytic learning mode which is benefitted by a representative (high variance) order. This is an active process that is similar to the hypothesis testing supportive of the classical model and leads subjects to focus on a subset of stimulus dimensions. The opposite pattern was found with subjects that adopted a non-analytic learning mode. For those subjects, starting with a low variance sample aided initial schema abstraction and these early gains are maintained throughout learning. This is predicted by the ACT* model proposed by Anderson.

While not varying strategy per se, Homa & Vosburgh (1976) studied the effect of sample variance on the learning of spatial knowledge (dot patterns). During learning, some subjects only saw stimuli that were similar to the prototype (low variance set), while others saw stimuli that were representative of the whole concept (high variance set). Given at least 6 exemplars of each category, category learning was better for the high variance subjects than for the low variance subjects. Homa (1978) concluded the subject can only learn the variance permissible in an ill-defined category when they are trained with a a high variance sample. Since subjects were not asked to state any hypotheses, these results contradict the results obtained by Elio & Anderson (1984) with verbal materials. It may be that spatial stimuli bias the learner toward analytic processing. This is consistent with data reported by Ward, Vela, & Hass (1990), but stands in contradiction to the model proposed by Miller (1987). It is also likely that there are big individual differences in preferred learning mode (Kyllonen & Shute, 1989).

Whether the learning strategy is most strongly determined by task demands, representational code, or cognitive style, the bottom line for training propositions by examples is clear: changing the order of instances within the training set produces large differences in acquisition rate. Further, no one order is optimal. To optimize learning, the order of instances must be congruent with the particular strategy used by the subject.

Conclusions

The most general conclusion to be learned from the literature is that declarative knowledge is qualitatively different from procedural knowledge. It further seems that spatial representations are qualitatively different from verbal representations and are differentially effected by visual or auditory instructions and by manual or speech responses. As a consequence, it is reasonable to investigate training differences within declarative and procedural knowledge. Initial investigations should be based on the very simplest components within each type of knowledge: propositions and rules. Since the mission of the branch is computer-based training, it is also reasonable to take advantage of graphic presentations and manual responses by focusing on spatial codes. The literature suggests two problem domains: classification and large-scale space learning. Each of these domains can be presented as either a declarative or procedural task to the learner. Thus a common knowledge base could be constructed, but some subjects could be lead to produce a propositional representation of that knowledge while others could be lead to learn rules. For a classification task, a set of instances for four concepts could be constructed and the learner could either be instructed to learn a label for sets of similar stimuli (propositions) or to learn specific response choices for specific stimuli (rules). On the other hand, a large-scale space could be constructed and the learner could either be given map training (propositional representation) or route-specific navigational views (rule representation).

Each of the task domains are also basic components of many military missions. Classification in a propositional sense is central to a spotter identifying an incoming aircraft, to distinguishing sonar signals, and to identifying a land vehicle based on its dust trail. Classification in a rule sense is necessary for selecting the appropriate armament system when encountering a novel target, for positioning an aircraft carrier given a specific weather condition, and for selection and packing of gear given specific mission expectations. An adequate representation of large-scale space is necessary for a pilot about to embark on a mission, for a sailor trying to remember the relative locations of vessels in a naval group, and for a general considering the viability of a flanking maneuver. As discussed above, the relative of efficacy of propositional and rule based representations of large-scale spaces depends on specific task demands.

For classification, a novel spatial set should be constructed to minimize the effects of prior knowledge on training, but set membership should be fuzzy in order to maximize relevance to naturalistic military tasks. While the general instructional domain for classification tasks is by examples, the previous research directly demonstrates the importance of three training variables: inclusion of prototypes in the learning set, learning mode (holistic or analytic), and whether the learner is given high or low variance sets of instances. It is also important to vary whether the learner passively receives the instances (Example learning in the STAMP taxonomy) or actively selects instances (Discovery learning in the STAMP taxonomy). This variable should bias the subject toward holistic or analytic learning modes and may well interact with either individual differences and with propositional or rule-based representations.

For large-scale spaces, the important lesson is that no single representation is ideal for all tasks. The important question is whether the way the person is trained for one representation both maximizes performance base on that representation and minimizes decrements on tasks better solved with the other representation. Computer-based instruction makes it possible to simultaneously provide the learner with a bird's-eye view and a navigational perspective. Such training might optimize learning by producing both representations or developing skill at translating between the representations. Alternatively, it might overload the student so that neither representation is adequately learned. Further, it is likely that any effect would interact with spatial ability. The dual training might optimize learning for high spatial ability students, but hurt learning for low spatial ability students. As with the classification task, it is also important to train some subjects with passive presentations (didactic within the STAMP taxonomy) and let other subjects actively explore the space (discovery learning within the STAMP taxonomy). It is expected that type of training would also interact with spatial ability. In computer-based training or army topographical map reading skills, Barsam & Simutis (1984) found that discovery learning benefitted high spatial ability students, but had no effect on low or average spatial ability students.

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Fundamental Skills and Air Force Accessions:
Linking Individual Abilities and Organizational Needs

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Abstract
This paper analyzes data from a wide variety of sources and compiles an inclusive assessment of fundamental skills in the Air Force accession pool. Data from a variety of sources such as The U.S. Census, The U.S. Department of Education, The Department of Defense, The U.S. Air Force, and The U.S. Bureau of Labor Statistics are used to link the material necessary for establishing a general profile of the typical Air Force recruit pool with respect to characteristics associated with fundamental skills and the training of those skills. This demographic information is further coupled with occupational growth patterns, delineating similarities/differences in civilian industries' and the Air Forces' personnel needs. The above information is joined with high school graduation rates and standardized test scores to relate indicators of individual fundamentl skill levels to organizational skill needs. Most data are projected from 1980 through the year 2000, taking into account the impact of any important demographic trends on this process.

Introduction

The role of fundamental skills training assumes greater importance for the U.S. Air Force as military jobs become more technically specialized. Job training programs developed for the purpose of providing well-trained, efficient workers to meet these technical demands require that all individuals involved have a solid foundation in fundamental or basic skills. Inability to complete the necessary training due to a lack of such skills has a direct negative impact on the Air Force mission. Skill deficiencies mean individuals may be unable to effectively perform their jobs and to achieve career advancement. This in turn relates to higher turnover and organizational inefficiency. Several characteristics of the U.S. population directly and importantly affect these processes.

First, demographic trends are a prominent source of information pertinent to issues related to fundamental skills because they define the available recruit pool. Second, changes in the industrial and organizational core affect the types of skills needed to sustain productivity. Finally, education levels and standardized test scores, to some extent, are supposed to identify individual abilities that relate to those skill requirements.

Utilizing data from a variety of sources, our research will attempt to provide a well-documented and inclusive assessment of fundamental skills levels in the primary Air Force recruit pool and link that information directly to Air force personnel requirements. Chart 1 presents our general model of fundamental skills assessment as it relates to the Air Force mission. This research also provides an overview of important sociological insights for creating a working definition of fundamental skills with respect to varying organizational levels within the Air Force.

Defining Fundamental skills

Most attempts to define or evaluate fundamental skills rely heavily on research in the area of cognitive psychology. Initial attempts to systematically review the theoretical and practical definitions of fundamental skills are presented by Schendel, Payne and Mathews (1991):

> The largest differences among the different orientations are in terms of explanatory and predictive power, current heuristic value, and practical value. ...Cognitive theories, particularly, have shown a clear advantage in terms of their ability to explain why behaviorally-oriented "generic" fundamental skills training programs have been relatively ineffective.

> Recent cognitive theories also have had tremendous heuristic value, both in terms of research they have fostered and in terms of the many new ideas they have generated.

This identifies one problem for this analysis: the lack of consensus in defining fundamental or basic skills. Research in this area offers valuable insights, particularly with respect to individual level criteria. However, such a strong concentration on theories and evidence from cognitive psychology fails to incorporate critical research from other social sciences such as sociology, anthropology and political science. The literature from psychology acknowledges the importance of remembering the impact of social structure on human processes, but deemphasizes the importance of these structures on individual decisions.

The cognitive psychology approach looks at outcome measures from individual performances and assumes they reliably and validly identify fundamental skills capabilities. Documented differences in outcomes across categories of individuals suggest that structural impacts are being measured as well. For example, data indicate that at all education levels, whites outperform African Americans and Hispanics on standardized tests. These aggregate or structural differences provide a basis for understanding individual performance variations among Air Force accessions and linking fundamental skills capabilities to shifting force demands.

Definitions of fundamental skills are socially constructed, varying with characteristics of the perceiver, the situational context and the actors involved. Therefore, information from disciplines such as sociology becomes critical for developing a more complete understanding. Definitions of fundamental skills range from the ability to read, write, and compute in a routine manner, to "higher-order thinking abilities" such as competence in sizing up a situation, making quick and accurate decisions, functioning effectively in new environments and both understanding and communicating the point of what is necessary to complete a task (see, for example, Collino, Aderman and Askov, 1988; Schendel, Payne and Matthews, 1991).

However defined, a plethora of available information supports the growing shortage of and requirement for workers with acceptable levels of fundamental skills[1]. Much of these data are contextual in nature, reflecting the concerns of a specific discipline, industry, organization or skill. For example, in the Air Force, fundamental skills are typically defined with respect to a specific occupational specialty (AFSC). Therefore, the basic skills needed to establish satellite communications links are seen as very different from those needed to perform as a crew chief on a KC-10. This exacerbates the problems associated with defining fundamental skills by making the available information appear scattered and unrelated and underscores the need to organize existing knowledge into a meaningful, comprehensive whole.

TERMS AND METHODS

Population projections for 18 to 24 year olds are derived from the following published tabulations of the Census Bureau's Curent Population Reports: Series P-25 No. 918 (1986) - Hispanic projections; Series P-25 No. 1018 (1989) - White and Black projections; and Series P-20 No. 443 (1990) - high school graduates and college enrollees. All calculations are based on the Bureau's middle series of projections.

The category "white non-Hispanic" was obtained by subtracting the number identified as Hispanic (Spanish Origin) from the number identified as "white", since over 95% of Hispanics are recorded as being of the white race. The "Asian/Other" category was derived by subtracting the "black" and "white" categories from the total projected population. Census Bureau weights were applied to each category in order to correctly calculate the number of non-institutionalized persons.

Projections of high school dropout and college enrollment rates are based on the average percent of change per year from 1980 to 1988 for each racial/ethnic category. In order to keep these estimates conservative, all such calculations were rounded downward. Since data for white non-Hispanics were not available, their graduation and enrollment data are based on the "white" category.

Demographic Trends

Changes in the Labor Pool

Aggregate changes in the demographic profile of the U.S. have important impacts for fundamental skills. The overall population growth rate has slowed primarily associated with the "baby bust" which followed the post World War II "baby boom." The 18 - 24 year old cohort will decrease in size through 1995 (see, Figure 1). Simultaneously, the proportions of African-Americans and Hispanics in this age cohort are expected to increase (see, Figure 2). Women currently comprise a majority of the population, and are expected to remain so at least through the year 2000.

A projected decrease in labor force growth from 2.0% during the period between 1976-88 to about 1.2% between 1988-2000 results from the above along with a decrease in the high growth rates in labor force participation of women. The projected general slowdown in the growth rate of the labor force will be less extensive for women and racial/ethnic minorities, resulting in a substantial shift in the composition of the labor force.

The labor force of 2000 will include more women and racial/ethnic minorities because their respective growth rates will continue at a faster pace than that of white men and women (see Figure 3). Women comprised 45% of the labor force in 1986 and are projected to increase to 47% by 2000 (Hudson Institute, 1987). Additionally, African-Americans, who made up 11% of the labor force in 1988 will comprise 12% by 2000; Hispanics, 7% in 1988, will increase to 10% by 2000; and Asians and other minorities are expected to increase from 3% in 1988 to 4% by 2000 (Hudson Institute, 1987).

African Americans are the largest U.S. ethnic/minority group, and are increasing in number relative to white, non-Hispanics. Furthermore this group is more likely than others to come from single parent families with resultant socioeconomic difficulties (Figure 4), higher high school drop out rates (Figure 5), and poor health, all of which can negatively impact labor force participation. Labor force participation rates of African Americans are typically lower than other population groups, and they also have higher unemployment rates. Furthermore, those employed are less likely to work in the higher paying technical jobs. This group has historically been an important source of military accessions; members have used the military as a means of attaining political representation and of furthering their socioeconomic status.[2]

Asians and Hispanics are the fastest growing population groups. Both groups have high immigration rates and come from a wide variety of countries and cultural backgrounds. While small in numbers, compared to other minority groups, Asian Americans have the highest levels of high school graduation, college-attendance, and academic performance. These individuals also have the lowest unemployment rates. Except for joining the Navy, Asian Americans have not been likely to participate in military service.

Hispanics are the youngest of the minority groups in the U.S., with a median age in 1987 of 26.1 compared to 31.9 for the population in general (Mckay, 1988). Hispanics are the currently the second fastest growing ethnic/minority group. According to Mckay (1988), one in twelve Americans were Hispanic in 1987, and according to figures distributed by the Defense Technical Information Center (1984) Hispanics are projected to comprise 12.1% of the total U.S. population by 2000. This is an increase of 36.1% from 1980, when they were 8.2% of the total population. Because of their young median age, the percentages are higher for younger age cohorts. As early as 1989, Hispanics made up 11% of 18-24 year old civilians (DoD, 1990). At present, few Hispanics join the military. According to DoD statistics, only 6% of all accessions, and 3% of Air Force accessions in FY 1989 were Hispanic. They could therefore provide a source of previously underutilized Air Force accessions.

Furthermore, important compositional changes are expected to occur in the age structure of the labor force. Increases in the relative size of the 25 - 54 age group should ensue, because the proportion of

employed aged 55 and over is projected to remain relatively constant, while the proportion aged 16 - 24 is expected to decline (see Figure 6). The cohort of 18 - 24 year olds who do not attend college typically are the group from which civilian industries draw entry level recruits. The military enlisted force competes for recruits from this same pool, which is further reduced because the AVF has primarily relied on white, non-Hispanic males within the 18 - 24 age cohort for volunteers (see Figure 7). The college enrollment rate for this group is increasing further reducing the available pool (see Figures 8 and 9). Put simply, the result will be more intense competition for youth among the military, educational institutions and civilian employers, especially for those with high scores on standardized
tests (Chart 2).

Changes in the Labor Market

Recent and projected changes in the labor market continue the shift from goods-producing industries to service industries. By 2000, the service sector is projected to account for 16.7 million of the 18.1 million newly available jobs (Kutscher, 1991). Within this sector, the major occupational groups projected to grow at a faster than average rate are: technical occupations, professional specialty occupations, and executive, administrative and managerial occupations (see Figure 10). The occupations with the slowest projected growth rates include operators, fabricators, skilled crafts, and laborers, while agriculture, forestry and fishing occupations are projected to decline (see, Figure 10).

The fastest growing occupations require the most education and/or training, while those occupations requiring the least education and training either have much slower growth rates, or are projected to decline. This process also holds true for military jobs in general, and the Air Force specialties in particular (see Chart 3). For example, most base maintenance jobs are contracted to civilian workers, while highly skilled jobs such as those in communications systems remain primarily as AFSCs, and the need for these AFSCs is expanding. Increasingly, all services rely on very sophisticated and complex weapons and communications systems to maintain adequate levels of readiness.

These facts combine importantly with the information on the labor pool presented earlier: African Americans and Hispanics are over-represented in occupations having the slowest rates of growth, and requiring the least education and training, while they are under-represented in occupations with the highest growth rates, requiring higher levels of education and training (see Figure 11). An important caution should be interjected here, the seemingly large percentage of ethnic/minorities in the service sector is deceptive. The service sector includes a wide variety of jobs from highly skilled medical technicians to semi-skilled waged laborers such as janitors. The fact that ethnic/ minorities are concentrated in very low-skilled, low-waged jobs within this broad category is easily lost (see Chart 4). This is also the case for women in the labor force (see Figure 12). Moreover, minorities who make up a growing proportion of the 18 - 24 year olds are less likely to go on to college (except for Asian Americans), are more likely to drop out, complete only associate degrees, or to transfer from two-year community colleges in order to complete their degrees (Mingle, 1987: Chapter 1).

This is exacerbated by higher civilian pay scales, relative to the military, for entry level workers. In other words, that portion of the 18 - 24 year old cohort with superior or sound fundamental skills will be able to demand premium wages in civilian organizations, and as a result be less likely to select the military as a viable post high school option. Burright (1990) notes the difficulties instituting changes to offset these facts:

> The ability and skill gap problem could be eliminated through changes in military compensation policies....New recruits will have to be paid more (emphasis added). Doing so would mean flattening the traditional relationship between earnings and age. The Services would have to pay able recruits more; enlisted bonuses would have to be based on a persons (sic) abilities and skills as well as on military occupation he or she was entering.

Compounding the pay differential, civilian corporations are furnishing training at a variety of levels to employees. New skills, leadership, and literacy are among corporate education offerings. According to Coates, Jarratt and Mahaffie (1990: 273), "almost 20% of companies that provide training teach remedial basic education." Moreover, over the next decade, 4 out of 5 industrial workers will have to upgrade their skills. Given present restructuring of the labor market, a large proportion of the labor force will need to be retrained in new jobs or taught fresh skills. Ford Motor company provides one example (Coates, Jarratt and Mahaffie, 1990: 279):

* employees receive up to $1500 a year in prepaid tuition at a college or university

* computer awareness, public speaking, goal setting, time management, and rapid reading are types of classes offered in-house
* basic skill-enhancement programs are offered in reading, math and oral communication, leading to high school diplomas or GED certificates
* English-as-second-language (ESL) courses are offered to employees

Sticht and Mikulecky (1984) reported that business such as Equitable Life, Chase Manhattan Bank, General Motors and Continental Bank were already directly addressing basic skills training needs within their organizations seven years ago. These programs have direct consequences for military recruitment.

On the one hand, the military, which advertises itself as a means of gaining needed job skills training, could become an even more attractive alternative employer for minorities unable to compete for jobs in technical and professional specialties. On the other hand, those individuals most likely to join the AVF may lack some of the requisite skills needed to train for today's high-tech military. Moreover, from now on, the military may find that it has to compete directly with civilian firms as a source of technical and job skills training for potential employees.

Educational Impacts

Direct links between education levels of the labor pool and education requirements of the labor market are difficult to establish. Some indicators suggest a general upgrading of the skills necessary to perform at current jobs. Collino, Aderman and Askov (1988) for example, write that "...jobs requiring lower skills will comprise 27% of all new jobs, compared to 40% of current jobs, while 41% of new jobs will require the highest group of skills compared to only 24% of current jobs."

And, as Sticht and Mikulecky (1984) argue, while not all jobs will require more years of training, the technologies required even in jobs considered low-skilled will require higher levels of basic skills than in the past. For example, even janitors will be required to use a range of mechanical equipment which could require reading written instructions and they may also have to write reports which can be coded into computer files.

A report issued by The U.S. Department of Education and The U.S. Department of Labor (1988) highlights the importance of job-related education and training for jobs of the future. Specifically the report confirms that:

* The majority of new jobs will require some postsecondary education for the first time in history
* Only 27% of all new jobs will fall into low skill categories, compared to 40% of jobs today
* Jobs that are in the middle of the skill distribution today will be the least skilled occupations of the future.

Moreover, the types of reading, writing and analytical tasks workers perform routinely may be different from those which students are taught to perform in the school system. For example, students read to retain information for <u>future use</u>, while workers need immediate "reading to do" and "reading to assess" skills (see, Huff, Sticht and Joyner, 1977). Training programs for employees are important even beyond the problems associated with linking skills learned in school to occupational demands. In the first place, a sizeable proportion of the high school population drops out before completing their diplomas. And secondly, 75% of the available labor pool for the next 15 years will have completed their schooling in the present educational system (The Bottom Line..., 1988).

Furthermore, the SCANS Report (1991) outlines the interaction of basic skills such as reading, writing and math with future work requirements. First, employees will have to read and understand a diverse set of descriptive materials including both words and numerical information in order to make decisions and recommendations. Second, most jobs will require the ability to write correspondence, instructions, explanations, illustrations and necessary requests. Additionally, almost all employees will have to maintain records, estimate and evaluate results or apply statistical process controls to inputs. Finally, communications skills including listening to others and articulating one's own perspective demand all of the academic bases described above.

Available data suggest that the projected supply of individuals with even the necessary academic skills could prove problematic. As indicated in Figure 13, while most individuals tested could perform adequately at the lowest level of proficiency, the number achieving proficiency dips rapidly as the difficulty level increases. Mikulecky (1987) identifies basic reading abilities as being able to:

* follow brief written directions
* select words, phrases, or sentences to describe a simple picture
* interpret simple written clues to identify objects
* locate and identify facts from simple informational passages
* combine ideas and make inferences based on short, uncomplicated passages

Above this level of difficulty, reading proficiencies decline rapidly. This decline is particularly evident for African Americans and Hispanics, who tend to have lower standardized test scores (see Figure 14), higher high school drop out rates, and lower socioeconomic statuses than their white, non-Hispanic counterparts. These trends are equally true for math (Figure 15) and science (Figure 16) proficiencies.

Koretz (1990) further illustrates the importance of demographic information for understanding trends in minority education: both age and sex have important impacts on educational attainment and dropout rates independent of minority group membership. His research focuses on African Americans, but underscores the importance of distinguishing subgroups within each minority group for fully understanding trends in minority education. Moreover, Koretz' (1990) analyses raise doubts about the appropriateness of using high school drop out and graduation rates and college enrollment rates alone as indicators of the academic success of minorities. In other words, standardized test results may be confounded by the influence of such factors as amount of spending on education by school districts (see, Harris, 1988).

Using data from a vocabulary test which is part of the General Social Survey, research by Harris (1988) shows that the gap between minorities and white, non-Hispanics <u>increases</u> as level of education increases (see Figure 17). These findings corroborate that of Mingle (1987) who states that, on average, African American and Hispanic 17 year olds read only about as well as 13 year old white, non-Hispanics. Harris' report concludes that any lack in academic preparation, regardless of the reason, compounds over time, and may ultimately lead to frustration and higher drop out rates (Harris, 1988). Furthermore, this suggests that relying solely on the current education system to solve skill deficiencies will not necessarily accomplish the task.

Women, along with ethnic/minority groups will comprise a growing proportion of the new labor force. As a group, women score slightly better than men on the verbal component of the SAT, but lower than men on the math component (see Figure 18). It is equally true that they outscore men on most portions of the ASVAB, except for the technical portion (Dod, 1984; 1987; 1988; 1990). This suggests that including more women into Air Force accessions will necessitate training them in fundamental skills related to technical operations.

As shown earlier at risk groups comprise a growing portion of the labor force and are least likely to have the competencies recently identified by the SCANS Report (1991) as being essential for work place competence. Furthermore research by Ree and Earles (1991) illustrates the absolute loss of potential Air Force accessions who would be likely to rank in the highest AFQT categories based on percentage decreases in aggregate scores. Figure 19 shows the distribution of AFQT Category I and II accessions over time, while Figure 20 illustrates the projected loss of individuals in these highest percentiles. While the AFQT may or may not measure fundamental skill capabilities, it may indicate degree of familiarity with the cultural context important for success in military job performance (see, Ree and Earles, 1990; Teachout and Pellum, 1991). If AFQT scores are related to job performance and if maintaining high levels of technical competence is important for the Air Force, then the decline in Category I and II accessions could have deleterious consequences for accomplishing the Air Force mission. In other words, "Air Force training activities will have to train less able and skilled people to do more complex jobs with fewer resources (Burright, 1990)."

A MODEL OF THE AIR FORCE ACCESSION POOL

Figure 21 illustrates our model of the Air Force accession pool relative to the 18 - 24 year old age cohort in the U.S. Note that at first appearance, demographic projections of the youth cohort (Figure 22) suggest that the Air Force would not have a problem maintaining necessary force strength. In particular, the decrease in the white, non-Hispanic males, between the ages of 18- 24 (the primary Air Force accession pool) is expected to turn around after 1995. However, if we factor in other demographic information, which we know will impact the availability of new recruits, we see a dramatically different trend (see Figure 23). The model was created using Lotus 1-2-3, which allowed us to subtract trend information for categories unlikely to be available for voluntary Air Force service from the initial recruit pool. Our estimates are conservative ones, because all trends and averages used were rounded down, and because global catalysts, which could create sudden need for increased personnel (such as another Operation Desert Storm), were not factored into our equation.

Once high school drop outs and college attendance rates are factored in, the result is a decreasing available accession pool through the year 2000 (see Figure 24). The shift in the distribution suggests an increasing proportion of African Americans relative to white, non-Hispanics because of combined increasing high school graduation and decreasing college attendance rates. Once again this is a conservative estimate, not accounting for increased competition from the civilian labor force, decreasing numbers scoring at higher percentiles of the AFQT, nor differential minority/sex inclinations to enlist.

In order to maintain necessary strength, during periods without a major conflict, it appears the Air Force will have to recruit from non-traditional groups. Barring the return to a draft military, another major conflict will necessitate reliance on a non-traditional recruit pool. This non-traditional recruit pool will have to include a higher representation of minorities, who tend to score lower on standardized tests, and women, who tend to score lower on mathematical and technical aptitude tests. Individuals who have dropped out of high school, or those scoring in the lower percentiles of the AFQT may also have to be considered. In either event, fundamental skills will be important for new accessions into an operational, efficient Air Force.

CONCLUSIONS

This report presents a strong demographic argument for why the fundamental skills project is important to the performance of the Air Force mission (see Figures 21 through 24). The data reported highlight the shrinking pool of young workers (ages 18-24), particularly white, non-Hispanic males. This results in a reduced Air Force accession pool, especially in combination with:

* increasing college attendance rates for those with higher academic skills
* current higher school drop out rates
* lower standardized test scores for minorities (except for Asian Americans)
* decreasing numbers scoring above Category IIIa on the AFQT.

Competition with the civilian labor force for well educated and technically skilled workers will increase as service sector as well as professional, technical and administrative jobs expand and manufacturing, agriculture, and skilled crafts and semi-skilled laborers, requiring little formal education decrease in importance. Overall poor performance on standardized tests, along with gaps in scores between Hispanics, African Americans and white, non-Hispanics suggests problems with relying on the present education system to supply workers with requisite fundamental skills. While the U.S. education system may reach a large proportion of the population, the academic preparation provided may be inadequate. Restructuring of the work place due to changes in technologies and communications may have redefined the types of skills needed for adequate job performance. Skills critical to the future work force may be in short supply. As presented by the SCANS report, such skills will include the ability to interpret as well as absorb information presented in the form of both words and numbers. To counter problems with entry level employees' lack of fundamental skills, many corporations are providing remedial basic training. This further magnifies the competition for entry level workers between civilian industries and the military, which has traditionally provided additional training and education to individuals needing and desiring them.

As Air Force jobs become more technically specialized, job training programs become even more important than ever for successful completion of the Air Force mission. Advanced training programs developed to provide highly skilled, efficient workers require a solid foundation in fundamental skills. Skill deficiencies lead to the inability to perform adequately on the job or in required training programs. Not only will this create ineffective operations at all levels of the Air Force, it can also lead to individual frustrations because of blocked career advancement, with serious adverse consequences for morale and the overall sense of esprit de corp needed to maintain the tradition of excellence in today's Air force. These forces impact minority subgroups more strongly than white, non-Hispanics. The net result is an Air Force that is neither cost effective nor representative of the population it serves.

IMPLICATIONS FOR FUTURE RESEARCH

This report was written as supporting documentation for a proposed larger research effort. The goal of the additional research will be to ascertain any predictive capability of ASVAB scores for assessing Air Force relevant fundamental skills. The definition of and indicators of fundamental skills used will be those generated by researchers from HAY Systems, Inc., who are in the process of completing the definition task. If the second portion of the task can not be completed, other available standardized aptitude and job performance measures will be used for the analysis.

Specifically this research will use regression models as a means of controlling for structural impacts (ie., race/ethnicity, sex, age, education level) related to individual performance. For example, if race and sex account for differences in skill performance indicators independent of ASVAB scores, this would suggest that such scores may not be valid predictors of fundamental skills capabilities.

Endnotes

1. See Coates, Jarratt and Mahaffie for a comprehensive presentation of demographic forces and skill levels which are "reshaping work and the work force in North America."

2. See, Janowitz, 1976 for a discussion of the military as an avenue for underprivileged groups to improve their education and skills.

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APPENDIX A. List of Figures and Charts

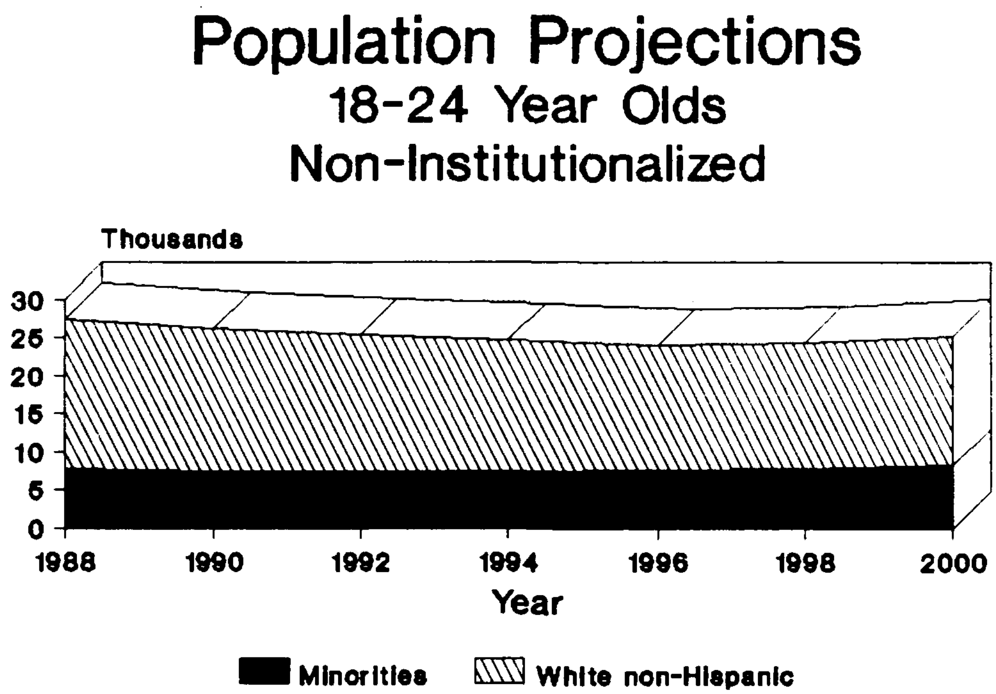
Figures

Charts

Appendix B. Figures and Charts

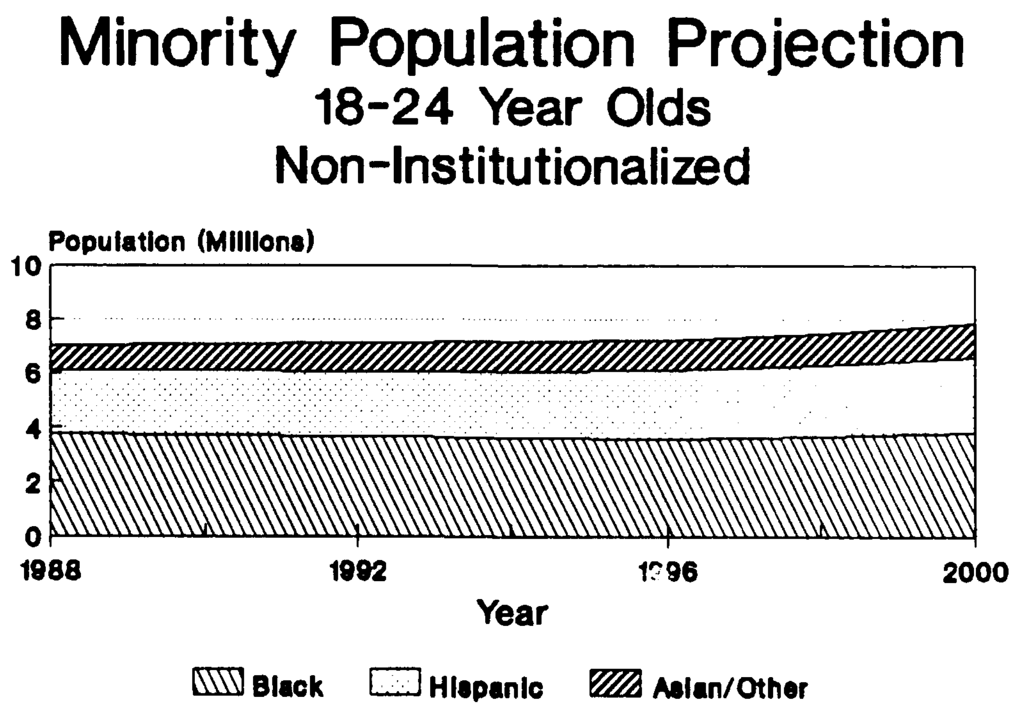
FIGURE 1

a.



Source:
Current Population Reports
Series P-25 Nos. 995 & 1018

b.



Source:
Current Population Reports
Series P-25, Nos. 995 & 1018

FIGURE 2

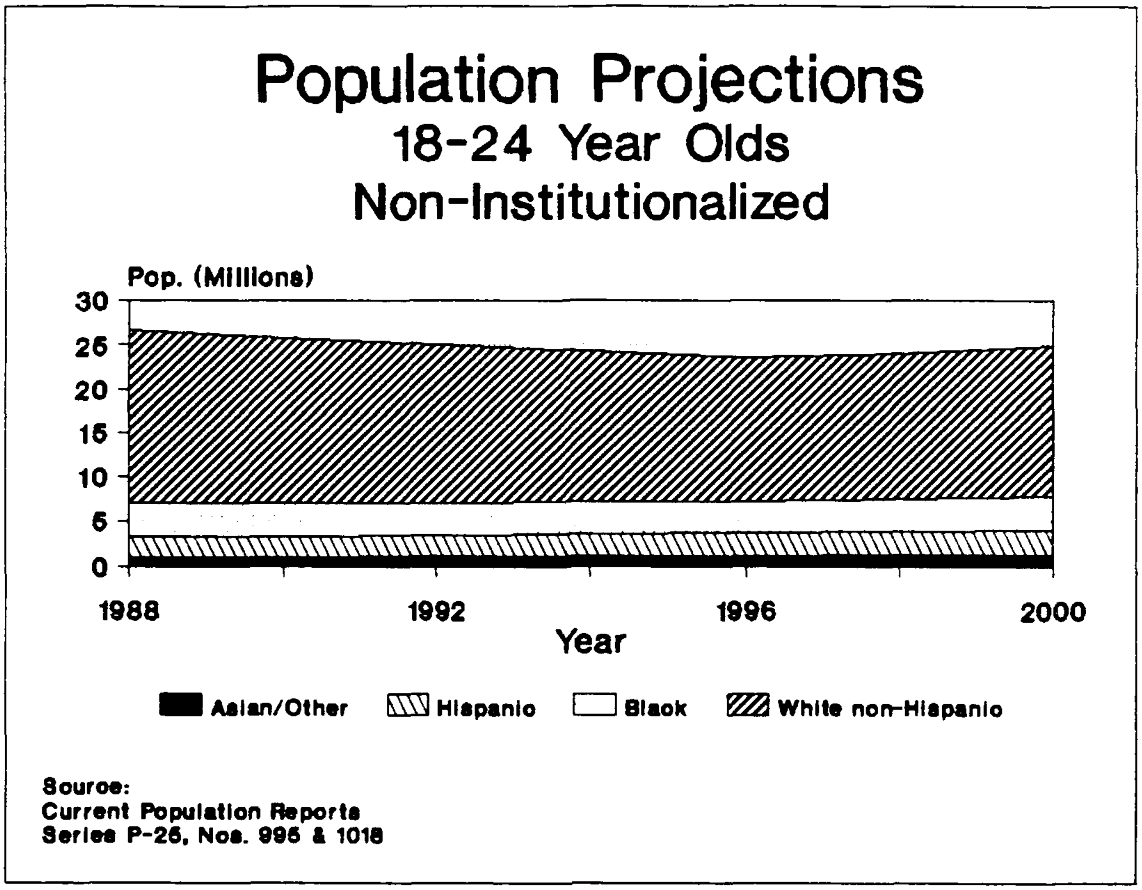


FIGURE 3

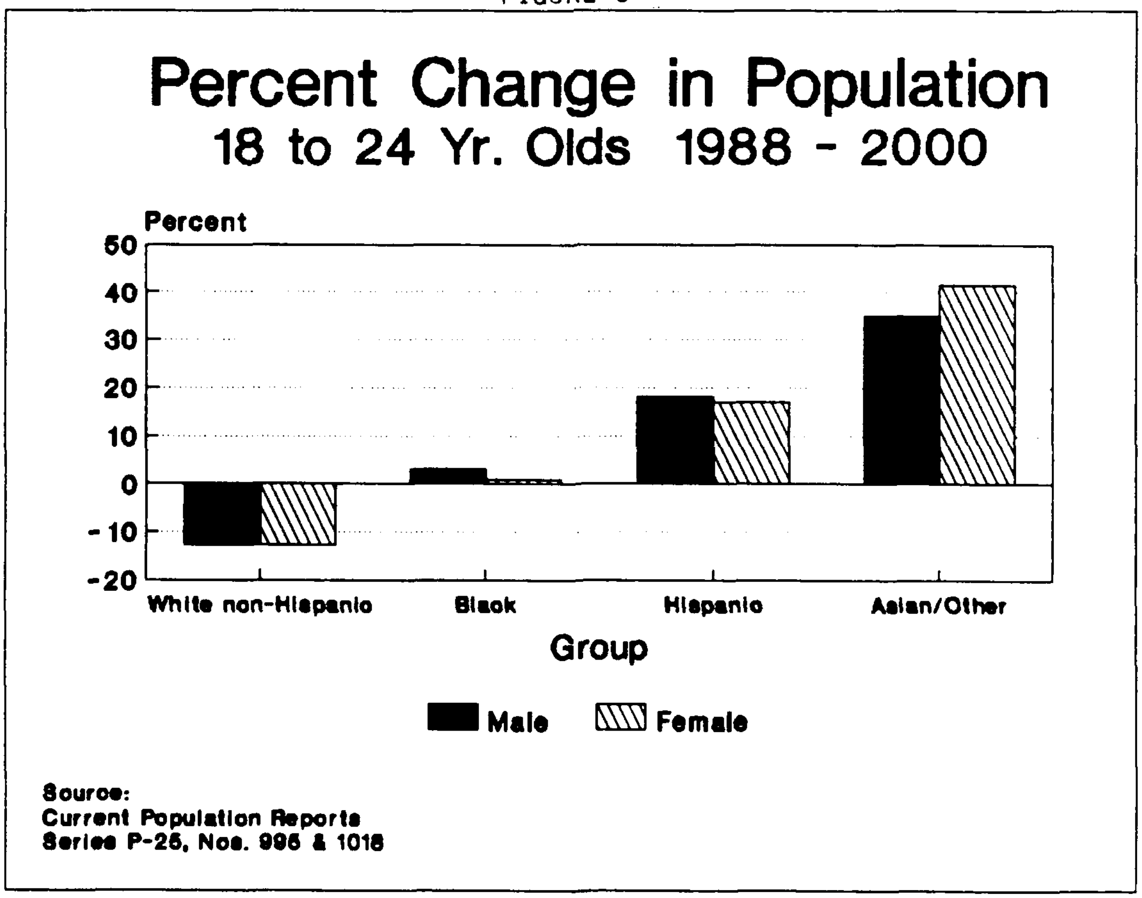
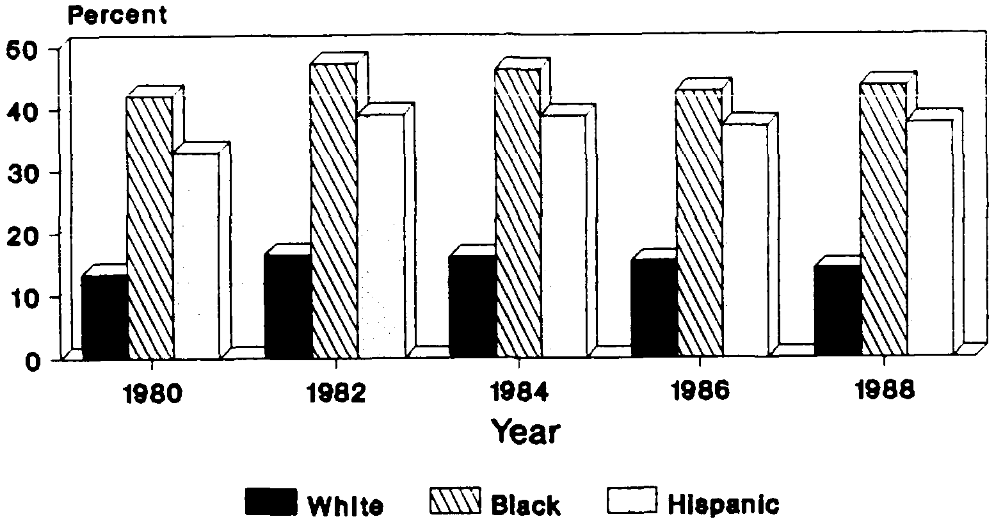


FIGURE 4

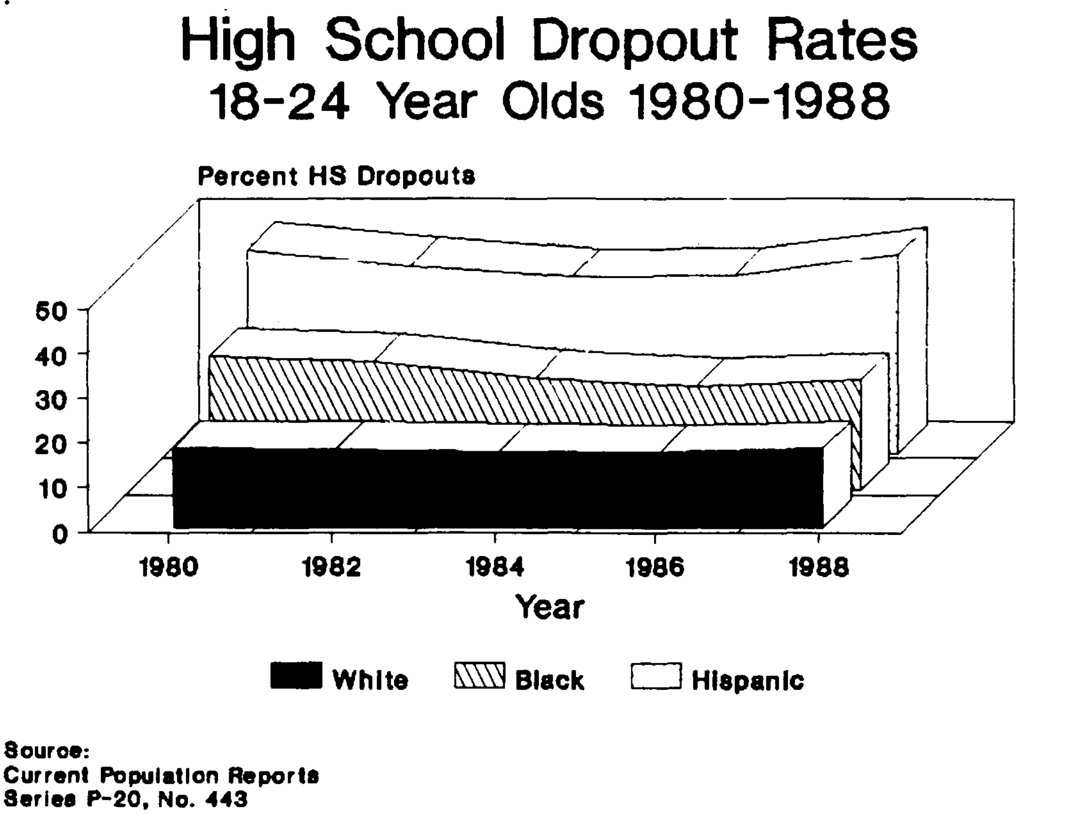
Children Growing Up in Poverty
Trends in the 80's



Source:
<u>Digest of Education Statistics, 1990</u>
National Center for Education Statistics

FIGURE 5

a.


High School Dropout Rates
18-24 Year Olds 1980-1988
Percent HS Dropouts
50
40
30
20
10
0
1980
1982
1984
1986
1988
Year
White
Black
Hispanic
Source:
Current Population Reports
Series P-20, No. 443

b.

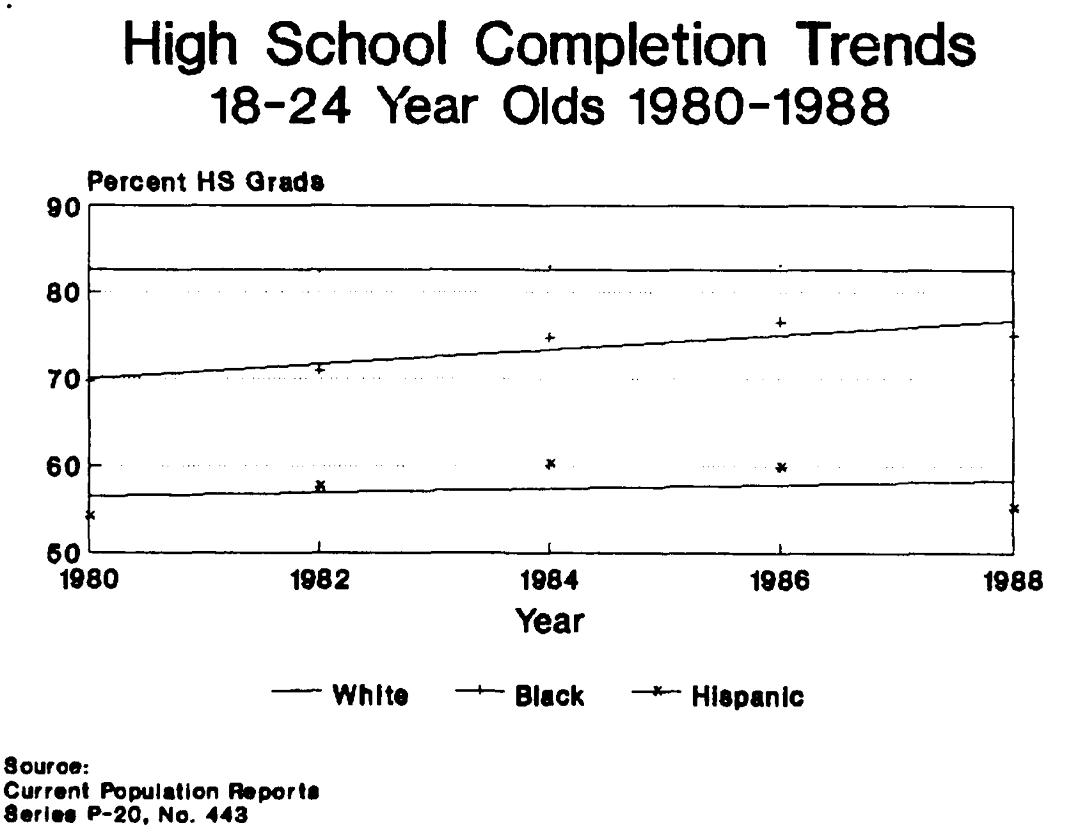

High School Completion Trends
18-24 Year Olds 1980-1988
Percent HS Grads
90
80
70
60
50
1980
1982
1984
1986
1988
Year
White
Black
Hispanic
Source:
Current Population Reports
Series P-20, No. 443

FIGURE 6

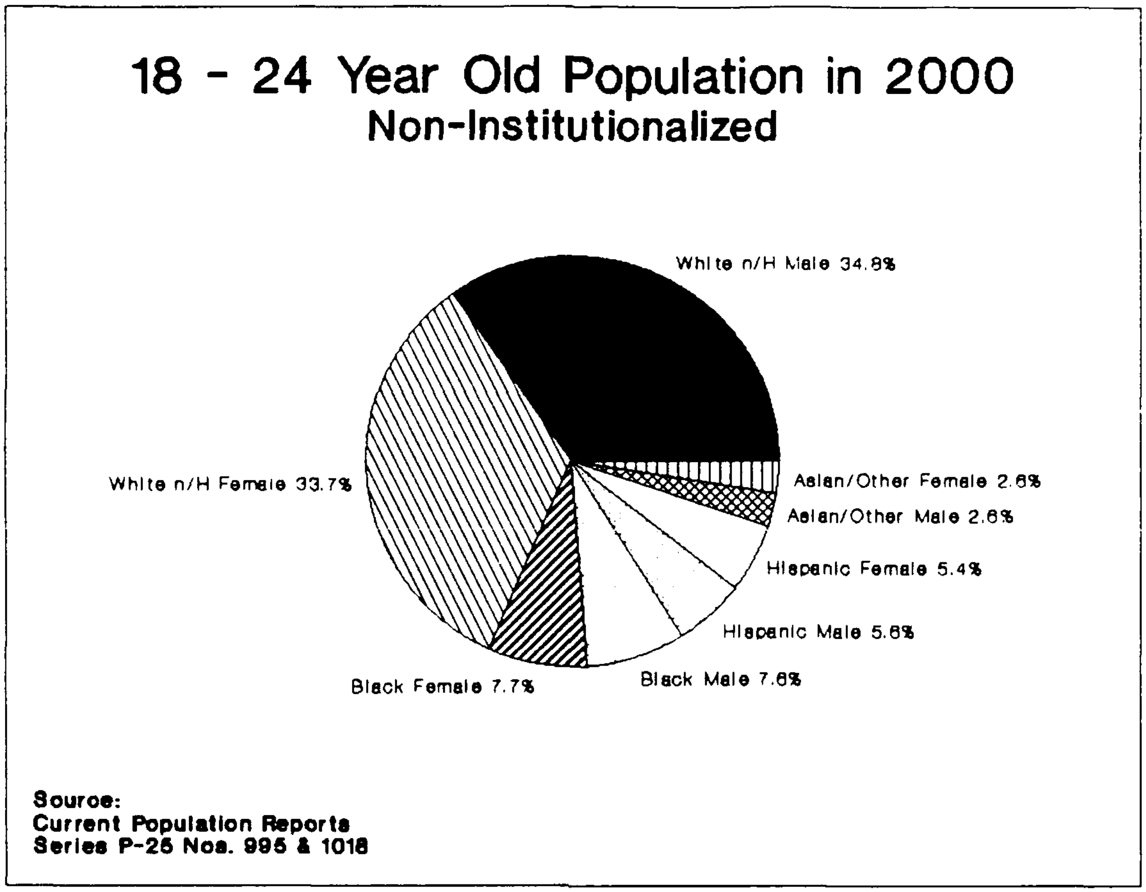


FIGURE 7

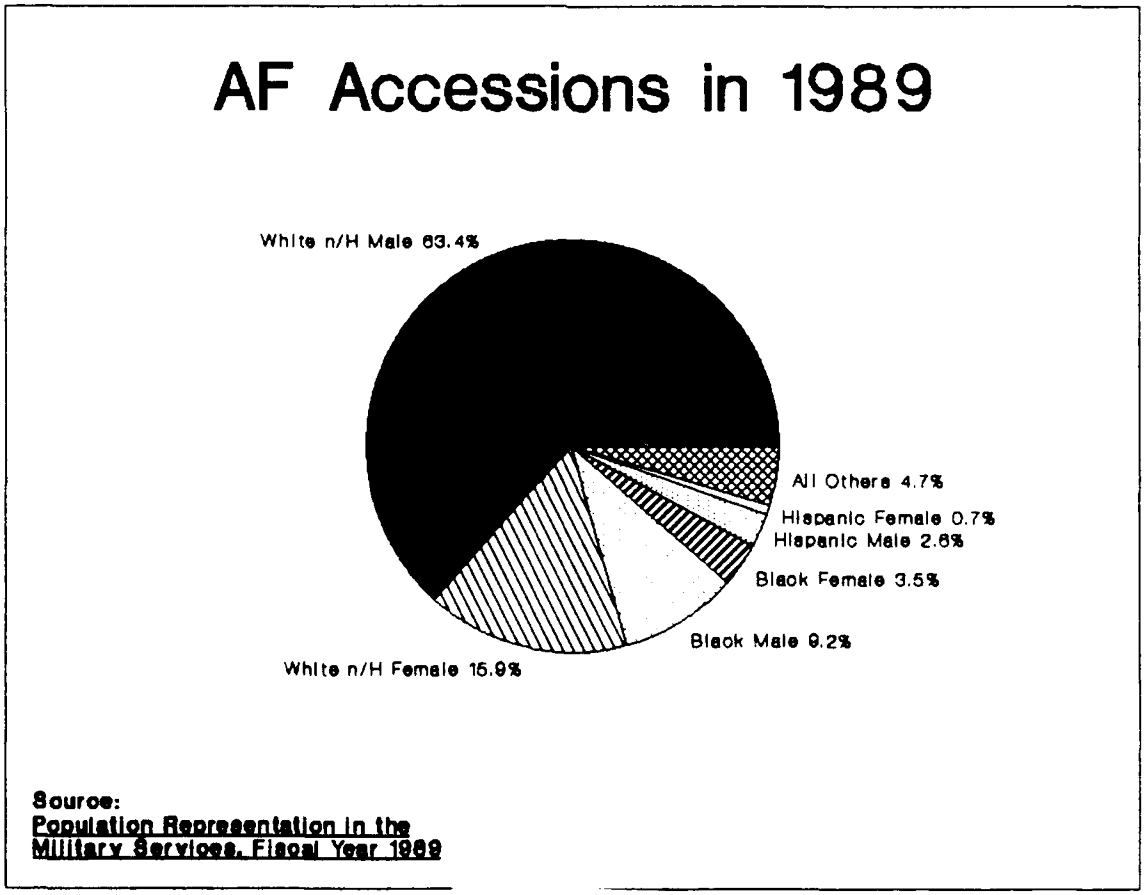


FIGURE 8

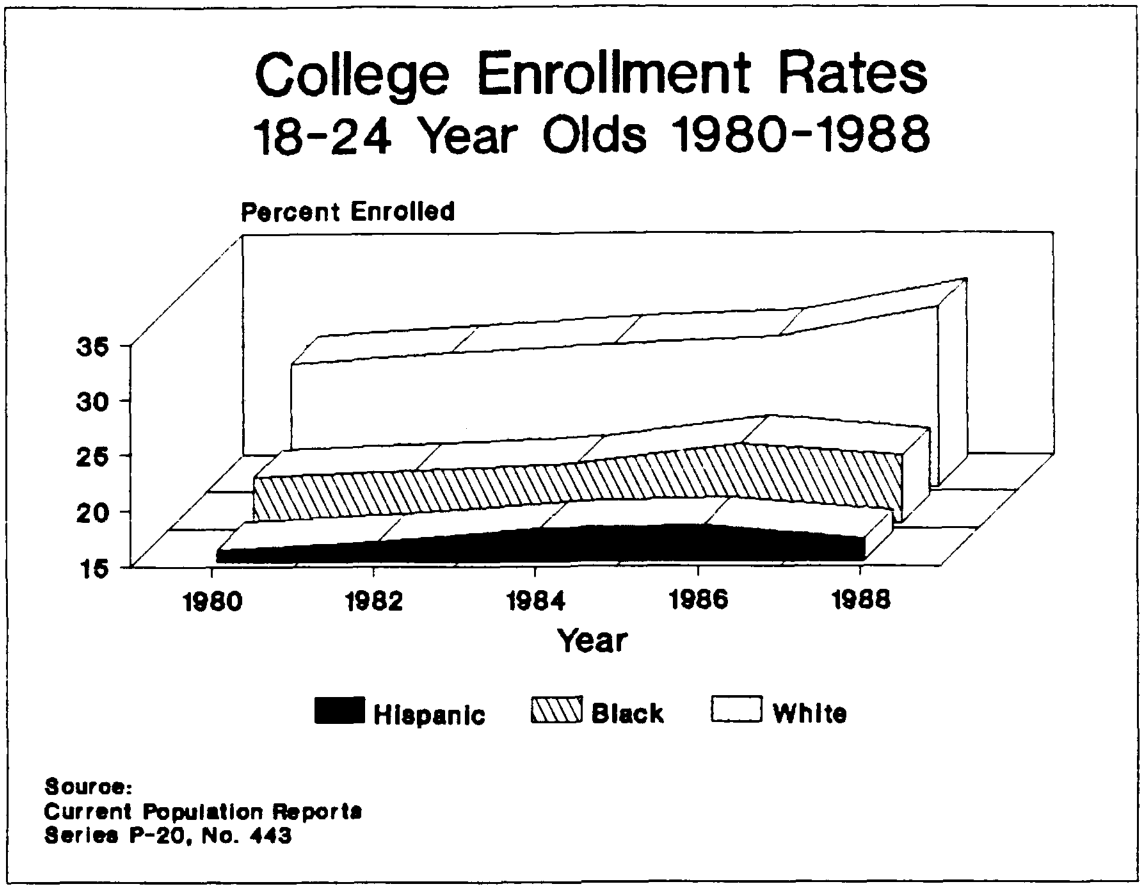


FIGURE 9

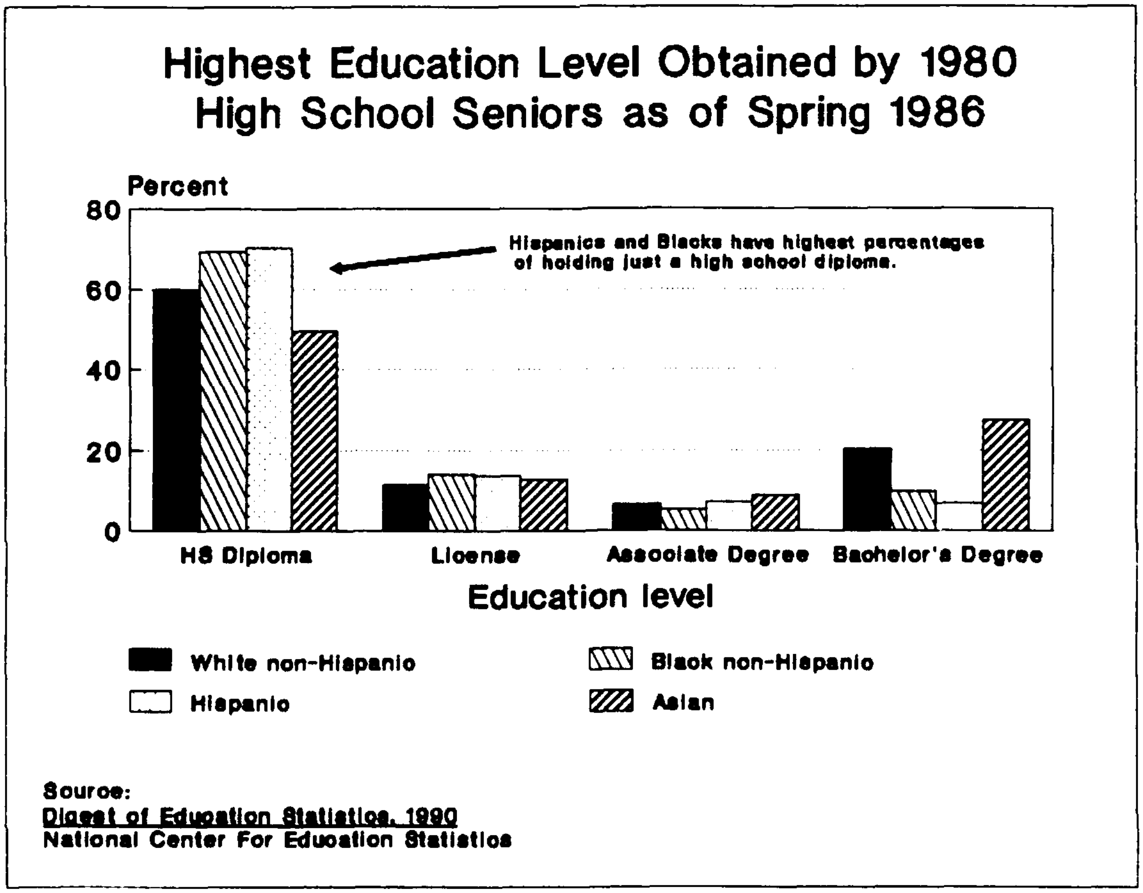


FIGURE 10

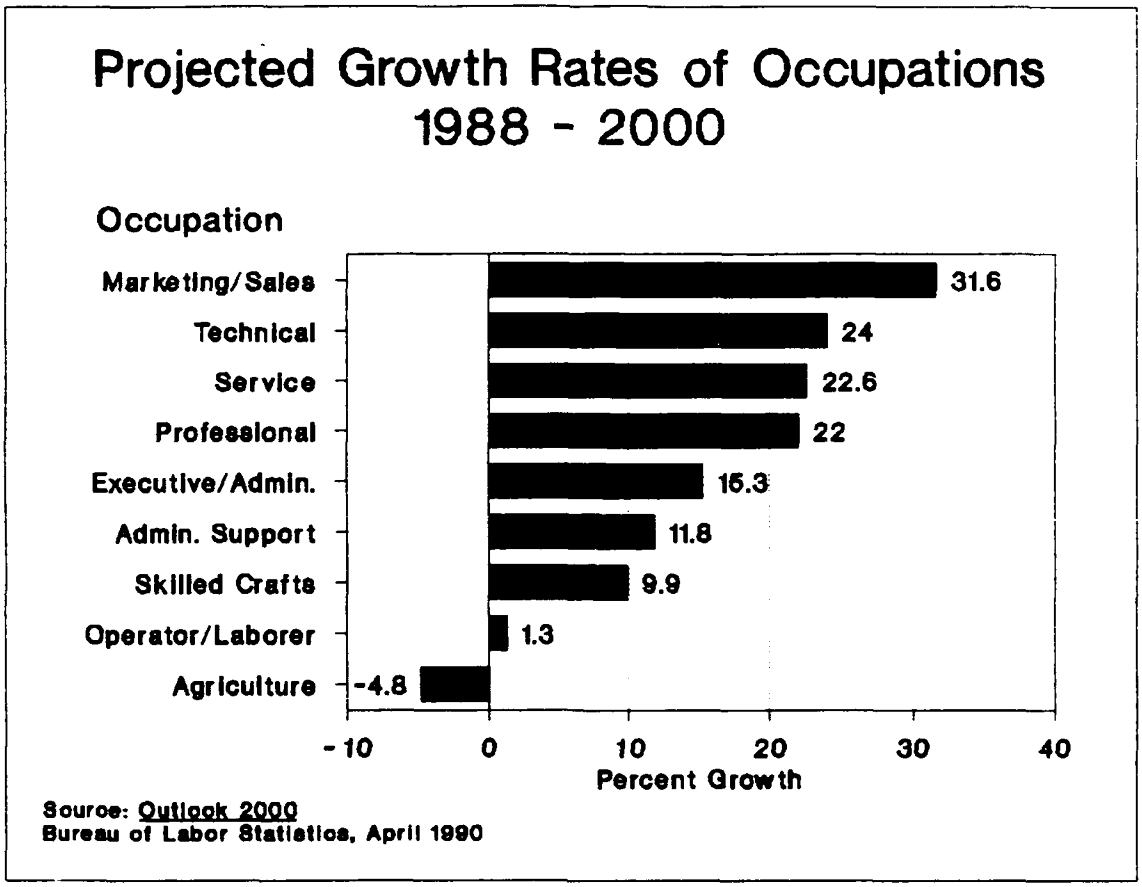
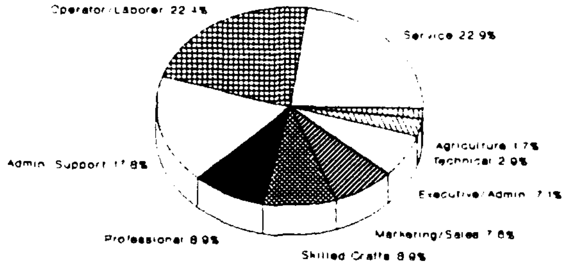

Projected Growth Rates of Occupations
1988 - 2000
Occupation
Marketing/Sales
Technical
Service
Professional
Executive/Admin.
Admin. Support
Skilled Crafts
Operator/Laborer
Agriculture
31.6
24
22.6
22
15.3
11.8
9.9
1.3
-4.8
-10
0
10
20
30
40
Percent Growth
Source: Outlook 2000
Bureau of Labor Statistics, April 1990

FIGURE 11

a.

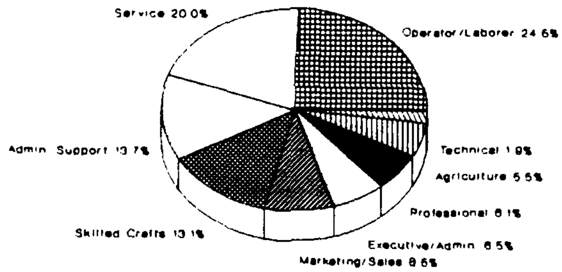
Occupational Distribution of Black Workers
(1990)



Source: <u>Employment and Earnings</u>
Bureau of Labor Statistics, Jan. 1991

b.

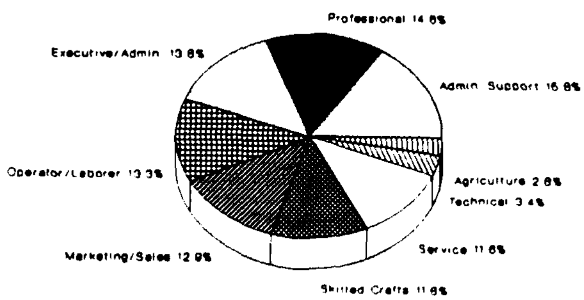
Occupational Distribution of Hispanic Workers
(1990)



Source: <u>Employment and Earnings</u>
Bureau of Labor Statistics, Jan. 1991

c.

Occupational Distribution of White non-Hispanic Workers
(1990)

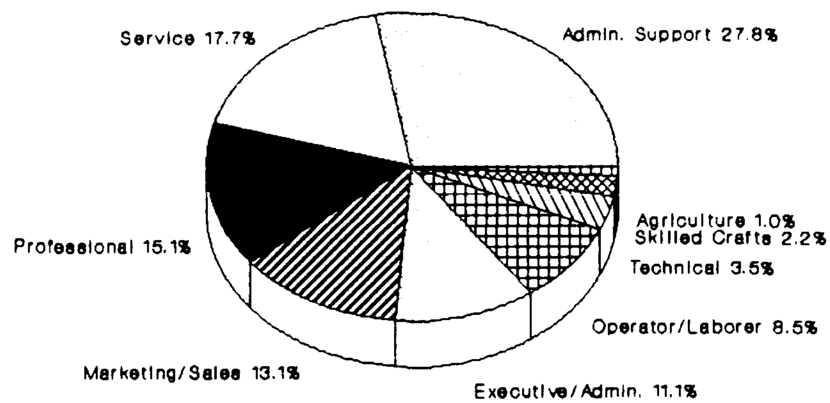


Source: <u>Employment and Earnings</u>
Bureau of Labor Statistics, Jan. 1991

FIGURE 12

a.

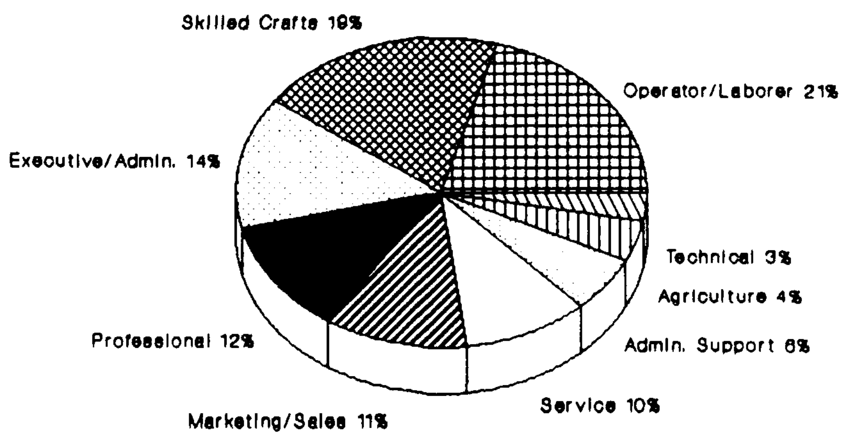
Occupational Distribution of Women Workers
(1990)



Source: Employment and Earnings
Bureau of Labor Statistics, Jan. 1991

b.

Occupational Distribution of Male Workers
(1990)



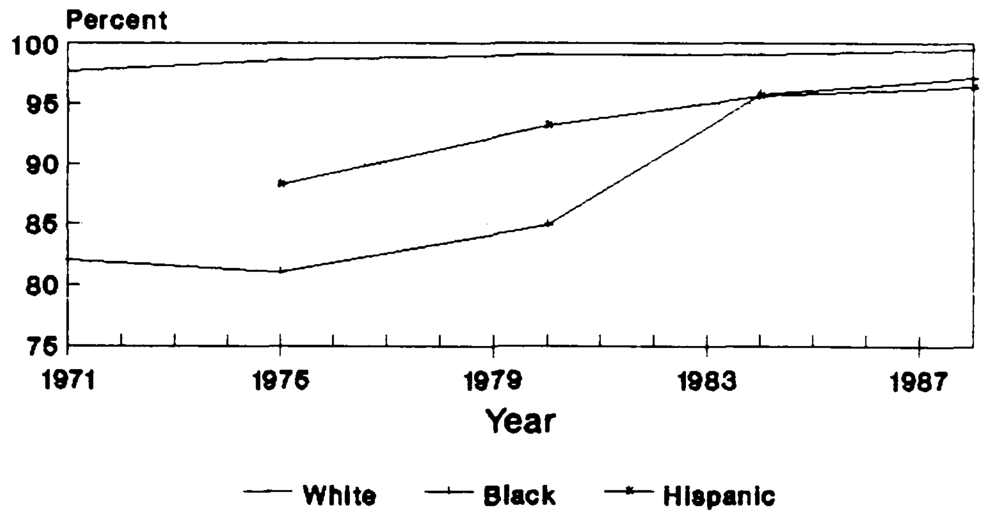
Source: Employment and Earnings
Bureau of Labor Statistics, Jan. 1991

FIGURE 13

a.

Percentage of Students at or Above A Basic Reading Level

17-year-olds, 1971 - 1988

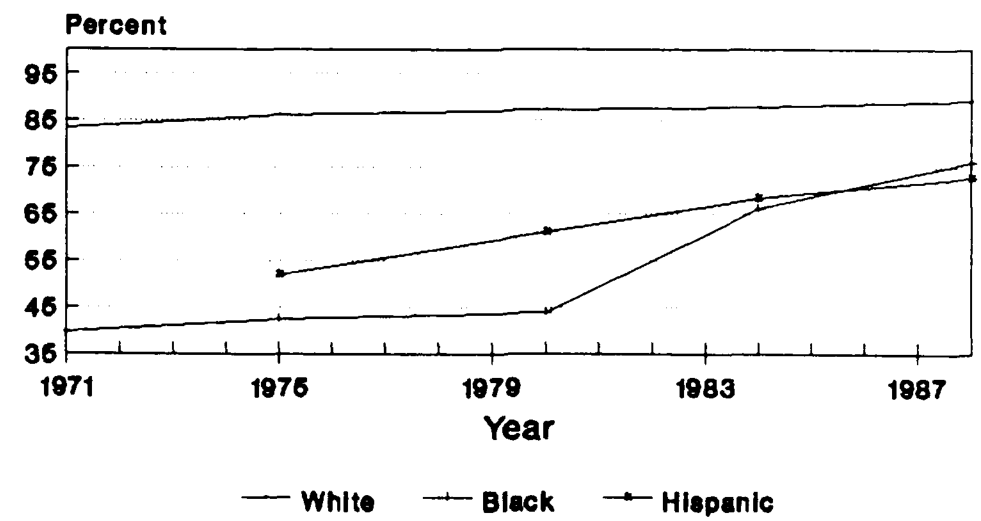


Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

b.

Percentage of Students at or Above An Intermediate Reading Level

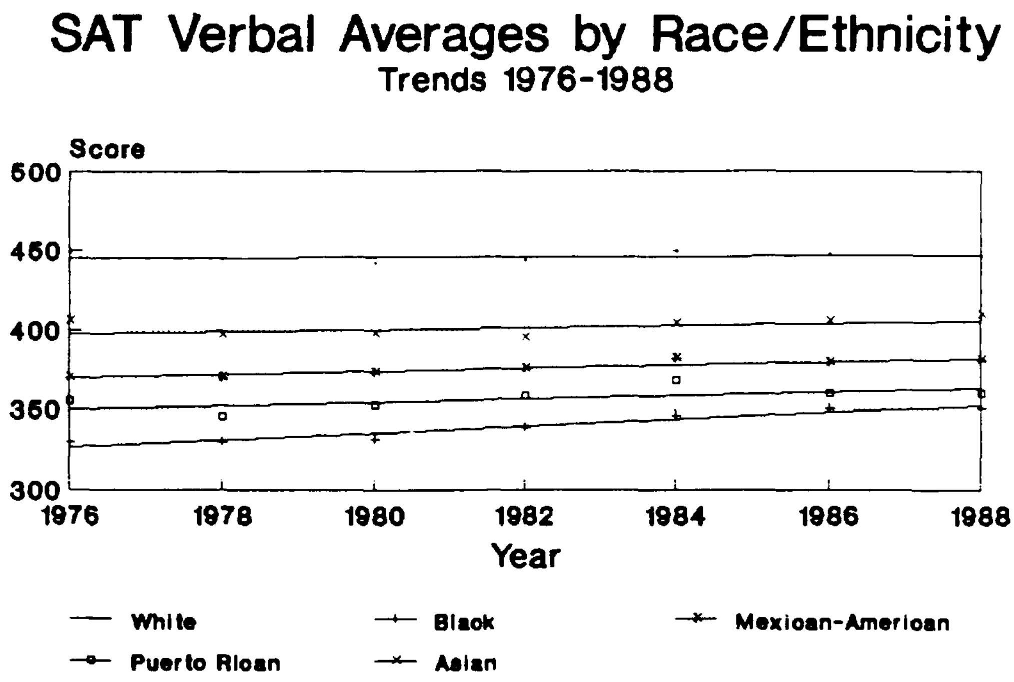
17-year-olds, 1971 - 1988



Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

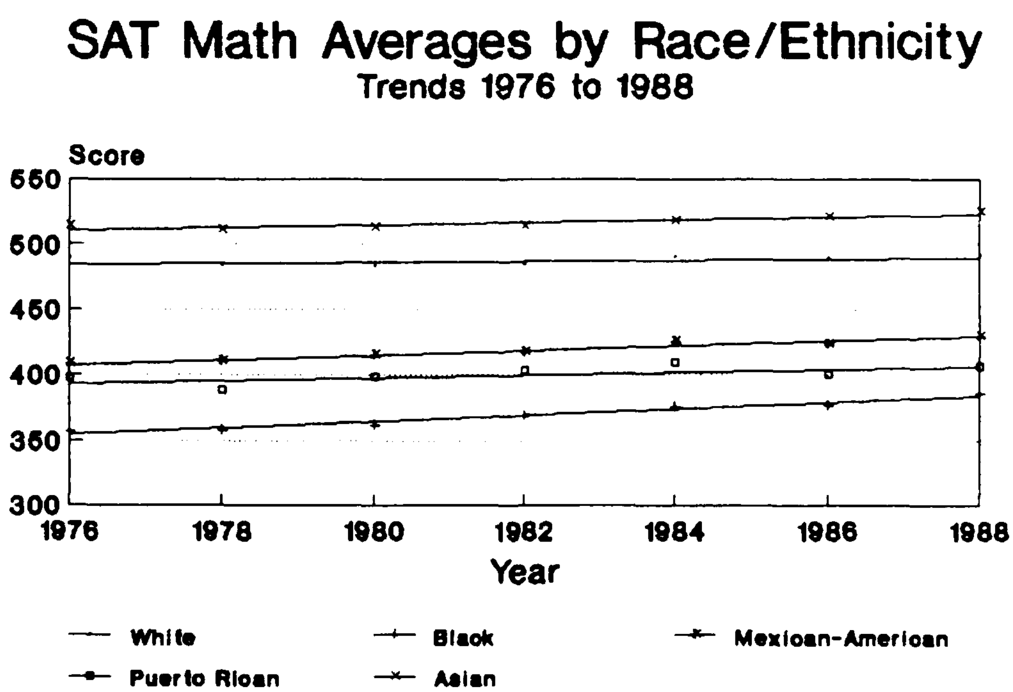
FIGURE 14

a.



Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

b.



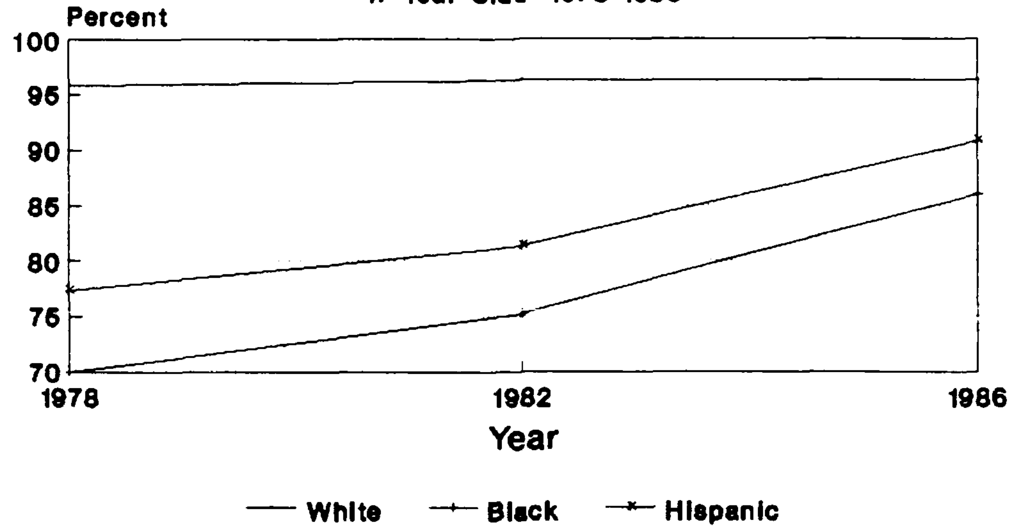
Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

FIGURE 15

a.

Percentage of Students Able to Perform Basic Mathematical Operations and Beginning Problem Solving

17 Year Olds 1978-1986

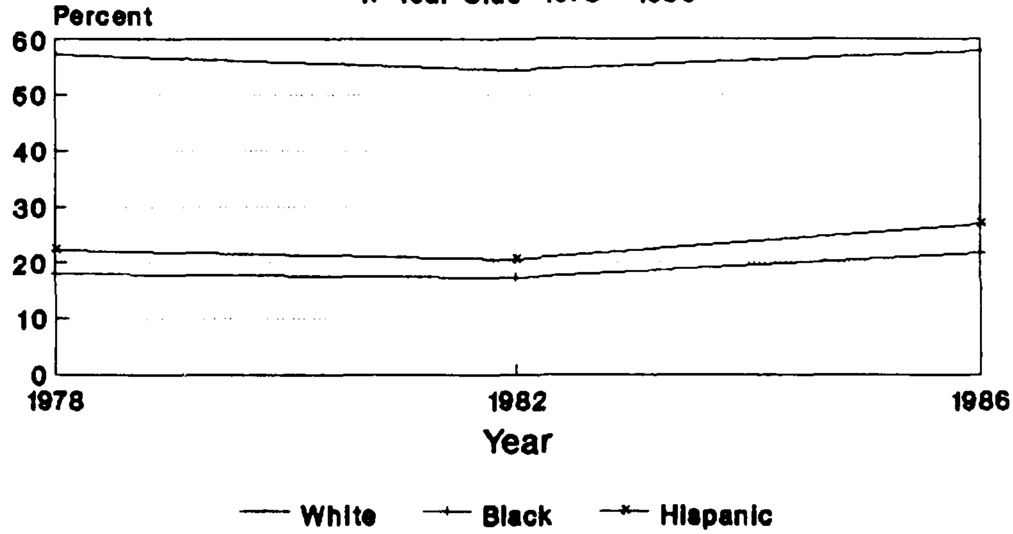


Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

b.

Percentage of Students Able to Perform Moderately Complex Mathematical Procedures and Reasoning

17 Year Olds 1978 - 1986

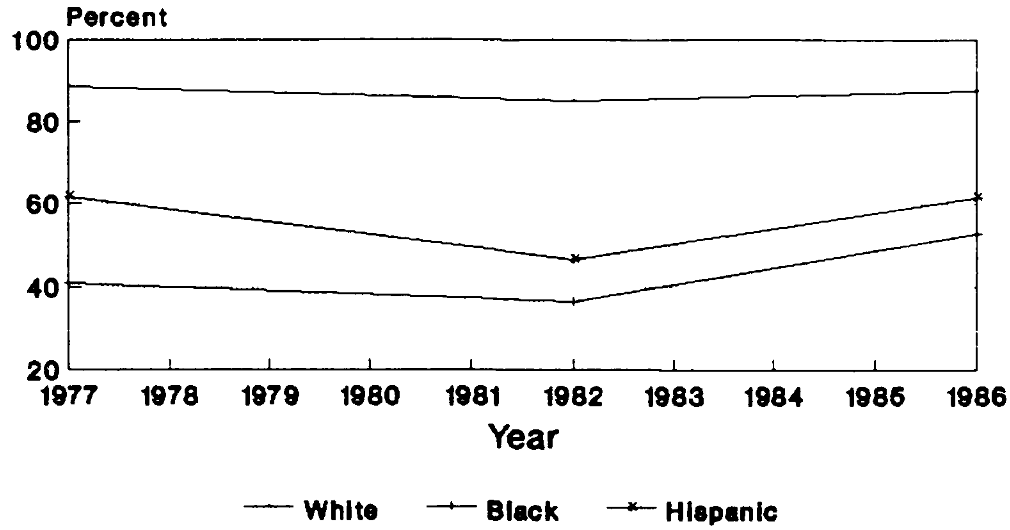


Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

FIGURE 16

a.

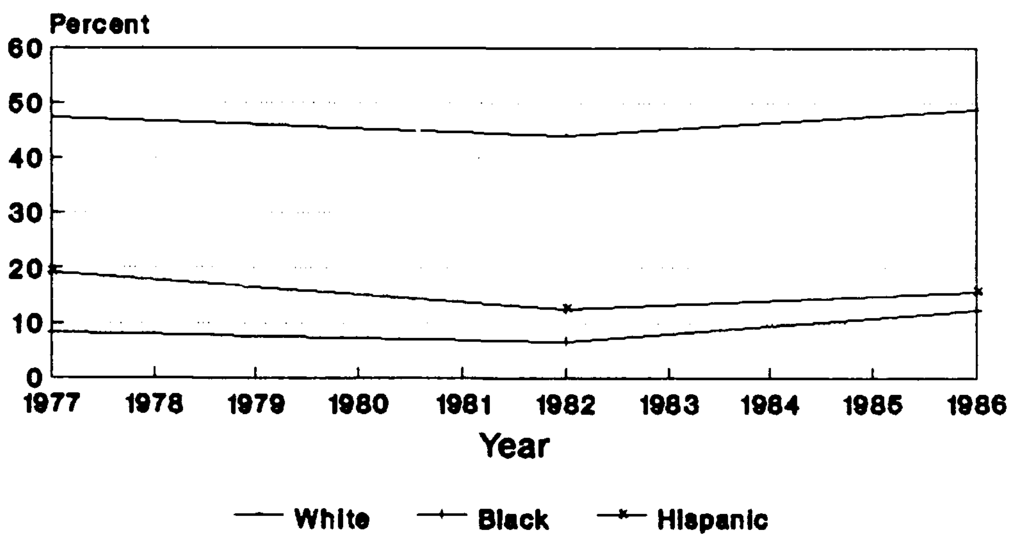
Percentage of Students Able to Apply Basic Scientific Information
17 Year Olds 1977-1986



Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

b.

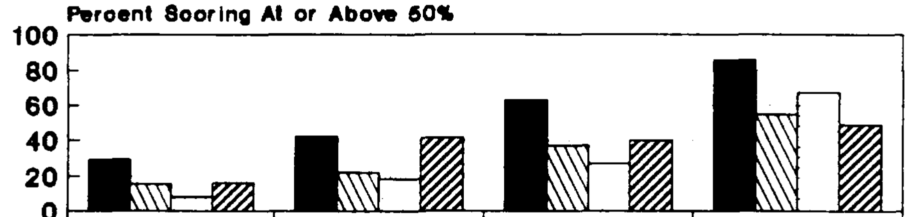
Percentage of Students Able to Analyze Scientific Procedures and Data
17 Year Olds 1977-1986



Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

FIGURE 17

Percent Scoring 50% or Better on the NORC 10 Word Vocabulary Test By Years of Education and Race/Ethnicity



	0-8	9-11	12	13-20
White	29.4	42.4	63	85.5
Black	15.1	21.7	37.4	54.5
Hispanic	8.2	18.2	27.3	67.1
Other	16.1	41.7	40.3	49.2

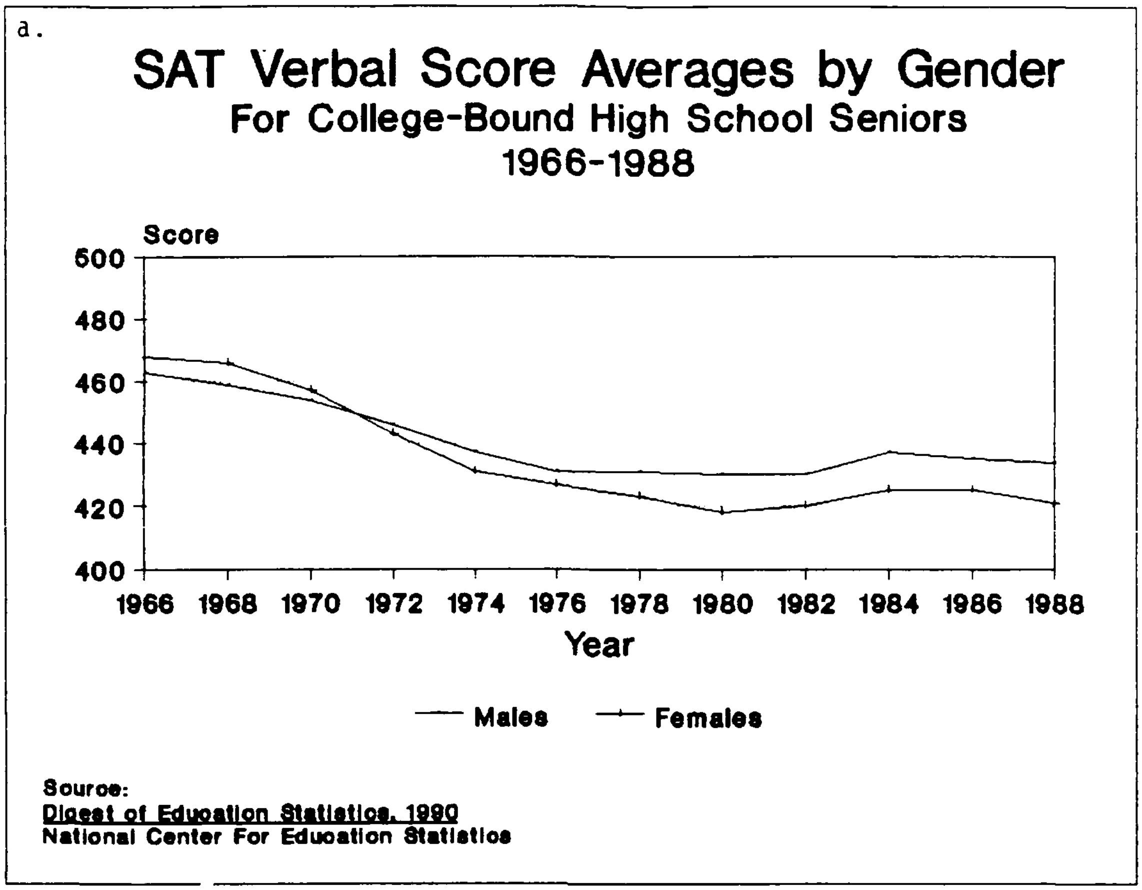
Years of School Completed

White   Black   Hispanic   Other

Source: R.J. Harris (1988) in
The Impact of Testing on Hispanics
Natl. Comm. on Testing & Public Policy

FIGURE 18

a.


SAT Verbal Score Averages by Gender
For College-Bound High School Seniors
1966-1988
Score
500
480
460
440
420
400
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988
Year
Males
Females
Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

b.

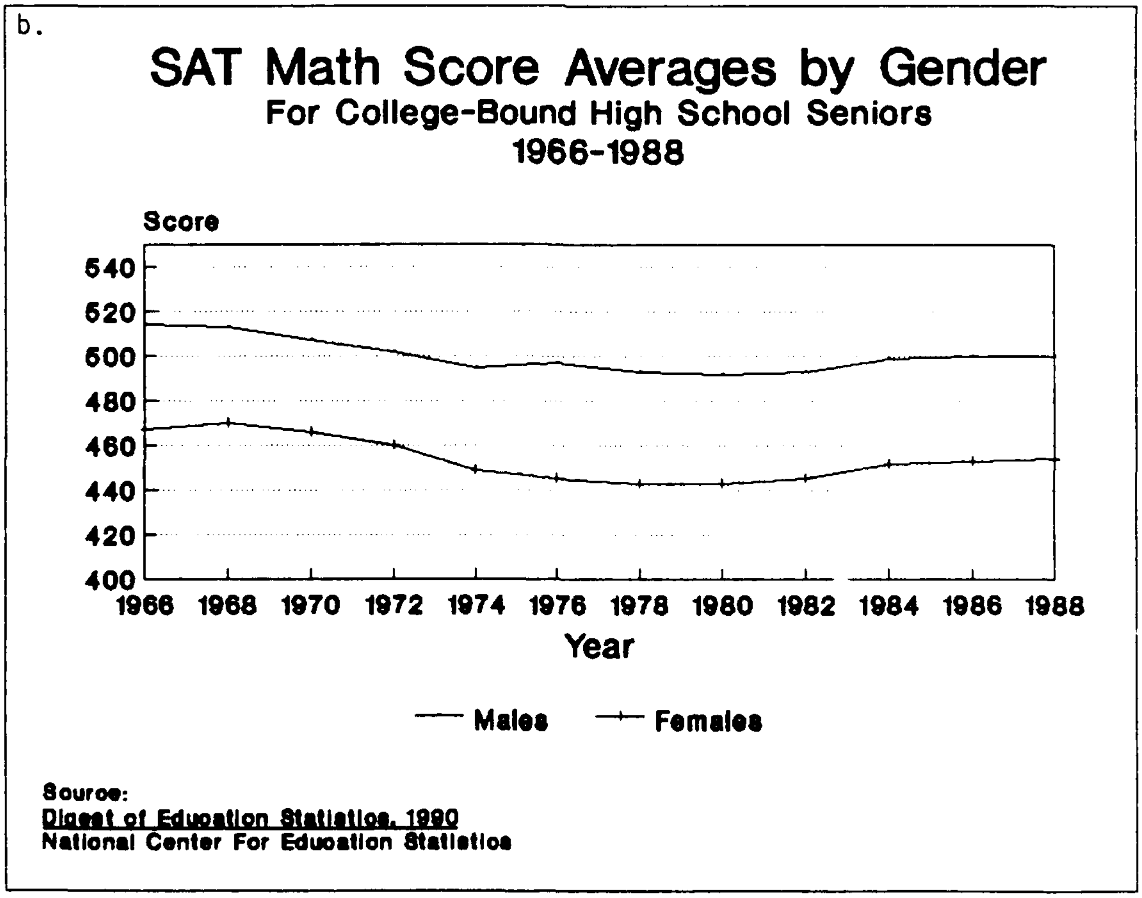
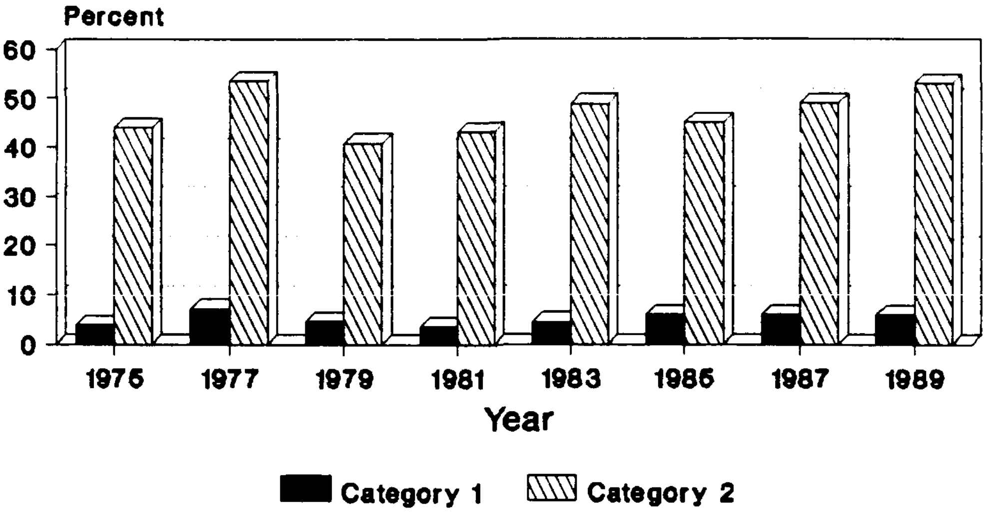

SAT Math Score Averages by Gender
For College-Bound High School Seniors
1966-1988
Score
540
520
500
480
460
440
420
400
1966 1968 1970 1972 1974 1976 1978 1980 1982 1984 1986 1988
Year
Males
Females
Source:
Digest of Education Statistics, 1990
National Center For Education Statistics

FIGURE 19

Percentage of Air Force Accessions in AFQT Categories I and II

1975 - 1989

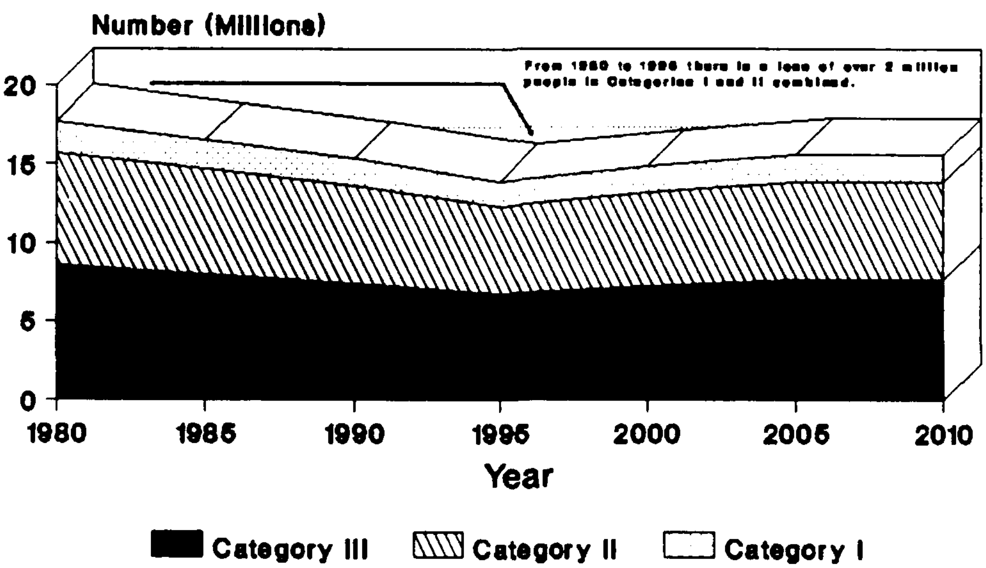


Source: Population Representation in the Military Services, FYs 1986, 87, 89; Screening for Service, 1984

FIGURE 20

Manpower Resource Trends

By AFQT Category 1980-2010



Source: AL-TP-1991-0019
Ree and Earles

FIGURE 21

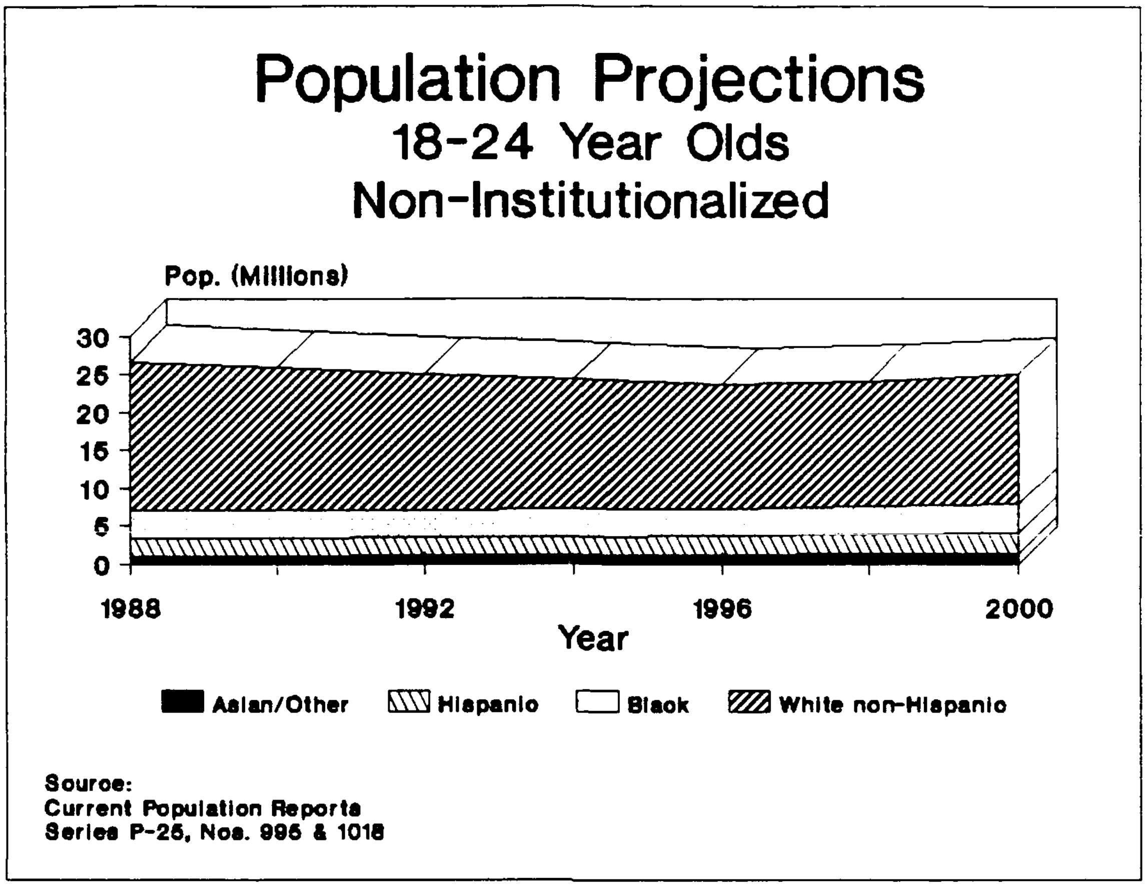


FIGURE 22

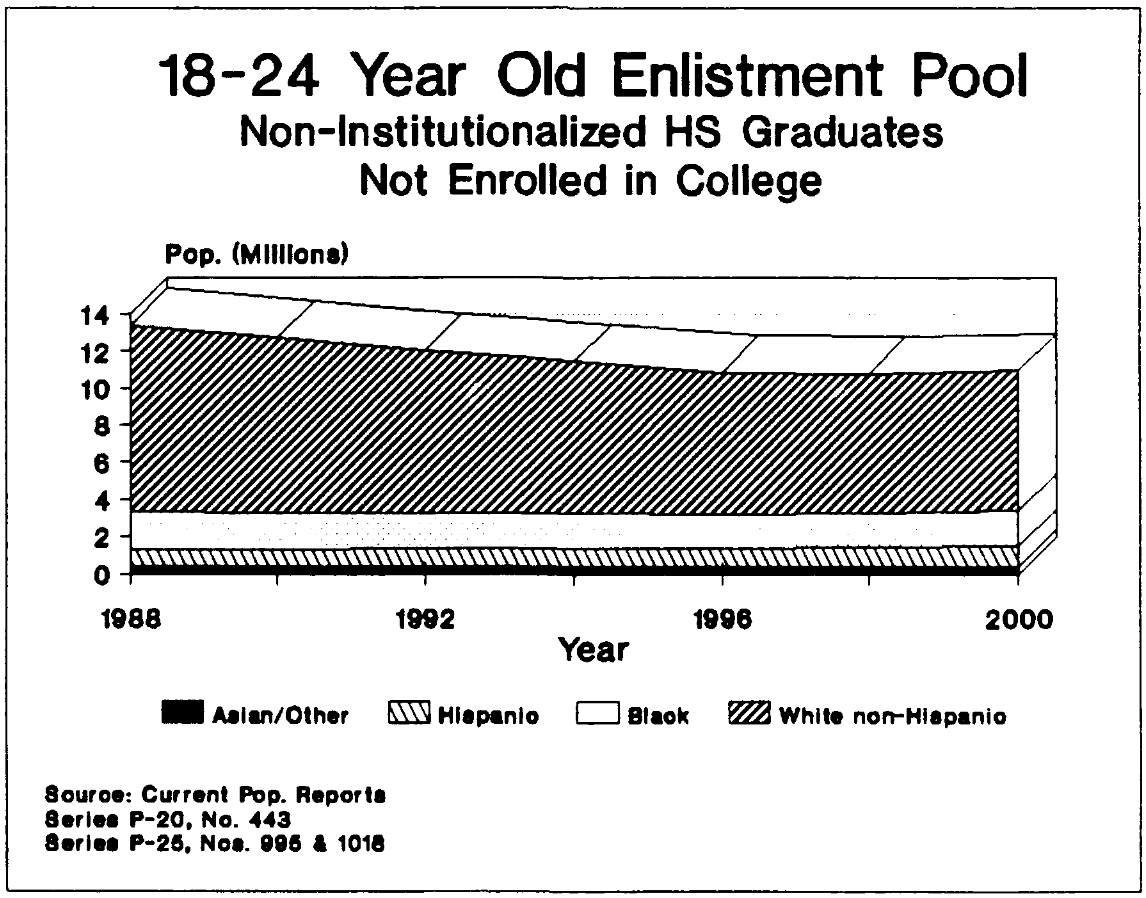
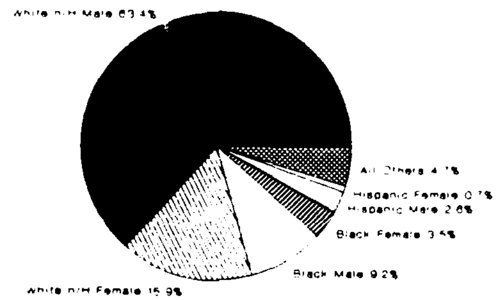


FIGURE 23

a.

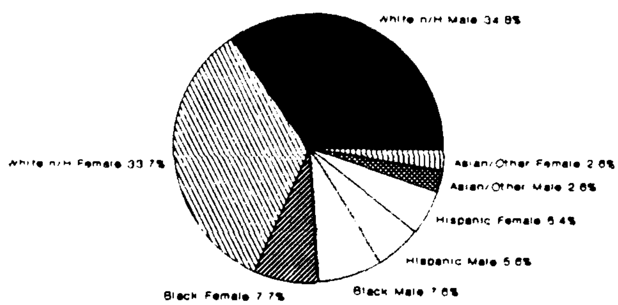
AF Accessions in 1989



Source:
Population Representation in the Military Services, Fiscal Year 1989

b.

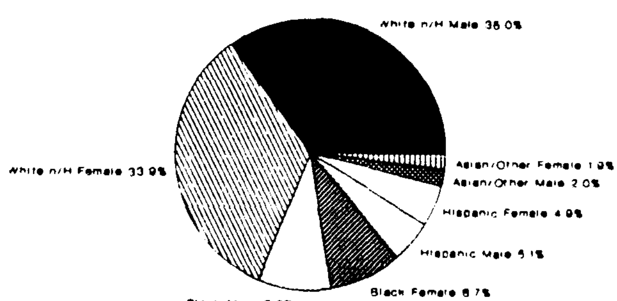
18 - 24 Year Old Population in 2000
Non-Institutionalized



Source:
Current Population Reports
Series P-25 Nos. 995 & 1018

c.

Enlistment Pool Distribution in 2000
Non-Institutionalized HS Graduates
Not Enrolled in College



Source: Current Pop. Reports
Series P-20, No. 443
Series P-25, Nos. 995 & 1018

FIGURE 24

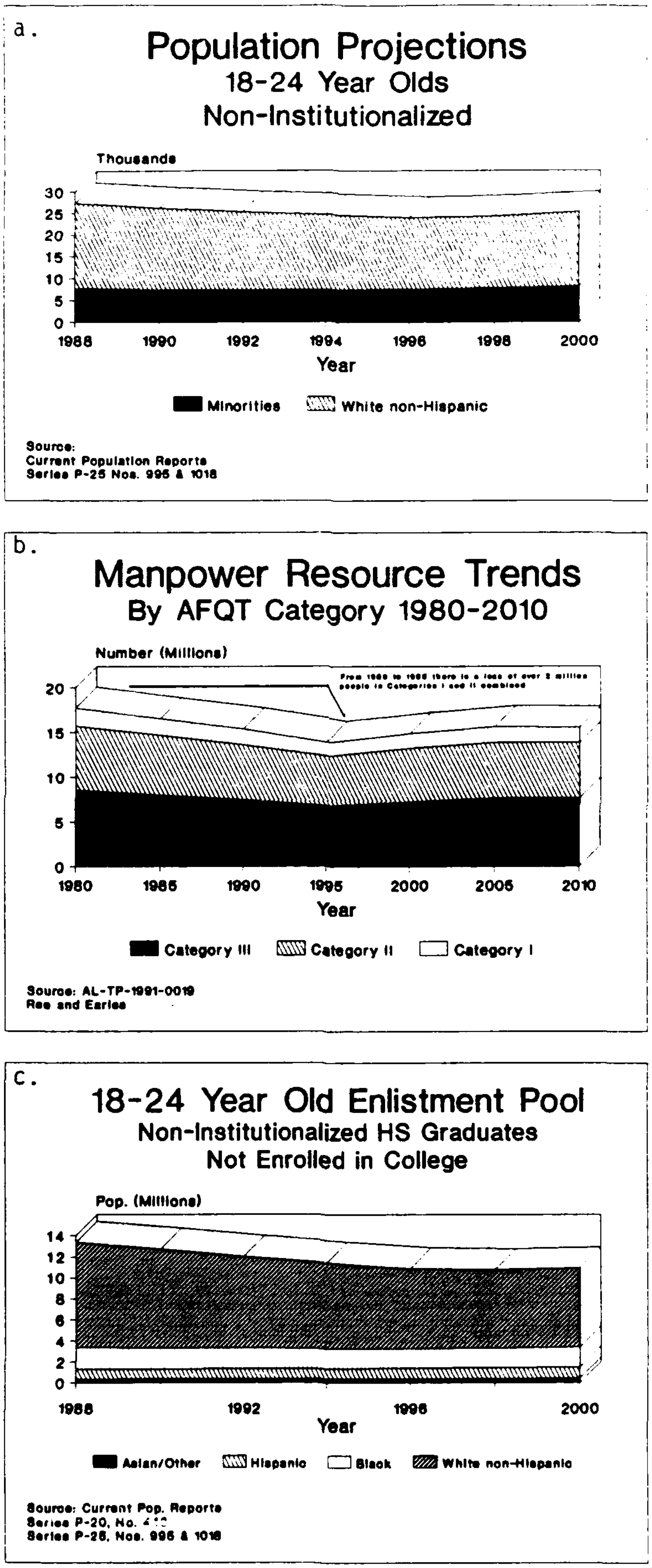

a.
Population Projections
18-24 Year Olds
Non-Institutionalized
Thousands
30
25
20
15
10
5
0
1988
1990
1992
1994
1996
1998
2000
Year
Minorities
White non-Hispanic
Source:
Current Population Reports
Series P-25 Nos. 995 & 1018
b.
Manpower Resource Trends
By AFQT Category 1980-2010
Number (Millions)
20
15
10
5
0
1980
1985
1990
1995
2000
2005
2010
Year
Category III
Category II
Category I
Source: AL-TP-1991-0019
Ree and Earles
c.
18-24 Year Old Enlistment Pool
Non-Institutionalized HS Graduates
Not Enrolled in College
Pop. (Millions)
14
12
10
8
6
4
2
0
1988
1992
1996
2000
Year
Asian/Other
Hispanic
Black
White non-Hispanic
Source: Current Pop. Reports
Series P-20, No.
Series P-25, Nos. 995 & 1018

CHART 2

COMPETITION FOR ENTRY LEVEL WORKERS

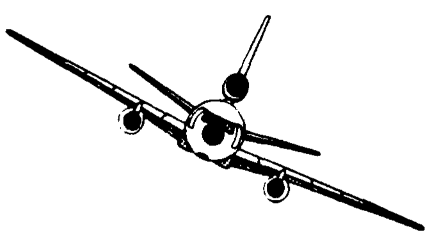
- SERVICE WORKERS WILL GET HIGHER PAY
- FEWER HIGH SCHOOL GRADUATES AVAILABLE
- HIGHER PROPORTION OF ESL WORKERS
- INDUSTRY WILL OFFER FINANCIAL INCENTIVES
- ACADEME WILL OFFER INDUCEMENTS TO ATTEND COLLEGE RATHER THAN JOIN AF
- IF FORCE BUILDUP IS REQUIRED THE COMPETITION WILL INCREASE

CHART 3

TRAINING SYSTEMS DIVISION
FUNDAMENTAL SKILLS PROJECT

AF TECHNICAL SKILL REQUIREMENTS

- **MATH/SCIENCE BACKGROUND DESIRABLE IN 75 PERCENT OF CAREER FIELDS**
- **ONE-THIRD INCREASE IN REQUIREMENTS OF RECRUITS WITH HIGH APTITUDES BY 2000**



SOURCE: AF MAGAZINE, DEC. 1986
USING BLS ESTIMATES

CHART 4

The Service Sector Dichotomy

In 1990 Blacks and Hispanics Comprised:

- 59.4% of all household cleaners
- 46.5% of all commercial maids/housemen
- 37.5% of all commercial janitors/cleaners
- 37.4% of all waiters' and waitresses' assistants

But only:

- 13.0% of all dental assistants
- 15.4% of all firefighters
- 19.0% of all police and detectives

Source: Employment and Earnings, Jan. 1991

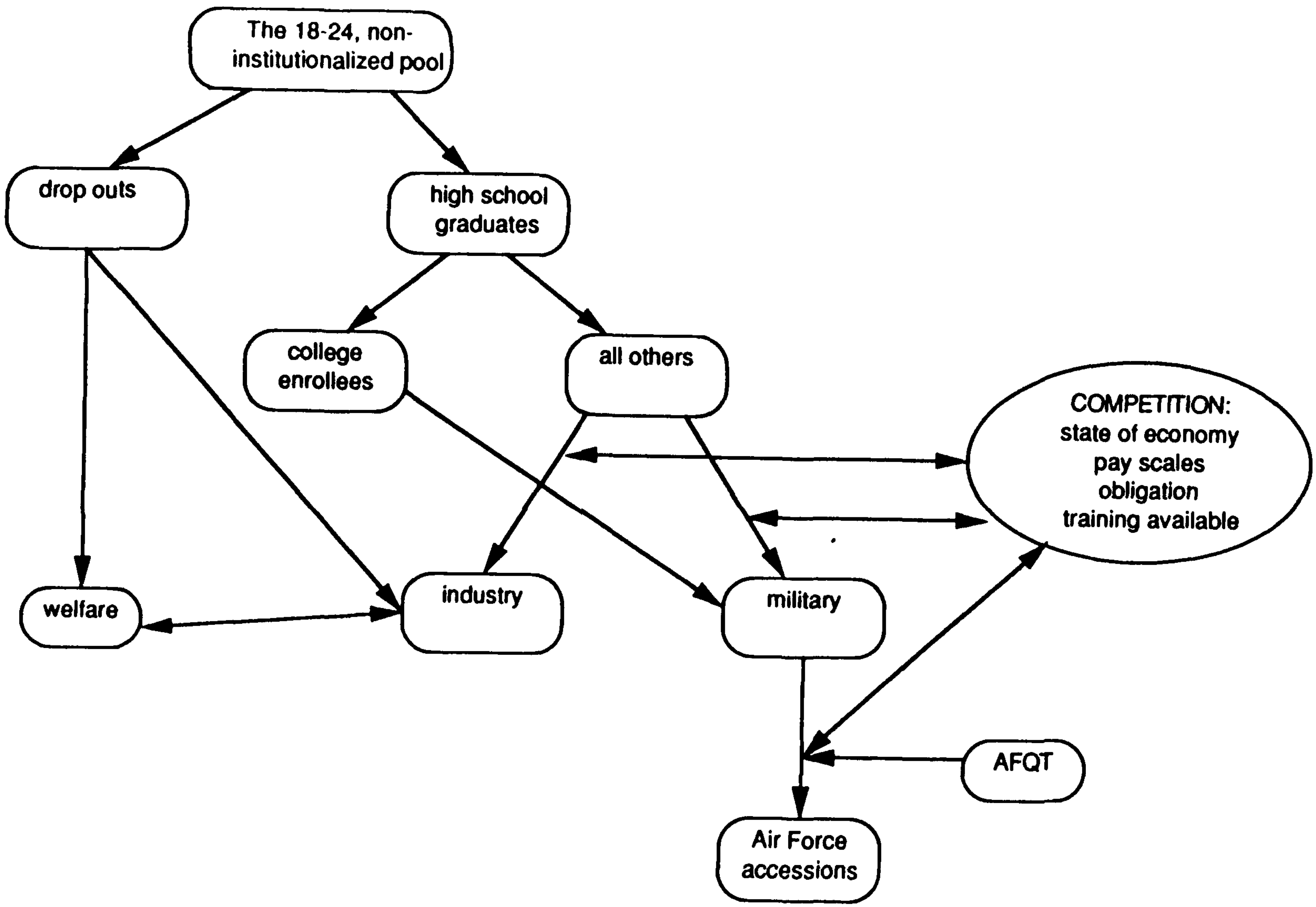


Chart 1. Simplified Model of Air Force Enlisted Selection Process

1991 RESEARCH INITIATION PROGRAM

Sponsored by the

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

Conducted by the

Research & Development Laboratories(RDL)

Research Topic: A Study of The Effects of Cognitive Style on Achievement When the Style of the Hypertext Matches the Style of the Learner

Research Location: USAF AL/HRTI
BROOKS AFB, San Antonio, Tx.

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Date: August 1, 1991

FINAL REPORT

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ABSTRACT

This study attempts to look at the effect of one dimension of cognitive style on performance in a hypertext environment. Subjects were classified as either field independent(FI) or field dependent(FD). Hyperdocuments were developed which emphasized either a top down(TD) approach or a bottom up(BU) approach to learning. The subject domain used was BASIC Programming. Subjects were randomly assigned to one of the two hyperdocuments. Each group browsed the hyperdocument for a variable period of time. A pre- and a post test were given in order to assess learning. A questionnaire was administered in order to assess satisfaction of experience.

Results were analyzed with a 2x2 factorial design using the post test as the dependent variable and the hypertext design type and cognitive style as the independent variables. Audit trails were also collected.

It is expected that the FD-BU and the FI-TD groups will do significantly better than the other groups on the post-test. The matching of the hypertext design with the learning style should produce better results. At minimum it is expected that those two groups will be more satisfied with the learning experience.

I. INTRODUCTION

INDIVIDUAL DIFFERENCES AND CBI

One of the primary motivating factors driving the development of Computer Based Instruction(CBI) has been the need to provide instruction tailored to the needs of the individual student or trainee. Traditional Computer Assisted Instruction (CAI), and more recently Intelligent Computer Assisted Instruction (ICAI) and Hypertext systems represent a trilogy of approaches to the solution of this problem. Traditional CAI approached this problem initially with drill and practice programs, and later, by the development and use of a) branching programs b) simulations and c) other mechanisms. A major shortcoming of the traditional approach was that the presentation and sequencing of the materials was largely or completely in the hands of the program designer. The branching programs represented a major attempt to tailor instruction to the needs of the individual user. The branching programs presented a major problem for the designer: How to anticipate all possible paths that all possible users might require in learning a concept or a task? Due to combinatorial explosion this is an obvious impossible task. Thus the branching programs, while not as rigid as their drill and practice predecessors, nevertheless were essentially generic in nature and not able to deal very well with individual differences.

A prime characteristic of this first generation of CAI programs was that the user had little or no control over the flow of instruction-

instructional strategy. He had little or no control over the presentation or sequencing of the activities or the materials and concepts to be learned.

Developers of ICAI attempted to improve on this traditional CAI approach by the incorporation of four modules in highly domain specific systems: 1) the student; 2) the pedagogical; 3) the expert and; 4) the curriculum modules. The student module along with the other modules allows for greater flexibility of the system in reacting to the learning needs of the individual student. The system keeps track of what the student knows as well as what he doesn't, but should, know. The sequencing of instruction is there by determined by the needs of the student, allowing for a level of individualization not possible with the traditional CAI programs. A limitation of the ICAI systems however is that though individual students may experience a different instructional sequence, one based more closely on their individual needs, the presentation and sequencing of the materials and in general the curriculum, is still in the hands of the program designer, i.e., the student has no explicit control over the instructional sequence. Thus these systems tend to support the traditional paradigm in which the student is a passive component in the learning process.

Hypertext systems represent a break with the traditional modes of CBI in that the role of the student is radically changed. Rather than acting as a passive figure soaking up prepackaged knowledge like a sponge he is transformed into a dynamic entity navigating about a knowledge base collecting facts and knowledge according to his own needs and style. Hypertext systems are student centered. In a hypertext learning system the students' individual style of learning is given a greater opportunity to develop and come into play in the learning process. This also represents a break with the traditional view of the relationship between knowledge and instruction, a view that sees knowledge as a collection of static inert skills and facts which can be "given" to learners (Wilson & Jonassen, 1989). Thus hypertext learning environments are different from traditional CAI and/or ICAI in a fundamental respect, i.e., hypertext is a student centered environment in which the student can actively access the knowledge base according to his own cognitive style.

A factor consistently missing in the design and development of traditional CAI programs and more recent ICAI applications has been the element of cognitive style. More generally, Goodman(1978) states that "among the factors least likely to be given due consideration in CAI are student variables." One reason for this he feels may be "ignorance of the nature and potential educational significance of learning styles." Other researchers have noted the need to consider cognitive styles in CBI development. According to Cosky (1980) cognitive style is a potentially rich but overlooked source of individualization in computer based instruction (CBI). He feels that individualization can be maximized by inclusion of information on cognitive styles in the design, development and evaluation phases of CBI development.

ICAI systems have the capacity to factor in elements of the students cognitive style by inclusion of appropriate information in the student and curriculum modules. A theoretical framework for inclusion of such a factor-cognitive style-in ITSs has been developed by Kyllonen and Shute (1989).

HYPERTEXT AND COGNITIVE STYLES

Hypertext systems present an good environment for studying cognitive styles in that they give the student considerable freedom to access the knowledge base. Jonassen (1988) gives a possible methodology for designing hypertext systems which are compatible with the cognitive style of the user. This 'Inductive Design Method' is based on an analysis of the audit trails of a group of hypertext users. The information gleamed from this process would be used to structure the hypertext according to the learning style of the user. Implicit in this statement is the idea that matching the hypertext design with the learning style of the user is desirable. More specifically, Jonassen (1988) states that "the willingness and ability of learners to use their own knowledge structures for assimilating information is dependent on individual differences, e.g., cognitive abilities and styles, p.14." Implicit in this statement is the idea that matching the document style with the learner style should produce better learning results.

THE MATCHING PROBLEM

A number of studies have investigated the relationship between cognitive style, achievement and the instructional strategy. While some studies have failed to show that matching cognitive style to instructional type produces better learning results (Burger,1985; Provost,1981) others have shown that such a matching is desirable. Provost (1981) did a study in which he looked for interactions of aptitude and treatment between two teaching strategies--passive responding and active responding--and two cognitive styles --FI and FD. The main idea of this study was to improve the performance of the field dependents by matching them with an environment which would encourage their responding in a more active way to instruction. He found no interaction between cognitive style and treatment as measured an a posttest. Provost also indicates a need to adapt the evaluation instrument to the style of the student.

Dunn and Dunn(1978) states that "research concerned with identifying the relationship between academic achievement and learning style has provided consistent support for the hypothesis that when students are taught through methods each prefers they do learn more effectively," p389. They found in the 1978 study in which math was the subject domain, that eight Learning Styles Inventory(LSI) variables "significantly discriminated between subjects who scored high or low in math," p399. One of their conclusions was that 'possibly' individuals who achieve in math are being taught in a style that accommodates their natural learning style while low math achievers are not.

A study by MacGregor et al.(1988) in which subjects were classified as field independent or field dependent found that the field dependents achieved better in a computer augmented learning environment while those with indiscriminate cognitive styles did better when receiving more traditional instruction. They concluded that the instructional mode produces different effects on students with different cognitive styles.

Marjorie Lee(1986) did a study involving the learning styles of Black children and microcomputer usage. She concluded that microcomputers could be used to facilitate a change in the traditional school methods resulting in a better match between Black childrens' learning styles and the curriculum.

These studies clearly indicate that a cognitive styles match can produce better achievement in some domains and under some conditions. Hypertext provides a good testing environment for continuing this line of research. Essentially what happens in a hypertext environment, as a result of greater student control, is that a natural match between the cognitive style of the student and the presentation of the material occurs. Theoretically (intuitively) this should allow for a maximizing of, what I call, the students "comfort factor" resulting in greater learning and greater satisfaction with the learning process. What is being advocated by Jonassen and others is that within a hypertext environment this matching can be maximized by the way in which the hypertext is designed-i.e. the 'style' of the hypertext.

The major thrust of this project is to determine if matching the style of the hyperdocument with the style of the user results in significantly improved learning. The specific cognitive style to be considered is field independence/dependence. The subject domain will be BASIC programming. A secondary consideration of this project is to determine if the 'matched' groups are more satisfied with the learning experience than the unmatched groups.

FIELD INDEPENDENCE AND FIELD DEPENDENCE

The dimension of cognitive style under consideration is field independence/dependence. A brief description of these styles follow:

Field Independents(FI): Those individuals classifiable as field independent have the ability to ignore irrelevant aspects of a task or situation. One widely used test for classifying field independents is the Group Embedded Figures Test (GEFT). In this test the subject is asked to locate a simple geometric figure within a complex design. In terms of learning style, the field independents tend to process information using a top-down approach. Namely, they tend to focus on the whole first and then the subparts later. They tend to grasp more general ideas initially and the specificities later.

Field Dependents(FD): Individuals who are classifiable as field dependent are on the opposite end of the scale as the field independents. They tend to favor looking at specific instances and examples of a concept before looking at the general concept itself. They generally use a bottom-up approach to learning. Subjects scoring low on the GEFT are classified as field dependent.

IIa. STATEMENT OF THE PROBLEM

MATCHING DOCUMENT AND LEARNER STYLES:THE HYPERTEXT CONNECTION

The literature on cognitive styles indicate a need for further research on the idea of whether a match between learner and cognitive style produces better performance. The hypertext environment provides a test bed for continuing research on this issue. This study will focus on one particular learning style dimensions: field independent vs field dependent.

Moreover cognitive style has an affective dimension in addition to the cognitive dimension(Cosky, 1980). Students may be more satisfied when they are matched with their cognitive style in a hypertext environment.

The Problem Statement: Will matching the design of the Hypertext(top down vs bottom up) to the cognitive style of the user (field independent vs field dependent) result in improved learning and/or greater student satisfaction?

IIb. Significance of the Study

Computer based system are increasingly being developed and used by the Air Force to assist with the education and training of Air Force personnel. Considerable R & D is going into the creation of hypertext systems and ITSs at AL/HRTI located at Brooks AFB. These systems are being developed at considerable cost. Thus their effectiveness is an important consideration. A review of the literature indicates that the effectiveness of CBI systems may be enhanced if users cognitive styles are given more consideration during the design and development phases(Cosky,1980). If it can be show that matching the cognitive style of the learner, or trainee, with the 'style' of the system results in improved achievement on the part of the user this would have important implications for all CAI developers. It would particularly point to the need for additional research in this area using different subject domains and different learning styles. If no significant differences are detected then hopefully what is learned will point to directions for future research.

III. METHODOLOGY

Subjects

Two sections of a course entitled An Introduction to Computer Concepts-COSI 118 will be used. This class is usually composed mostly of underclassmen who have little or no computer experience. The enrollment for the two classed usually totals about 60 students. Generally, none of the students are computer science (CS) majors. Also as the course required of all students except CS majors, it usually contains a good cross-section of the student population. Finally, this is the course in which we introduce BASIC Programming to our students.

Materials and Procedures

Subjects will be classified as either field independent or field dependent. The Group Embedded Figures Test (GEFT) will be used for this purpose. Students scoring from 0 to 9 will be classified as low , from 10 to 13 as medium and from 14 to 18 as high. Thus the high and low groups will be classified as FI and FD respectively. Each group will study a topic from BASIC programming using a hyperdocument.

The Hyperdocuments: There will be two distinct hyperdocuments each having a different structure but each containing identical nodes. One will be designed to be compatible with the field independent type of cognitive style. The other will be designed to be compatible with the field dependent style. Specifically, in the first case the design will emphasize a top down approach to the subject matter. Subjects will first be given the opportunity to look at general concepts, diagrams, flowcharts, definitions, etc. Finally the subject will be given definite examples illustrating the various concepts and subjects will have the option of executing code and examining the output generated.

The design of the second hyperdocument will be compatible with the learning style of the field dependents and will emphasize a bottom up approach to learning. Before a general concept is taught a number of examples will be available. The student will be encouraged to look at the examples first by prompting or by use of a default path. He will also be given the opportunity to run sample programs and examine their outputs. After looking at several examples, the general concept will then be presented and elaborated upon.

Two types of design will be used in order to adhere to the above stated principles. The first will be a hierarchial structure which will be used by the field independents. The second will contain an index as the root document. In this design each node will be accessible from every other node.

A pretest will be given to eliminate those with prior knowledge of the subject domain. Students will be given enough time to read through the material and will be given a posttest at the end of the session. One variable to be looked at will be the time needed to complete the session.

Time Frame for the Project

First Semester-Fall 91:

Development of the hypertext applications.

Design evaluation instruments.

Obtain GEFT.

Select the classes.

Second Semester-Winter 92:

Do the experiment and data analysis.

Summer 92:

Write up the results.

Disseminate results.

Data

The following data will be collected for analysis:

- audit paths
- nodes visited
- nodes not visited
- visit time per node
- exam results--pre/posttest
- satisfaction--questionnaire

THE STATISTICAL DESIGN

The basic model used will be a 2x2 factorial design with blocking on the cognitive science factor. The cognitive science variable will have two levels as determined by scores on the GEFT. The hypertext design will have two levels corresponding to two instructional modes: hierarchial and non-hierarchial. Students will randomly be assigned to the two instructional modes. The dependent variable will be the score on the post-test.

The pretest will be used to eliminate those with prior knowledge of the subject domain. The statistical analysis will be done using the software package SPSS PCX.

IV. EXPECTED OUTCOMES

This study will attempt to throw some light on the relationships between cognitive style and learning within a hypertext environment. The dimension of cognitive style to be considered are field independence and field dependence. Hypertext systems will be designed so as to be accommodating to these two styles. A number of research studies have shown that a significant correlation exists between cognitive style and achievement(Dunn and Dunn,1978). Intuitively, it seems clear that cognitive style should have a significant effect on student achievement and motivation in learning settings. Hypertext provides an environment in which the student has maximal freedom to explore a network of information according to his own style of learning. It thereby provides a good mechanism for testing out some of the ideas about cognitive style and learning.

The main idea in this study is to get at the problem by identifying subjects who are either field independent(FI) or field independent(FD), designing compatible hypertext applications and testing for significant differences in group performance on a posttest. We would hope for two outcomes 1) significantly improved achievement by the matched groups and

2) greater satisfaction on the part of the matched groups. Specifically we expect field independents subjects to do significantly better on and to be significantly more satisfied with the top-down-designed application and the field d endent to do better on the bottom-up one.

Data on the audit paths of the users will be collected. We suspect that the field independent subjects will show some commonality of navigational characteristics within the somewhat restricted hyperdocuments. This information may be useful in determining if there are common path characteristics for the differing groups. We expect the answer is Yes. Are there significant correlations between the variables in the study? Probably.

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STRUCTURED LANGUAGE TRAINING USING A PSEUDO LANGUAGE KERNEL

Professor
Gerald N. Pitts

ABSTRACT

The AFOSR Summer Research program provided this researcher the opportunity to investigate ITS's, receive hands on experience with authoring shells, and initiate a two pronged research effort. One research avenue is the application of fuzzy logic to the intelligence module of an ITS as a replacement of the knowledge based inference engine. The second topic area that "bubbled to the surface" was the concept of applying pseudo language structures to the constructs of programming language training. These research ideas have definite potential utility in the long term Air Force project labeled STAMP and possible applications to most all training research projects. The holistic view of a proposed ITS using fuzzy predictors is provided in the first section of this report. The balance of this report describes a new innovative approach to programming training strategy along with detailed structure development.

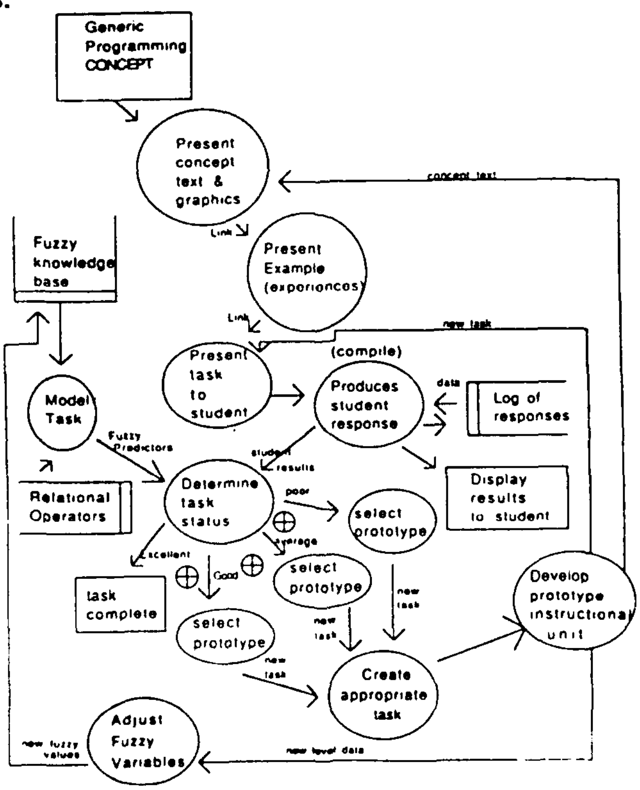
INTRODUCTION

The 1990 U.S. Census Bureau statistics indicate that over 1.2 million civilian computer programmers were identified by occupation (excludes consultants, partnerships, users for accounting, engineering, etc.). Literature research states that for every professional programmer by occupation, there is 10 fold casual programmers, programmer hobbyists, small business owners, etc., (Shneiderman, 1980). The National Center for Education Statistics indicate that 95% of the countries public schools offer computer programming classes providing precollege training for over 9 million students per year. This researcher believes that approximately 10 million programmers (professional and otherwise) struggle to learn a new language or software system each year. The Air Force provides programming courses (in house and contracted) for over 1800 students each year. Most all software that is developed including compilers, operating systems, utilities, as well as package software is programmed in a structured language. C has major support in the civilian community, while Ada is the accepted DoD language.

An innovation in programming teaching strategy would have a tremendous impact just by shear numbers. The goal of this proposed research project is to design, develop, and implement a pseudo language and compiler (syntactic and semantic) as the kernel module for an ITS. This could provide an instructional testing unit for one of the targeted curriculum goals (applied technical skills) of the ongoing STAMP project.

PROPOSED METHODOLOGY

Figure 1 represents a logic flow diagram of the new FBITS (Fuzzy Based Intelligent Tutoring System). Each of the seven generic programming constructs is presented to the student in both text and graphic visuals when appropriate, under the umbrella of accepted learning strategies.



A task completion is then asked of the student for the purpose of identifying the learning status of this student for this particular construct as well as assessing remedial needs. The task could include creating a programming construct that must be tested in order to provide adequate assessment. This requires a compiler (language translator) that converts the pseudo language construct to a machine executable form. The module is then executed to provide a display of results to the student and result data to the intelligent module.

Fuzzy relation sets are formed by composition of fuzzy knowledge (provided by experts) and task result variables into fuzzy predictors. These fuzzy predictor variables provide immediate inference rule selection. From the inference engine comes performance ratings and task determination. Possible ratings are:

A. Excellent - task is complete, continue to next concept.
B. Good - minimum remediation prototype to be general.
C. Average - more substantial remediation prototype to be selected.
D. Poor - very substantial remediation prototypes to be selected.

Prototype remediation is further individualized by fuzzy logic mapping of individual performance data to date upon learning theory arity to provide evidence combinations. This learning evidence indicator adjusts the prototype task (generated previously) level to fuzzy predictor tasks remediation. This remediation prototype is now an intelligently generated learning task customized to the student's needs and the learned experience of the FBITS.

An exhaustive literature search for programming language tutors, in an attempt to extract relevant methodologies, was launched first. An intensive investigation (literature search) into the cognitive skills required in learning a programming language, provides cognitive theory framework for pseudo language development. Review of structured programming concepts and pseudo language development rounds out this researchers "toolkit" for design and development of the targeted pseudo language and language compiler. Comprehensive testing of the compiler for each of the constructs is intended as the final phase. The deliverable product will be an instructional module that can be incorporated into a tutor shell for technical skills learning.

PROPOSED METHODOLOGY INSIGHT

In support of the proposed pseudo language model, a preliminary literature investigation is included in order to provide definitions, and subgoal insight to the reader.

Prior to STAMP, creative ITS endeavors to teach novices a programming language have been developed in reality for testing some cognitive learning theory (Anderson, Kline, Beasely, 1979; Snow, Frederico, Montague, 1980; Brooks, 1978) or isolated to a single language domain (Anderson, Sauers, Farrell, 1984; Bonar, Cunningham, Beatty, Weil, 1988). This proposed generic programming construct model will facilitate a students learning of any structured computer language (C, Pascal, ADA). The basic constructs of structured programming have long been a mainstay of program design.

The term structured programming is often referred to as "goto-less", "top-down development", "proper program development", etc. John K. Hughes (Hughes,79) defines structured programming as "the coding of a problem in which the basic structures, that are sufficient for solving any computing problem, are used". Therefore, a structured programming language is a language that follows the following three basic constructs:

1) procedural constructs discourage unconditional transfers
2) all variables must be declared as to type and size before use
3) the three basic structures are available (selection, sequence, repetition)

Other well known qualities of structured programming such as top-down, modularity, ease of documentation, and blocking are fruitful products of the application of the three basic structures.

A hypothesis that the three basic structures of a language are all that is needed to solve any problem that was developed and proven in 1966 (Bohm and Jacopini, 1966). Edsger W. Dijsktra (Dijsktra, 68) was challenging in his criticism of GOTO statements within programs. He stated "the quality of programmers is a decreasing function of the density of GOTO statements in a program .... I became convinced that the GOTO statement should be abolished from all high level programming languages....". The structured approach to programming has evolved into the guiding template for computer languages education in all university curriculums. Most language texts utilize the structured approach. The structured approach has been adopted by the ACM (largest computer society) and has influenced the development of all new computer languages. The languages PASCAL and C (also C+, C++) are highly structured languages. Even FORTRAN and COBOL have gone through ANS standard changes to provide enhanced basic structures. ADA is a structured language and has gone through some recent changes to upgrade its capabilities. MODULA, PROLOG, and FORTH have basic structuring primitives, but were created with string/symbolic manipulation applications in mind. They fall into the category in which LISP and SNOBOL reside. The structured approach lies heavily in the ALGOL based languages such as PASCAL, C, C++, and ADA while having some effect on PROLOG, MODULA, and FORTH. LISP and SNOBOL are influenced indirectly, but have a very specific domain of application.

Structure nesting provides the key to "Goto-less" programming by eliminating the need to transfer program control to another sequence of instructions. Nesting provides this alternative by providing modular sequence control within the domain of a different module structure. Violation of structure boundaries requires the programmer (student) to rehabilitate the structure (nested or otherwise). Once all errors have been removed from the structures, the student can be assured that unknown (usually unwanted) control transfers have been eliminated. Endless looping is still possible, but not very probable, because of the forced structure monitoring provided by the processor. This structured approach provides a blocking method that inherently urges modular development. Modular programming habits can be easily upgraded to subprogram development (more complex modularization).

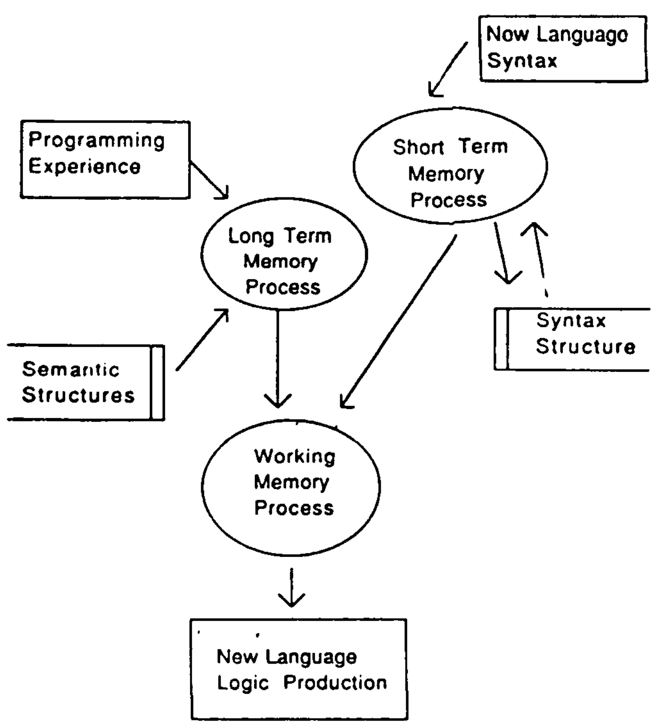
The question arises as to what cognitive processes are utilized in learning a structured language and if they differ from learning an unstructured language. An interesting application of the ACT learning theory to LISP programming (Anderson, Farrell, Sauers, 84) discusses both composition and proceduralization in terms of learning the language LISP. Composition is the combing of several contextual productions into fewer productions without losing the desired effect of the set of productions. Proceduralization is the effective utilization of memory stored information to build new productions or evaluate existing productions. The authors were able to provide convincing evidence that ACT was indeed the cognitive vehicle of learning LISP. The study also brought forward the idea of inductive learning (generalization and discrimination). This was discovered during analogy building and attempted error correction sessions with the simulated model GRAPES.

Other attempts of ACT application to programming languages is sparsely distributed in research literature. However, analogous learning was exemplified in SIMPLE, a program created for the purpose of assessing programmer psychology (Schrager, Pirolli, 83). This language was an overly simplified attempt at using a limited pseudo language for researching programming cognitive skills. The conclusion of this project does support the use of a pseudo language for problem solving skill acquisition. Highly respected researchers (Pirolli, Anderson, 85) concluded after studying the learning of recursive programming skills, that learning a general strategy (structuring template) early, greatly enhances recursive programming learning. Prior research to date summarily points to the need for a structured pseudo language approach to programming skill acquisition.

It is this researchers opinion that the foundation of structured languages provides a natural vulnerability to a modified ACT learning theory. In learning to provide the proper structure, one must first commit to rote memory the syntax of the structure. Examples provide fruit for analogies that can lead to proper structure production. The nesting of structures is simply a form of composition. Modularization (blocking or submodules) by concept\algorithm, is proceduralization. The language processor forces correct composition by checking the structure and requesting correction, an ideal opportunity for induction. Generalization to new structure conception and discrimination for backtracking errors converge to a structure "mindset" that is filed away in long term memory.

The next question to be answered is why not just "dig in" to the actual language instead of pre-learning a pseudo language. One must realize that these high level languages are very complexly packaged for universal application and can be very intimidating to the novice. Literature supports this researcher's conjecture that novice programmers are subjected to multileveled cognitive structures in learning to program in a computer language (Shneiderman 1980; Mayer, 1979; Bonar, Cunningham, Beatty, Weil, 1988; Brooks, 1977). The syntactic knowledge (specific keywords, rules of formation variable definitions, etc) is the first attempt in developing a "vocabulary", sufficient to comprehend the semantic structures (meaningful units of logic instructions). Experienced programmers can easily learn to program in other computer languages because they have semantic structures of programming logic stored in their long term memory and only need present the syntactic structure of the new language to short term memory. Logic productions in the new language are combinations of semantic structures "clothed" in new language syntax figure 2. The "chicken or the egg" analogy raises it's ugly head. How does one learn a computer language without any prior long term memory resident semantic structure knowledge? Presenting a subset of the language is impossible because the basic structures are clothed in complex syntax, restricted by integrated variable scoping, etc. The backbone of any structured language is the production of basic structures, yet so much peripheral learning (syntactic structure) must be accomplished that novices are seldom able to distinguish the structures from the preparatory syntax. The novice therefore is very seldom able to induce proper structure production for specific application. Problem solving skill is bogged down and frustration usually impedes development of a confident programmer. This researcher has experienced this novice frustration in literally thousands of students that I have attempted to teach structured programming languages to, at the university level, in high school, and in business. Structure emphasis has provided this researcher some positive feedback in recent attempts to teach structured languages and provides rationale to develop a pseudo language that disrobes the basic structures to allow a more constructive approach to learning any structured language.

Figure 2



This technique would provide the long term memory resident semantic structure knowledge (egg) sufficient to construct logic productions (chicken) packaged in the syntax of any structured language.

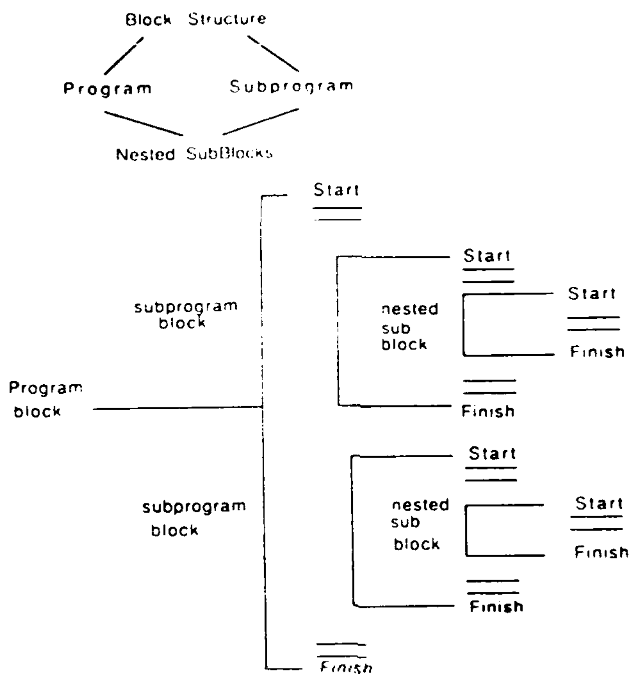
This new pseudo language will aptly be given the acronym PITTS (Pseudo Instruction To Teach Structures). PITTS will utilize a modified ACT learning theory in developing specific learning strategies with intention of providing one major criterion task for utilization in the STAMP project. The term "pseudo" is defined as similar, not actual, representative. A pseudo programming language is a virtual programming language that is transparent to the student in that it has instructional purpose, but no application ability in the "real" world. It is an instructional vehicle that presents programming structures in an uncomplicated form as a building block to proceduralization of actual languages. Pseudo language structures developed for teaching problem solving skills should have a positive effect upon student performance (Rohwer, Thomas, 89).

The following fundamental programming constructs (includes the three basic structures) proposed for PITTS are:

1) Blocking (domain delimiting)
2) Selection (conditionals)
3) Storage assignment
4) Input/Output
5) Declaration
6) Repetition (looping)
7) Sequence of execution

The resulting syntax with graphic representations for each construct follows:

1) <u>BLOCK STRUCTURE</u>

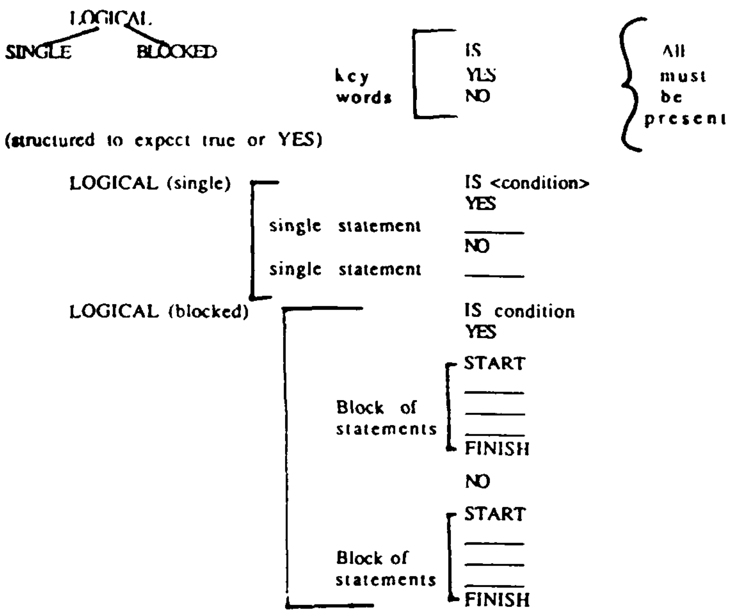


The block structure provides the physical domain for sequential instructions. This grouping (blocking of instructions infer a semantic grouping of elements of a concept or algorithm. This logical collection of instructions provide the format for subgoal (modularization) development, and sets the physical constraints of the overall program module as well as the nested modules.

The selection of the keywords START and FINISH should be obvious as natural task domain delimeters.

The programmer must learn to FINISH each task that is STARTed. This will disallow any open ended instruction sets, a program maintenance horror. Visual inspection of the programming structure easily allows block perception and dissemination.

2) <u>SELECTION (CONDITIONAL)</u>



<u>Relational Operators:</u>

Bigger than	Greater than or >
Smaller than	Less than or <
Equal to	equal (same as) or =
Not equal	Not equal (not same) =

<u>Boolean Operators</u>
AND
OR

Testing conditions to determine instructional sequences is the mainstay (backbone) of deductive logic within a programming domain. Choices of semantic execution provide flexibility, capability of complexity, and some restricted intelligence to the program module. The student attempting to learn programming is faced with an abstract concept in choosing the proper syntax structure to fulfill the semantic need. The student must be trained to:

1) recognize the need for a conditional construct at this particular breakpoint within the overall program structure

2) be able to translate the condition to be tested into relational operators provided in the language. This can be complicated when the need for logic arises, TRUE or YES being the expected result of the conditional

3) provide the proper instructional sequence either single or blocked within the appropriate realm of the syntactic structure

The "English like" relational operators reduce the abstraction by one level because many students do not automatically perceive the mathematical operational symbols for their relational capability. Symbolic abstraction can be easily learned once the logical abstraction for conditional semantics has been bridged.

3) STORAGE ASSIGNMENT

syntax:
STORE <value> INTO [Label]

value can be a number, character string, an expression, or labeled location.

expression can be any combination of numbers, and operators on numbers and/or labels containing numbers.

these arithmetic operators are for expression evaluation, and are hierarchial:

same level	^	exponentiation
	*	multiply
	/	divide
same level	+	add
	-	subtract

Hierarchial grouping can be accomplished using the ( ) parenthesis. One could think of the ( ) parenthesis as the highest operator in that operations within the internet ( ) parenthesis are executed first.

The Label denotes a name of a memory location that will contain a stored value. This label is to be created by the student and must begin with an alphabetic character (A-Z).

keywords:
STORE
INTO

The symbol (Label) that provides a name for recalling the value that was stored there can be a source of abstract error when the label itself (literally) is utilized instead of the contents residing at the memory location named by the label. The indirection of the symbolic abstraction can be overcome through learned analogical reasoning. Tutorial analogy with several experiences normally provide the student with a working understanding of the assignment concept.

4) <u>DATA INPUT</u>

syntax: RECEIVE < Label >

Label is the name of the memory location in which the value given (from keyboard) by the user is stored. (assigned)

Multiple input items must be RECEIVED one at a time.

keyword:
RECEIVE

<u>DATA OUTPUT</u>

syntax: SHOW < Label >

Where Label is the name of the memory storage location that contains the value to be displayed on the screen.

keyword:
SHOW

5) <u>DECLARATION</u>

Declaration storage of type is a requirement of any structured language. An analogy could be: the delivery of a truck load of chickens to an egg warehouse that could bring immediate attention to the truck driver that a declaration of what the warehouse is expecting to be stored there, could avert costly mistakes.

Syntax:

DECLARE <name> type

where: type is either a
number (numeric)
or
text (alphanumeric)

and name is	a. any combination of characters and numbers b. less than equal to 4 characters in length c. 1st character must be alphabetic (A-Z)

number may be float (with decimal) or integer (no decimal) simply by the appearance of the value.

Text is a character or a string of characters (including digits 0-9) up to 254 characters in length excluding blanks. The first blank encountered left to right is considered a break delimeter.

6) REPETITION

```
                                unconditional

                                 REPEAT [ number ] TIMES
          ┌─Single
          │ instruction          ____
     OR   │                 ┌─── START
          └─Block           │    ____
            structure       │    ____
                            └─── FINISH

                                conditional

                                 REPEAT UNTIL < expression >
            Single
          ┌─instruction          ____
     OR   │                 ┌─── START               Key words:
          │                 │    ____                REPEAT
          └─Block           │    ____                TIMES
            structure       └─── FINISH              UNTIL
```

In the conditional loop, the expression is evaluated as TRUE or FALSE. Testing is done before the instructions are executed. A TRUE condition terminates the repetition, while FALSE continues repetition.

CONCLUSION

The final product is an instructional module (PITTS) that contains both a pseudo language presentation manager, and a compiler that allows program units written in the pseudo language to execute as well as provide results to the student. A compiler response could be in the form of diagnostics when structure units are incorrect. This module can then be incorporated into existing tutor shells for testing which is beyond the scope of this report. This new module could very well be accepted as one of the major criterion tasks for applied skills learning in the STAMP project.

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Final Report to RDL

Stanley Bashkin

July 26, 1991

Introduction

The purpose of my Fellowship was to enable me to make and test a novel detector for neutrons, which I had invented. The Armstrong Laboratory at Brooks Air Force Base in San Antonio, Texas, includes the Occupational and Environmental Health Directorate, which, among other things, has a major responsibility for the testing and calibrating of radiation instruments. Consequently, their concerns and facilities made it apparently appropriate for me to carry out the proposed activity under their program.

When I arrived at Brooks, I was told that Dr. Robert Mania, from the Department of Physics at Kentucky State College, had also been selected as a Fellow in the same group as myself; Dr. Mania generously agreed to assist in the prosecution of my project, pending the start of his own work.

Principal Activities

Although the fundamental nature of my detector had been outlined earlier, and a disclosure prepared as the basis for potential patenting, the detailed design had not been made prior to my arrival at Brooks. Thus, one of the first matters was to prepare a schematic description of the detector so that one could be constructed. This was done, and two prototypes were made. At the same time, a number of other essential requirements were specified. These included the following:

1. A vacuum system, so that all the air could be exhausted from the detector. Provision was needed for measuring the system pressure and leak-testing the complete structure.

2. The reactive gases. Three kinds of gas were of particular interest, namely, ^{3}He, boron trifluoride (BF_3), in which the boron was to be enriched in the light isotope, and nitrogen. In fact, two forms of BF_3 were requested, one being prepared with natural boron, the other enriched in ^{10}B.

3. Various fittings for the gas containers and the system. It was not feasible to specify those fittings until the gases arrived, at which time the particular kinds of adapters that were needed could be determined.

4. A neutron source. Two were available. One was ^{252}Cf, the other, Pu-Be. The latter appeared to be the more suitable of the two, primarily because it was in a relatively small container which could be moved from its normal location to another more appropriate for the tests we wished to carry out.

On my arrival, I found that certain of the above were not immediately available. Of particular concern was the unavailability of any vacuum equipment. While two mechanical pumps were found on the Base, both were quite old and, despite my efforts to clean and resuscitate them, neither performed satisfactorily. Moreover, there was no gauge for measuring the pressure in the vacuum system.

I then turned to the Department of Physics at the University of Texas, in Austin, and, thanks to the courtesy of Professor Peter Riley, was able to borrow a pump, along with two thermocouple vacuum gauges and a gauge circuit. It turned out that the pump was also old and of marginal utility. Nonetheless, it was at that moment the only one I could obtain that offered any possibility of working. At the same time, one of the vacuum gauges and the associated circuit did work satisfactorily.

On July 12, Captain Michael Mayo kindly loaned me a turbomolecular pump. I designed the coupling needed to attach it to my system, and the machine shop made it on July 15. That pump was then installed on my system. The turbomolecular pump was considerably better than any of the others I had at my disposal, and the acceptable pressure of 60 milliTorr was attained.

Needless to say, it was also necessary to buy the reactive gases. Initially, orders were placed for ^{3}He and (un-enriched) boron trifluoride. Given the constraints of time, it was impractical to order the enriched form of boron trifluoride.

The (un-enriched) boron trifluoride arrived on June

30, but then a delay, discussed in the next paragraph, was incurred. It was also then found that a special valve was needed to couple the gas container to my system. I ordered the valve immediately, but it was not delivered until July 8, at which time I connected it to my system. The ^{3}He was delivered on July 11.

Almost immediately after the boron trifluoride arrived, it was restricted by Lt. Kirk Phillips, the Base bio-environmental engineer, because:

1. Somehow, the purchase and delivery of the gas had by-passed the normal procedures for dealing with potentially hazardous materials.

2. No plan for using the gas had been approved as regards health precautions.

I carried out suitable calculations of worst-scenario exposures from accidental releases of boron trifluoride into the room in which the work was to be done. I also prepared a document which detailed my plan of action. Following a visit from Lt. Phillips, I was authorized to receive and use the boron trifluoride. This final permission was received on July 8. It was then that the system was completed.

In addition to the vacuum features and the connection to the boron trifluoride, the system included a tank of nitrogen gas. I decided to include the nitrogen because of an important finding I had made in the course of my customary research at the University of Arizona. That research has to do with the optical excitation of gases under the impact of energetic charged particles, and, of course, was the basis for the proposal to make my neutron detector.

Now the products of the neutron-induced disintegration of ^{10}B are ^{7}Li and ^{4}He. The energy released in the disintegration is approximately 3 MeV, which is shared by the residual nuclear species. That means that these energetic particles undergo collisions with the surrounding gas. One of the consequences is that light is generated. However, the spectrum that arises is unknown.

On the other hand, my Arizona work showed that nitrogen, when struck by energetic hydrogen ions, is an especially intense source of light over a wavelength range of some 5 nm at a peak wavelength of 319.4 nm. There are other bands, as well, altogether giving a considerable amount of light in the visible portion of the spectrum. It therefore seemed sensible to incorporate some nitrogen in the detector, along with the reactive gas. Accordingly, provision was made for having both nitrogen and the reactive gas introduced into the system, with valves so arranged that the two vacuum lines could be pumped out separately and the detector filled with the desired amount of the two gases. Of course, the optimum mix of the gases was - and remains - unknown.

One of the experimental problems was that the system included a large number of joints. The joints were vacuum-sealed with either teflon tape on screwed connectors or Swagelock fittings. It was essential that the system be vacuum-tight, and considerable effort was devoted to locating and repairing leaks. Some of the testing was done by pressurizing the system to 10 psig, and using soap solution on the joints. That method revealed some leaks, but others were too small to be detected that way. The second method was to evacuate the system to the best vacuum the pumps could produce, and then spray acetone on the joints, one by one. The thermocouple vacuum gauge served as a detector. If there were a leak at one of the teflon joints, the pressure indication fell, because the acetone caused the teflon to swell and seal better. At the metal-metal joints, a leak showed up as a rise in the pressure indication, since the acetone cooled the thermocouple junction more than the residual air did. By means of these two techniques, the system was made vacuum-tight; the best pressure that could be reached was 60 milliTorr. While that isn't very good, it was adequate. The limitation was due to the quality of the pumps.

The plutonium-beryllium neutron source available to us was encased in a paraffin-filled drum. The paraffin served to moderate the neutron energy, and degrade it close to the thermal value. Using one of the standard neutron detectors from the Armstrong Laboratory, we measured the neutron-equivalent dose rate at the outer surface of the barrel. It was roughly 12 millirem per hour. The

Pu-Be source was small enough physically that it could be moved into a room that could be made completely dark.

I proceeded to fill one of the detectors with 300 milliTorr of nitrogen and one atmosphere of (un-enriched) boron trifluoride. The filling system worked well.

The apparatus was moved into the experimental room, and all sources of light were turned off or sealed. The detector was placed on the floor, as close to the Pu-Be barrel as possible. After my eyes became adapted to the dark condition, I looked carefully at the detector. Unfortunately, I could not see any signal at all.

Subsequently, I obtained a photomultiplier tube, which had been removed from a non-operative scintillation counter, and attempted to obtain a signal from it. That also failed. However, it should be mentioned that the photomultiplier tube hardly responded to room light, so it was not the most sensitive instrument one could have.

After the negative result with the boron trifluoride detector, I filled the second cell with ^{3}He, again with 300 milliTorr of nitrogen. It was much harder to bring the total pressure up to one atmosphere using the ^{3}He than with the BF_3. The reason is that the pressure in the ^{3}He supply vessel is only 70 psig, in contrast to the 1600 psig for the BF_3. Nonetheless, it was possible to reach the operating pressure of 1 atmosphere, and an eye examination, identical to that carried out with the first cell, was then made. Again, however, the result was negative.

Still another test was made by removing the Pu-Be source from its container and both detectors were placed adjacent to it. The neutron rate at a distance of six inches from the Pu-Be source was measured to be 75 mrem per hour. The dark-adapted eye was again used as a detector, but nothing could be seen in the course of a two-minute observation. (A longer observation time was considered inappropriate because of the health hazard.)

Plans for the Further Work

The failure to see any response from the detectors was disappointing, but not discouraging. There are several other routes to explore, and a good reason for doing so. The reason is that the basic interaction clearly occurs. The question which has to be answered is, What is the sensitivity of the detector to incident neutrons?

Since the detectors tried this summer were not sufficiently sensitive to give a signal, I used the experience to design another system which is more promising. Because the supply pressure for ^{3}He is only about 70 psig, whereas that for the boron trifluoride is roughly 1600 psig, I intend to restrict the next series of experiments to the latter substance.

One way of increasing the sensitivity is to increase the gas pressure. Instead of using a glass ampoule, in which safety considerations limit the gas pressure that can be used, I propose to make a metal cylinder, capped at one end by a quartz flat. The cylinder would be 3 inches long, and 1 inch in diameter. (A longer cylinder would probably not be useful.) The quartz plate would be sealed to the cylinder with a teflon gasket. To provide sufficient pressure for the seal, a clear plastic cap, threaded on the inside, is to be screwed to the outside of the cylinder, so as to press against the quartz. In addition to providing the sealing force, the plastic will serve as a safety measure in case the quartz should break. Hydrostatic tests will be carried out to determine the safe pressure limit of this system.

If the hydrostatic tests are satisfactory, the detector will be filled to a pressure of 10 atmospheres. By itself, this will increase the sensitivity of the device by a factor of ten. If the boron trifluoride is enriched in the light isotope of boron, another factor of about 5 will be attained, for a total gain of a factor of 50 over what we could get this summer.

In addition, a light-tight holder will be made to fit over the plastic piece, and a piece of fast film will be inserted. A movable shield will be incorporated into the holder, so that different pieces of the film can be exposed to the quartz window.

This instrument will then be placed in the neutron port of the Triga nuclear reactor in the Nuclear Engineering facility at the University of Arizona. Exposures will be carried out for different amounts of time, for each portion of the film. Probably four exposures will be possible for each piece of film.

Because the film is an integrating element with relatively low background, such observations ought to provide definitive information about the inherent sensitivity of the detector. Should a positive signal result, it will then be practical to adapt the detector to a photomultiplier tube or photodiode.

It was mentioned earlier that some nitrogen was added to the reactive gas, so as to enhance the light signal. However, as was pointed out, the best value for the relative partial pressures of the nitrogen and reactive gas is unknown. Indeed, in the case of boron trifluoride, the spectrum due to the impact of energetic particles is also unknown. Consequently, there is the interesting problem of finding out what that spectrum is. My standard equipment in Arizona is well suited to such a study.

Whether the film gives a positive signal or not, a final step in the program will be to couple a sensitive photomultiplier tube to the window of the detector. That should improve the detection sensitivity and permit a quantitative evaluation of the detector's utility.

Incidental Work

In addition to the experimental research, I described my effort in a seminar given on my last official day at Brooks. Also, I helped one of the regular members of the Laboratory with the preparation of documents prescribing procedures to be followed in disposing radioactive and other waste materials.

Comments on Working Conditions

The mission of the Occupational Environmental Health Directorate is clearly important, but necessarily restricted to its well-defined functions. Thus it was not surprising that some of the apparatus I needed was not part of the group's ordinary inventory of equipment. However, this handicap was overcome, thanks to the superb spirit of cooperation and the technical skills of the people into whose activities I had intruded. Everyone associated with the laboratory was as helpful and congenial as one could wish, and I take the greatest pleasure in acknowledging my debt to them. Those who were of particular help included:

Lt. Col. Edward F. Maher
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Capt. Michael Mayo
1Lt. William Pramenko
TSgt. Richard C. Howell
SSgt. David Martin

TSgt. Jocelyn Nixon
Ms. Latrice Derry
Ms. Lisa Hamilton
Mr. Joseph Hillsbury
Ms. Carol Luskis

Finally, I wish to record my gratitude to Professor Mania for his kindness in working with me on this project.

Respectfully submitted,

Stanley Bashkin

GC/FTIR ANALYSIS OF BENZENE IN COMPLEX MIXTURES USING THE HP 5965A INFRARED DETECTOR

PROFESSOR VERNE L. BIDDLE

I. ABSTRACT

An analytical method using capillary column GC for the analysis of benzene in complex mixtures, such as JP-4 jet fuel, has been devised and compared with the presently used method. Hewlett-Packard's 5965A FTIR detector is shown to be superior to FID in terms of accuracy, using actual field samples.

II. INTRODUCTION

At the time of the beginning of this investigation, there was no officially approved method for the analysis of benzene in jet fuel environments, by either NIOSH or OSHA. Previous investigations (see AFOEHL report 90-126SA00687HAE) had shown that a packed column GC/FID method consistently gave results that were too high, but capillary column GC/FID showed good correlation between the spiked and measured amounts of benzene. However, it was further noted that at an 80 degree Celsius analysis temperature using a 60-m X 0.75-mm wide-bore DB-5 capillary column, cyclohexane coeluted with benzene. Thus, in cases of high apparent benzene concentrations, such coelution was suspected and the analysis rerun at 60 degrees Celsius where separation was effected. The need to rerun a sample when cyclohexane was suspected, along with the inability to verify the presence of benzene based on anything but its retention time, led to the present research project -- one of finding an acceptable method for positive benzene identification and quantitation in complex environments.

The value of Fourier transform infrared (FTIR) spectroscopy has long been recognized for its much greater sensitivity than dispersive IR -- as much as 2-3 orders of magnitude greater. Such sensitivity is essential when IR spectroscopy is used as the mode of detection for capillary GC, where only nanogram quantities of sample are available to the detector. The speed of obtaining spectral information about the sample via FTIR is also essential, since the sample is available for only a few seconds as it elutes from the GC column.

The Hewlett-Packard HP 5965A Infrared Detector and HP IRD ChemStation were designed for capillary GC; together they serve as a detector for the GC eluent and subsequently analyze and quantify the stored data. The ability of the IRD to not only produce an IR spectrum of a given GC peak, but also to identify the peak by searching a stored library, makes it a potentially valuable tool in GC analysis of unknown mixtures. In the present situation, the presence of benzene can be proved, not only by its GC retention time, but also by its IR spectrum.

III. DISCUSSION OF THE PROBLEM

All investigations were made using a Hewlett-Packard HP 5890 gas chromatograph with the HP 5965A Infrared Detector and HP IRD ChemStation analytical workstation, which includes an HP 59970C ChemStation and HP 5995A IRD operating system software. The HP 59970C ChemStation has an HP 9000 Series 300 computer as its "heart," and includes 2 Mb of memory and a hard disc for data storage. Helium was used as the GC carrier gas.

The initial plan was to use the same type of GC column as is presently used for benzene analysis: a 60-m X 0.75-mm wide-bore glass column coated with Supelco SPB-5, 1.0 um film thickness. However, the column had broken prior to the beginning of this research, and therefore could not be used.

As described below, much of the research time was spent on optimizing GC parameters for benzene analysis. Initial investigations were made using a 60-m X 0.32-mm ID fused silica capillary column, coated with a 1.0 um film of DB-1 (a dimethylpolysiloxane stationary phase). Inability to detect any peak for a JP-4 jet fuel mixture resulted in switching to a new 30-m DB-5 column, 0.25 um film thickness, but to no avail. Further problems with water and column bleed appearing in the spectra were solved by (1) repacking the drying tube for the IRD sweep gas with fresh molecular sieves (type 5A, 50-60 mesh), (2) using a high-pressure (230 psi) nitrogen tank for purge gas, and (3) by conditioning the column at a high temperture. It was not until a splitless liner--generally used for trace component analysis--was installed in the inlet that the GC separation of JP-4 jet fuel into its components could be observed. Having changed columns, optimization of GC parameters was again necessary.

In the splitless mode, too short an inlet insert purge delay may result in loss of sample components, whereas too long a purge delay may result in interference from the solvent tail. For this particular solvent, CS2, and a 2 uL injection volume, significant differences in benzene peak areas and degree of solvent tailing were not observed when the delay was changed, except at very short delays. A 2.0-min purge delay was eventually used.

Another GC parameter to investigate was the septum purge flow rate. The manual recommends 0.5-3 mL/min--i.e., a rate that should be determined to give maximum peak area with no evidence of "ghost" peaks caused by septum bleed from previous samples. In this system, septum purge flow rates of 0.8-6.4 mL/min were tried with little significant difference noted. A purge rate of about 3 mL/min was eventually adopted for subsequent analyses.

According to the manufacturer, the optimum flow rate through the IRD flow cell is 1.8 mL/min; column volumetric flows less than this should have make-up gas added by way of the sweep gas in the GC/IRD interface, such that the total flow of column plus make-up gas is 1.8 mL/min. Too high a flow reduces residence time in the cell and, hence, sensitivity; too low a flow tends to degrade the chromatographic resolution. Ultimately, the inlet and outlet sweep gas pressures used for data reported below were 1 psi and 5 psi, respectively.

Given the ultimate goal of analyzing benzene in complex environments, the optimum oven temperature needed to be determined, as well as whether a temperature program was needed. In order to allow the solvent to concentrate the sample vapor at the head of the column, the maximum recommended initial column temperature was 30 degrees Celsius (see HP 5890 GC manual). However, this was far too low a temperature for the less volatile hydrocarbon components of JP-4 to elute in a reasonable time, yet if the temperature was raised too rapidly, benzene was too close to the solvent tail for a good baseline. Several oven programs were tried in an effort to take advantage of the "solvent effect" and still elute less volatile components in a reasonable amount of time. (See Table 1 below for program ultimately used).

The HP IRD and accompanying software has the ability to generate a "selected wavenumber chromatogram" (SWC) which not only simplifies the total response chromatogram (TRC) but also can be integrated and used for quantitation. Of the three types of SWCs that are possible (second difference, integrated absorbance, and maximum absorbance), the second difference algorithm (similar to a second derivative) was chosen, due to the large peak areas that were obtained -- generally, at least two orders of magnitude greater than those from the TRC. The SWC thus permitted the detection of much smaller amounts of benzene than would be possible for the TRC alone, especially since benzene eluted very close to the CS2 solvent tail. Hence, even where there was no observed peak in the TRC, calculation of a second difference SWC at the strongest benzene absorption (665 - 675 cm-1) resulted in a peak and no solvent interference, since CS2 does not absorb in that region. (See Figure 1 in Results section). Based on maximum area and smoothest peak, a function value of 100 for the parameter known as the function width appeared to be best, and was used in the calculation of all SWCs.

In a complex hydrocarbon mixture such as that encountered in the analytical laboratory, other aromatic compounds are also often present and could pose a potential interference problem. However, none of the commonly encountered aromatics -- toluene and o-, m-, or p-xylene --

were found to interfere since they are chromatographically separated from benzene.

In a split sampling mode of injection, rapid sample injection is important; however, in splitless sampling, a slower injection should be performed. The differences between rapid and slow injection were much less dramatic (an approximate 15% reduction for rapid injection) when a glass wool plug was placed in the splitless liner, in keeping with the recommendations for the HP 7673A automatic sampler. Hence, all data reported herein was obtained using a manual injection rate of about 1uL/second and a 2-3 mm glass wool plug in the splitless liner.

It was not until after some quantitative work had been done that it was discovered that cyclohexane and benzene coeluted from the aforementioned 30-m DB-5 column, even though the starting temperature was 30 degrees Celsius. Since a longer column has more theoretical plates and results in better separation, the 60-m DB-1 column used initially was reinstalled and shown to effect good separation of benzene and cyclohexane (tr = 6.670 min and tr = 6.799 min, respectively), though at the expense of elution time. Of course, using a different column meant rechecking other parameters for optimization (e.g., oven program and purge delay). The conditions under which analyses were ultimately performed are given in Table 1.

Having explored and optimized the GC and IRD parameters for benzene analysis in a CS2 solvent, quantitative analysis was the next logical step. The IRD ChemStation has the ability to report results in a variety of formats, both uncalibrated (area % or height %) and calibrated (norm %, external standard, or internal standard, and single- or multi-level calibration). Though the external standard (ESTD) method is the simplest to use for quantitation, frequent check samples and recalibration are necessary. Nonetheless, since it is the simplest to use, it was tried first. A multilevel calibration plot over the range 17.6-211 mg injected benzene (2 samples each of 4 concentrations) gave a least squares fit correlation coefficient of 0.991, indicating good linearity over the range. However, when using this plot to quantitate other known benzene concentrations on a succeeding day, the results showed an average error for several sets of samples of as much as 18%, though results more typically were in error by an average of 10%. Repeated attempts to quantitate benzene, both by single- and multi-level ESTD calibration plots and by using both peak height and peak area, were met with unacceptably large percentage errors.

Part of the variation in peak height could be traced to the IR source whose voltage was found to vary from day to day and even during the day. Over a period of two weeks, the source voltages were recorded at the beginning and sometimes at the ending of each day's work. The maximum variation noted during any one day was 4.6%; the maximum variation noted during the 2-week period was 6.2%. Another cause for the observed variations could be the fact that manual injections tend to be less reproducible than automated ones, even though great care was exercised to minimize this source of error. In any case, it appeared necessary to use an internal standard (ISTD) method.

It was desirable to find an internal standard that eluted prior to the solvent, since the baseline was flat there and since it would not be in the region of the TRC where the commonly encountered components of jet fuel elute. Freon 113 was found to be an unacceptable internal standard since it elutes within the time frame for the solvent. Since a DB-1 column is designed to separate hydrocarbons primarily, and polar compounds are only slightly retarded, an alcohol would seem to be a good choice for an internal standard. Methanol (MeOH) was the first choice, eluting at 2.92 minutes.

A 5-point calibration plot (17.6-211 mg) gave correlation coefficients of 0.995 and 0.983 for ISTD and ESTD, respectively, where MeOH was the internal standard (0.2 uL/mL or 316 mg per 2 uL injection). Using this calibration plot resulted in 7% and 21% average percentage errors for ISTD and ESTD, respectively, for a series of "knowns" that was analyzed the succeeding day, leading to the obvious conclusion that the ISTD method was far superior to the ESTD.

However, in the preparation of a concentrated solution of MeOH for spiking samples, MeOH was found to be relatively insoluble in CS2. A spiked field sample, usinq 4 uL of 20 uL/mL MeOH in CS2 added to 400 uL of sample, failed to show up any MeOH peak in the TRC; this led to the conclusion that, though nominally the same concentration as a standard prepared by adding 1 uL of MeOH to 5 mL CS2, the "spike" must have been less concentrated than expected, due to low solubility. Isopropyl alcohol (2-propanol) was much more soluble, but its chromatographic peak was quite skewed and it seemed to exhibit lower sensitivity. Despite these observations, an attempt was made at using isopropyl alcohol as internal standard with very poor results, both by ESTD and ISTD.

Further investigations with these two alcohols, as well as ethanol (EtOH), showed some strange and unexplainable behavior when they were dissolved in CS2 and chromatographed. That is, a much lower response (by a factor of at least 2.5) was observed for a sample prepared by diluting a concentrated alcohol stock solution in CS2 than for one prepared by adding pure alcohol to CS2, though both resulted in virtually the same alcohol concentration (i.e., 20 uL of 10 uL/mL alcohol + 1.0 mL CS2 vs 1 uL alcohol added to 5.0 mL CS2)! Furthermore, the latter solution exhibited a decrease in response with time as it was allowed to stand. Both EtOH and MeOH exhibited this phenomenon. Hence, the alcohols were abandoned as internal standards.

Other potential ISTD compounds which were tried and rejected were methylene chloride, ethylene chloride, dioxane, and methyl ethyl ketone (all elute in the CS2 range); ethylene glycol, acetic acid, acetonitrile, and triethylamine all had one or more problems, such as low solubility in CS2, weak absorption, or absence of an IR library spectrum in the IRD software. Eventually, chloroform was chosen, even though it elutes on the CS2 solvent tail. However, it is well separated from benzene (tr=5.92 vs tr = 6.64 for benzene). Its high solubility and large density are also advantageous for an internal standard. Since time remaining for research was running short at this point, no effort was made to try a lower ISTD concentration than the previously used 0.2

uL/mL; for chloroform this was equivalent to 576 ng chloroform per 2 uL injection.

Previously acquired experimental data gave strong support to the linearity of the calibration plot for benzene using the IRD, at least over the range normally encountered (i.e., 0-211 ng per injection or 0-0.106 mg as reported in this lab). Early work showed linearity to even larger amounts, i.e., to at least 352 ng per injection or 0.176 mg as reported, but since these cases are rare, attention was focused on the more common amounts of benzene detected. Hence, rather than using a multilevel calibration plot -- found to be only slightly more accurate (less than 1%) than a single-level plot -- a single-level plot was used for the data reported below. In addition, the ISTD method using peak height was found to be slightly more accurate (by approximately 1% or less) overall than that using peak area.

IV. RESULTS

The operational parameters used in gathering the following data are given in Table 1. The procedure for obtaining quantitative results was as follows. Using the GC and IRD parameters given in Table 1, a TRC was obtained (Figure 1a); a closer, zoomed-in look at the region of interest is given in Figure 1b. Underlined regions of the TRC indicate where FTIR spectra have been stored; such an IR interferogram (IFG) file must first be converted to an energy spectrum (ESP) file, accomplished by using the "convert File" softkey in the chromatogram softkey set when in the DataEditor program. The region to convert was between 5.70 and 6.75 minutes. Several minutes were required for the conversion. The converted file may then be opened (use "New Data File" softkey in DataEditor) and a SWC calculated by using the "Sel Wave Chromat" softkey in the chromatogram softkey set (see Figure 1c). The time range used for the calculation was the same as that used for the IFG-to-ESP conversion, and the wavenumber ranges were 665-675 cm-1 (benzene) and 765-775 cm-1 (chloroform), performed separately for ease of integration. Registers X and Z were then exchanged by typing "EXCHANGE X,Z" and doing a carriage return, followed by opening an integration file for storing integration data, and finally running the integration. This was repeated for each wavenumber range, followed by closing the integration file. The integration results file was subsequently used in the Report program, where the ISTD type was employed. Chloroform served as both a time reference and an internal standard peak.

The linearity of response by the IRD to benzene (up to 180 ng) can be seen in Figure 2. These amounts correspond to concentrations up to 0.103 uL/mL benzene for a 2-uL injection. No corrections were made for possible changes in instrumental parameters over the data acquisition time period (i.e., they are ESTD data). Figure 3 illustrates the linearity of the IRD using the ISTD method up to 211 ng (0.12 uL/mL) benzene using 576 ng chloroform as the internal standard; this translates to reported amounts, according to this laboratory's method, up to 0.106 mg benzene. There appears to be a dropoff in linearity at the 352 ng level (0.176 mg reported), but time did not permit determining the point at which linearity begins to fall.

Table 2 gives the results for known benzene samples, using a 141-ng sample of benzene to obtain a single-level calibration plot; 576 ng of chloroform served as the ISTD. Except as noted, results are averages of three samples, with a separate ISTD plot obtained on each of the two days during which the data was obtained. Also given with the average amounts found is the standard deviation (σ) for each set of samples. Peak height rather than area was used, as previously noted.

Encouraged by the close correlation between amounts of benzene present and that found, it was time to analyze some "field samples" and compare the GC/IRD results to those obtained by GC/FID. All ISTD samples analyzed were prepared as follows: to 300. uL of sample was added 6 uL of a 10. uL/mL chloroform in CS2 solution. In order to have a degree of confidence in the "unknowns," samples with known amounts of benzene were interspersed with the unknowns, quality-control (QC) style. The results are given in Tables 3 and 4. The same single-level calibration plot, obtained on Day 1, was used for all three day's data, and the same two "QC" samples were used all three days. An obvious trend toward larger values for the "QC" samples (Table 3) as they stood at room temperature clearly indicated that they were becoming more concentrated due to loss of CS2 solvent, even though capped in vials. Hence, the best procedure would be to prepare fresh samples when checking the method's accuracy. This concentration effect would probably have been minimized had the "QC samples" been stored in the refrigerator.

The percentage difference probably does not accurately reveal the good correlation between the two methods (especially for small reported values), except for some notable and interesting exceptions (see Table 4). Those samples whose values by GC/IRD are higher than by GC/FID (e.g., samples B, C, G, P) may have undergone concentration by loss of solvent through the cap between the time of FID analysis (always performed first) and the time of IRD analysis. Most samples analyzed differ by an amount that is probably due to experimental error. Several notable differences need to be discussed, however.

Sample J contained roughly comparable amounts of benzene and suspected cyclohexane (based on retention time); unless the sample was rerun at 60 degrees Celsius in the GC/FID method, coelution would result in about double the actual or GC/IRD value, just as was observed. Figure 4 shows the TRCs for this sample.

Samples M and O both exhibited very similar results, with the GC/FID method reporting double that for the GC/IRD method. An examination of the TRC for each (Figure 5) will reveal an almost unresolved peak adjacent to benzene (both with similar areas), tentatively identified by library search as 3,3-dimethylpentane. However, due to the lower resolution under the GC/FID column conditions, the two compounds probably coeluted, resulting in the reported value being about double the actual value.

To summarize the above results, in the presence of relatively small amounts of cyclohexane (where the sample may not be rerun at 60 degrees Celsius) and other more difficult to resolve components, the GC/FID method now in use would report an erroneously high value for benzene.

Finally, in order to show that the presence of a complex mixture such as JP-4 jet fuel does not affect the quantitation of benzene by this method, several samples containing a measured amount of JP-4 (10 uL/mL) and varying amounts of added benzene were analyzed, using the ISTD method establisehd in this research. Results are shown in Table 5 in terms of percent recovery. The JP-4 employed contained benzene, so this "blank" was subtracted from the amount of benzene found in order to calculate "percent recovery." In all three cases, better than 95% recovery was observed.

V. CONCLUSION

The HP IRD has the distinct advantage over the FID of being able to verify the presence of benzene, if it is in question, by a spectral search of the stored EPA library. Interference from nearby peaks is virtually eliminated in a SWC; the analysis of benzene in the presence of large amounts of closely eluting components is thus possible. Quantitative analysis for benzene is as good as or better than that obtained by FID, which often gives erroneously high results. A possible disadvantage of the IRD method is the longer time of analysis necessary, which includes file conversion, but even this could be improved by automation -- an aspect that was not explored due to time constraints. All in all, the GC/IRD method herein discussed showed great potential for accurate quantitation of benzene even in difficult samples.

Since different columns were used, a strict comparison of the IRD and FID methods is not totally legitimate, however. Further investigations using identical columns are recommended. Possible coelution of other components in the sample mixture could prove to noninterfering with the IRD, in contrast to what was first thought. Information obtained from Hewlett-Packard too late in the research period for verification implied that quantitation is possible using a SWC, even for coeluting peaks, once the detector response to the component of interest has been determined. Research in this area may be advantageous in that a shorter analysis time would be possible with a wide-bore column.

Table 1. GC/IRD Data Acquisition Parameters

IRD		GC	
Scan Resolution	8 cm-1	Injection Port Temperature	190 degr Celsius
Pre-Peak Storage	5.0 s	Injection Port Type	Split/Splitless
Post-Peak Storage	4.0 s	Injector Sampling	Splitless, Manual
Time Table	0.00 Store None 5.70 Store Peaks 6.00 Store None 6.55 Store All 6.75 Store None	Purge Delay	120 s
		Column	60m X 0.32 mm DB1, 1um film; 162 kPa (23.5 psi) column head pressure; 3 mL/min inlet purge, 80 mL/min split vent flow, 41 cm/s linear flow
Temperature Zones	Transfer Lines A,B: 200 degr Celsius Flow Cell: 200 deg Celsius	Oven Program	Initial: Temp 30 C, Time 2.5 min Ramp Rate 25 deg/min; Final Temp 125 C, Time 0.7 min Ramp Rate 65 deg/min; Final Temp 180 C, Time 12.0 min

Table 2. Quantitative Analysis of Benzene in CS2 using ISTD

Actual amount (ng)	Found (ng), average, ±σ	% Error
17.6	17.5 ± 1.4	-0.6
35.2	35.1 ± 1.0	-0.3
180.	191. ± 4.6	+6.1
211	214. ± 2.2	+1.4
352	*303. ± 5.4	-14

*Average of 4 samples

Table 3. "QC" Check Sample Results

	Actual Amount (ng)	Found (ng)	% Error
Day 1	141	136	-3.5
	70.3	67.1	-4.6
Day 2	141	147	+4.2
	70.3	69.1	-1.7
	0.0 (blank)	3.1	—
Day 3	141	151	+7.1
	70.3	72.9	+3.7

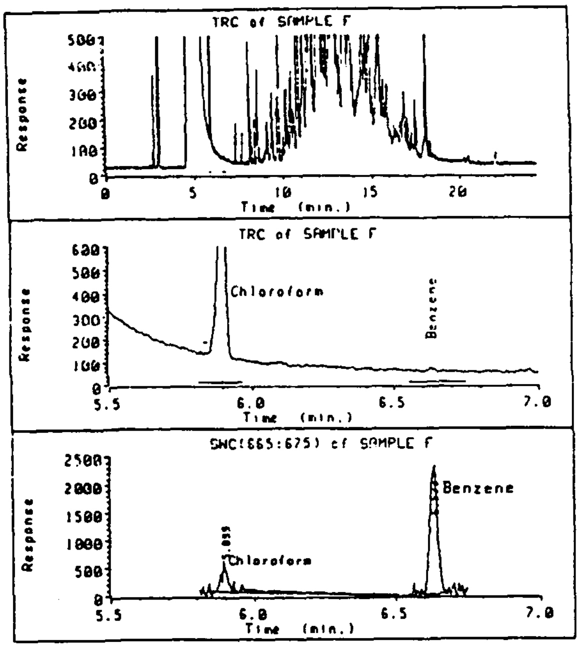
Table 4. Comparison of GC/IRD and GC/FID

Sample		Found, as reported, GC/IRD (mg)	Found, as reported, GC/FID (mg)	Difference (% Difference), relative to FID
Day 1	A	0.082	0.084	0.002 (-2.4)
	B	0.038	0.028	0.010 (+36)
	C	0.004	None	0.004 (N.A.)
	D	0.009	0.010	0.001 (-10)
	E	0.018	0.019	0.001 (-5.3)
	F	0.020	0.022	0.002 (-9.1)
	G	0.010	0.007	0.003 (+43)
Day 2	H	0.009	0.008	0.001 (+12)
	I	0.090	0.098	0.008 (-8.2)
	J	0.068	0.149	0.081 (-54)
	K	0.011	0.011	0 (0)
	L	0.017	0.016	0.001 (+6.2)
Day 3	M	0.045	0.091	0.046 (-50)
	N	0.002	0.005	0.003 (-60)
	O	0.044	0.095	0.051 (-54)
	P	0.005	0.002	0.003 (+150)
	Q	None	None	0 (0)

Table 5. Percent Recovery of Benzene in JP-4

Sample	Found (ng)	Added (ng)	[Found - Blank]	% Recovery
Blank	14.7	None	0	—
1	82.8	68.3	68.1	99.7
2	148	136	133	97.8
3	112	102	97	95.4

Figure 1



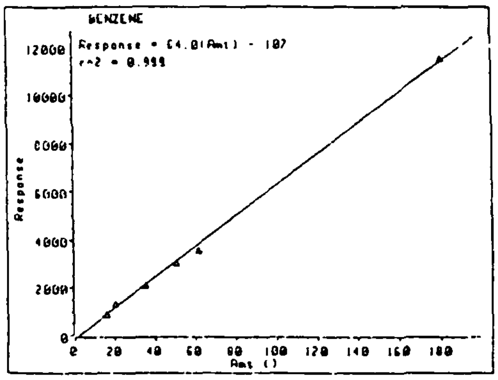


Figure 2

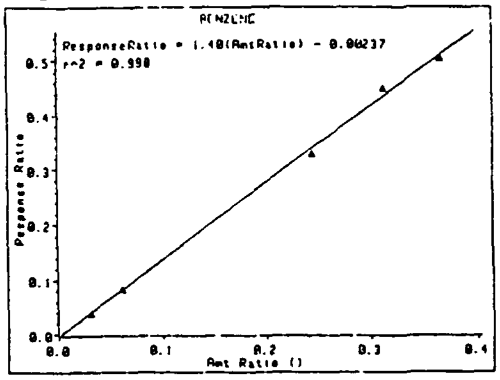


Figure 3

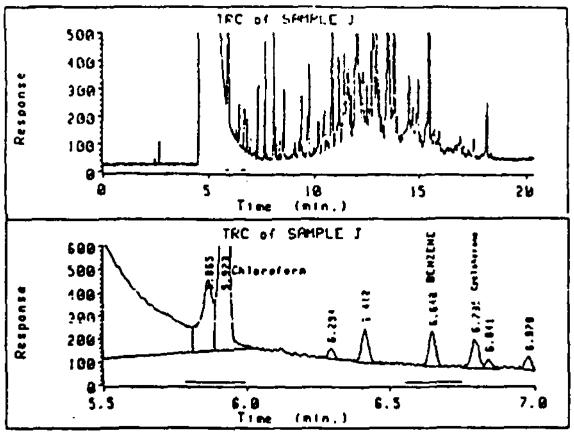


Figure 4

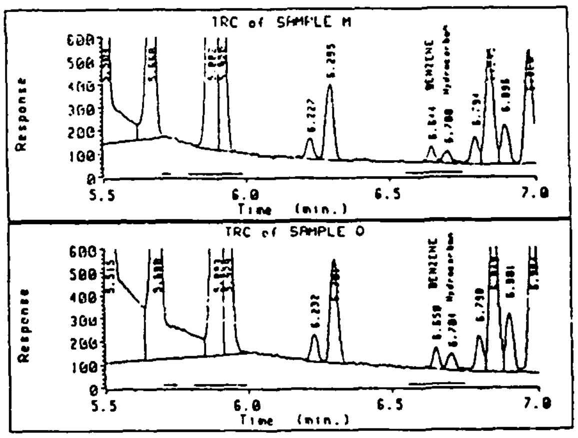


Figure 5

NEW SCINTILLATION DETECTOR

Robert C. Mania Jr.
Associate 99

ABSTRACT

A new scintillation detector, for the detection of neutrons, was designed, built, and tested. Two detectors were built, one using Helium-3 and the other Boron Triflouride. The detectors use the neutron-nuclear interaction to produce ions. These ions come from the detector gas atoms splitting upon interaction with the neutron. The excess energy of interaction is carried away by the motion of the ions produced. These ions while traveling through the gas should excite the electrons in the gas. When the excited electrons decay back to the ground state, light is emitted. Nitrogen gas was added to the tube to increase the amount of light emitted. When the detectors were exposed to a PuBe neutron source, supplying approximately 6,330,000 neutrons/sec, no light was detected. It is felt that a larger neutron source is needed to produce more interactions and either a photomultiplier tube or photodiodes are needed to observe the light signal.

NEW SCINTILLATION DETECTOR

INTRODUCTION

A new scintillation detector was proposed for the detection of neutrons. The proposed design is based on two observations: 1) Charged particles moving through a gas results in the excitation of the gas. 2) When the excited electrons decay back to their ground state light, is emitted. A detector was designed, built and exposed to a PuBe neutron source. Nitrogen gas was added to the tube to increase the amount of light emitted by the detector.

THEORY

When charged particles move through a gas, they will excite the electrons in the gas. When these electrons decay back to their ground state light, is emitted from the gas. Experiments carried out by Dr. Stanley Bashkin at the University of Arizona and others have shown that Nitrogen gas easily emits light due to interactions with charged particles.

The charged particles used in the excitation of the nitrogen gas come from the interactions of neutrons with several detector gasses. The detector gasses used were ^{3}He and $^{10}BF_3$. When neutrons interact with either of the detector gasses the following interactions will occur

$$^3_2\text{He} + ^1_0\text{n} \rightarrow ^3_1\text{H} + ^1_1\text{p} + 0.765 \text{ MeV}$$

or

$$^{10}_5\text{B} + ^1_0\text{n} \rightarrow ^7_3\text{Li} + ^4_2\alpha + [2.792 \text{ MeV (gs) or } 2.310 \text{ MeV (es)}].$$

When the reaction products are produced, they are initially ionized. The energy produced results in the imparting of kinetic energy to the reaction products causing them to move through the Nitrogen gas. As the ionized reaction products move through the nitrogen gas they should collide causing the excitation of electrons in the nitrogen gas. These electrons, upon decaying to their ground state, will emit light which should be able to be detected with either a photodiode, photomultiplier tube, or possibly the human eye.

The amount of light produced will depend upon the amount of charged particles produced in the interactions with the neutrons. The cross section for interaction of charged particles with the gas is much larger than the cross section for the interaction of the neutron with the detector gasses. Thus, the cross section of interaction of neutrons with ^{10}B and ^{3}He will determine the ability to use this process as a scintillation detector for neutrons.

EXPERIMENTAL PROCEDURE

A cell, shown in figure 1, was evacuated using a Welch mechanical and Turbo Molecular pump until the pressure in the cell was about 60 millitorr. At this time nitrogen gas was allowed to enter the cell through valve one on the cell until the pressure reached approximately 200 millitorr. Since the original air in the tube contains approximately 78% nitrogen gas, the pressure of nitrogen in the tube would be approximately 185 millitorr with the remaining 15 millitorr made up of primarily oxygen and carbon dioxide.

The valve to the cell was then closed and the system was again evacuated. The detector gas, either ^{3}He or BF_3, was allowed to enter the cell until the pressure in the cell reached atmospheric pressure. Atmospheric pressure was chosen so that glass could be used to construct the cell, allowing the eye to be used to detect the light. It was hoped that the detector would be sensitive enough to allow the eye to be used. Figure 2 shows the system that was constructed to fill the cell with the appropriate gasses. Two cells were made. One was filled with ^{3}He and the second was filled with BF_3.

Once the cell was filled it was brought to a PuBe neutron source using two different configurations. In one configuration, the PuBe was kept inside of its paraffin filled steel storage container; in the second configuration, the detector, was placed next to the bare PuBe source. When placed next to the storage container with the neutron source in the container, approximately 14($\pm$ 1) mrem/hr of neutron dose was measured. When placed next to the bare neutron source, the dose rate was approximately 150($\pm$ 10) mrem/hr. The configurations are shown in figure 3.

The PuBe neutron source and the detector cell were taken into a room that could be darkened. The room could not be completely darkened, but it was felt that the room

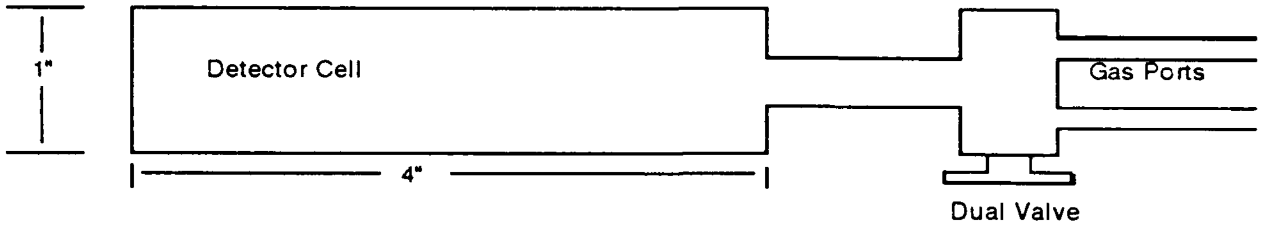


FIGURE 1: Cross section of detector cell used to contain either Helium or Boron Triflouride gas.

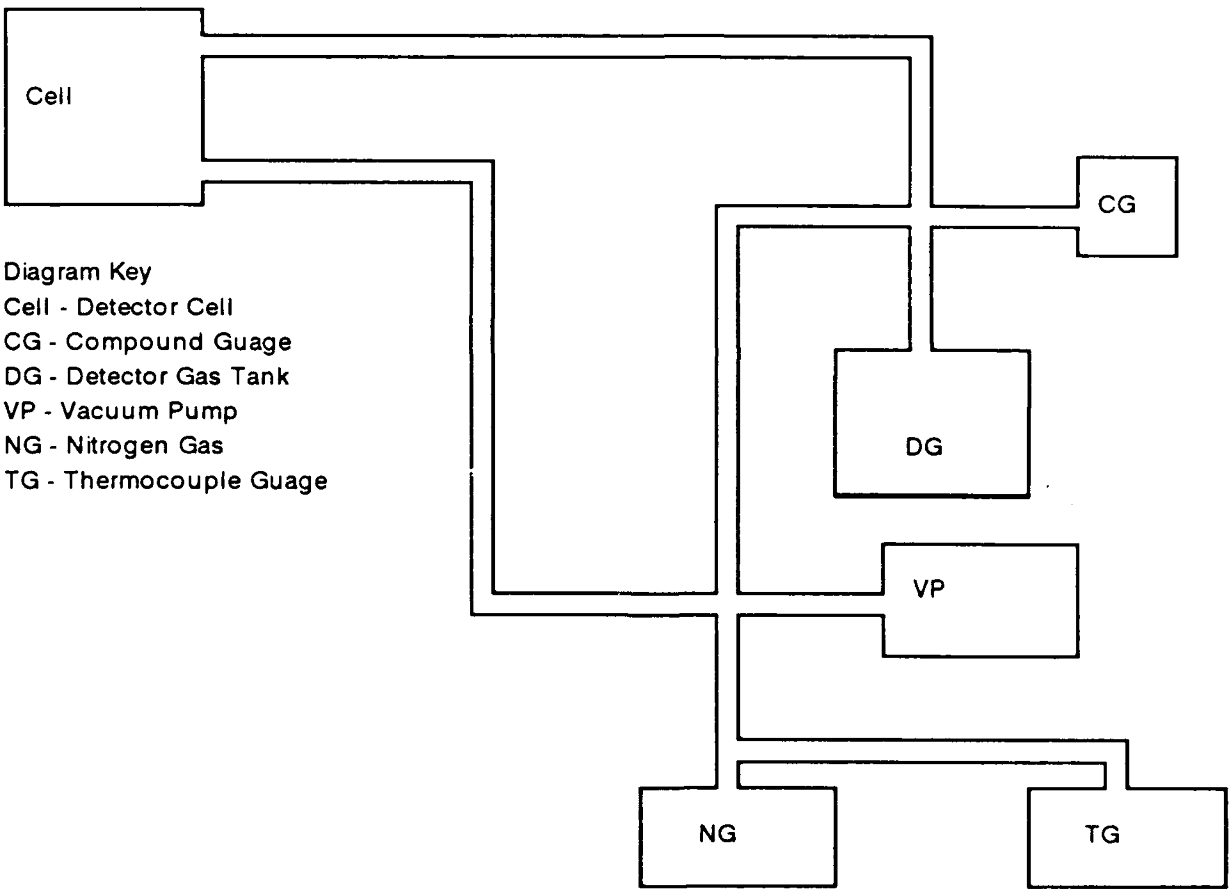


FIGURE 2: Schematic diagram of the system used to fill the detector with the detector gasses.

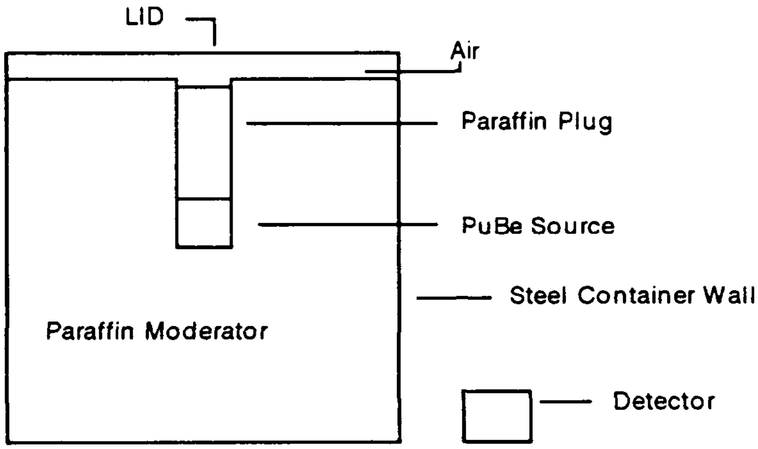


FIGURE 3A: Configuration used for thermal neutron flux experiment. PuBe source in paraffin moderated storage container with detector outside and source inside. Thermal neutron dose rate at detector was determined to be approximately 14 mrem/hr using the ADM 300 with a neutron probe. The detector was placed approximately 2 inches from the outside of the storage container.

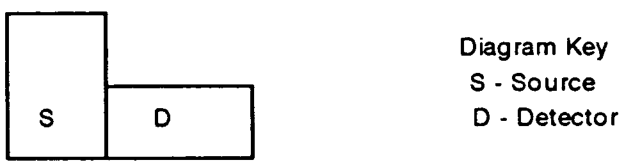


FIGURE 3B: Configuration used when source pulled from storage container and placed in contact with the detector cell. The dose rate determined by the ADM 300 detector was approximately 150 mrem/hr.

was adequate for the work attempted. In addition to using the eye as a detector, an attempt was made to use a photomultiplier tube. However, since the tube and preamplifier were not matched, no conclusion could be drawn from the results obtained.

EXPERIMENTAL RESULTS

When the cells were placed near the PuBe neutron source no light was detected with either the eye or the photomultiplier tube. This observation was the same for both the helium and BF_3 filled cells. The tubes were successfully filled, since when the tubes were opened at the end of the experiment both
^3He and BF_3 were detected.

CONCLUSIONS

It is felt that the strength of the PuBe neutron source (approximately 6.33×10^6 neutrons/sec) was not large enough and did not result in enough interactions with the helium or the boron. It is necessary to increase either the flux of neutrons, the amount of detector gas present in the cell, the sensitivity of the light detector, or all three.

To increase the neutron flux the cell could be taken to a nuclear reactor or a large californium neutron source. The light detector sensitivity could be increased by connecting the system up to a properly matched photomultiplier tube or to a photodiode system. Finally, the number of active detector atoms could be increased by working at higher pressure; and in the case of BF_3, one could go to enriched Boron.

FURTHER STUDY

A tube should be made out of metal instead of glass. One end of the tube should contain a quartz window in which a photomultiplier tube has been connected. The pressure of the gas in the tube should be increased to approximately 10 atmospheres pressure and in the case of BF_3, the gas should be enriched in ^{10}B.

FIELD NEUTRON SPECTROMETER

INTRODUCTION

The United States Air Force is under Department of Energy and Nuclear Regulatory Commission mandate to determine the radiation levels in their nuclear weapons storage facilities. As part of the program to do this analysis a Field Neutron Spectrometer was developed by Battelle Corporation for doing neutron detection and dose rate determinations in the different facilities. This detector consists of a TEPC (Tissue Equivalent Proportional Counter), a ^{3}He detector, and a set of Bonner Sphere's using a LiI scintillation detector. The system uses an IBM compatible computer, as the control module, for the data acquisition and analysis. The system is the only working system of its kind in the world. This project did not involve the TEPC detector. It was not returned from Battelle in time for analysis.

In using the Field Neutron Spectrometer, the Air Force had problems and wished to have the system analyzed and its operation improved. They wished to determine if it could be used in low neutron fluxes. The Air Force personnel at Brooks Air Force Base also want to have any software problems found and fixed. If needed, a training course in the proper use of the detector is to be developed.

The work this past summer involved the analysis of the system and determining if it could be used in the weapons storage facilities and what modifications were needed. Included in the analysis is a determination of the time of count needed for different neutron fluxes. This time of count gives the operator an idea of how long the system must run in order to get good statistical data, so that one can be confident in the results obtained.

THEORY

Neutrons are detected through their interactions with the nucleus of the detector materials. The FNS (Field Neutron Spectrometer) uses three reactions to gather the information concerning dose rate, quality factor, neutron flux, and neutron energy spectra.

For the Bonner Multisphere portion of the system the following reaction is used:

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{4}_{2}\alpha + 4.78 \text{ MeV of energy.}$$

Various configurations of polyethylene spheres are used to thermalize the neutrons coming toward the detector. The smaller spheres are covered in cadmium to suppress the thermal neutrons and enhance the energy response above the cadmium cutoff. The neutron energy spectrum is determined from the data using an unfolding routine[1]. The response function of the detector is used to determine the count rate in each detector from the neutron fluence in each data bin. The response functions have been calculated by Battelle based on the calculations performed by Sanna[2]. The workings of the Bonner Sphere system are well documented (e. g. Knoll[3]).

For the helium proportional detector the following reaction is used:

$$^{3}_{2}He + ^{1}_{0}n \rightarrow ^{3}_{1}H + ^{1}_{1}H + 0.764 \text{ MeV of energy.}$$

The helium detector is a proportional counter. The workings of a proportional counter are well documented (e.g. Knoll[3]).

According to the Quality Assurance Measurements made by Battelle using a calibrated californium source, the measurements are often close to 20% off of the theoretical values. The dose rate obtained by the multisphere arrangement was approximately 16% below the accepted value. The average energy values are often quite different from the accepted values. This is a result of the energy bins being quite large. Energy values of 1.4 and 2.3 MeV are placed in the same energy bin. The quality factor is quite close to the accepted value. Overall errors of 10 to 20% are quite common in neutron measurements.

EXPERIMENTAL PROCEDURE

Both the helium detector and the multisphere spectrometer were operated with no source, various distances from a PuBe source, a depleted uranium source, at the opening of a Cf source (source shielded), and the PuBe at 1 meter through a concrete wall. The results were compared to a neutron detector connected to an ADM 300 made by NRC Industries. The ADM 300 uses a neutron quality factor of 10 in its determination of dose rate, while the Field Neutron Spectrometer determines the value of the quality factor. The differences can be accounted for mathematically. The 10 inch sphere of the multisphere spectrometer can also be used as a neutron survey detector. Appendix A shows the experimental arrangement including the proper connections needed to set up the Field Neutron Spectrometer. The operations manual supplied with the detector does not give this information.

EXPERIMENTAL RESULTS

Figure 4a gives a typical raw data output for the multisphere spectrometer. The neutron peak is well defined. All seven different modes of operation result in a similar output. The multisphere spectrometer also gives some information concerning the neutron flux versus energy, shown in figure 4b. Typical output from the Helium Proportional counter is shown in Figure 5a. The helium detector also gives information of the neutron flux versus energy, as shown in Figure 5b.

The experimental results are summarized in the following six tables. The various tables include the results from the Multisphere Spectrometer, the Helium Proportional detector, and the ADM 300 survey meter. In several of the tables, the Corrected Dose Rate is given. This value is used to compare the different detectors. This value is obtained by taking the dose rate given, for a particular detector, and dividing by the quality factor and then multiplying by 10 (the quality factor for the ADM 300). This allows a comparison between the ADM Survey meter and the other detectors.

Several tables refer to the System Configuration. This terminology is used to label the relative positions of the source to the detector and what source was used. Background refers to no source being used. The Cf Port involved the detector being placed six inches above the port on the californium storage container with the port open. It should be noted that no direct beam was emitted from the port since the Cf source sits in a U-shaped tube. All that is emitted from the port is scattered neutrons. The PuBe source was used at various distances from the detector. These distances were 1 foot, 1 meter, 15 feet, and 1 meter through the concrete wall of the building housing the radiation facility. Finally, approximately 420 grams of depleted uranium was used as a source.

Table One gives the Dose Rate, Quality Factor, Average Energy, and Flux as determined using the Multisphere Spectrometer. The table also has a theoretical value of the flux determined from the size of the source and its distance from the detector. Finally, the corrected Dose Rate is given for the Multisphere System.

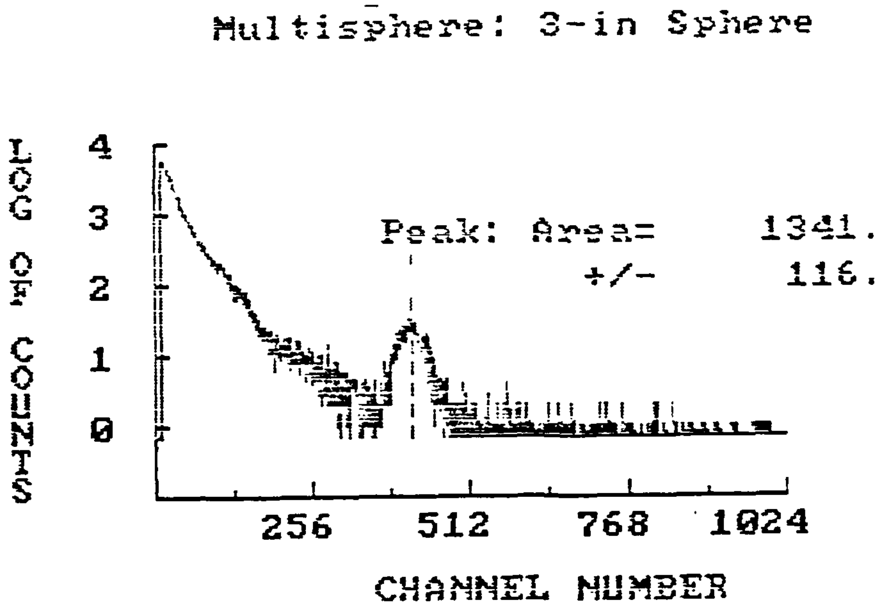


FIGURE 4A: Typical monitor output for counts versus channel number obtained using the Multisphere Spectrometer. Printed output was obtained using the print screen from the keyboard.

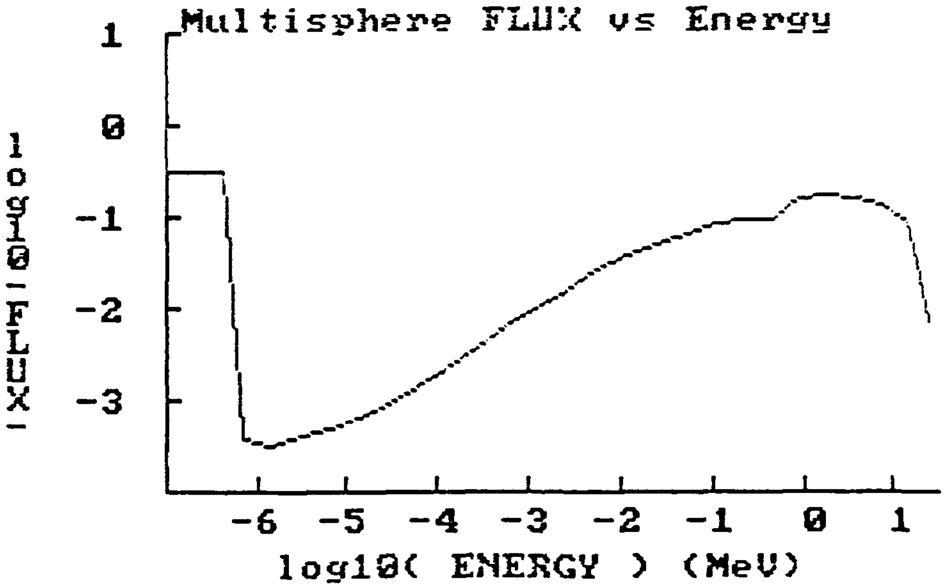


FIGURE 4B: Typical monitor output of the neutron flux versus energy for the Multisphere Spectrometer. Output was obtained using the print screen from the computer keyboard.

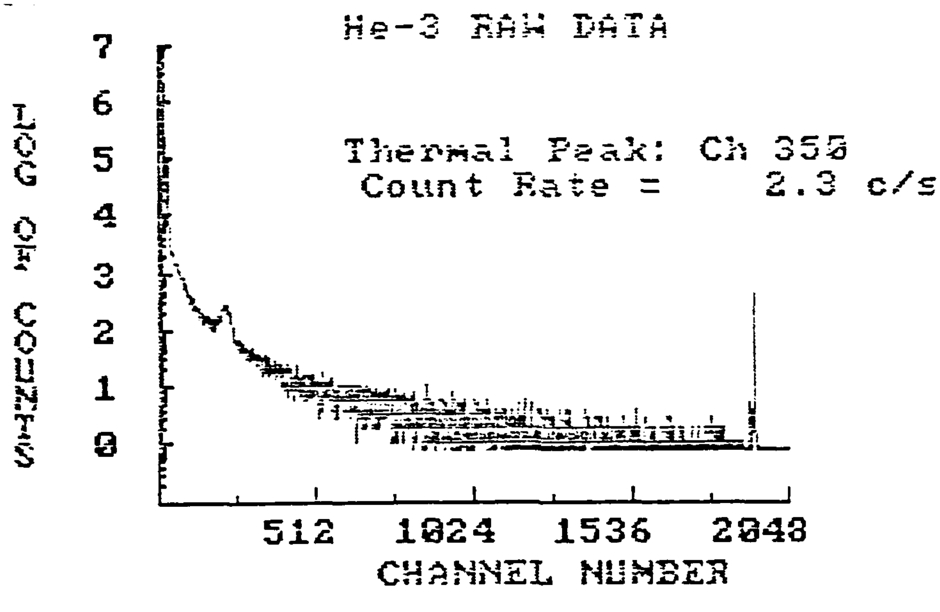


FIGURE 5A: Typical output from Helium detector, obtained using print screen from the computer keyboard. This gives sample output of counts versus channel number, which is related to energy.

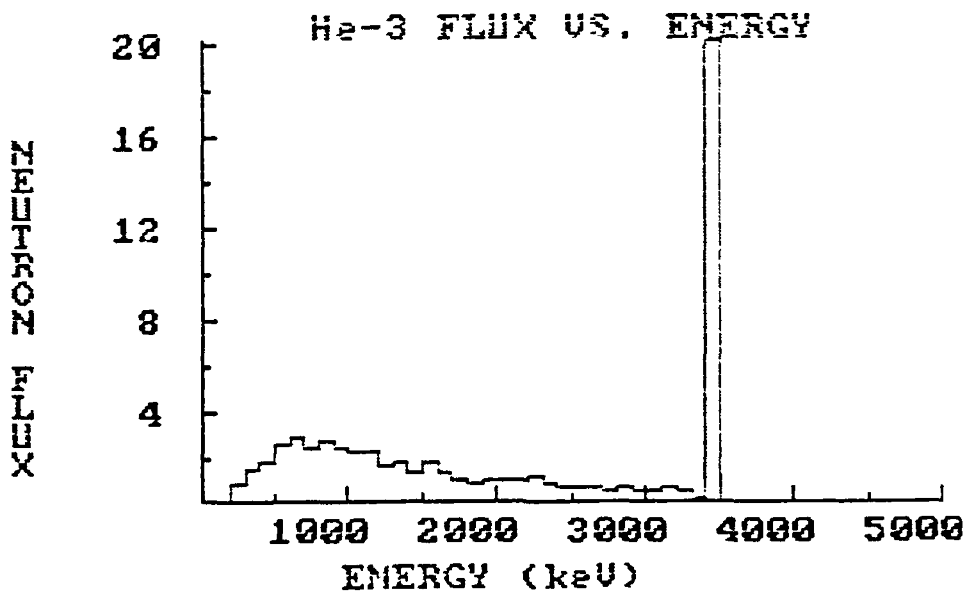


FIGURE 5B: Typical output from the Helium detector for the neutron flux versus energy. Output obtained using print screen from the computer keyboard, which shows typical monitor output.

System Configuration	ADM 300 Dose Rate mrem/hr	Multisphere Spectrometer				Theory Flux n/sqcm/s	Corrected Dose Rate mrem/hr
		Dose Rate mrem/hr	Quality Factor	Ave. E MeV	Flux n/sqcm/s		
Background	0.095	0.060	7.100	1.941	1.090	Unknown	0.084
Cf Port	2.450	1.880	7.000	0.591	61.400	Unknown	2.686
PuBe (1 foot)	81.000	64.100	8.900	1.967	608.000	542.000	72.022
PuBe (1 meter)	13.000	8.640	7.800	3.419	86.000	50.300	11.077
PuBe (15 feet)	0.465	0.336	7.600	1.974	5.270	2.410	0.442
PuBe (1 meter Wall)	1.330	0.800	7.000	0.838	22.360	Unknown	1.143
Depleted Uranium	1.440	0.099	7.700	1.763	1.570	Unknown	1.290

TABLE ONE: Multisphere Spectrometer output including comparison to ADM 300.

Detector Arrangement	Count Tim ADM 300 Dose Rate in mrem/hr						
	0.095 mrem/hr	0.465 mrem/hr	1.330 mrem/hr	1.440 mrem/hr	2.450 mrem/hr	13.000 mrem/hr	81.000 mrem/hr
Bare Det.	0.817	0.259	0.299	1.398	0.279	0.111	0.215
Cd Cov. Det.	2.592	0.430	0.299	1.540	0.524	0.264	0.390
3" Sphere	0.936	0.360	0.299	0.374	0.213	0.134	0.025
5" Sphere	0.605	0.263	0.299	0.257	0.136	0.080	0.025
8" Sphere	0.662	0.239	0.299	0.230	0.215	0.077	0.025
10 " Sphere	0.578	0.234	0.299	0.365	0.351	0.090	0.024
12" Sphere	0.750	0.155	0.299	0.453	0.627	0.087	0.177
Total	6.940	1.940	2.093	4.617	2.345	0.843	0.881

TABLE TWO: Multisphere count time versus Dose Rate determined by ADM 300 detector.

Table Two gives some information concerning the count time needed to obtain good statistical results from the computer analysis program. This table does not give the minimum time needed to obtain good results (quoted errors below 10%). It gives a set of information that can be used as a rule of thumb.

The 10 inch Bonner Sphere from the Multisphere Spectrometer can be used as a survey meter. Table Three shows that the 10 inch sphere output and quoted error level off quickly in time. While only the ten inch sphere is used in this analysis, it can be inferred that the results should be similar for all sphere configurations. The actual length may be larger but should level off fairly quickly.

Table Four gives the experimental results for the Helium Proportional detector. The table includes the Dose Rate, Quality Factor, Average Energy, the dose rate determined using the ADM 300 survey meter, and the Corrected Dose Rate. The same source and detector configurations were used for the helium and the Bonner spheres.

Table Five gives some information concerning the stabilization of the helium detector's output as the count time was increased. This experiment was carried out for only one configuration of the source and detector.

Table Six gives a comparison of output values for the ADM 300 survey meter, the Helium Proportional detector and the Multisphere Spectrometer. The values compared are the *Quality Factors, Average Energy, and the Corrected Dose Rate.*

Figure 6 gives a typical experimental arrangement used. In the case of the helium detector the detector was set perpendicular to a line connecting the detector with the source. This meant that most of the radiation entering the detector would do so from the side. The Li(I) scintillation detector used with the Bonner sphere was arranged so that a line connecting the source to the detector would strike the end of the detector.

DISCUSSION OF RESULTS

The results will be discussed in the order that they are presented in the tables. This will be followed by a comparison of the neutron flux versus energy given by both the helium and multisphere detectors. In the discussion it should be remembered that errors of 15 to 20% in neutron measurements are not uncommon. This is especially true when portable measurement devices are used: The system analyzed was designed to be moved from site to site.

Count Time Minutes	Dose Rat mrem/hr	Error %
1.667	0.370	34.800
6.667	0.350	7.400
16.667	0.350	3.200
31.667	0.350	2.300

TABLE THREE: Dose Rate and Error versus Count Time.

System Configuration	ADM 300	He Proportional Detector			Corrected
	Dose Rate mrem/hr	Dose Rate mrem/hr	Quality Factor	Ave. E MeV	Dose Rat mrem/hr
Background	0.095	6.671	9.100	2.436	7.331
Cf Port	2.450	5.910	8.900	2.595	6.640
PuBe (1 foot)	81.000	70.900	9.300	2.277	76.237
PuBe (1 meter)	13.000	11.609	9.500	1.850	12.220
PuBe (1 meter Wall)	1.330	6.828	9.800	1.442	6.967
Depleted Uranium	1.440	6.200	10.100	1.338	6.139

TABLE FOUR: Experimental Results from the Helium Detector, includes corrected value of Dose Rate and ADM 300 value for comparison.

Time Minutes	Quantity Measured				
	Channel Number	Rate CPS	Ave. E MeV	Quality Factor	Dose Rat mrem/hr
5.000	350	2.400	1.744	9.700	8.700
20.000	350	2.300	1.914	9.600	7.800
35.000	350	2.300	2.060	9.400	7.786

TABLE FIVE: Experimental values from Helium detector versus time of count in minutes.

Source Configuration	Quality	Factor	Ave. E.	MeV	Corrected Dose Rate mrem/hr		
	He	MS	HE	MS	He	MS	ADM 300
Background	9.100	7.100	2.436	1.941	7.331	0.084	0.095
Cf Port	8.900	7.000	2.595	0.591	6.640	2.686	2.450
PuBe (1 foot)	9.300	8.900	2.277	1.967	76.237	72.022	81.000
PuBe (1 meter)	9.500	7.800	1.850	3.419	12.222	11.077	13.000
PuBe (1 meter Wall)	9.800	7.000	1.442	0.838	6.967	1.143	1.330
Depleted Uranium	10.100	7.700	1.338	1.763	6.139	1.290	1.440

TABLE SIX: Comparison of the experimental results from the Multisphere Spectrometer and the Helium Proportional Detector. The ADM 300 Survey meter is used for comparison.

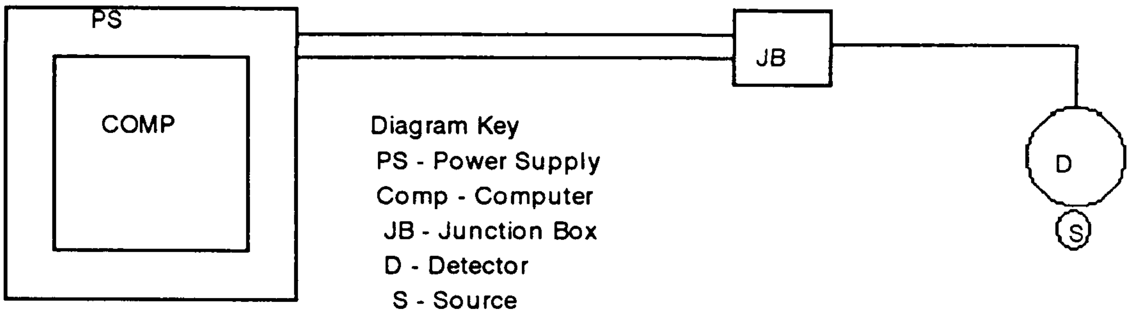


FIGURE 6: Experimental arrangement for the Multisphere Spectrometer and the Helium Proportional Detector.

As seen in Table One the corrected dose rate for the multisphere system compares very well with the results obtained with the ADM 300 survey meter. The manufacturer claims the ADM 300 should give results within 15%. It must be remembered this is assuming a neutron quality factor of 10. If the quality factor differs from 10 the results will be off. This would imply that the results for the MS system for dose rate determination is fairly accurate. The neutron flux determination is good for a high flux. However as the flux decreases, the accuracy of the total flux goes down. For a flux of over 600 neutrons per cm^2 per second the error was less than 10%. However for a flux of 5, the error was over 50%. The manufacture of the detector says that for a dose rate below about 20 mrem/hr the results are not as good as for higher rates. It is interesting to note that the dose rate obtained is quite good. Finally, the quality factor for the same PuBe source varied by as much as 30%. The quality factor decreased as the flux decreased.

Table Two gives a rule of thumb to estimate the count time needed to get good statistics for use by the computer program to calculate the different results. One can obtain calculated accuracy of better than 10% by using the information in the table. For dose rates below about 200 μrem/hr as measured by the ADM 300 survey meter, the count time was very long. According to the table, it took approximately seven hours. This was watched very closely and is an indication of the time needed for very low dose rates. When the dose rate reaches about 500 μrem/hr, the count time is about two hours; and this holds until dose rates reach about 3 mrem/hr. The long count at 1.44 mrem/hr in the table resulted from allowing two of the measurements to be taken while seminars were held. Once the dose rate reaches about 10 mrem/hr, the count time drops to less than one hour. A complete set of measurements using the Field Neutron Spectrometer (using all detectors) can be made in less than ten hours. The time values for each individual Bonner Sphere is given at the different dose rate values.

The ten inch sphere can be used as a survey meter. When used as a survey meter the results are nearly the same as when the whole system is used. The quoted dose rate in Table Three is about 350 μrem/hr while the value for the whole system was 336 μrem/hr. The interesting observation from this table is that the value of the dose rate leveled off quickly and the error dropped off drastically. One can hypothesize the leveling off and error drop off would be the same for all the sphere.

Table Four gives the results for the helium proportional detector. The quality factors do not vary less than 15% from each other. The helium detector gives inconsistent results for the dose rate. For high dose rates the helium detector appears to give good results, while at lower dose rates the detector gives very poor results. The detector seems to level off at a dose rate between six and seven mrem/hr.

Table Five shows that the values obtained from the helium detector level out quite quickly. Five, twenty and thirty-five minute counts were used. The detector was placed about 10 feet from the PuBe source. The peak channel number remained the same and the count rate dropped by only about 4%. The Dose Rate recorded dropped about 13% in the first twenty minutes but then leveled off. The Quality Factor slowly dropped by about 3%.

Table Six gives a comparison of the numerical output from the Helium detector with that of the Multisphere detector. The quality factor obtained from the helium detector is consistently higher than that from the multisphere spectrometer. Given the error in calculating the average energy in the multisphere spectrometer, no real statement can be made concerning a comparison of average energies between the different detectors. The three detectors compare quite well in their dose rate determinations at higher neutron fluxes. At lower fluxes, the helium detector appears to give spurious results.

The appendix gives several neutron flux graphs versus energy for both the multisphere detector and the helium detector. No direct comparison can be made due to the extreme differences in the scales used. At present, the program used by the Field Neutron Spectrometer does not keep the raw data from the Bonner Sphere system. This does not allow for rescaling the plotted output of neutron flux versus energy

CONCLUSIONS

It would appear that the Multisphere component of the Field Neutron Spectrometer can be used to monitor nuclear facilities. The largest drawback is that for low dose rates the system may have to be used for about ten hours. This should not cause an inconvenience since for the components with longer counts the system can be left alone for long periods of time. The helium detector can be used at higher dose rates. At lower dose rates its results become inconsistent with the other detectors. It is unfortunate that the Tissue Equivalent Proportional Counter did not arrive back so that it could be used in this analysis and as a comparison for the dose rates with the other two detectors. Having to use the PuBe in a jury rigged situation instead of the Cf sources caused some problems with keeping consistent source and detector alignment. Also, it is difficult to compare this study with the Quality Assurance Quality Control work done by Battelle, since they used a Cf source which has significant spectral differences from that of PuBe.

FURTHER STUDY

The program that operates the detector would often lock up and the system needed to be restarted. The program needs to be worked through to determine why this periodically happens and put an interlock to prevent it from shutting down the detector. This can be serious, since for some of the longer counts the operator may not be there to catch the shut down and time could be lost waiting for the system to be restarted.

The operator of the system needs a comprehensive set up and operating manual. The one supplied by the manufacturer does not show the connections to set the detector up and does not give detailed directions in the use of the system.

Another weak point in the program is that the raw date for the Bonner spheres is not kept by the program as the helium raw data is kept. If one wanted to study this raw data in detail and use an alternate analysis, they can not do it. The program needs to be rewritten to allow the raw data to be retained.

Finally the TEPC needs to be analyzed and compared to the other two detectors. Finally, a complete analysis of the efficiency of all the detectors needs to be made, so that Minimum Detectable Activity can be determined.

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Appendix:

This section gives a complete diagram of the connections used in setting up both the Multisphere Spectrometer and the Helium Detector. The operations manual does not give this information.

Figure A1: The connections for the Multisphere Spectrometer:

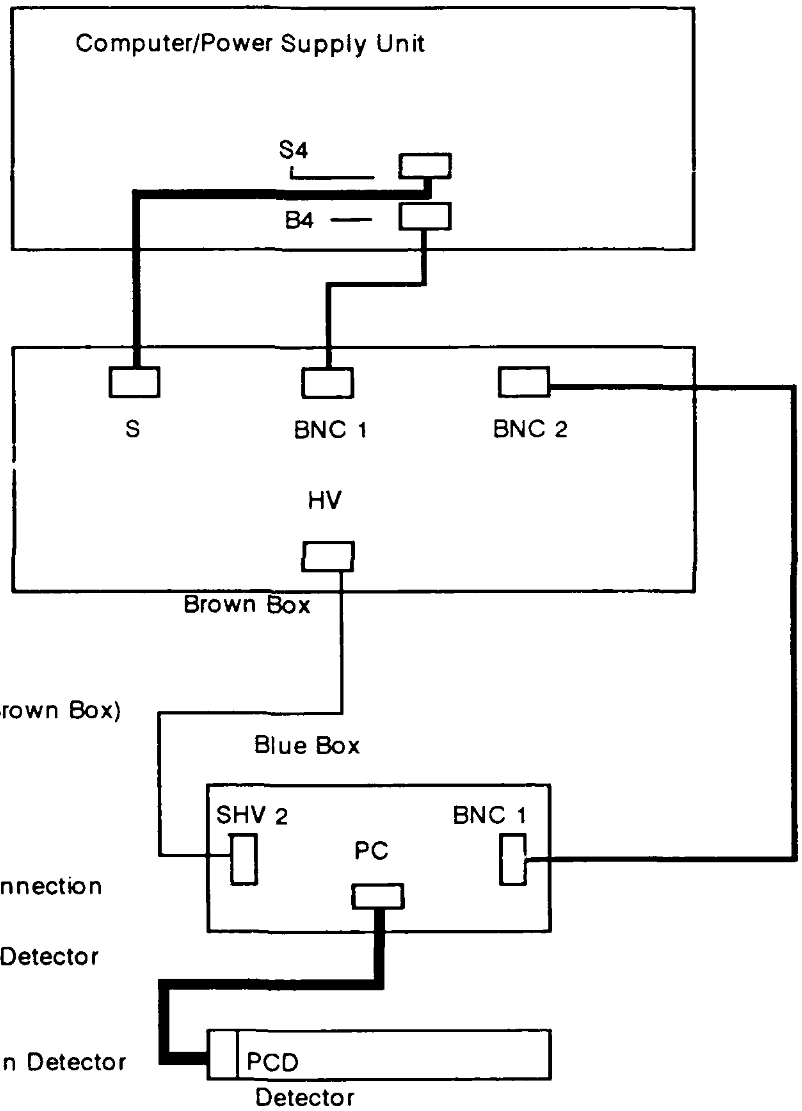


Diagram Key
S4 - Serial Connection Port 4
B4 - BNC Connection Port 4

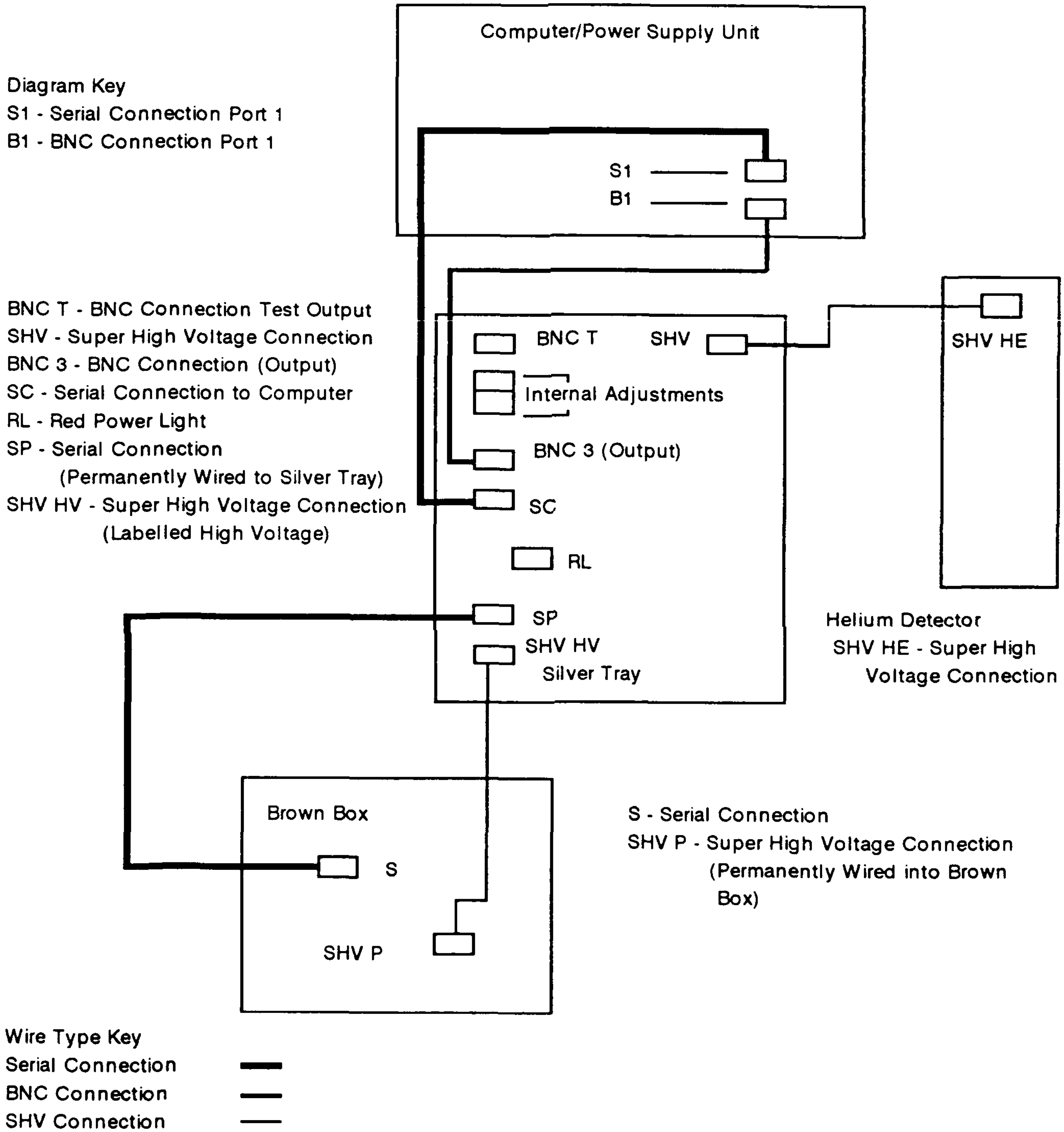
S - Serial Connection
(Power)
BNC 1 - BNC Connection
(Output)
BNC 2 - Bnc Connection
(Input)
HV - High Voltage Connection
(Permanently Wired into Brown Box)

BNC 1 - BNC Connection
(labelled 1)
SHV 2 - Super High Voltage Connection
(labelled 2)
PC - Permanent Connection to Detector

PCD - Permanent Connection on Detector

Wire Type Key
Permanent Wire
Serial Cable
BNC Cable
SHV Cable

Figure A2: The connections for the Helium Proportional Detector:



ULTRASOUND PRODUCTION BY ADULT RATS (RATTUS NORVEGICUS)

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Abstract

The literature on ultrasonic vocalizations of adult rats (Rattus norvegicus) was reviewed. The "22-kHz" call, which is emitted in a variety of contexts, has been hypothesized to indicate a state of anxiety or distress. The occurrence of the 22-kHz call during the presentation of startle-eliciting acoustic stimuli was examined in both STS soman-treated rats and untreated controls. Twenty percent of STS rats emitted the 22-kHz call during startle tests, while 22% of the controls did so. Complete acoustical analyses were not possible, but the physical characteristics of the call did not appear to differ between groups. Rat vocalizations also were recorded during presentation of shock and during exploratory behavior. In addition, recordings of rhesus macaque (Macaca mulatta) vocalizations were made in several testing and housing situations, in order to develop a baseline data base for investigating the expression of emotionality and stress in macaque vocalizations.

Introduction

Ultrasound production by rats (Rattus norvegicus) was reported as early as 1954 by Anderson, but it was not until the work of Noirot (1968) and Sewell (1967, 1968, 1970) that systematic study of this phenomenon began. Noirot's work focused on ultrasounds produced by infant rodents. Sewell's early studies of adult rat ultrasound suggest ed a rich variety of vocalizations produced in many behavioral contexts. Later work focused on sounds occurring in a few restricted contexts; the most common situations examined have been male-male aggressive interactions and sexual encounters between a single male-female pair. Other studies have examined drug effects on shock-elicited ultrasound (e.g., Sales et al, 1986), ultrasound produced by pregnant females (Lewis & Schriefer, 1982), and ultrasound in isolated individuals (Francis, 1977). An annotated bibliography of published literature on adult rat ultrasound was prepared during the summer fellowship period. What follows is a brief review of this literature.

Agonistic Behavior

Sales (1972a) presented the first detailed description of rat ultrasonic vocalizations associated with agonistic (i.e.,aggressive and submissive) behavior. She reported two types of calls which occurred during agonistic interactions between males - "short" pulses (3-65 msec) of 45-70 kHz and "long" pulses (800-1600 msec) of 23-30 kHz. Short pulses often showed marked frequency fluctuations; they occurred in association with overt aggressive acts, displacement behavior, or one rat "crawling over" another. Long pulses were of constant frequencies, or showed slow drifts in frequency. They occurred most often when one animal was crouched in a submissive posture and the other was active.

While some authors (Sewell, 1970; Sales, 1972a; Sales & Pye, 1974; Brown, 1976; Ghiselli & LaRiviere, 1977) have published sonagrams of these calls, detailed quantitative descriptions of the structure of these calls apparently have not been published. Rather than examining the structure of the calls, most researchers have simply used a heterodyne receiver tuned to a narrow frequency band to detect the rate of occurrence of the vocalizations.

Sales' early work suggested that the long pulses appeared to be submissive and the short pulses aggressive. Subsequent studies focused on determining the communicative function of these calls. These studies examined male-male aggression, generally using the "resident-intruder" paradigm, in which a stranger (an "intruder") is introduced into the home cage of a "resident." This procedure elicits aggression on the part of the resident. Early on, it was suggested that the long pulses produced by the submissive animal (the intruder) may function to stop attack by the resident aggressor. In fact, Lore et al (1976) found that experienced intruders produced more long pulse vocalizations and were attacked less than naive intruders; this seemed to indicate a relationship between these calls and the cessation of aggression by the resident. Later studies, however (e.g., Takahashi et al, 1983; Thomas et al, 1983), were unable to demonstrate a relationship between vocalizations (either long or short pulses) and aggression. The question of the communicative function of ultrasound in aggressive contexts thus remains unanswered.

The studies of rat ultrasound during aggressive behavior have thus far been rather limited in scope. As was noted above, these studies examined only male-male aggression. Sales (1972a) reported short and long pulses during agonistic encounters between males and lactating females; apparently this is the only published observation of ultrasounds during male-female aggressive encounters. In addition, the contexts in which aggression was observed during these tests were very restricted. In the wild, rats form large stable colonies of both males and females (see Barnett, 1975); an animal would thus come into frequent contact with familiar individuals with which it had established relationships. Studies of ultrasonic vocalization, however, have typically examined brief encounters between strangers in small cages. It seems possible that ultrasounds might have evolved in the natural setting to have some communicative functions not obvious in these restricted testing situations (e.g., recruitment of colony mates; indication of intent to flee (which would not have been possible in small testing cages)). These possibilities have not been explored thus far.

Sexual behavior

Both males and females produce a variety of ultrasounds during sexual behavior. One of the most frequently-studied sounds is the male-produced "22 kHz" call, which primarily occurs following ejaculation (see Barfield & Geyer, 1972, 1975). Early studies concentrated on the occurrence of this call during the male's post-ejaculatory refractory period, but the call is also emitted prior to ejaculation, and females also emit the call on occasion (Barfield & Geyer, 1972, 1975; Thomas & Barfield, 1985). This call consists of a single component of approximately 22-23 kHz with little frequency modulation. Typical duration of the call is approximately 1000-3000 msec, and intensity has been measured at up to 80 db (Barfield & Geyer, 1972, 1975).

Other calls emitted during sexual behavior were first described in detail by Sales (1972b); they typically range in frequency from 40-70 kHz, with some calls having components as high as 120 kHz. Some of these calls consist of a single component with slow drifts in frequency throughout their length. Others are "trains" of very brief pulses (2-40 msec) with a great deal of frequency modulation (30-50 kHz). Sales reported duration of these calls to range from 2 to 500 msec. The calls apparently occur during all phases of a copulatory episode. Barfield and his colleagues, who are responsible for the majority of studies of rat ultrasound during sexual behavior, (e.g. Barfield & Geyer, 1975; Geyer, McIntosh, & Barfield, 1978; Thomas, Talalas, & Barfield, 1981; White & Barfield, 1990) often examined the occurrence of these vocalizations by using a heterodyne receiver tuned to 50 kHz; generally no attempt was made to differentiate among calls on the basis of physical characteristics such as duration or frequency modulation patterns (but see White, Cagiano, Moises, & Barfield, 1990).

Despite the fact that considerable research on rat vocalizations during sexual behavior has been conducted since 1972, surprisingly little has been clearly established concerning the structure or the functional significance of these sounds. As is the case for ultrasounds produced during aggression, published sonagrams and acoustical analyses of the calls are rare (Sales, 1972b; Thomas & Barfield, 1985; White, Cagiano, Moises, & Barfield, 1990), and no studies have included complete quantitative descriptions of the calls.

Barfield & Geyer (1972, 1975) originally hypothesized that the male 22-kHz postejaculatory call functioned to keep the female away from the male during the male's postejaculatory refractory period, but later research did not indicate a clear relationship between the call and female behavior during this period (Anisko et al, 1978; Thomas et al, 1982a). The most common and consistent finding indicating a behavioral response to ultrasonic calls is that female darting (a type of proceptive behavior) is more frequent when male vocalizations are present during the pre-ejaculatory period. When males are devocalized, darts decrease relative to control conditions (e.g., Thomas et al, 1981; Thomas et al, 1982a; Thomas et al, 1982b).

In the wild or under "free-ranging" captive conditions, rats live in large, mixed-sex colonies, and mating generally occurs among several males and females at once, with the animals "taking turns" at copulation (see McClintock et al, 1982). Females often play a major role in the pacing of sexual behavior, actively approaching and avoiding males in order to solicit mounts. Despite the complexity of rat sexual behavior in the natural setting, sex-related ultrasounds have generally been examined in very restrictive, artificial conditions in which a single male and female are introduced to one another in a small enclosure and allowed to copulate for a brief period (often as brief as 5 min, or for only the first few ejaculations of a copulatory episode). In early studies, female behavior was often ignored, and it was assumed that the male produced most, if not all, of the vocalizations detected. Later studies indicated that females vocalize throughout a copulatory episode. Given that rats live and mate in groups, it seems possible that vocalizations emitted during sexual behavior may be designed to communicate with group members other than the sexual partner. Males may be coordinating their behavior with other males; females may also coordinate their behavior among themselves. These possibilities apparently have never been examined in these studies.

In addition, the majority of these studies utilized heterodyne receivers tuned to a small frequency range (often 45-55 kHz) to detect ultrasounds. These receivers produce an audible signal whenever a sound within the selected frequency range is detected. This hardly seems to be a reliable method for examining the rate of occurrence of a signal which varies from approximately 30-120 kHz, as do higher frequency rat ultrasounds. Sounds which did not fall into the selected frequency range would have been missed. It seems likely that these undetected calls may be important units in the sequence of vocal and non-vocal behavior occurring during copulation.

Other Contexts

Despite Sales' early work indicating that rats produce ultrasound in a variety of contexts, little research has examined situations other than sexual and aggressive (but see Francis, 1977; Lewis & Schriefer, 1982; Rosenzweig et al, 1955). One topic which has been the subject of several reports is shock-elicited ultrasound, and drug effects on these vocalizations (Sales et al., 1986; Tonoue et al, 1986; Tonoue et al, 1987; van der Poel et al, 1989). Apparently no detailed studies of shock-elicited ultrasound per se have been published; however, these vocalizations reportedly are very similar to the "22-kHz" call emitted during agonistic and sexual behavior. Sales et al (1986) report unpublished data on 20-30 kHz ultrasonic calls in response to aversive stimuli. Tonoue et al (1986) present the most detailed data; they report 22-28 kHz pulses of 300-1200 msec in response to shock. The calls were emitted "for several minutes" following delivery of shock. Several substances, including beta-endorphin, diazepam, and chlorpromazine, attenuate these vocalizations.

Recent work by Kaltwasser (1990) examined the occurrence of vocalizations in response to startle-eliciting acoustic stimuli. She reports calls slightly lower in frequency (approximately 19-21 kHz) than those reported to occur following shock, during aggression, or during the postejaculatory period. Other characteristics of the sound were similar to the "22 kHz" call reported in these contexts. Kaltwasser reasons on this basis that the startle-eliciting stimulus evokes anxiety in the rat.

Criticisms of the Literature

Several important limitations of this literature have been discussed above. In particular, many of these studies tested animals in small enclosures which restricted normal activities and in highly artificial, unnatural social situations. Given this, it may not be surprising that the communicative functions of these calls remain unclear. Wild rats live in colonies, and it appears that none of the research on these sounds has examined the possibility that the communicative function of these calls may not be apparent in behavioral tests between pairs of strangers.

In addition, in some studies, the use of a tuned heterodyne receiver to detect occurrences of sounds may have resulted in a seriously distorted picture of the relationship between ultrasound and behavior. Early studies reported the occurrence of vocalizations ranging from 20 kHz to over 100 kHz during sexual and agonistic encounters. The use of an instrument responsive to only a small range of these frequencies could result in an underestimation of the amount of vocalization occurring, and would not enable observers to discern relationships between the detected calls and calls outside the detected frequency range, or between non-vocal behavior and calls outside the detected range. In other words, in many cases, researchers may have been missing important behavioral sequences and relationships by ignoring much of the animals' vocal behavior.

Another criticism noted above is the lack of published quantitative descriptive data on the acoustic characteristics of the vocalizations themselves. A few researchers have published sonagrams, but there are few basic data on temporal and spectral characteristics of the calls. In addition, little is known concerning the developmental course of these vocalizations, strain differences in vocal behavior, or vocal behavior in wild Rattus norvegicus. Sales (1979, 1972a) and Noirot (1968) examined these topics, but they have not been investigated further by researchers.

It is important to acknowledge the difficulties involved in performing studies which would address these criticisms. Ultrasonic vocalizations typically do not travel far due to their extremely short wavelengths, which are readily reflected and absorbed by objects in the environment. Collecting vocalization data from a group of animals in a complex testing apparatus would present difficult problems. The use of appropriate acoustical recording equipment, rather than heterodyne receivers, would allow investigators to study in detail the physical characteristics of these vocalizations. However, equipment designed for accurate recording and analysis of ultrasound is considerably more expensive than heterodyne receivers.

Important questions remain concerning the functions of rat ultrasonic vocalizations. Very few conclusions can be drawn based on published literature. The "22-kHz" vocalization has been of particular interest to researchers, since it appears to occur in a variety of contexts. In tests of sexual behavior, it is occasionally emitted by males and females prior to ejaculation, and is emitted by males almost continuously for several minutes following ejaculation. It is also emitted by the submissive animal in male-male aggression tests, and occurs in response to shock and to other stimuli which may be considered aversive (e.g., startle-eliciting acoustic stimuli). Because it is emitted in these latter contexts, it has sometimes been referred to as a "distress" call, and the effects of various drugs on the rate and duration of 22 kHz calls have been taken as evidence of the anxiety-reducing properties of these agents. However, it is important to note that there apparently are no published reports demonstrating a relationship between rate, duration, or other acoustic characteristics of the 22 kHz call and intensity of aversive stimuli. The exact nature of the relationship between this call and aversive stimulation thus remains to be delineated.

Ultrasonic Responses to Startle-Eliciting Acoustic Stimuli

One objective of the research performed this summer (in collaboration with Dr. B.E. Mulligan, AFOSR Summer Research Program, Univ. of Georgia) was to examine in more detail the relationship between startle-eliciting acoustic stimuli and rat 22-kHz ultrasonic vocalizations.

The acoustic startle response has been utilized by the Human Extrapolation Function Laboratory of OEDR to examine the effects of the OP agents soman, as well as other substances, on rats. The startle response of STS soman-treated rats differs from that of untreated controls. These rats generally show greater startle responses relative to controls (M. Murphy, pers. comm.). We hypothesized that this hyper-reactivity demonstrated by the STS rats might be reflected in increased 22-kHz calls in the startle situation relative to controls. Rate or duration of 22-kHz calling might be a valuable assay of reactivity or "emotionality" during acoustic startle testing as well as other testing paradigms (Kaltwasser, 1990).

Methods

Subjects were 19 adult male Sprague-Dawley rats. Ten subjects (STS group) had received at least one injection of 100 micrograms/kg of soman 96-99 days prior to the present study. (Soman-treated animals which did not convulse following the first soman injection received a second injection the following day.) Animals which convulsed in response to soman injections and lost at least 30g in body weight were classified as STS animals. All STS animals had recovered to normal body weight levels prior to testing. Both the STS and Control (n=9) subjects utilized here had participated in 3 testing sessions in activity monitoring apparatus, once following injection with amphetamine, once following caffeine injection, and once following saline. All STS animals utilized here were classified as "low responders;" their activity was not greatly affected by amphetamine exposure. All subjects (both STS and control) had also had one prior testing session in the startle apparatus.

The testing apparatus (San Diego Instruments) consisted of a cylindrical plexiglass chamber mounted on a vibration-sensitive platform. The chamber and platform were housed inside a larger chamber. Delivery of the acoustic startle stimulus and measurement of the startle response were performed by computer. The startle stimulus was a broadband 40 msec pulse with rapid onset and offset. Sound pressure level of the startle stimulus was measured at approximately 112.7 dB inside the testing apparatus, using a Bruel & Kjaer 2230 sound level meter with type 1625 octave filter set. Each rat was exposed to a series of 15 stimuli at 30 sec intervals. The testing session ended approximately 5 sec following the 15th stimulus. Total testing time for each animal was therefore approximately 7 min.

Vocalizations were recorded using a Sennheiser MKH 416T microphone and a Uher 4000 tape recorder, with a tape speed of 7.5 inches per sec. Frequency response of this system is flat to approximately 20 kHz. The microphone was located inside the startle apparatus, at a distance of approximately 3.5 inches from the subject's head.

Results

Three measures of startle response were examined: MAX, the maximum amplitude of the startle response; TIME, the time from the onset of the startle stimulus to MAX; and AVG, the average response amplitude over a 250 msec period beginning at the onset of the stimulus and ending 210 msec after stimulus offset. Only the results for AVG differed significantly between groups (MAX: means - STS=1067.56, Control=577.21,

$F(1,17)=3.94$; TIME: means - STS=39.51, Control=35.21, $F(1,17)=0.84$; AVG: means - STS=110.24, Control=44.53, $F(1,17)=6.375$, $p<.05$).

Vocalization tapes were examined using a Kay CSL Model 4300; tapes were played back at half-speed (3.75 inches per sec) to ensure that high frequency calls would be detected. Two of the 10 STS subjects emitted 22-kHz vocalizations during testing; 2 of the 9 control subjects did so. These vocalizations generally took the form of a series (or "bout") of 2 or more individual calls (or "units"). Each unit generally lasted approximately 400-800 msec. The first unit of a bout was generally longer and usually lasted 1000 msec or longer. Units were separated by intervals of approximately 100-250 msec. Complete analyses of temporal patterning of the calls was not completed; however, in a sample of 14 call bouts examined from all 4 vocalizing animals, unit duration ranged from 281 to 2120 msec, while inter-unit intervals ranged from 85 to 300 msec. The calls did not appear to differ systematically between groups; however, there was a great deal of individual variability in the temporal patterning of the calls. Data on mean number of units per bout are presented in Table I. Temporal patterning of calls did seem to be influenced by the startle stimulus, in that animals would sometimes pause immediately following a stimulus. However, startle stimuli did not appear to "elicit" vocalizations; that is, calls did not closely follow startle stimuli.

Detailed analyses of the spectral characteristics of the vocalizations could not be performed due to narrow bands of high-frequency energy which were detected by the recording equipment. This energy was quite intense and resulted in distortion of the recordings of the rats' ultrasonic calls. This energy does not appear to be due to an auditory stimulus. It was not audible during recording sessions and was not detected by sound level meter prior to data collection. Frequency of these calls appeared to be between 19 and 24 kHz, with individual units often having sharp upward or downward frequency modulations at the beginning and/or end of the unit. The first unit of a bout generally showed a pronounced, gradual downward frequency shift at the beginning of the pulse. This frequency modulation was sometimes as large as 6 kHz.

Discussion

The acoustic characteristics of the calls generally matched those of the "22-kHz" call reported by other authors. However, the percentage of animals vocalizing during testing was lower than that reported by Kaltwasser (1990) under similar testing conditions. Greater percentages of Kaltwasser's subjects responded during later test days, so it is conceivable that more animals would have vocalized if testing had continued longer than 1 day. Although conclusions based on only 4 vocalizing animals must be regarded as preliminary, it does not appear that the pattern of 22-kHz calls exhibited by the STS rats differed from that of the Control subjects. The 22-kHz calls thus do not indicate greater emotionality or distress on the part of the STS animals, based on the limited testing done here. In future studies, tests should be continued for several days. In addition, the use of special apparatus which would shield the recording equipment from high intensity electrical signals should be used.

Other Research Activities

I collaborated with Dr. B.E. Mulligan (AFOSR Summer Research Program Faculty Associate, Univ. of Georgia) and Dr. M.R. Murphy (AL/OEDR) on several additional research activities during the summer period.

Recordings of rat vocalizations were made in several experimental settings utilized in OEDR laboratories. Our purpose was to examine the incidence of calling in these situations in order to establish some baseline measures of vocalization. Four rats were recorded while receiving unavoidable shock in standard operant chambers. Several rats were recorded during exploratory behavior in two different laboratory settings. We hypothesized that rats would vocalize at a high rate in response to shock, as has been reported in previous studies (e.g., Sales et al, 1986; Tonoue et al, 1987). Recordings from these sessions have not yet been analyzed.

Recordings were also made of rhesus macaque (*Macaca mulatta*) vocalizations in several testing and housing situations (see Table II). This was done in order to collect data on the feasibility of recording monkey vocalizations in these settings at the Armstrong Laboratory, and to examine the acoustic characteristics of calls normally emitted in these situations. We hypothesized that physical characteristics of these vocalizations might be extracted which could then be correlated with "emotional" states of the vocalizing animal.

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TABLE I

VOCALIZATION DATA

Subject	Group	# of Bouts	x Units/Bout	Range
6-2	STS	3	2.0	(1-4)
7-2	STS	14	7.86	(3-18)
43-2	Control	5	2.2	(2-3)
44-2	Control	18	5.28	(3-8)

TABLE II

MONKEY VOCALIZATION RECORDINGS

A. Testing and Training Situations

1. PEP (Primate Equilibrium Platform) Testing
2. PEP Training Session
3. Restraint Chair Training
4. Blood Alcohol Level Tests

B. Housing Situations

1. Single-housed animals, indoor caging
   a. During feeding and caretaker maintenance activities
   b. During undisturbed periods
2. Group-housed animals, outdoor caging

DAVID W. BARNETT

REPORT NOT AVAILABLE

AT TIME OF

PUBLICATION

COMPUTER ASSISTED MICROSCOPY OF CELLS

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Trinity University

Abstract:

The project described herein dealt with performing both light and electron microscopy of cells of interest to the lab of Dr. Johnathan Keil, Directed Effects, Armstrong Lab, Brooks Air Force Base, Texas. The microscopy data acquired from Bacillus anthracis and RAW 264.7 mouse macrophage cells were subjected to various computer analysis routines developed for this purpose. Graduate students Christopher Collumb and Tod Romo worked with me on different aspects of the project. Mr. Collumb in his summer report has reported on the efforts to monitor RAW cell growth with an optical scanner. Mr. Romo developed techniques for the three dimensional visualization of the RAW culture growth and early identification of RAW foci formation. My role, in addition to directing the two graduate students, was to assemble the visualization equipment, to visualize the Bacillus, and to develop extensions for the computer analysis techniques devised for cell analysis. We found that microcomputer image analysis could provide a very useful adjunct to the microscopy of cells.

Introduction:

Microcomputing has progressed to the stage where low-cost image analysis is now possible of biological materials seen through the microscope, both light and electron. This new approach involves in successive stages: 1) image acquisition, 2) image manipulation , 3) image analysis, and 4) data display/visualization. During the project period the hardware and software needed to perform these operations was assembled and experience was gained in their use.

The problem addressed with the microcomputer imaging equipment were multiple and oriented primarily with the needs of Dr. Kiel's lab at Brooks Air Force Base. Dr. Kiel has been examining growth factor elaboration by RAW 264.7 mouse macrophage cells. Further, he has been developing a fast assay for the identification of Bacillus anthracis. Related to data visualization, Dr. Frei, also of the Directed Effects Division at Brooks Air Force Base, was trying to display large data sets of temperature response by microwave treated rats. We applied the new equipment in the Scientific Visualization Lab at Trinity University to these problems. In essence we became a service facility to the visualization needs of the Directed Effects Group at Brooks AFB. This approach proved to be quite exciting.

Methods

The microcomputer system at the Trinity visualization lab is based on a Macintosh 2ci microcomputer. The CPU has 20 Megs RAM and an internal 80 Meg hard drive. An additional Gigabyte of external storage is possible through a WREN drive, TEAC tape drive, and Syquest drive. Four such CPU's are Local Talk networked to each other and operating under the new Apple System 7 protocol. Each machine has a 13-inch Apple high resolution RGB monitor. One CPU has an additional E machine 16-inch monitor which is equipped with a 24 bit color interpretor card and a Technology Works cache card for additional speed. This same machine can also operate under the UNIX operating system through Apple AUX-2. Each of three CPUs has a Data Translation DT2255 frame grabber card and one machine has a RastorOps 364 image grabber card. This is the basic computer hardware configuration used in this study.

A wide variety of microscopy is possible. One Zeiss BK-2 compound light microscope is coupled to a Javelin JE 3462 RGB camera rated at 480 line resolution. Two Nikon Labophot 2 compound light microscopes are similarly equipped with Javelin cameras as is a Nikon TMS inverted compound microscope. A Nikon SMZ-2T dissection scope equipped with a Sony DXC-151 460 line color camera completes the light microscopy equipment. An ISI-40 scanning electron microscope and an Hitachi HS-8 transmission electron microscope were also available to the project.

Images from the light microscopes are captured by means of the frame grabber boards. Electron microscope images are read by use of optical scanners including an HP ScanJet Plus and a Microtek 600SZ. Digital images are stored as either PICT files or TIFF files.

A very wide range of software is available for acquiring, manipulating, analyzing, and displaying images and data. The most important software package is NIH Image 1.XX (currently version 1.41). NIH Image can address the Data Translation board output directly but only in real time black and white. The RasterOps board allows real time color image capture but all image analysis requires interpolation of the RasterOps files before porting into NIH Image.

Image enhancement is possible through Enhance 2.0, Photoshop 2.0, and NIH Image. Acquired data can be analyzed and displayed with JMP 2.0, Excel 3.0, DeltaGraph 1.5, Wingz 1.0, and Sypglass suite.

Both data and images can be further processed using MacroMind Director 2.0, RenderMan 1.1, Authorware 1.6, and Hypercard 2.1. Display can be further output to VCR through a RasterOps VCR box or to a Polaroid CI 5000 coupled to Power Point software.

The method for growing and visualizing RAW cells is found in Mr. Collumb's summer report. The procedure used for imaging and 3-D visualization of RAW cells is recorded in Mr. Romo's summer report. The methodology for examining the bacilli cultures is found below.

1. The cultures were inoculated with experimental bacilli on appropriate media as determined by Dr. Kiel's lab. After 24 hours of culture at 37°C, the coded samples were given to Dr. Blystone.
2. The clear plastic petri plates were optically scanned with an HP ScanJet Plus. The resultant image was examined with NIH Image software.
3. Bacterial colonies were lanced and dispersed in a drop of water and heat fixed to a glass slide. This preparation was examined by light microscopy.

4. A slide was prepared as in #3 above, except the dispersion was Gram stained.

5. An innoculum of bacteria was suspended in a drop of water which in turn was coated onto a glass cover slip. The coverslip was air dried and attached to an SEM specimen stub. The preparation was then sputter coated with gold (50Å thick) in a Hummer V coater. The preparation was examined and photographed with an ISI-40 scanning electron microscope.

6. TEM was attempted but gave poor quality results and will not be reported here.

Dr. Frei's data was visualized using SpyGlass software. He had earlier subjected a rat to microwave emissions and recorded the animal's temperature response by electrodes implanted on either side of the body (right, left), colonic, and in the middle ear. The temperature data was entered into an Excel spreadsheet at the data array of 140 points per temperature sample site per microwave heating cycle (less than 30 minutes in duration). The animal was exposed to the microwaves in two orientation planes: E and H. The Spyglass Transform was used to pseudocolor the temperature points as if they were gray scale points. The color visualized data was organized to mimic the dimensional organization plane of the rat: left, colon, right, and middle ear. The data points were smoothed by interpolation. Thus with this initial visualization, 640 data points were reduced to one color thermogram of the microwave treated rat.

Results:

The results of Mr. Collumb's work may be found in his report. The results of Mr. Romo's work may be found in his report. The results of the bacterial work may be seen in three attached photomicrographs labelled Figure 1A,B,C.

The SEM procedure clearly described different morphologies for the coded bacteria provided. Dr. Kiel was satisfied that *Bacillus anthracis* could be quickly identified by the technique employed. By using NIH Image, quantitative data regarding size was also possible.

The thermograms representing the microwave experiment of Dr. Frei's are seen in Figure 2A,B. Dr. Frei was quite pleased with these initial efforts but suggested that the thermograms would be more useful if visualized through time.

Discussion:

The basic core of the summer work is best summarized by Figure 3. This figure represents the research abstract submitted to the American Society for Cell Biology for presentation at its annual meeting in Boston. The paper has been accepted for presentation on Dec. 9, 1991. A corresponding article is now in preparation. Through this work we have described a process where cells in culture can be rapidly visualized *in situ*. The advantage of such a methodology is to determine how much of an influence the culture conditions may have on the growth of cells, a poorly understood area.

Figure 1A Bacillus spores at 2000X.

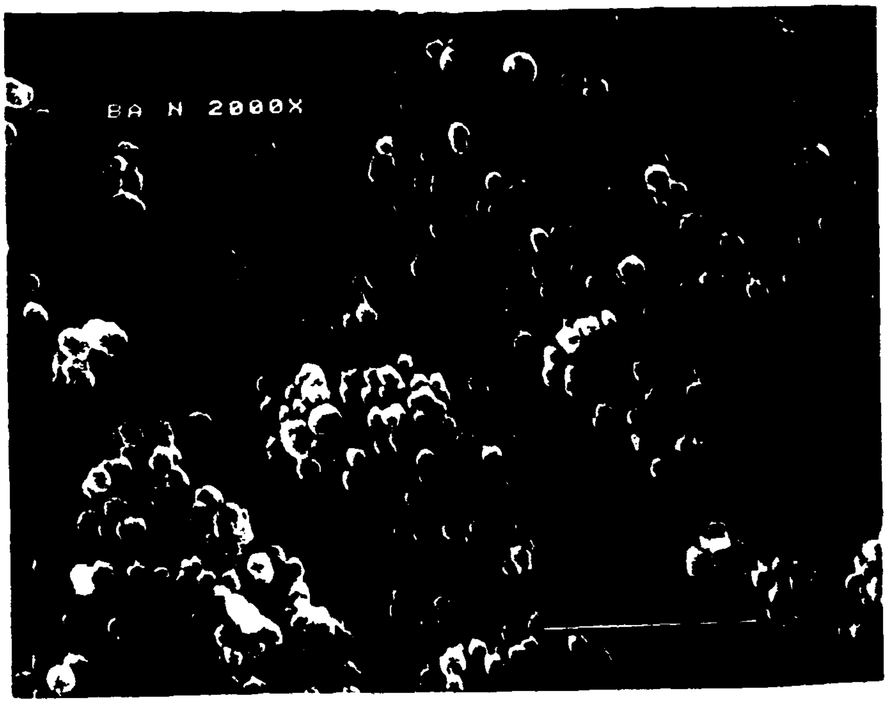

Figure 1B Bacilli at 2000X.

Figure 1C Treated Bacilli at 2000X.

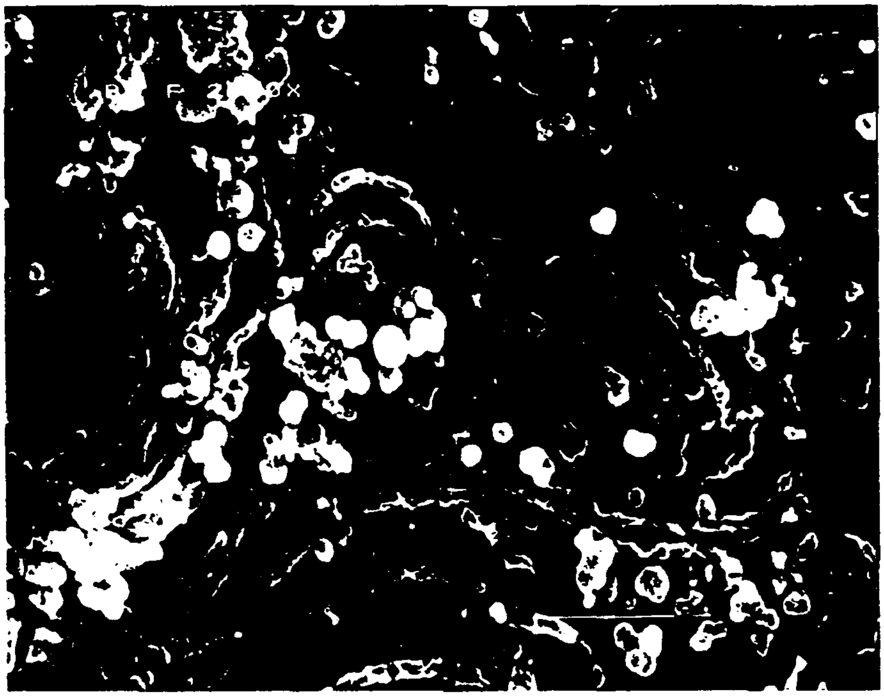

Figure 2A Thermogram of rat at 140 time points. Interpolated graph points read left side, colonic, right side, middle ear. The microwaves were issued in the H orientation.

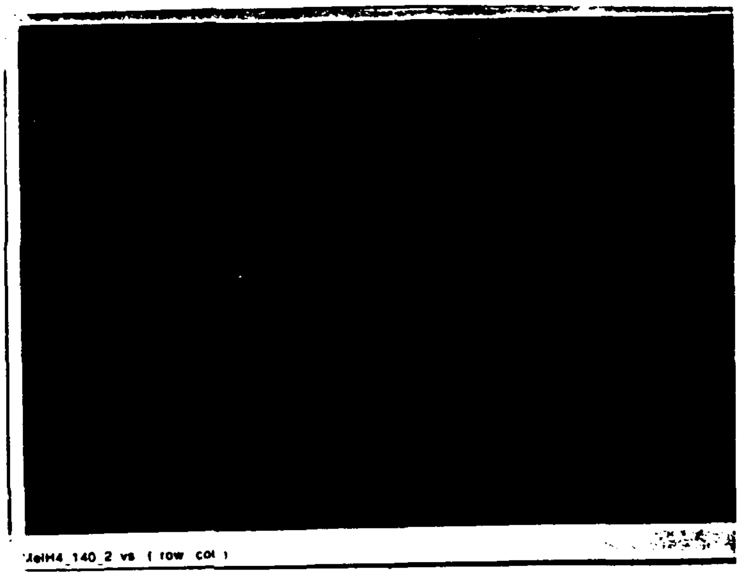

Figure 2B. Thermogram of rat at 140 time points. Interpolated graph points read left side, colonic, right side, middle ear. The microwaves were issued in the E orientation.

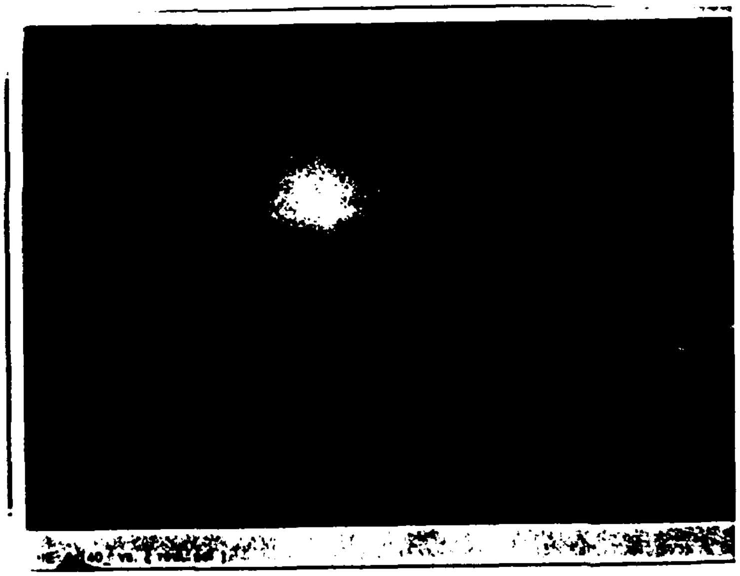

Figure 3. Copy of research abstract to be presented at the American Society for Cell Biology annual meeting in Boston December 9, 1991.

Three Dimensional Morphology of 2D Densitometric Scans of *in situ* RAW 264.7 Macrophage Cultures . T. Romo, C. Collumb, R. V. Blystone, and J. Kiel*. Department of Biology, Trinity University, San Antonio, TX 78212 and *Radiofrequency Radiation Branch, Armstrong Lab, Brooks AFB, TX 78235.

Computer visualization can be used to study *in situ* growth characteristics of cell cultures. Using inexpensive Macintosh equipment, optical density data can be processed to reveal extensive information about growth. Two dimensional optical densitometry data obtained via non-intrusive microscopy or flat-bed scanning represents *in situ* population density per unit area. This grey-scale image data is used as nodes defining a control surface for interpolation and rendered as an isosurface height field. More information per data point can be visualized by interpolated color schemes or textural surface mapping. Additionally, this visual model can be geometrically transformed to show different views through rotations, tilts, and scaling. Morphological-based algorithms can then be applied to characterize the surface, extracting relevant quantitative data such as stippling, growth rates, or foci. A series of scans over time can be animated to show population density developments. Since each pixel represents the population density per unit area over time as a discrete value, a stack of pixels can be fitted with a cubic spline and intervening densities approximated. Applied to each pixel, entire scans can be interpolated between the sample nodes prior to animation and analysis. The dataset needed is reduced as is the disturbance of the culture by handling.

During the course of the summer we have established a low-cost imaging and visualization lab which can support a variety of Air Force projects. As can be seen by this reading much of what was accomplished was to get a visualization lab in operation. That process is now essentially complete.

Two areas bear great investigation. We intend to continue with the thermogram visualization project for Dr. Frei should funding be possible. It is far easier to interpret large data sets a single images than as rows and columns of numbers.

The foci discrimination project bears closer scrutiny. A rapid method to determine early the foci forming ability of transformed cells has many uses.

Also a great deal of time was spent in reviewing the literature on Lipopolysaccharide treatment of cells. A year ago a project was undertaken to follow this process; however, little success was met. A better grasp of the literature has suggested to me ways in which this work could be successfully completely.

Acknowledgements:

To Johnathan Kiel, many thanks. He has allowed to pursue many exciting avenues through access to his lab. Dr. Jill Parker has been patient and extremely helpful in helping us get a tissue culture facility running. Sgt. Alls has given us much time is assisting with tissue culture and information. The personnel at Brooks have made our time there a home away from home.

Chris Collumb and Tod Romo have been the best of students. They have applied themselves diligently over the last two years. The rapid pace of progress would have been impossible without them. Both Dan Blystone and Lea Tupa at Trinity have provided countless hours of assistance.

And closing, I appreciate the AFOSR summer program administered through RDL. Such programs really help college instructors grease the research wheels which are vital in so many ways.

FINAL REPORT

AFOSR SUMMER FACULTY RESEARCH PROGRAM

Proposed Methodology for Synthetic Task Construction

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Abstract

The assignment was to review synthetic work activities and devise a method for relating them to both the real-world (or simulated) systems they abstractly represent and to performance test batteries that measure abilities. Task taxonomies, verbal protocol analysis for cognitive task analysis, and some of the recent task paradigms used for studying complex human behavior in laboratory experiments were all reviewed. General principles for constructing synthetic tasks are suggested based upon this review. Problems in generalizing from performance batteries and synthetic tasks are also discussed.

1.0 Introduction

Here we discuss the context of the assignment: the problem statement, prior approaches, their limitations, and the present perspective on a better solution.

1.1 The Problem Context

Sustained combat operations impose a wide variety of stressors (fatigue, weapons effects, etc.) known or expected to degrade human performance. The behavioral impacts of stressors studied in the laboratory provide the basis for estimating the probable operational impacts. The question is how to generalize the results from laboratory research to the real world, a rather large leap.

1.2 Problem Approaches

Experts in the domain of interest are often called upon to make estimates of degraded performance impacts on mission outcomes, based on their knowledge, experience, and best judgment. The credibility and validity of their predictions depends on the domain expert's ability to apply what is known, generalizing to a new and unusual context. Repeatable predictions are never assured in such ad hoc approaches.

Modeling has been used to provide a means for systematizing the extrapolations from laboratory to system and mission consequences. The problem then becomes one of providing the modeler with a basis for: a) representing behavior under nominal operating conditions, and b) degrading that behavior to reflect the known or expected impact(s) of stressors. The major problem is getting the data in a suitable form.

1.3 Limitations

Modeling limitations exist in three exercises: a) extrapolation, b) validation, and c) speculation.

Extrapolating results of behavioral data are difficult because of a lack of standardization in terms, methods, and measures. The characterization of tasks, variables affecting behavior, and the measurement of consequences varies from study to study making it difficult to estimate what might occur in operational systems. Studies done in operational settings are typically limited to relatively benign operating conditions. The extrapolation requirement from lab data to operational tasks still exists in any case.

Validation of degraded performance from laboratory studies can best be attempted in systems simulators appropriately instrumented. This requires use of operational personnel, is expensive, and takes considerable time. A simpler approach is desired, not as a substitute but as a supplement.

Speculations about conditions that cannot be studied using humans can then be addressed by speculating whether the effects seen in animals might also be seen in humans, and to what degree. While there is no way to validate the resultant estimates of degraded human performance, models can be used to explore whether system performance and mission outcomes are sensitive to the postulated degradation in human behavior. Speculation should be done using previously validated models, based on laboratory and systems simulation validation studies.

1.4 Present Perspective

Since the leap from lab to world is so great, it seems reasonable to introduce an intermediate step, providing predictions based upon synthetic tasks which measure more than native abilities but require less training than full system simulations. There is a need though to be able to link the synthetic task both: a) to the operational environment it is supposed to represent and b) to the test batteries used to quantify the degradation induced by specific stressors.

The problem solution must recognize that there are metrics differences between performance scoring of test battery behavior, behavior in the synthetic tasks, and behavior in the simulated system. Test batteries measure individual performance. Synthetic tasks may be single person or multi-person by design. Real systems are usually operated by trained and experienced teams. Also, systems studies require metrics at several levels: individual, team, system, and mission. The measures and environments across these domains differ substantially.

Also, there is no agreed upon, integrated modeling method that guides the collection of behavioral information needed for modeling. A variety of approaches exist, and their interrelationships are not well understood. Conceptual bridges are still needed to move successfully from one representation scheme to another.

2.0 Problem Discussion

The summer's activities were spent in three primary work areas: a) reviewing what the Airborne Warning and Control System (AWACS) Weapons Director (WD) does during the commit portion of an engagement, b) reviewing literature related to the description of human operator activities and the construction of synthetic tasks, and c) conducting requested seminars on IDEF modeling and other topics.

2.1 Analysis of Weapons Director's Duties

The IDEF0 model of the WD's Commit task was reviewed and recommendations for changes provided. A complementary IDEF1 model was developed to illustrate that approach. Two alternate demonstration packages for IDEF tools were acquired for evaluation by SRL as possible aids to model building.

The review of WD's activities also included a review of the Positional Handbook and flow chart drafts prepared to describe the logic of doing the job. From these materials it was hypothesized that the prioritization of threats was a critical element in the overall chain of processing events.

2.2 Review of Literature

In order to develop a methodology for constructing synthetic tasks, three sources of literature were reviewed: a) the task taxonomy efforts of Fleishman et al., b) a collection of papers on synthetic tasks now in use, and c) studies of cognitive processing and cognitive task analysis.

2.2.1 Detailed Review of Fleishman's Work

Fleishman and Quaintance (1984) provide a thorough review of how different investigators have attempted to address the problem of classifying and categorizing tasks. Many of the proposed methods for task analysis have not been subjected to reliability and validity testing. Moreover, there is no integration of perspectives.

Tasks have been categorized by: a) behavioral description, b) requirements specification, c) task characterization, d) abilities assessments, and e) criterion measures. Additional concerns include: a) strategies for accomplishing tasks, b) description of the environment, c) motivational influences, and d) personality impacts. Team behavior necessarily also includes small group organization and team dynamics considerations.

2.2.2 Synthetic Task Paradigms

In their frustration with the simplicity of typical laboratory tasks and test batteries, a number of investigators have developed "games" which are more complicated and purportedly better capture the dynamics of real world tasks. These reductive synthetic tasks are abstractions of real tasks, either reconceptualizing the task or filtering certain details (or both).

The oldest of these was constructed by Morgan and Alluisi (1972) and dates back to earlier interests in sustained performance research (Adams, Levine, and Chiles, 1959). This battery of tasks has been modernized by the FAA Civil Aeromedical Institute (CAMI) at the Mcroney Aeronautical Center in Oklahoma City. Hosted on a VAX, using color-graphics Tektronix 4025 terminals, the new Multiple Assessment Battery (MAB) is being used to study the effects of age on performance.

Tulga and Sheridan (1980) devised a task which was later revised and reused by Pattipati, Kleinman, and Ephrath (1983) to study how people traded off performance of multiple tasks of differing importance under time stress. Kirlik, Markert, and Shively (1990) are also using a variant of the Tulga task to extend their studies of perceptually-primed dynamic decision making.

The Tulga paradigm has been further enhanced in the so-called POPCORN task (Hart, Battiste, and Lester, 1984), being used by Dr. John

Patterson (AL/AOCN). Other tasks (eg. STRESSFUL, and STAR CRUISER) are being used at the Univ. of IL in a continuing series of NASA sponsored studies, extending the investigation of task scheduling (Moray et al., 1990). Also under NASA funding, Hancock et al. at the Univ of MN are studying the role of strategies in task performance using SCORE.

Under ONR sponsorship, Kleinman, Serfaty, and Luh (1984) developed a paradigm for studying distributed, team decision making in the context of Navy Command and Control operations. Lindquist, Fainter, and Hakkinen (1985) produced GENIE (a Generic ENvironment for Interactive Experiments) to study human-computer interaction.

For workload research, Wickens et al. (1988) have devised a synthetic flight task called TASKILLAN. King (undated) has developed a four-window flight task for NASA Ames called Window/PANES. It presents a tracking task, moving map, instruments, and a memory task. Under an earlier NASA program, Kirlik, Miller and Jagasinski (1989) developed their own synthetic flight environment to look at single versus two person crews and ways to aid workload sharing and shedding. The task they constructed is no longer operational.

DARPA funded the development of SPACE FORTRESS for The Learning Strategies Program. Developed for a PDP-11 using a Hewlett-Packard display no longer manufactured, it was been rehosted on a PC for Israeli pilot training (of divided attention), and Dr. Donchin at U. of IL has modified it for continuing research. Its characteristics and use for studying meta cognitive task strategies is documented in a Special Issue (Donchin, 1989) of Acta Psychologica.

An alternate form of synthetic task is beginning to emerge: a composite of several separate tests presented concurrently, requiring time sharing or divided attention. The synthetic task authoring system NTI is developing under contract to the Army using ACTOR falls in this category.

2.2.3 DTIC Search and Other Bibliographies

The Strughold Library conducted a literature search of DTIC holdings on the topic of task analysis. Since that term is not a controlled term, the search by keyword becomes quite difficult. Many of the classic publications known to be in the DTIC collection were not found, however, some recent new work was identified.

Personal contacts (at CAMI, CTA, and Human Technology, Inc.) were also used to solicit materials and bibliographies on cognitive task analysis, a topic of current interest to the FAA. Materials on this topic are still accumulating.

2.2.4 Performance Assessment Batteries

Three performance assessment batteries were reviewed: a) the Criterion Task Set (CTS), b) the UTCPAB, basically an upgrade of the

CTS, and c) the CCAB. Schiflett (1991) reviews the evolution of tests in the UTCPAB, discussing the rationale for selecting a subset of those tests for proposed studies of cognitive decrement in extended spaceflight. The Learning Abilities Measurement Program (LAMP) has also been developing an abilities test battery (Kyllonen, 1991).

All of these batteries are designed to assess basic human abilities on typical laboratory tasks. Three problems are to be noted. First, the cognitive components required for each task can only be identified by further decomposition (Carroll, 1976; Sternberg, 1979). Second, the relationship to real tasks is not clear. Third, tasks are typically performed independently, while real-world task environments often require concurrent task performance, controlled by strategies for divided attention.

2.3 Seminar

A series of seminars (including a workshop) was conducted on IDEF0 to train visiting graduate students how to apply this modeling method, developing a model that could be compared to published results of others' efforts.

3.0 Results

The results of this summer's effort fall into three areas: a) recommendations about task analysis (the process), b) recommendations regarding modeling tools, and c) empirical studies of (a) using (b).

3.1 Need for Testing Selected, Previously Proposed Methods and Providing an Integrated Analysis Methodology

Fleishman and Quaintance (1984) repeatedly point out that many of the proposed task analysis methods are of unknown reliability and validity. Redding (1989) also states that there is no integrated method for doing cognitive task analyses, but there is interest in moving that direction (Redding, 1990).

The concept mapping techniques used by McNeese et al. (1990) are also recommended by Andriole and Adelman (1989) for the analysis of verbal protocol data (Ericsson and Simon, 1984). Concept maps are not yet directly relatable to conventional engineering analysis techniques, such as IDEF0 and IDEF1. Storyboard design techniques (Andriole and Adelman, 1989) tend to by-pass the analysis phase and go directly to prototyping. Methodological links between these approaches should be carefully developed.

By itself, the IDEF0 model of the WD Commit activity gives an incomplete picture of the AWACS operating environment. IDEF1 modeling, done as an independent exercise, does not arrive at information immediately useful for modeling crew performance. Before IDEF1 or IDEF0 can be used for dynamic modeling of crew activities, other information [illegible] [illegible] information, like systems having hard (versus soft) real-time task constraints (Stankovic and Ramamritham, 1988).

While IDEAL (Chubb and Hoyland, 1989) describes how to go from IDEF0 to SAINT simulation models of procedural activity, the behavior-guiding cognitive activities are not well represented. IDEF1 provides the basis for improving such models, but the details of transitioning IDEF1 to SAINT have not been worked out.

3.2 Specifying Synthetic Task Requirements

To achieve comparability between real and synthetic tasks, seven principles emerged: a) from mission, system, and task requirements analysis, isolate the critical task to be synthetically specified (bound the problem), b) identify the characteristics of the real task, c) define the performance criteria for the real task, d) identify the abilities and characteristics of the domain population (perhaps stratified by experience level), e) describe (or define) the typical scenario context (operating environment), f) prescribe constraints on allowable strategies (prepare goal specific instructions), and g) construct (incorporate) explicit and/or implicit incentives.

The abstraction process from real to synthetic task environments is an art, not a science, and criterion-referenced, predictive, empirical validation is the only assurance that all essential aspects of the ecological context of the real task have been adequately captured in the synthetic task paradigm.

Based on a cognitive task analysis literature review, the biggest single barrier to accomplishing the abstraction process for specifying synthetic task requirements is the lack of specificity in definitions of cognitive processes and component elements of those processes. Until a stable set of terms emerges, only arbitrary selections can be offered, which may later prove unacceptable for reasons that cannot be foreseen. In the interim, any method is as good as any other, until two or more alternatives are proposed that can be tested. A teachable cognitive task analysis methodology does not exist (Redding, 1989), but may be emerging (Redding, 1990).

Performance assessment batteries incorporate tasks which are not themselves elemental tasks (Carroll, 1976). They can be further decomposed (Sternberg, 1979). While such batteries may be used to assess certain kinds of abilities identified from factor analytic studies, predicting synthetic or real task performance from assessment battery scores requires finding a comparability basis. Tested abilities still need to be related to the real world task(s) they are meant to mimic This might be done by rating skills that compose both real task abilities requirements and abilities tested by the PABs (or their subsets), appropriately calibrated (translated and rotated).

The conventional approach still appears to be the only method available. One rates how much of a testable ability is required for the task. One tests subjects on the battery and in the real (or synthetic) task context, and by regression, predictions of real (or synthetic) performance criteria (dependent measures) are made from test scores.

If estimates of degradation in performance can be made using the abilities scores as an index, then predictions of real (or synthetic) performance are obtained by using appropriately derated data in the regression equations. Whether synthetic tasks can improve these predictions appears to be a testable research hypothesis.

A Calibration Model for this process is proposed to improve estimates of real-world performance decrements from laboratory task data. First, raters would assess the presence of abilities as they apply to the test battery tasks, using the 52 MARS scales developed by Fleishman, Cobb, and Spendolini (1976). Correlations will then show the alignment of test scores with abilities ratings, allowing rotation into a neutral reference coordinate frame. Second, the tasks are rated using the same 52 MARS scales. This shows the alignment of the task to the same <u>common</u> reference frame.

An alternate use of performance assessment batteries would be to calibrate the synthetic task subject sample with the real world subject population by using such scores as one of the bases for matching the two groups: operational personnel and synthetic task test subjects

3.3 Development of an Integrated Modeling Environment

Development of a synthetic task by reductive analysis of real world task (or work) environments requires appropriate systems engineering and task analysis tools. The integration of such tools is a challenge currently being addressed in a variety of separate efforts.

There are at least three different computer aided human engineering modeling environments currently under development that might be used to represent nominal and degraded task performance in system and mission contexts: a) the General Systems Analysis Workstation (GENSAW), b) the Cockpit Automation Technology (CAT) set of tools, and c) the Army/NASA(Ames) Aircrew-Aircraft Integration Program's Man-Machine Integration Design and Analysis System (MIDAS).

All of the foregoing approaches are relatively expensive, out of the reach of most small businesses and many universities. A simpler, more affordable, alternate approach would link IDEFine with C-SAINT, all of which could be run on a PC.

3.4 Testing the Synthetic Task Authoring Package

To validate the proposed synthetic task specification methodology, it will be necessary to construct both existing and new task paradigms using the Actor-based authoring system being developed by NTI under an Army contract. This would include both reductive and composite synthetic tasks.

4.0 CONCLUSION

The reliability and validity of selected task analysis techniques needs to be determined, integrated, and combined with a cognitive task analysis methodology so the derivation of synthetic tasks can be traced to their origins.

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NUTRITION FOR TAC PILOTS: A REVIEW OF LITERATURE

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Abstract

This report provides a chronological overview of approximately five decades of nutrition research applicable to Tactical Air Command (TAC) pilots under operational conditions with an emphasis upon diet and acceleration tolerance. Current sources of nutrition recommendations and information for TAC pilots are also surveyed. Areas where paucity of data exist are identified and recommendations for nutrition research outlined.

INTRODUCTION

"Lack of recognition of this relationship between ingestion of food and tolerance for acceleration has in the last few years undoubtedly lead to accidents due to collapse of the pilot." In 1939, this statement was made by Ruff and Strughold based on the first human experiments investigating the relationship between diet and acceleration which were conducted by the Germans prior to World War II (51,52). Approximately fifty years later methods to enhance G tolerance and prevent loss of consciousness continue under intensive investigation (3,10). Contemporary high performance aircraft design and computer technology allow maneuvers at sustained high G loads which stretch the limits of human performance and place greatly increased demands on the cardiovascular compensatory mechanisms to retain consciousness (3, 63). In addition, the contemporary complex cognitive demands required by pilots necessitate more sophisticated intellectual preparation and decision-making skills (Personnel Communication, W. Ercoline).

Adequate nutrition and regular meal patterns are emphasized in the physical fitness program to enhance G tolerance (56, 63). However, recently erratic schedules and long hours with repeated sorties in a hot desert environment were superimposed on the basic physiological and cognitive demands of pilots who fly tactical jet aircraft. In addition, food resources varied and pilots sometimes missed meals (Limited Questionnaire from Returning Flight Surgeons). Concerns about adequacy of diets and G-tolerance under rigorous conditions prompted inquiry into what is the present state of knowledge regarding the nutritional needs of TAC pilots. No recent review provides a historical and critical overview of the nutrition research literature specifically applicable to this group. Therefore, this report will review current recommendations on diet, and chronologically discuss investigations of meal patterns, energy, and nutrient categories conducted since Ruff first studied diet and acceleration in 1938. Areas of concern where data is nonexistent or limited will be identified and recommendations for further research presented. Although cognitive demands of the TAC pilot are of a high order and the relationship between nutrition and cognitive performance in the military arena has been a focus of the Committee on Military Nutrition Research (13), this report will be limited to research pertaining to the physiological aspects of pilot performance.

CURRENT NUTRITION RECOMMENDATIONS

Current nutrition recommendations to pilots are derived from several sources. Nutrition standards for all the Armed Forces of the United States are established by the Surgeon General, Department of the Army (2). Since these military nutrition standards are general in nature and designed for professional use and specifically defined purposes, further interpretation and official recommendations are provided through publications specific for TAC pilots.

General Military Nutrition Standards and Recommendations

The Military Recommended Dietary Allowances (MRDA) (2) are based on the 1980 Recommended Dietary Allowances (RDA) (20) which are nutrient recommendations intended to meet the needs of most of the healthy United States (U.S.) population. The MRDA have been appropriately modified to provide for the needs of a majority of the healthy military population (17 to 50 years) who are moderately active in a temperate climate. These recommendations are intended as the military guidelines for menu planning, research, education, product development, and assessment of the military population nutrient intake. The joint regulation (2) also includes nutrition education guidelines for promoting a healthy diet among military personnel and nutrient standards for operational and restricted rations. Since the RDA was revised in 1989 (21), the MRDA are currently under review for possible revisions (Personnel Communication, Carol Baker-Fulco, USARIEM).

The Committee on Military Nutrition Research, Food and Nutrition Board, National Research Council, National Academy of Sciences established in 1982 at the request of the Assistant Surgeon General of the Army is also important in nutrition recommendations to the military (13). The Committee reviews the nutrition standards and guidelines which are prepared by the Surgeon General, Department of the Army, establishes nutrition research priorities, and makes recommendations for nutrition research related to performance and feeding systems of military personnel (13).

Nutrition Recommendations Specific to TAC Pilots

Several pamphlets specifically written for TAC pilots provide nutrition recommendations to support the physical conditioning program to enhance G tolerance and general nutrition information (63, 56). Another publication (1) prepared for the wider aircrew audience provides more basic nutrition information.

The Basic Fighter Training Program includes a nutrition component and the three year refresher course in physiological training includes a section on diet and physical fitness. In addition, nutrition information, including hydration, are occasionally included on the agenda at Flight Safety Meetings. (Communication with Personnel in Each Area)

Recent textbooks and references for flight surgeons provide sparse general nutrition recommendations for pilots (45), are limited to discussions on food and survival techniques (18) or address only hypoglycemia-related concerns (46). However, a British reference included a more extensive summary of very basic nutrition concepts (26).

A variety of articles on nutrition for the pilot community are written in newsletter format and non-technical style. Some articles provide well-documented nutrition information such as the recent series by Troxler (61,62) which focused on the role of nutrition in prevention of common chronic diseases. Others lack specific documentation and loosely interpret research findings such as the recent article which presented the results of a self-reported questionnaire as if the findings were from a study designed to elicit cause and effect (48).

MEAL PATTERNS AND FASTING

Recommendations to TAC pilots vaguely stress the importance of nutrition. Pilots are warned that fasting, skipping meals or eating inadequate meals can result in fatigue and reduced performance (56). Furthermore, aircrew are advised to eat breakfast or an adequate and easily digested meal before flying (1). What research has been done to determine desirable meal patterns, the effect of skipping meals prior to flying, and the level of compliance of pilots to these recommendations?

Intervention Studies on Meal Patterns and Fasting

The first studies on the effect of meal omission on acceleration were probably conducted by the Germans just prior to World War II (51). German literature warned pilots that flying on an "empty stomach" would decrease G tolerance (52). In 1938, Ruff (51) compared the estimated G tolerance of nine subjects in the fasted state with G tolerance 1-1.5 hours (h) after consuming a heavy meal. Subjects sustained + 3.0-5.6 G on a 2.5 meter radius centrifuge and showed increased G tolerance in the fed state. The G tolerance was estimated by the occurrence of calf pain, visual dimming, blackout and loss of consciousness. Although the overall G tolerance was not quantified by Ruff, an analysis of the data by Clark and Jorgenson in 1945 (11) estimated that meal consumption increased G tolerance by approximately +0.9 G with a range of +0.4-1.5 G. Clark and Jorgenson (11) also estimated that Ruff's centrifuge reached maximum acceleration at a rate of +1.0 G per 15 second (s) and sustained a maximum +G for 10-25 s or until loss of consciousness. Ruff speculated that the splanchanic area has priority for blood supply during digestion resulting in vasoconstriction and reduced blood supply to other areas. Thus, the impact of acceleration on displacement of blood volume was mitigated because of previous engorgement of the splanchanic region and vasoconstriction in other areas (51,52). Although Ruff reported several G_Z acceleration studies in the 1938 article, the work pertaining to food intake and acceleration was in a chest to back position simulating G_X acceleration.

A later summary by Ruff and Strughold (52) indicated that exposure to acceleration of 3-4 s in the fed state increased G tolerance 1.5-2G. Although the focus of Burmeister's work (8) in 1939 was not on diet and acceleration, he determined that subjects tolerated acceleration better shortly after eating. Thus, he scheduled his centrifuge experiments between 1:00-3:00 p.m. in the afternoon. However, Rook and Dawson (50) observed that the symptoms associated with acceleration exposure intensified when subjects were flying after a heavy meal.

Ruff's (51) findings and also the rationale for the increased G tolerance after ingestion of food, were further tested by Clark and Jorgenson in 1945 (11). After a 12 h fast, eight subjects were tested for G tolerance using a 23 foot radius centrifuge at the rate of 3 G_Z per s with a maximum acceleration sustained for 15 s. Following the centrifuge runs in the fasted state, most subjects consumed 1.5-2 liters (l) of milk or water on separate occasions and then repeated the centrifuge runs 10-20 minutes (min) after the fluid ingestion. Three of the subjects were also tested in the fasted state and then again after they consumed a heavy meal, high in protein. All data were considered as G tolerance on either an "empty" or "full" stomach. Means of the parameters of G tolerance (visual symptoms, ear opacity, intrarectal pressure changes and black out) were used to analyze results; no statistical analysis was conducted. An overall mean increase of +0.3 G_z tolerance (0.0-0.8 G) was observed. One subject showed a maximum increase of +1.1 G_z tolerance based on blackout data. An increase in intra-abdominal pressure resulting from the ingestion of food was the rationale given for the increase in G tolerance, which differed from the original speculation by Ruff (51). In spite of the great diversity of the diet-related treatments, no attempt was made to assess differences among all the treatment groups. The authors suggest that prior food and fluid consumption is an important consideration for standard centrifuge assays and may account for some of the individual variation observed in the threshold for loss of peripheral vision and blackout.

A more recent investigation (32) studied the effects of a 24 hour fast prior to exposure to a simulated altitude of 3,810 meters (m) for 1 h 48 min followed by 2 min of lower body negative pressure (LBNP) (40 torr) equivalent to $+2G_z$. Physiological displacements measured (systolic blood pressure, mean arterial pressure, temporal artery blood flow and heart rate) when exposed to $+2G_z$ were greater in the fasting state; however, they were not significantly different than the responses in the fed state. One subject was incapacitated during exposure to $+2G_z$ after fasting; two other fasting subjects reported impending syncope at the end of the test. Significant reductions in circulating blood and plasma volumes were reported as a contributory factor to the reduced LBNP tolerance observed in some subjects. The authors warned against prolonged and repeated maneuvers greater than or near $+2G_z$ following fasting with specific reference to crop dusting and aerobatic flying. However, since the relationship between LBNP and $+G_z$ is being questioned, the results of this investigation may need further assessment.

Surveys on Meal Pattern Practices

Six retrospective surveys investigating the dietary habits of military aircrew from the United States and England were designed to determine the number and pattern of missed meals (especially breakfast), the food intake before flying, and the composition of the breakfast meal plus other meals (6,14,16,19,47,49).

Dietary surveys of United States military pilots during the 1950's and 1960's focused primarily on breakfast habits. These earlier findings indicate that 23% of the 189 United States Navy (USN) officers flying high performance jet aircraft (6) and 11.1% of the 587 United States Air Force (USAF) pilots (16) failed to eat breakfast on the survey day (16) or as part of their customary dietary habits (6). Furthermore, 16.8% of the USAF pilots surveyed by Davis and Beyer (16), and 14% of the F-100 instructors and students studied skipped breakfast on the day of flight (49). Thirteen percent of the USN pilots (6) and 34.2% of the USAF pilots (16) ate a "small" or "light" breakfast consisting of coffee, roll or toast and juice on the survey day. Thirty-two percent of the USAF pilots eating a light breakfast were scheduled for flight the day of the survey (16). Since studies (6,16,49) are considerably dated and involve assessment of lifestyle characteristics, which have undoubtedly changed over time, the findings are probably are no longer relevant to contemporary pilots.

Two recent surveys (14,47) looked at meal patterns of USAF pilots. A consecutive three day recall of meal patterns of 447 USAF pilots, focused primarily on patterns of missed meals, and analyzed data according to classification of aircraft flown. Among the 96 F-16 pilots, 46% missed the morning meal while 21% missed the midday meal and a smaller percentage (8%) missed the evening meal. Thirteen percent of the F-16 pilots missed both the breakfast and afternoon meal. Another survey (14) showed that a total of 63% of the 30 fighter pilots studied did not eat breakfast every day; however, this figure included 33% who ate breakfast "almost every day" and 20% who ate breakfast "sometimes." Other missed meals during the day were not reported.

Fisher and Atkinson (19) looked at the usual dietary intakes of Royal Air Force (RAF) Strike Air Command fast-jet aircrew (pilots and navigators) and focused on missed meals. Calculations based on their data indicated that approximately 20% of the subjects missed breakfast and another 50% ate a continental breakfast. A majority of the group (64.7%) ate only one full meal per day and only 4.5% ate three meals daily. Among those who ate only one full meal per day, the meal would be more likely in the evening if day flying and at lunch if flying at night. Many missed lunch if day flying and the evening meal if night flying.

Therefore, the research on meal patterns and acceleration tolerance is limited primarily to two pre-flight dietary intervention studies (11,51), conducted with the technology available approximately 45-50 years ago, and one more recent investigation (32) which simulated $+3G_z$ using a LBNP method with questionable applicability. The earliest study (51) actually evaluated G_x (not G_z) tolerance. The second intervention study (11) lacked statistical analysis and also categorized three different food/liquid regimens as one treatment. Recent retrospective surveys reveal that a considerable percentage of pilots skip meals (14,19,47). A key issue is whether pilots skipped breakfast or a meal prior to flights and if pre-flight diets deviated from customary food intake. Only the British survey (19) attempted to assess this point. Thus, among U.S. pilots, pre-flight food intake and the level of compliance to current recommendations not to fly on an empty stomach are unknown.

ENERGY EXPENDITURES

The MRDA kcal recommendations are 3200 kcal (2800-3600) for men and 2400 kcal (2000-2800) for women with increases suggested for heavy physical work, larger body sizes and environmental extremes (2). Operational rations supply 3600 kcal per day. No studies have investigated the daily kcal expenditure of TAC pilots to determine if these recommendations are appropriate. However, Popov (39) chronologically reviewed studies of the daily energy requirements of various types of Soviet pilots and reported that findings and recommendations varied from 3,000-4,300 kcal per day. A recent two month study of eight Indian Air Force pilots during combat training in supersonic jets showed a mean energy expenditure of 2668 kcal (54).

English language studies of the energy cost of specific activities involved in piloting an aircraft are primarily limited to older planes or simulations of older technology (15,28,59) with only two investigations using jet aircraft in flight (29,33). A 1946 study by Karpovich and Ronklin (28) using indirect calorimetry techniques on 27 enlisted men showed that the energy expended during simulated flying conditions was 55 kcal/m^2/h or 37.5% higher than when subjects were seated at the controls in the fasted state. Using only 2 experienced military aviators and 2 non-aviators, Corey (15) found that the fasting energy needs of the military aviators seated at the controls in a Link Trainer increased 12% increase when flying the pattern and an additional 11.2% when the pattern was performed in rough air. The metabolic cost of operating in these simulated conditions increased with the complexity of the task and was attributed to increased muscular tension. Tiller et al.(59) studied combat pilots, and other subjects, under 5 conditions in an F9F-5 simulator. Energy costs of various flying tasks were compared to the resting rate of the pilot in the simulator before takeoff. Based on estimates from bar graph data, the energy expended by two combat pilots for straight and level, combat, emergency flying and landing was approximately 60, 81, 78 and 72 kcal/m^2/h, respectively.

Kaufman et al.(29) found that the mean energy expenditure of 21 engineering test pilots was 49.3 kcal/m^2/h for routine flying and 70.2 Kcal/m^2/h for a simulated emergency flight situation in two internal combustion engines (C-123 and C131), a jet (KC-135) and a helicopter. The emergency energy expenditure, without the pilot assist system, was similar to the workload of truck drivers and about half of that of a soldier in a field march.

In 1965, Lorentzen (33) investigated the oxygen consumption of pilots at moderate G loads and found that the average oxygen consumption of trained pilots in a T-33 was 635 ml/min during strenuous flying routine which included 5-9 repetitions of a cloverleaf followed by a 90-degree turn. Oxygen consumption at this level was considered moderate and comparable to rapid walking or slow jogging. Energy expenditure during exposure to a constant load of +3G_z in a five minute turn without an anti-G suit was slightly lower than during strenuous flight, but higher than during level flight. Kaufman et al.(29), using specified assumptions, converted the oxygen consumption data of Lorentzen to energy production based on body surface area and reported the following: rest and routine flying, 46 kcal/m^2/h; emergency flying, 83 kcal/ m^2/h and combat, 97 kcal/m^2/h. Kaufman (29) also used specified assumptions and converted respiratory ventilations data of World War II fighter pilots to routine and combat flight energy expenditures . Routine flight energy needs were similar to calculations based on data from Lorentzen (33) and combat values were slightly lower at 81 kcal/m^2/h and 65 kcal/m^2/h.

Several nutrition surveys have assessed the kcal consumption of pilots. Data from questionnaires on usual dietary patterns estimated the mean kcal intake of 266 Royal Air Force Strike Command pilots and navigators at 2000 kcal per day (19). The authors suggest that the method they used probably underestimated energy intake; however, little description of the instructions for estimating portion size, etc. to attain the quantitative data is given. Indiana Air Force pilot trainees consumed 3846±446 kcal daily which was more than their energy expenditure (54). A recent 24 hour dietary recall of 30 U.S.fighter pilots estimated daily energy consumption as 2585±776 kcal and less than the MRDA (2,14).

Thus, earlier studies indicate that the energy cost of piloting a plane is probably moderate and does not require heavy work. However, no recent work has investigated the kcal expenditure required to fly the contemporary high performance aircraft with the accompanying physiological demands to tolerate the high $+G_z$ environment. If the earlier interpretation by Corey (15) is valid, and the metabolic cost of flying an aircraft increases as the complexity of the task increases, then the cost of flying contemporary aircraft should be high. When Lorentzen (33) studied the effect of moderate G loads on oxygen consumption, the use of the anti-G straining maneuvers were not included in the methods. Burton (9) speculates that the energy cost of performing the M-1 maneuver is considerable, but suggests that as the subjects are exposed to repeated simulated aerial combat maneuvers, they become more efficient and use less energy. Only one published survey reports kcal intake of U.S. pilots who fly in the high G environment (14).

CARBOHYDRATE

Historically carbohydrate has been an energy nutrient with a somewhat prominent, but confusing and conflicting role in dietary recommendations to pilots. A diet containing 55-60% of total kcal from carbohydrates, with an emphasis on complex carbohydrates, is currently recommended during training for enhanced G tolerance (56,63).

Altitude Studies

During World War II carbohydrates became a focus of study in relation to altitude. During 1942-43 researchers used a battery of objective and subjective tests to assess altitude (15,000-17,000 ft) tolerance after fasting and the consumption of diets of varying energy nutrient composition (30,31). Preflight and in-flight diets high in carbohydrate (85% of total kcal) resulted in optimum performance while diets high in protein (higher than 10-15% total kcal) had a negative effect. Fats did not influence altitude tolerance unless in larger quantities and then reduced tolerance. Type and source of carbohydrate or protein did not influence outcome. Under normal circumstances, pressurized cabins no longer necessitate concern about altitude tolerance: therefore, the body of literature investigating altitude and diet composition that followed the work of King et al.(30,31) will not be covered in this review. Coverage of earlier work is provided in a review text (37) and other studies (17,22,25).

Interestingly, King et al.(30,31) in the altitude studies fed pre-flight and in-flight diets with a carbohydrate content as high as 85% of total kcal from a variety of simple and complex carbohydrate food sources, but did not observe signs of hypoglycemia with adequate calorie intake. However, a series of studies which also began in the mid-1940's and continued into the 1960's focused on the possible danger of pre-flight diets causing rebound hypoglycemia or fasting hypoglycemia and reduced pilot performance.

Nutrition-related Concern: Hypoglycemia

Present recommendations warn pilots to avoid a high carbohydrate meal before flying (46), and replacement of a meal by high simple sugar type snacks (e.g., cola drinks and candy bars) (56). These recommendations are made to avoid the possibility of rebound hypoglycemia associated with fatigue and reduced G tolerance (56). Several studies investigated G tolerance using subjects in a hypo- or hyperglycemic states (7,12). Numerous surveys also monitored blood sugars and assessed the incidence of hypoglycemic responses among aircrew, particularly with reference to aircraft accidents.

Using only three subjects, Clark et al.(12) investigated the effect of hypo- and hyperglycemia on G tolerance. Indirectly, this study also examined the effect of a simple sugar intake on G-tolerance. Three fasted subjects were given either 2.0 g/kg sucrose, 1.9 g or 2.2 g/kg dextrose 30 minutes before centrifuge testing. Hypoglycemia (50-55 glucose mg/dl) was induced in the same three subjects using insulin injections following a light breakfast. These subjects were immediately exposed to a $+G_z$ environment and then administered food on completion of the test. After 1 hour, blood sugars were determined and subjects were again given centrifuge runs. All centrifuge tests were of a 5 s duration and G tolerance was assessed by ear opacity and responses to light and sound signals. An average of $+0.2\ G_z$ protection was gained from the administration of simple sugars prior to the centrifuge testing with one subject biasing the mean upward. A similar decline in $+G_z$ tolerance was observed with induced hypoglycemia. This study showed differences of a small magnitude, used a small number of subjects, and lacked statistical analysis.

Many years later, Browne (7) also studied the influence of hypoglycemia on acceleration and demonstrated a significant reduction in G tolerance compared to a control threshold when centrifuge experienced subjects had insulin-induced hypoglycemia. The G-tolerance threshold was measured by loss of central light in the dark adapted eye. During the 30 min period after the insulin injection, when the blood sugar was falling to approximately 50% of control values, the mean G threshold dropped to 80% of the control value ($2.85 \pm 0.21\ G_z$). The author estimated that a pilot with hypoglycemia who would normally lose consciousness between $+6 - 7\ G_z$ would encounter the problem between $+4.5\text{-}5.5\ G_z$ with hypoglycemia of the magnitude tested. However, due to the complexities of exposure to higher $+G_z$, as compared to the G forces used in this study, such interpretation of data can be questioned.

Lundberg (34) studied the effect of stresses encountered in the Swedish Air Force on the blood sugar responses of 42 pilots and 113 recruits. He concluded that preflight meals should be moderately sized, high in protein and not carbohydrate. For intervals greater than 3 h between meals, the author recommended consumption of a small quantity of food which was not composed of simple carbohydrates.

Two prospective studies monitored pre- and post-flight blood sugar levels of subject, observed a considerable blood sugar concentrations decline in some subjects, but recorded no symptoms of hypoglycemia (49,57). Among 193 instructors and pilots during single engine basic jet training, 13 subjects showed a blood sugar decrease of 60 mg/dl or greater, but no symptoms of hypoglycemia were reported for the entire group (57). Breakfast composition obtained from a 24 hour recall was examined with respect to those who showed the greater declines in blood sugar concentrations. These subjects had a lesser intake of protein and a greater intake of sugar and carbohydrates. The authors concluded that diet was related to the decline in blood sugar; however, statistics to validate this point are not given. The carbohydrate and protein composition of the meals were not clearly specified.

USAF jet aircrew (114 subjects) failed to show hypoglycemic reactions even though post-flight blood sugars of some subjects had declined more than 60 mg/dl (49). Investigators did not relate time of most recent food consumption to time of pre-flight blood sugar determinations. Length of flights also varied. Composition of the most recent meal was assessed for a subgroup of pilots (F-100 instructors and students) and included fasting as well as a variety of meal sizes with different levels of carbohydrate and protein. They concluded that for some "non-susceptible" individuals the consumption of a high carbohydrate meal may not be adverse and a pre-flight high protein intake may not be particularly advantageous. Furthermore, the authors suggested that missing a single meal may also not have an adverse effect. No specific amounts nor type of carbohydrate consumed were included in the report.

The relationship between fasting and hypoglycemia was also prospectively studied during flight, but the subjects were not actually flying the aircraft (38). After a 12 h fast, venous blood glucose concentrations were monitored in normal subjects pre- and post-flight, as well as during a 1 h flight in a NF-100F, and a 6 h flight in a C-97. No occurrences of hypoglycemia were observed in these eight subjects

In addition to prospective studies, several retrospective investigations also assessed the relationship between dietary factors and symptoms of hypoglycemia with a focus on missed meals, rather than the carbohydrate content of pre-flight diets. A survey of USAF pilots did not associate missed meals with a 2 week recall of symptoms of sweating, fatigue and irritability (47). Forty-four percent of the RAF Strike Command navigators and pilots reported symptoms which were possibly associated with hypoglycemia (19). Missing the breakfast meal was not correlated with these diet-related symptoms; however, missing a meal later in the day, which was usually consumed was more likely associated with these observations. Based on this self-reported subjective data, the investigators concluded that the importance of missing a full complete breakfast may not be as significant as previously speculated.

Although not a a military population, 25% of civilian airline pilots, primarily 40 years of age or older, met a defined hypoglycemic criteria following a glucose tolerance test (23). Concern for flight safety and the need for dietary consultation were expressed following this 3 year study. However, the age of this population, prior diet, and other factors must be considered.

Investigations of accident data have also considered hypoglycemia, pre-flight meal composition and missed meals as contributory factors. Powell (42) noted the importance of an adequate breakfast for pilots to protect against hypoglycemia , a possible causative factor in the loss of consciousness cases reviewed at the Royal Canadian Air Force Institute of Aviation Medicine in 1955. Five of the 8 cases of unconsciousness reviewed by Powell (43) in the following year were thought due to the synergistic effect of two or more of the following: exposure to G_z forces; occurrence of hypoglycemia after consumption of a "light carbohydrate" meal; or hyperventilation. Rayman (44) reported that one case out of 32 in-flight loss of consciousness incidents was due to functional hypoglycemia in a student pilot sustaining $+3.5G_z$ during the period of January 1966 through 30 June 1971. Although Lyons (36) considered data on missed meals, rather than hypoglycemia, he failed to find a higher percentage of missed meals among flight fatalities due to G-LOC from 1982 to 1990 than among the general USAF pilot population.

Surveys on Carbohydrate Consumption

Three recent surveys of pilots estimated the carbohydrate content of their diets. A prospective survey (24) of 118 F-15 and F-16 pilots and a retrospective survey (14) of 30 fighter pilots showed a carbohydrate consumption of 44.56 ± 8.27 % and 48 ± 9.3% of total kcal, respectively. Both findings are lower than the present recommendations to TAC pilots (63). Indian Air Force pilots in high performance jet training consumed 59% of total kcal from carbohydrate, but this is a population more likely to consume a vegetarian diet with a high complex carbohydrate content (54). None of the surveys differentiated between simple and complex carbohydrate intake.

Therefore, only one intervention study (12), which was done over 40 years ago and used only 3 subjects, evaluated the influence of pre-flight carbohydrate intake on G tolerance. Virtually no detailed evaluation of the type of carbohydrate consumed by US fighter pilots is known. Two experiments (7,12) examined the influence of blood sugar concentrations on acceleration tolerance and reported increased and decreased G-tolerance in the presence of hyper- and hypoglycemia, respectively. Prospective surveys failed to show a high incidence of hypoglycemia signs or symptoms among aircrew with a diversity of pre-flight food intake, although methodology problems were involved in the dietary evaluation component of these studies (38,49,57). Current retrospective surveys on the association between missed meals and symptoms of hypoglycemia are limited, based on highly subjective data, and the findings are contradictory (19,47). No summary statements can be made regarding accident data and missed meals or hypoglycemia because of the time lags between studies and the diversity of approaches to analyzing this information. Furthermore, the literature on hypoglycemia and military aviators is clouded because some investigations focused on hypoglycemia as related to carbohydrate intake while others studied fasting and hypoglycemia.

PROTEIN

Protein recommendations for the military are 100 g per day for men and 80 g for females which is higher than the recommendation to the general population (2,21). TAC pilot recommendations focus on dispelling the frequently encountered myth that a high diet will enhance muscle development and strength (56).

Other than the negative impact of protein on altitude tolerance (30,31) and the previously discussed literature where high protein diets were advocated to prevent hypoglycemia, no other studies on protein and pilot performance were uncovered.

Three recent surveys assessed the protein intake of high performance pilots. The protein intake of fighter pilots was 16.5.2±5.2% of total kcal and slightly above the MRDA for protein (2,14). A recent 3 day food record of TAC pilots showed similar findings with a protein consumption that was 15.05±2.66% of total kcal (24). The Indian Air Force pilots during training consumed 11% of total kcal from protein, primarily vegetable protein (54).

FAT

According to the MRDA recommendation, military diets should provide no more than 35% of kcal from fat (2). Since fat is the most calorically dense nutrient, a higher percentage is allowed in military rations under defined conditions including combat (2). Recent assessments of fat consumption of USAF fighter pilots indicated that mean intake of fat was 34.25±6.31 and 34±9.8% of total kcal (14,24). Other than earlier altitude studies (30,31,37), the fat content of the diet and pilot performance has not been the subject of investigation.

VITAMINS

Historically the studies on the vitamin needs of pilots began in the 1930's and continued into the 1950's with a focus on the role of vitamins in night vision, eye fatigue, altitude tolerance and motion sickness. In 1940, Kafka (27) wrote on vitamin recommendations for pilots and emphasized the importance of vitamin A as "...the vitamin most urgently required by the pilot." The author emphasized that lack of vitamin A would result in night blindness and other maladies resulting in impaired performance by pilots. A historical review (41) of diets for flight personnel in the Soviet Union also emphasized the vitamin A content of rations because of the relationship to eyesight.

In a British study during World War II, 7-10% of the 601 RAF trainees had some degree of reduced riboflavin status as measured by clinical and visual signs (35). Administration of comparatively large doses of riboflavin to Royal Canadian Air Force aircrew during the same time period reduced vascularization of the cornea and symptoms of eye fatigue (60). Approximately 50% of the 198 men originally examined showed vascularization of the cornea, but only 12 wore shaded protective eyewear in the air which produced a confounding variable.

Studies on the physiological requirements of vitamins at high altitudes and the potential benefits of vitamin supplementation to increase altitude tolerance began in the 1940's. These investigations included studies on vitamins A, D, E, C, niacin, B_6, riboflavin, niacin and thiamin and were extensively reviewed elsewhere (37).

Vitamin B_6 was included in the diet of Soviet pilots because of a possible role in preventing air sickness (41). However, Smith failed to show an anti-motion sickness benefit of B_6 (53). A later German study (4) reported improvement in motion sickness with extremely high does of vitamin B_6 oral tablets or rectal suppositories, but among subjects on an ocean voyage rather than pilots. Several more references about this vitamin and motion sickness were given in a review article, but need English translation (41).

A recent 24 hour dietary recall of USAF fighter pilots showed that the mean intake of 9 vitamins was higher than the MRDA (14). Mean pantothenic acid consumption, for which a recommended range, rather than a specific figure is given, also fell within the range. Only folate was the below recommended intake at 78% of the MRDA. However, the newly revised RDA (21) has considerably lowered the recommendations for intake of folate to the healthy public. Possibly the next revision of the MRDA might also reflect this change. Other than for folate, the findings of this survey indicate that the vitamin intake of the pilots studied appears to meet the military standard (2,14).

Although recent surveys on vitamin consumption of pilots are available, experiments to determine the vitamin requirements of pilots probably ended sometime in the

1950's. In 1986 van der Beek reviewed work done on the role of vitamins with potential application to military performance (64). Even this extensive review of the literature with general application for the entire military, and not specifically for pilots, is sparse or nonexistent for some vitamins.

MINERALS

While several minerals have been studied with regard to altitude tolerance (37), sodium appears to be the only dietary mineral studied with regard to acceleration tolerance (55). This investigation also belongs under the classification of hydration studies because subjects were fed diets containing 10, 50, 100 or 150 mEq of sodium for 6 days along with a daily 2000 cc water restriction. Prior to intervening with dietary treatments, baseline G tolerance of gradual onset runs (GOR, 1 G/15s) and rapid onset runs (ROR, 1 G/1 s) was measured using peripheral light loss as the criterion. A significant difference in G tolerance between baseline values and G tolerance was observed after 5 or 6 days on the diets when subjects were analyzed together. G tolerance did not differ among treatment groups. Reductions in plasma volumes varied considerably up to a 23% reduction. A baseline sodium assessment would have been helpful since plasma volumes during the experimental period were compared to plasma volumes on the normal diet; however, G tolerance after the diet period showed no significant differences from baseline values. The authors advise against slight negative sodium and water deficits for pilots exposed to G forces.

Three dietary surveys of high performance jet pilots in the U.S. and India included some assessment of mineral consumption (14,24,54). Mean iron (49 mg) and calcium (1.2 g) intake of Indian Air Force pilots was higher than the international standard used (54). Based on a 24-hour recall, the mean consumption of 9 dietary minerals was higher than the MRDA or within the estimated safe and adequate daily dietary intake range for 30 fighter pilots (2,14). The mean sodium intake of pilots was approximately 3916 mg (14) and 4000 mg per day (24).

A review of the research on minerals with potential application to military performance was included in a recent workshop (65). Most studies were drawn from the literature on minerals and athletic performance. No specific references to pilots of any type were included. Overall the research on mineral consumption and requirements of tactical jet aircraft pilots is sparse.

FLUID NEEDS AND HYDRATION

The Committee on Military Nutrition Research placed study of fluid requirements for military personnel as one of the top four priorities (13). This Committee published an extensive bibliography of studies with possible relevance to the military (13), but none of these references were specifically for pilots. Adequate hydration is stressed as important to

G tolerance and included in manuals directed to pilots (56,63). However, it is beyond the scope of this paper and the time allowed for the Faculty Summer Research Program to include a complete review of the literature on this topic.

OTHER CONSIDERATIONS

The problem of the expansion of intestinal gas at high altitudes and dietary methods to reduce the occurrence of this problem are included in literature for pilots (1,45). Pilots are advised to avoid foods which may result in gas formation when preparing for altitude chamber training flights or actual flights. A high protein, low-residue pre-flight diet is recommended under specific conditions (1). Since all energy usage for high G air to air or air to ground engagements by high performance aircraft occur at 25,000 feet or less (W. Ercoline, Personal Communication), the topic of intestinal gas expansion will not be a focus of this review. However, two of the earlier reports of the effect of food and beverages on gas production at 35,000 to 38,000 feet and two review articles are included in the reference list to provide a bibliography for the interested reader (5,37,40,58).

SUMMARY AND RECOMMENDATIONS

The following summarizes the major findings of the review of the literature on nutrition for TAC pilots:

Nutrition information is included in conditioning and training programs, flight safety meetings and in general recommendations to fighter pilots.

The limited intervention studies on diet and acceleration, which were conducted over 40 years ago or simulated G tolerance with LBNP, found increased G-tolerance in the fed versus fasting state (11, 32, 51). The centrifuge studies used a small number of subjects and lacked statistical analysis. Other than a 1945 experiment (12), which administered simple sugars to only 3 subjects, no data on the quantitative or qualitative aspects of pre-flight diets and G-tolerance is available. No study of the impact of the long-term adequacy of diets nor the nutritional status of pilots on G-tolerance has been conducted.

Two intervention studies (7,12) found that insulin-injection induced hypoglycemia reduced G-tolerance. Several prospective surveys, with limited assessment of pre-flight nutrient intake and no assessment of G-tolerance, monitored aircrew changes in blood sugar concentrations and found few occurrences of the signs and symptoms of hypoglycemia (38,49,57). However, 25% of civilian airline pilots showed a hypoglycemic response to a glucose tolerance test (23). The limited data on the association of food intake and self-reported symptoms of hypoglycemia has contradictory findings (19,47).

Recent survey data indicate that the breakfast meal is frequently skipped by U.S. fighter pilots (14,47). Only limited information is known about U.S. pilot meal patterns for the rest of the day. No survey data is available on pre-flight meals and whether this food intake deviates from customary food habits.

Based on earlier studies, the energy cost of piloting aircraft is moderate; however, no recent studies have evaluated the energy cost of sustaining the high G environment demanded by current aircraft technology.

Current and relevant data on the protein, fat and vitamin requirements of pilots is nonexistent. Sodium was the only mineral for which a fairly current intervention study was found (55).

Two surveys focused on the nutritional adequacy of the nutrient consumption of fighter pilots and found that carbohydrate consumption was less than the present recommendations (14,24,63). Neither survey differentiated between the amounts of simple and complex carbohydrates consumed. In most cases vitamin and mineral intake met the military nutrition standards (14).

Limited information is available concerning the need for substitute meals during multiple sorties; data is needed to substantiate the appropriate food choices under stressful conditions when time to eat and access to food are limited.

In 1983, the Committee on Military Nutrition advocated that more knowledge is needed about diet and nutritional needs of the military under physically and mentally demanding operational conditions (13). Based on the findings of this literature review, the following list summarizes research recommendations specific for TAC pilots. While this list is far from comprehensive, it focuses on issues with practical application to operational conditions as follows:

°**expand the present literature review** to include fluid requirements, hydration and G tolerance; functioning of the gastrointestinal tract during and after exposure to sustained high G_z forces; and sports nutrition research as applicable to TAC pilots. Apply these findings to research recommendations listed below where appropriate.

°**design and conduct intervention studies** to determine the optimum composition, size and timing of pre-flight food consumption.

°**design and conduct studies** to determine optimum meal substitutes and fluid recommendations for operational conditions where time to eat and access to food are limited.

°**evaluate** findings of literature review and subsequently design studies of hydration needs and nutrient solutions for use in the cockpit.

°**further assess and evaluate** dietary practices of TAC pilots including the timing and composition of pre-flight meals.

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THE ANALYSIS OF PULSE PROPAGATION IN LINEAR DISPERSIVE MEDIA WITH ABSORPTION BY THE FINITE-DIFFERENCE TIME-DOMAIN METHOD

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ABSTRACT

The finite-difference time-domain (FDTD) method is used to solve the Maxwell equations in media which exhibit frequency dependant complex permittivity using two conceptually different approaches. The first approach uses a convolution integral to relate the electric field (**E**) to the electric flux density (**D**) while the second approach relates the two via an ordinary differential equation. It has been observed that the differential equation method is the more accurate technique. Several examples illustrating pulse propagation in both Debye and Lorentz dispersive media are presented and the results obtained with the FDTD method are in good agreement with other available data. While the present work addresses only the one dimensional problem of a dispersive half-space, the method itself is applicable to general two and three dimensional problems as well.

INTRODUCTION

The calculation of electromagnetic pulse propagation in dispersive media is of fundamental importance when investigating the effects of radiation on biological tissue. The existence of field precursors can lead to unexpected field levels in the material. The classic works of Sommerfeld [1] and Brillioun [2] address the problem using asymptotic analyses. More recently Oughstun and Sherman [3] have made improvements on the original asymptotic analyses of Sommerfeld and Brillioun. Albanese, Penn and Medina [4] and Durney, Moten and Stockham [5] have applied a Fourier series analysis to investigate the formation of transients in media exhibiting Debye dispersion. In [6] Wyns, Foty and Oughstun used a Laplace transform analysis to calculate the Sommerfeld precursor. In all of these analyses the problems investigated have been one dimensional in nature. Due to the techniques used, the extension of these methods to the analysis of arbitrary three dimensional structures is not an easy task.

More recently techniques have been proposed to analyze dispersive media in the time domain via direct discretization of the Maxwell equations. The well known finite-difference time-domain (FDTD) method developed by Yee [7] has been modified to account for dispersive media in the time domain [8,9]. The advantage of applying the FDTD method to this class of problems lies in its ability to handle complex three dimensional geometries.

The purpose of the research being reported here has been to investigate the accuracy of using the FDTD method to model pulse propagation in linear dispersive media. Two different approaches to the problem have been investigated and the accuracy of each approach assessed. It has been found that accurate results in both Debye and Lorentz dispersive media can be obtained with the FDTD method.

In this report the formulation of the FDTD method in dispersive media is briefly outlined and the results for pulse propagation in a dispersive half-space are presented. The data obtained with the FDTD method is found to be in good agreement with data obtained from other techniques.

While the present work addresses only the problem of one dimensional wave propagation, the FDTD method is a general three dimensional technique. The next logical step of this research is, of course, the development of two and three dimensional FDTD models for dispersive media.

FORMULATION

Two different approaches have been investigated. The first was developed by Leubbers et. al. [8] and uses a convolution integral to relate **E** to **D**. In [8], only a Debye material was investigated. Extension of this convolution integral technique to Lorentz media has been met with some difficulties as is outlined in a companion report [10]. The second technique which was developed by Joseph, Hagness and Taflove [9] relates **E** to **D** using an ordinary differential equation. The latter approach has been applied to both Debye and Lorentz media and in the Debye case has been found to be more accurate than the convolution integral approach.

In this section the formulation of the two approaches is briefly discussed and the pertinent time-stepping relations are presented.

Convolution Integral Technique: We wish to find solutions to the Maxwell curl equations

$$\nabla \times \mathbf{E} = \frac{\partial \mathbf{D}}{\partial t} \tag{1a}$$

$$\nabla \times \mathbf{H} = - \frac{\partial \mathbf{B}}{\partial t} \tag{1b}$$

If we assume that there exists only a y-directed component of electric field (E_y) and a z-directed component of magnetic field (H_z), and assuming field variation only in the x-direction, then (1) becomes

$$\frac{\partial Hz}{\partial x} = - \frac{\partial Dy}{\partial t} \tag{2a}$$

$$\frac{\partial Ey}{\partial x} = - \frac{\partial Bz}{\partial t} \tag{2b}$$

We further assume that the media of interest is non-magnetic (i.e., μ_r = 1.0) so that

$$B_z = \mu_o H_z \tag{3}$$

The relation between **D** and **E** is given in the time domain by

$$D_y(t) = \varepsilon_\infty E_y + \varepsilon_o \int_0^t \chi(\tau) E_y(t-\tau)\, d\tau \tag{4}$$

where

ε_o = permittivity of free space

ε_∞ = infinite frequency permittivity

$\chi(\tau)$ = time domain susceptibility function

using central difference approximations for the derivatives in (2), and with (3), we obtain the following finite-difference equations:

$$\frac{D_y^{n+1}(i) - D_y^{n}(i)}{\Delta t} = - \frac{H_z^{n+1/2}(i+1/2) - H_z^{n+1/2}(i-1/2)}{\Delta x} \tag{5a}$$

$$\frac{H_z^{n+1/2}(i+1/2) - H_z^{n-1/2}(i+1/2)}{\Delta t} \approx - \frac{E_y^{n}(i+1) - E_y^{n}(i)}{\Delta x} \tag{5b}$$

where the index n is for time and i is for space (see reference 6).

By assuming all field components to be constant over each time step we can approximate (4) as

$$D_y^n(i) = \varepsilon_\infty E_y^n(i) + \varepsilon_o \sum_{m=0}^{n} E_y^{n-m}(i) \int_{m\Delta t}^{(m+1)\Delta t} \chi(\tau)\, d\tau \tag{6}$$

Using (6) in (5a) and solving for $E_y^{n+1}(i)$ yields a time-stepping relation for the electric field given by

$$E_y^{n+1}(i) = \frac{1}{\varepsilon_\infty + \chi_o}\Big[\varepsilon_\infty E_y^n(i) + \sum_{m=1}^{n-1} E_y^{n-m}(i)\Delta\chi_m - \frac{\Delta t}{\varepsilon_o \Delta x}\Big(H_z^{n+1/2}(i+1/2) - H_z^{n+1/2}(i-1/2)\Big)\Big] \tag{7}$$

where

$$\Delta\chi_m = \chi_m - \chi_{m+1}$$

with

$$\chi_m = \int_{m\Delta t}^{(m+1)\Delta t} \chi(\tau)\, d\tau$$

From 5(b) we obtain the time following time-stepping relation for H_z:

$$H_z^{n+1/2}(i+1/2) = H_z^{n-1/2}(i+1/2) - \frac{\Delta t}{\mu_o \Delta x}\Big(E_y^n(i+1) - E_y^n(i)\Big) \tag{8}$$

The FDTD algorithm is thus comprised of the repeated operation of equations (7) and (8).

For a Debye media the frequency domain permittivity is given by

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega t_o} \tag{9}$$

where

ε_s = DC permittivity

t_o = relaxation time of media

ω = radian frequency

Using the inverse Fourier transform it is easy to show that the time domain susceptibility function is

$$\chi(\tau) = \frac{\varepsilon_s - \varepsilon_\infty}{\varepsilon_o} e^{-(\tau/t_o)}u(\tau) \qquad (10)$$

where $u(\tau)$ is the unit step function.

For the Debye media the summation term appearing in (7) can be performed recursively. This eliminates the need to store all but one of the previous electric field values at each spatial point. The derivation of the recursion relation is given in detail in [8] and will not be repeated here.

In a Lorentz media the permittivity is given by

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_o^2 (\varepsilon_s - \varepsilon_\infty)}{\omega^2 + 2j\omega\delta - \omega_o^2} \qquad (11)$$

where

ω_o = resonant frequency of the media

δ = damping coefficient

Attempts to implement the above FDTD formulation for the Lorentz media have presented problems due to difficulties with the recursive evaluation of the convolution integral. Details are presented in [10].

Differential Equation Technique: The differential equation technique developed by Joseph, Hagness and Taflove [9] relies on being able to obtain an ordinary differential equation that relates **E** to **D**. For both Debye and Lorentz media this relation is relatively simple to derive.

Consider first the Debye media with

$$\varepsilon(\omega) = \frac{D(\omega)}{E(\omega)} = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)}{1 + j\omega t_o} \qquad (12)$$

Cross multiplying and taking the inverse Fourier transform of (12) yields the differential equation

$$D_y + t_o \frac{dDy}{dt} = \varepsilon_s E_y + t_o \varepsilon_\infty \frac{dEy}{dt} \tag{13}$$

applying a central difference to (13) we obtain the following which relates E_y at the current time step to D_y at the current and previous time steps and E_y at only previous time steps:

$$E_y^{n+1}(i) = \frac{\Delta t+2\tau}{2\tau\varepsilon_\infty + \varepsilon_s \Delta t} D_y^{n+1}(i) + \frac{\Delta t-2\tau}{2\tau\varepsilon_\infty + \varepsilon_s \Delta t} D_y^{n}(i) + \frac{2\tau\varepsilon_\infty - \varepsilon_s \Delta t}{2\tau\varepsilon_\infty + \varepsilon_s \Delta t} E_y^{n}(i) \tag{14}$$

Thus, the new FDTD algorithm consists of finding the magnetic field from equation (8), calculating the electric flux density using

$$D_y^{n+1}(i) = D_y^{n}(i) - \frac{\Delta t}{\Delta x}\left(H_z^{n+1/2}(i+1/2) - H_z^{n+1/2}(i-1/2)\right) \tag{15}$$

and determining the electric field from (14).

The procedure for the Lorentz media is very similar. Inverse Fourier transforming (11) as before and applying differencing yields

$$\begin{aligned} E_y^{n+1}(i) = \frac{1}{(\varepsilon_s \omega_o^2 \Delta t^2 + 4\delta\varepsilon_\infty \Delta t + 2\varepsilon_\infty)} \Big[& (\omega_o^2 \Delta t^2 + 4\delta\Delta t + 2) D_y^{n+1}(i) \\ & + (\omega_o^2 \Delta t^2 - 4\delta\Delta t - 4) D_y^{n}(i) + 2D_y^{n-1}(i) \\ & - (\omega_o^2 \Delta t^2 \varepsilon_s - 4\delta\Delta t\varepsilon_\infty - 4\varepsilon_\infty) E_y^{n}(i) \; 2\varepsilon_\infty E_y^{n-1}(i) \Big] \end{aligned} \tag{16}$$

The algorithm is the same as for the Debye media except that (16) is used in place of (14) for calculating the electric field from the electric flux density at each time and space point.

It should be pointed out that other types of dispersive media can be modeled using this technique provided the inverse Fourier transform of the permittivity function yields an ordinary differential equation relating D and E.

In the next section numerical results will be presented and compared to other available data in order to validate and assess the accuracy of the above dispersive FDTD formulations.

NUMERICAL RESULTS

Here results are presented for pulse propagation in dispersive media as calculated with the FDTD algorithms described above. For the Debye media it has been found that the differential equation approach is more accurate than the convolution integral approach under the same simulation conditions. Results from these algorithms will be compared to each other as well as results from a Fourier series analysis. Results obtained for the Lorentz media are presented and compared to data available in the literature.

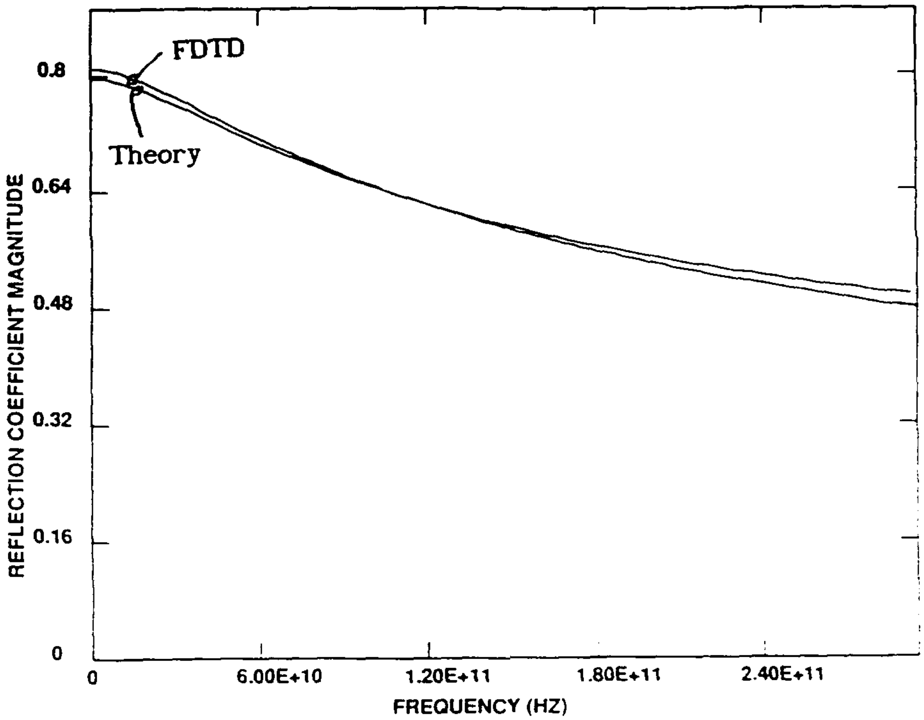
Debye Media Results: For a Debye media the frequency dependant permittivity is given by (9). In the following examples the material parameters are the same as those used in [4] for modeling water, namely

$$\varepsilon_s = 78.2\varepsilon_o \qquad \varepsilon_\infty = 5.5\varepsilon_o \qquad t_o = 8.1\text{x}10^{-12} \text{ sec}$$

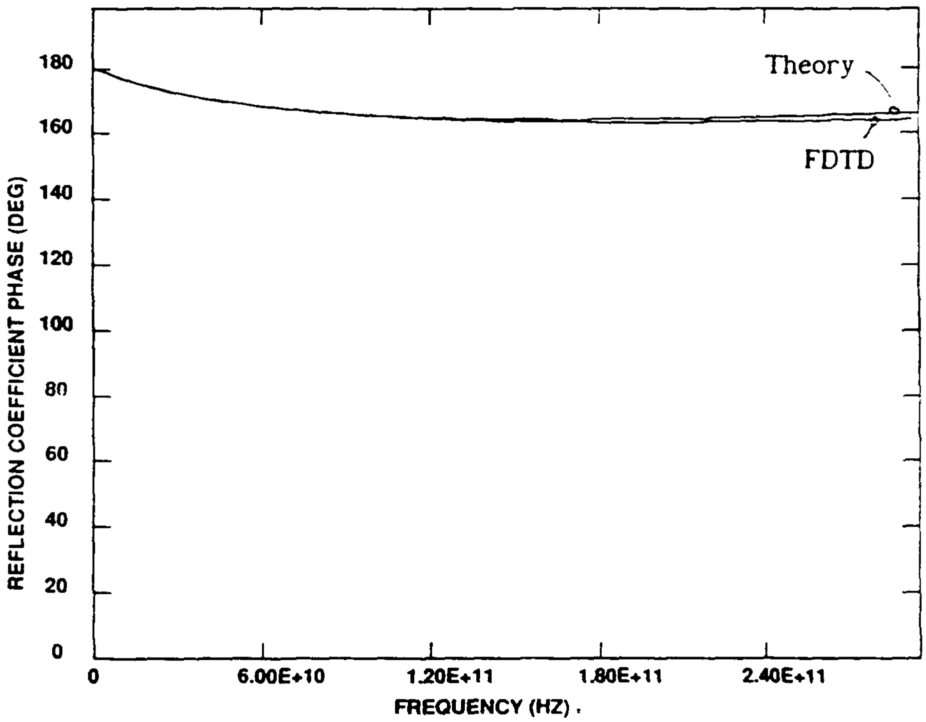
The geometry is an infinite half-space.

For the first example a Gaussian pulse of width 13.33 ps between -60dB points is taken to be normally incident on the half-space from free space. Using the FDTD algorithms, the complex reflection coefficient at the interface has been calculated by discrete Fourier transforming the reflected electric field and dividing by the spectrum of the incident Gaussian pulse.

The results obtained using the convolution integral approach are shown in Figure 1 along with the theoretical values. Figure 2 shows the



(a)



(b)

Figure 1. Reflection coefficient of Debye dispersive half-space using the convolution integral FDTD technique. (a) Magnitude and (b) phase.

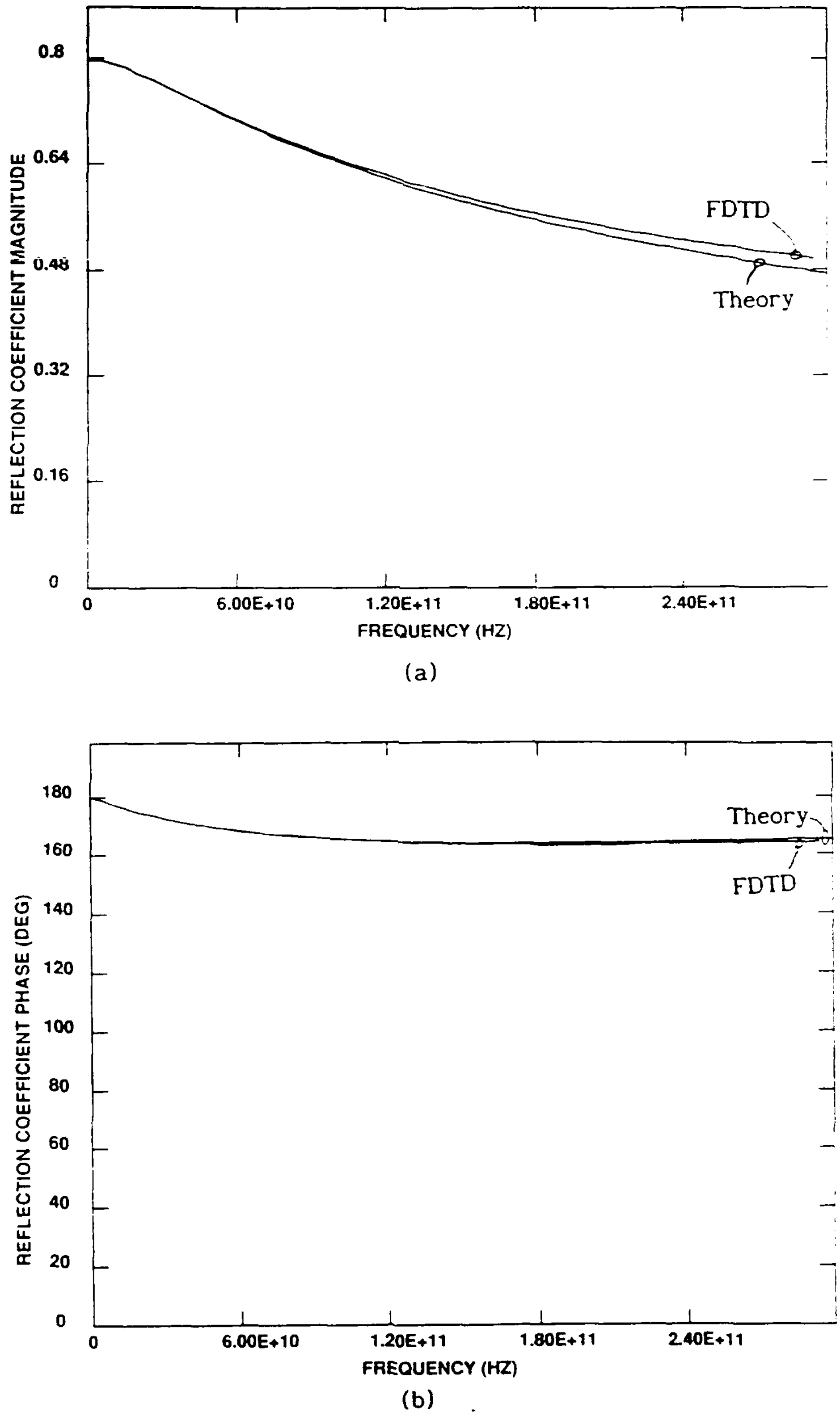


Figure 2. Reflection coefficient of Debye dispersive half-space using the differential equation FDTD technique. (a) Magnitude and (b) phase.

results of the same problem obtained using the differential equation approach.

We see that the accuracy for both methods is fairly good. It is interesting to observe that the convolution integral approach is less accurate than the differential equation approach at low frequencies for the parameters used in this test case, while both methods exhibit the same level of accuracy at the upper end of the frequency band. For both of these simulations the space and time increments were identical; Δx = 40 μm and Δt = 133.33 fs.

The next example demonstrates the propagation properties of the dispersive FDTD schemes. The same half-space as before is used with a normally incident plane wave with the incident electric field in the free space region being given by

$$E_y^i(t) = \begin{cases} \sin(20\pi \times 10^9 t) \ \ \text{V/m} & 0 \le t \le 1\text{ns} \\ 0 & t > 1\text{ns} \end{cases}$$

The temporal variation of the electric field at various points within the dispersive media was observed. An example waveform is shown in Figure 3. As reported in [4], leading and trailing edge transients corresponding to the Brillioun precursor are observed and have magnitudes exceeding that of the carrier frequency component.

In order to more quantitatively assess the accuracy of the two dispersive FDTD formulations, the maximum magnitude of the transient and the magnitude of the carrier frequency component are tabulated for observation points within the material at various distances from the material interface and compared to the results obtained from the graphs

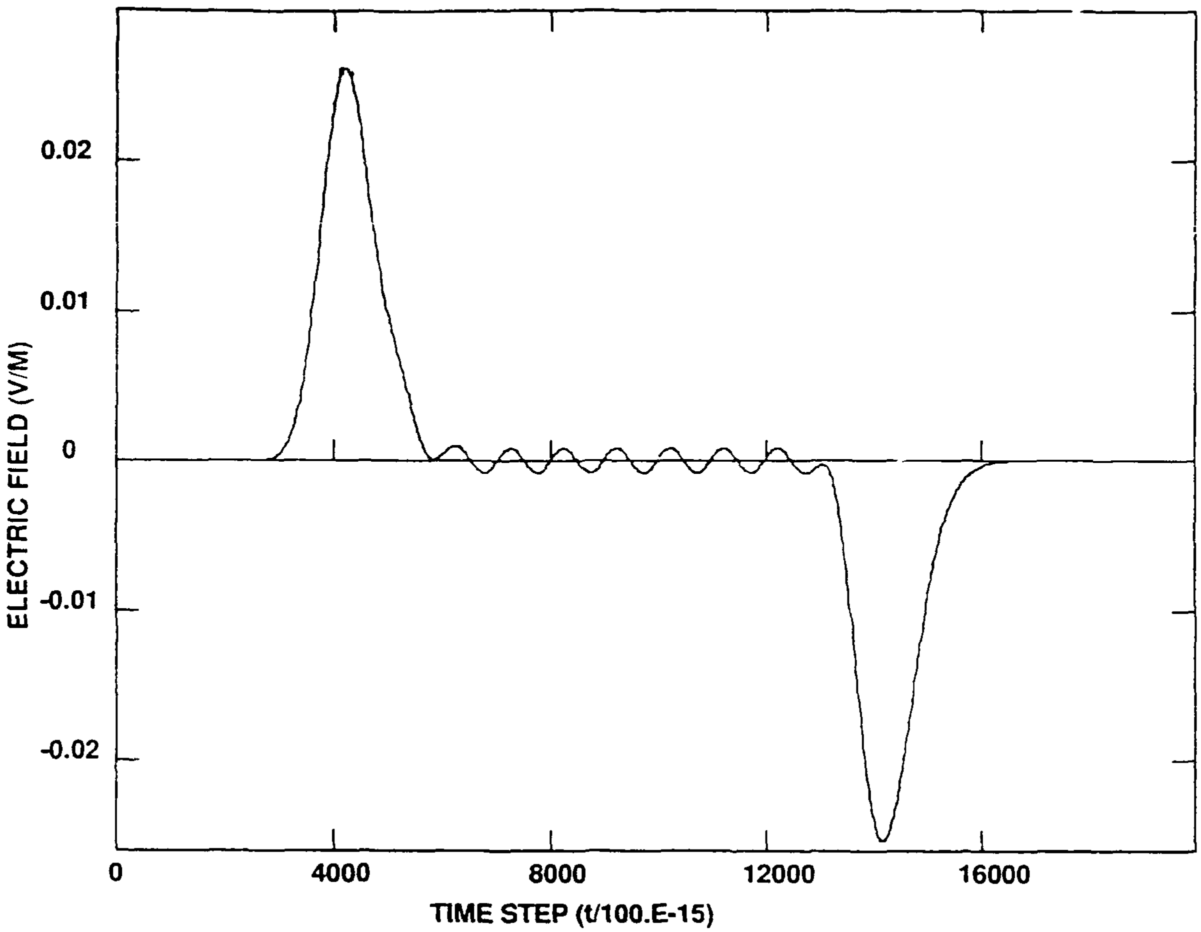


Figure 3. Temporal electric field behavior in Debye dispersive half-space at a distance of 14.7mm from the interface.

given in reference 4 which were calculated using a Fourier series technique. The results tabulated in Table 1 are for a mesh spacing of $\Delta x = 30\ \mu m$ and time step $\Delta t = 100$ fs.

From the data in Table 1 we see that the differential equation FDTD approach agrees with the Fourier series approach much better than the values obtained using the convolution integral approach.

TABLE 1

Electric field values in Debye dispersive material. D.E. is the differential equation approach and C.I. is the convolution integral approach.

Distance from Interface (mm)	Maximum Transient Amp (V/m)			Maximum Carrier Frequency Amp. (V/m)		
	D.E.	C.I.	Ref. 4	D.E.	C.I.	Theory
1.2	0.1456	0.1343	0.14	0.1364	0.1241	0.136
2.7	0.1005	0.0902	0.10	0.0774	0.0662	0.077
7.2	0.0483	0.0419	0.05	0.0141	0.0100	0.014
10.2	0.0355	0.0307	0.038	0.0045	0.0029	0.0046
14.7	0.0262	0.0209	0.033	0.0008	0.0004	0.0008

In order to determine the reason for the differing accuracy between the two methods a propagation analysis of the two techniques must be performed. This task has been begun but more work is needed before definitive results can be presented. Numerical experimentation has demonstrated that both methods approach the Fourier series and theoretical results for successively finer grid resolutions. In view of the better convergence of the differential equation method it was decided to concentrate efforts on this approach rather than the convolution integral method. The differential equation approach also has the advantage of being easily adapted for the Lorentz media.

Now, some results from a convergence study of the differential equation FDTD method will be presented. The same problem as above was solved using several different mesh sizes. Table 2 summarizes the results of this convergence study.

TABLE 2

Electric field values in Debye media for several mesh resolutions. Tran is the maximum amplitude of the transient and fc represents the amplitude of the carrier frequency component.

Δx (μm)	Distance from Interface (mm)									
	1.2		2.7		7.2		10.2		14.7	
	Tran	fc	Tran	fc	Tran	fc	Tran	fc	Tran	fc
30	.1456	.1364	.1005	.0774	.0483	.0141	.0355	.0045	.0262	.0008
60	.1456	.1364	.1005	.0774	.0483	.0141	.0355	.0045	.0262	.0008
150	.1459	.1368	.1459	.0773	.0481	.0148	.0354	.0045	.0261	.0008
250	.1437	.1350	.1437	.0756	.0474	.0141	.0350	.0042	.0260	.0007
500	.1553	.1536	.1536	.0822	.0470	.0130	.0348	.0036	.0261	.0006

We see from this data that reasonably accurate field values can be obtained using a mesh that is substantially coarser than the original 30 μm mesh. Thus, since coarser meshes can yield accurate results, larger problems can be solved with reasonable computer resource requirements, suggesting that extending the technique to solve two and three dimensional problems involving penetration into and scattering from dispersive bodies in the microwave frequency range can be accomplished without requiring unrealistic run time and memory requirements.

Lorentz Media Results: To test the differential equation FDTD approach for the case of Lorentz media the material parameters originally used by Brillouin [2] have been used. These parameters are as follows:

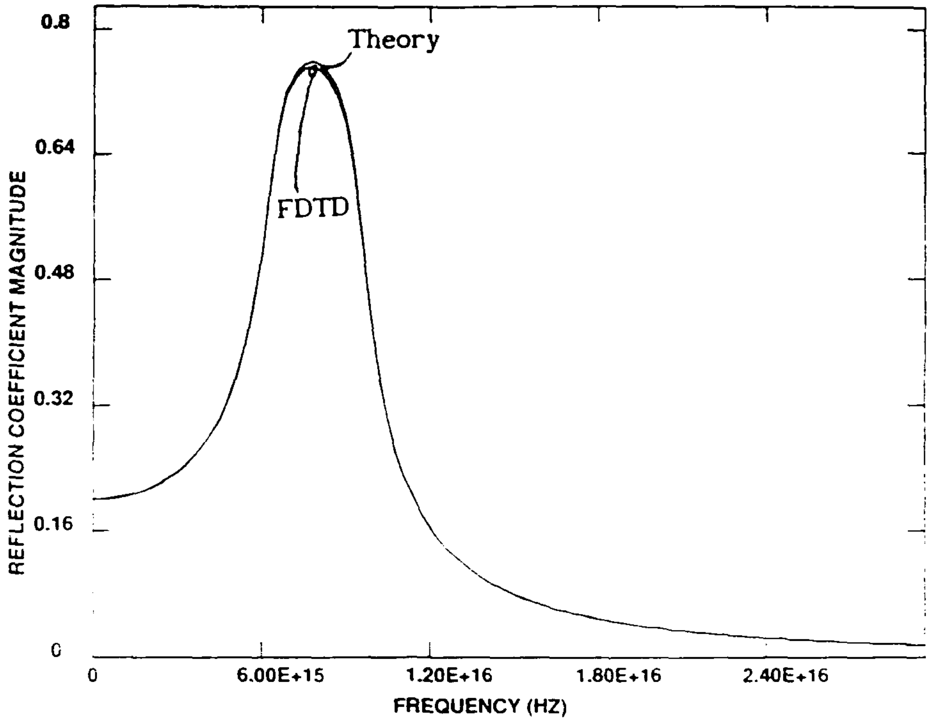
$$\varepsilon_s = 2.25\varepsilon_o \, , \quad \varepsilon_\infty = \varepsilon_o, \quad \omega_o = 4\text{x}10^{16}, \quad \delta = 0.28\text{x}10^{16}$$

As before, the reflection coefficient for a plane wave normally incident on the interface has been computed. For this simulation Δx is taken to be 60×10^{-12} m resulting in a Δt of 200×10^{-21} s. A Gaussian pulse narrow enough to provide data from DC up to 3×10^{16} Hz was used as the incident signal. Figure 4 plots the magnitude and phase of the reflection coefficient from the FDTD simulation along with the theoretical answer. Excellent agreement is observed.

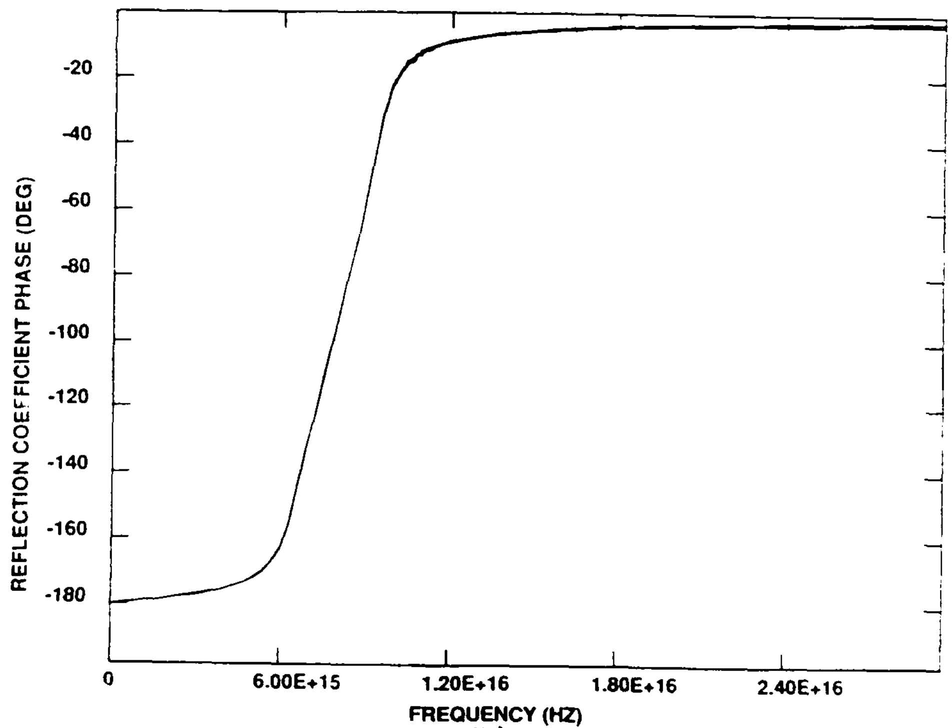
Next, the observation point was moved to 1μm from the interface and the incident plane wave was changed from the Gaussian pulse to a unit step modulated sinusoid of frequency 1×10^{16} Hz. The purpose of this test case was to try and observe the formation of the first, or Sommerfeld, precursor in the dispersive media.

Figure 5 plots the temporal variation of the electric field 1μm from the interface. For this simulation the modeling parameters were $\Delta x = 20 \times 10^{-12}$m and $\Delta t = 66.67 \times 10^{-21}$s. Clearly this data displays the same behavior as associated with the Sommerfeld precursor as reported in [1], [3] and [6]. Before giving a more quantitative comparison to other data the convergence of the FDTD model for this problem will be addressed.

To test the convergence of the FDTD algorithm three different cases were run. The spatial increment (Δx) for these cases was 20×10^{-12}m, 30×10^{-12}m and 60×10^{-12}m with corresponding time steps of 66.67×10^{-21}s, 100×10^{-21}s and 200×10^{-21}s, respectively. Figure 6 shows the early development of the Sommerfeld precursor for all of these cases. It has been found that the zero crossing points converge faster than the amplitude. Also, notice that the high frequency ripple on these



(a)



(b)

Figure 4. Reflection coefficient for Lorentz dispersive half-space. (a) Magnitude and (b) phase.

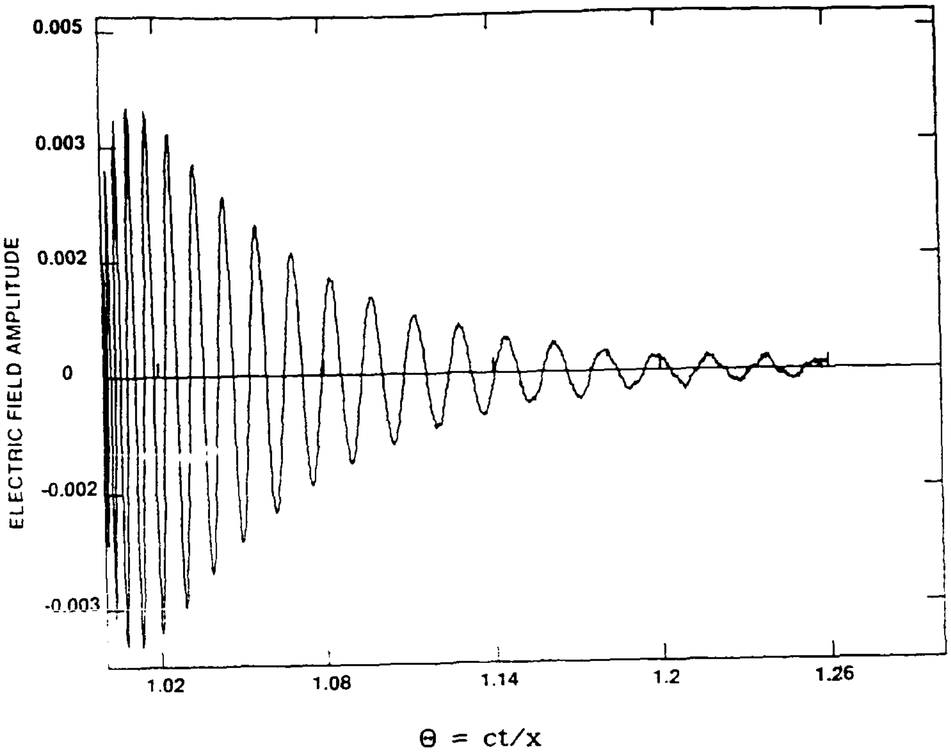


Figure 5. FDTD computed Sommerfeld precursor in the Lorentz half-space at a distance of 1μm from the interface.

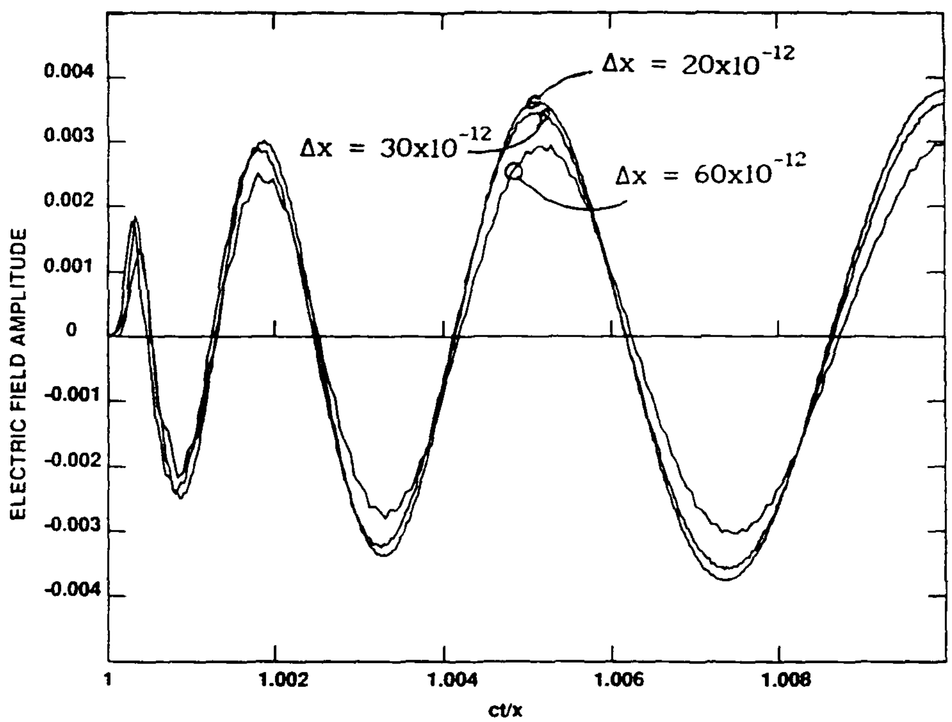


Figure 6. FDTD computed Sommerfeld precursor in Lorentz half-space at a distance of 1μm from the interface ,for $\Delta x = 20 \times 10^{-12}$, 30×10^{-12}, and 60×10^{-12} m.

waveforms, which is due to the discrete sampling associated with the FDTD method, is reduced, as would be expected, for successively smaller mesh spacings.

Due to the computational requirements of simulating the infinite half-space with such a fine mesh, no cases with Δx smaller than 20×10^{-12}m were run. For more realistic problems such as a finite slab of material, it will be possible to use a finer mesh (thus obtaining better convergence) and still maintain reasonable computer run times.

For comparison purposes Figure 7, taken from reference 6 shows the Sommerfeld precursor as calculated from a Laplace transform analysis. The trends certainly agree with the FDTD data. In Figure 8 the FDTD data for the early development of the precursor is plotted with data points taken from a graph in [6]. We observe agreement to be fairly good. We note again that the amplitude discrepancy can more than likely be decreased by using a finer mesh at the expense of increased computer resources.

CONCLUSIONS

In this report the results of research aimed at applying the FDTD method to the analysis of electromagnetic penetration into dispersive materials has been reported. It has been found that the FDTD method is capable of predicting transients that are associated with propagation in dispersive media and whose prediction is very important when analyzing penetration into and propagation in biological tissues. The data obtained using the FDTD algorithms has compared favorably to theoretical solutions when available and to data obtained by other researchers using different analysis techniques. The results obtained in this research

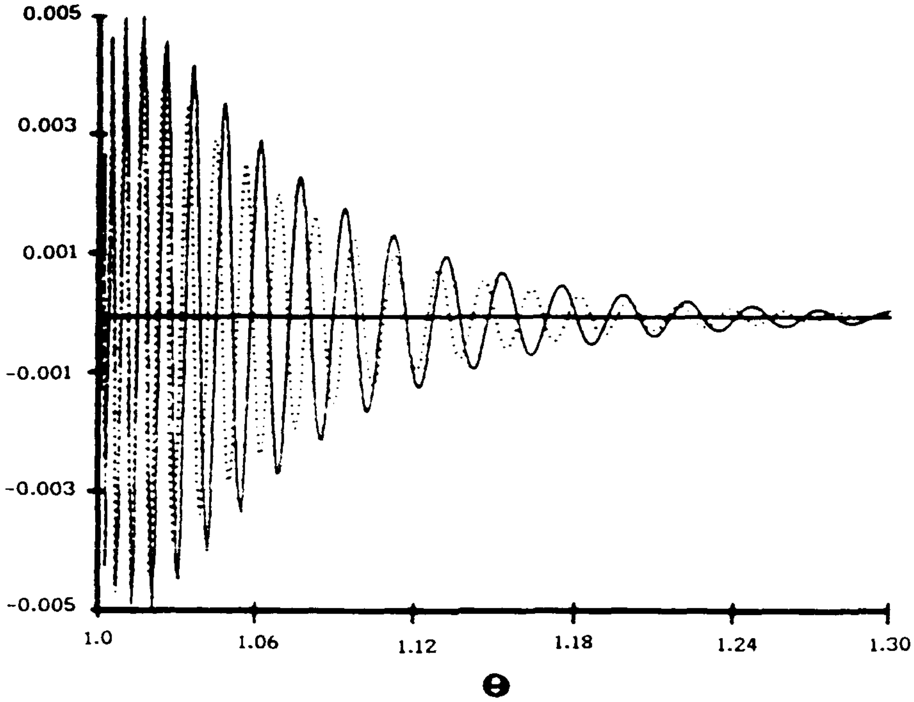


Figure 7. Sommerfeld precursor from reference 6 for comparison to Figure 5. (... - Laplace analysis, —— - asymptotic analysis)

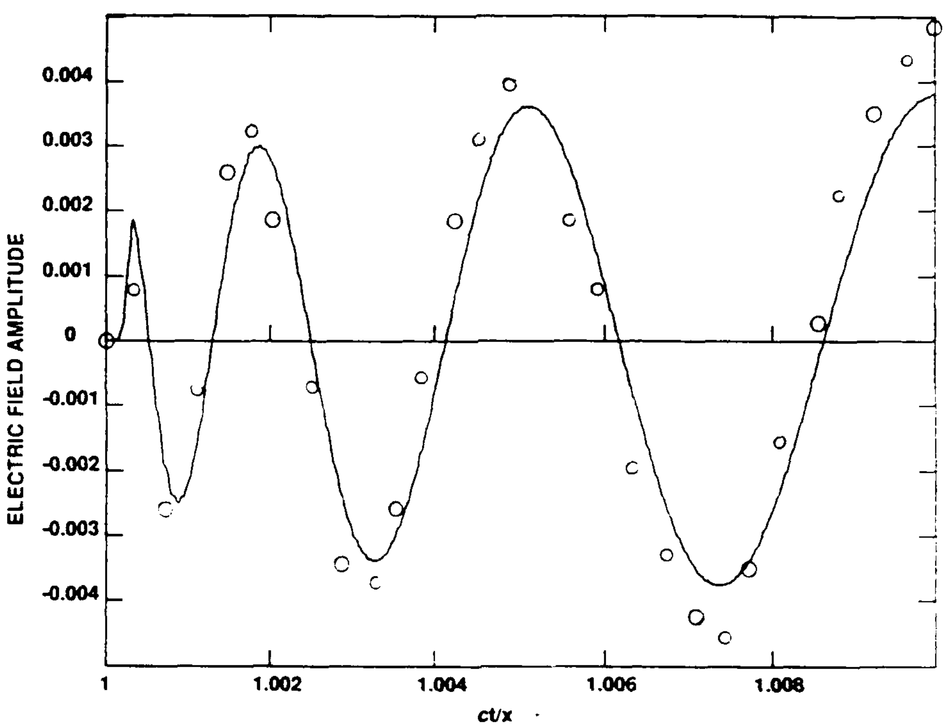


Figure 8. FDTD computed Sommerfeld precursor in early time with Laplace analysis values from [6] shown for comparison. (—— - FDTD, o o o - from [6])

demonstrate the feasibility of using the FDTD method for the solution of electromagnetic scattering and penetration problems involving Debye and Lorentz dispersive media. The next logical step in this research is the development of two and three dimensional computer programs that will allow the simulation of more realistic problems.

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FINAL REPORT

EFFECTS OF LOSS OF CONSCIOUSNESS ON THE MEMBRANE POTENTIAL OF NEOCORTEX CELLS OF RATS: A MODEL OF GRAVITY-LOSS OF CONSCIOUSNESS (G-LOC)

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ABSTRACT

The effects of loss of consciousness (LOC) on membrane potentials of neocortex cells of the rat was examined with microelectrodes. Loss of consciousness was induced by performing an aortic transection, thus, resulting in cerebral ischemia. Preliminary experiments were conducted to characterize different types of membrane potential recordings. Two types of recordings were note. First, most recordings of membrane potential were "flat" and were greater than - 50 mV. Some cells had membrane potentials which were greater than - 80 mV. The second type of recording of membrane potential possessed "spike" activity. Generally, cells which exhibited spike activity had membrane potentials which ranged between - 50 to -60 mV. Recordings of membrane potentials from cells which were subjected to LOC due to cerebral ischemia showed various recordings. Once again, cells had membrane potentials greater than - 70 mV. Once the aorta was transected, the EEG was isoelectric within 14 - 25 sec and the membrane potential went through varying phases of depolarizing and hyperpolarizing potentials. Additional studies are needed to further characterize the effects of LOC on the membrane potential of neocortex cells. These results, though preliminary, represent a good "bench-top" model of LOC which will provide important additional information which can aid in the evaluation of the physiological phenomena of gravity-induced loss of consciousness (G-LOC).

OBJECTIVES

To examine initial and sustained changes in membrane potential of neocortex cells of the rat at the onset and during loss of consciousness (LOC) (cerebral ischemia "bench-top" model of LOC).

SIGNIFICANCE

There is a growing concern among officials of the U.S. Air Force (USAF) with the potential for loss of life and aircraft due to gravity-induced loss of consciousness (G-LOC) with pilots flying high performance aircraft (Burton 1988, Burton and Whinnery 1985). Under rapid flying maneuvers, G-LOC can result in the incapacitation of a pilot resulting in disorientation, confusion and the inability to properly control an aircraft, therefore, increasing the potential of a Class A mishap (Burton and Whinnery 1985, Whinnery et al. 1987). Recent efforts have begun to improve human tolerance to high sustained G such as increased physical conditioning of pilots, development of improved G-valves and G-suits and the training of pilots in anti-G straining maneuvers (Burton and Whinnery 1985, Burton 1991). However, with these innovations, the USAF still reports loss of pilot life and aircraft due to G-LOC. It is apparent that a better understanding of the physiological phenomena of G-LOC is imperative in an effort to construct appropriate strategies to reduce a pilot's risk of G-LOC. At present, G-LOC has been described as "a state of altered perception wherein (one's) awareness of reality is absent as a result of sudden, critical reduction of cerebral blood circulation caused by increased G force" (Burton 1988).

In humans, cerebral ischemia results in loss of consciousness (LOC) within seconds (Rossen et al. 1943). Present dogma suggests that LOC occurs due to decreased cerebral blood flow resulting in decreased delivery of oxygen and glucose to the brain. However, the actual chronology of the physiological and biochemical events leading to LOC (and G-LOC) is not fully understood (Hansen 1985, 1987; Werchan 1991).

Recently, much research of LOC due to cerebral ischemia has focused on changes in the ionic composition across membranes and the high energy phosphate metabolites of neuronal tissue during and after LOC. It is reasonable to assume that neuronal activity would be one of the first elements of brain function which might be altered during LOC.

Hansen and co-workers (Hansen 1985, 1987; Hansen and Zeuthen, 1981; Siemkowicz and Hansen, 1981) have characterized ionic homeostasis and alterations in ionic composition in the rat brain cortex during LOC due to cerebral ischemia. The described events of cerebral ischemia are as follows: a) electroencephalograph (EEG) activity stops (isoelectric) within seconds, b) initially interstitial potassium concentration $[K^+]$ shows a slow increase, c) after two minutes $[K^+]$ increases abruptly and levels at 70 mM and interstitial sodium $[Na^+]$ and calcium $[Ca^{2+}]$ concentrations are decreased, and d) DC potential (across the blood brain barrier; normally slightly positive) becomes strongly negative. Most of the measured ionic changes occur minutes after the EEG becomes isoelectric (LOC occurs) and the first apparent depolarization of the DC potential occurs. Therefore, it is unclear what happens to the membrane potential of neurons of the rat cortex prior to and during the inital stages of LOC.

Fundamental questions to be asked about LOC and and G-LOC are, first, how does the ionic changes seen during LOC in the rat cortex due to cerebral ischemia relate and compare with the initial events of G-LOC? And secondly, how can similar experiments conducted with the "bench-top" model be conducted under high sustained G conditions?

Recently, a small animal centrifuge (SAC) was constructed in the laboratory of Dr. Paul Werchan (Armstrong Laboratory, Brooks AFB, TX) that has the capability of generating high sustained positive G-forces (+Gz) to produce G-LOC in small rodents (rats and mice). Dr. Werchan has begun a comparison of the biochemical characterization of high energy phosphates of animals subjected to LOC (cerebral ischemia caused by an aortic transection) and G-LOC (SAC) (Werchan and Shahed, in preparation).

At present, no information is known about the alteration of ionic composition of the rat cortex when rats are subjected to high sustained +Gz. The nature of this summer research project was two-fold, first, to conduct a preliminary characterization of membrane potentials of neocortex cells of the rat and changes in membrane potential when the rat was subjected to loss of consciousness due to acute cerebral ischemia (aortic transection). Therefore, the rationale for first conducting microelectrode experiments with a "bench-top" model of LOC is to examine the "workability" of the microelectrode technique for measuring membrane potentials of neocortex cells of the rat. Microelectrodes are very fragile with tip diameters of 1 micron and smaller. Proper handling must be observed in order to prevent damage to the microelectrode during use. Second, is the feasibility assessment of implementing the microelectrode technique to study the effects of high sustained G force (SAC) on the membrane potential of neocortex cells of the rat.

MATERIAL AND METHODS

Laboratory Animals

Sprague-Dawley rats (males, 300 - 600 g) were used for all experiments. Animals were housed in the USAF-Armstrong Laboratory vivarium with water and food available ad libitum and a 12L:12D light:dark cycle.

Animal Anesthesia and Surgery

Animals were weighed on a triple-beam balance (to the nearest 0.1 g). Animals were anesthetized by giving a combined intramuscular injection of Ketamine HCl (35 mg/kg) and Xylazine (5 mg/kg). Level of anesthesia of an animal was monitored by observing whether a pain reflex would be elicited by pinching an extremity.

Once anesthetized, the head and upper neck of the rat was shaved. A dorsal midline incision was made posterior to the eyes and extended posteriorly to the back of the head. A scalpel blade was used to scrape back overlying muscle and fascia to expose the skull. Afterwhich, a 4 mm x 2 mm craniotomy was prepared within the left parietal portion of the skull with a dental drill (Fig. 1). Once the craniotomy was prepared, the exposed dura mater was carefully punctured with a needle and removed. Blood was blotted with cotton applicators. Using a finger drill and screw tap, three holes were drilled and tapped for placement of electroencephalographic (EEG) electrodes (see Fig. 1 for location of EEG electrodes). The electrodes consisted of a stainless steel screw and a washer connected to a shielded wire. Electrode leads were connected to a preamplifier (DAM 70, World Precision Instruments, Sarasota, FL) which was connected to an eight channel chart recorder (Model 2800S, Gould Inc., Cleveland, OH). The calculated time to loss of consciousness was determined to be the amount of time from the aortic transection until the EEG recording became isoelectic (i.e., cessation of brain wave activity).

Cerebral ischemia was produced via a modified aortic transection method described by Winn et al. (1979). Briefly, through an abdominal incision, the descending aorta and inferior vena cavae were isolated 2 cm caudal to the left renal vein. A stainless steel wire was passed around the vessels and exposed through the abdominal incision. Both ends of the wire were then passed through a sharp 18 gauge needle. Cerebral ischemia was produced by quickly pulling the wire with the enclosed vessels through the sharp needle to transect the vessels.

Prior to an experiment, animals were positioned in a head stereotaxic apparatus (Model 900, Kopf Instruments, Tujunga, CA) to prevent head movement during microelectrode impalement attempts and aortic transection. The exposed skull was bathed with 0.9% saline.

Electrophysiology

Microelectrodes were constructed from borosilicate glass tubing (BF120-60-10, 1.2 mm O.D., 0.6 I.D.; Sutter Instrument Co., Novato, CA) and pulled to a tip diameter of 1 micron or smaller on a single stage vertical pipette puller (Model 700C, Kopf Instruments). Tip resistances of electrodes ranged from 20 - 80 megaohms when filled with 3 M KCl. Microelectrodes were placed in a Ag-$AgCl_2$ half-cell, which was mounted on a three-dimensional micromanipulator (M3302, Narishige, Japan) and connected to a high impedance electrometer (Model M-707A, World Precision Instruments). A Ag-$AgCl_2$ wire served as a ground electrode and was placed in the saline bathing the skull of the animal. Output signals (membrane voltage) from the electrometer were observed on a dual storage oscilloscope (Model 5111, Textronic, Channel Islands) and recorded with a chart recorder. Before and after every experiment, the chart recorder was calibrated for a full scale voltage of 0 to -100 mV with a DC voltage source.

Due to the sensitivity of the fragile micropipette tips, experiments were conducted on an isolation table. Such isolation reduced the vibrational interference (i.e., building vibrations, local movements) from the surrounding area and, thus increased the probability of prolonged microelectrode impalements.

Criteria for Microelectrodes Impalements

Criteria for an acceptable impalement of a micropipette was a quick downward deflection indicative of negative membrane potential once the micropipette entered the cell. Likewise, a good impalement was noted if a quick upward deflection of voltage occurred when the micropipette was moved out of the cell (by tapping the set-up table, see Fig. 2).

All membrane potentials are presented as the mean ± one standard deviation.

RESULTS

Observed Membrane Potentials

The mean resting membrane potential of an impaled neocortex cell of the rat brain was measured to be -58 ± 19 mV (n = 83, range -20 to -90 mV). However, Table 1 shows membrane potentials of cells grouped into three different voltage categories. Of the cells examined, 55% of the cells (46/83) had membrane potentials more negative than -60 mV with a mean voltage of -72 ± 8 mV. A typical trace of a membrane potential recording of one of these cells is shown in Fig. 2. Some impalements lasted as long as 13 minutes at which time the micropipette was moved out of the cell to verify the impalement as acceptable. Membrane potential recordings were also grouped as those below -49 mV and those between - 50 mV and -59 mV (31 and 14%, respectively).

Most of the membrane potential recordings (94%, 78/83) exhibited "flat" traces as seen in Fig. 2. However, 7% (5/83) of the cells examined exhibited membrane potentials which possessed spike activity. Spike activity was observed only in cells which had membrane potentials ranging between -49 mV to -58 mV (Table 1). Typical recordings of cells with spike activity are shown in Fig. 3. In Fig. 3A, the spike activity of the cell was so fast that the frequency response of the chart recorder was inadequate to record the peak of the change in voltage during the spike activity. However, in that particular cell, the peak voltage reached 0 mV as monitored on the storage oscilloscope. Spike activity was noted more often than recorded (20 to 30 observations without recordings). Once again, cells which possessed spike activity had membrane potentials slightly more negative than - 50 mV.

Membrane Potential During LOC

Figure 4 shows recordings of membrane potential of impaled neocortex cells of rats subjected to loss of consciousness via an aortic transection. In Fig. 4A, the resting membrane potential prior to the aortic transection was - 80 mV. However, after the transection, membrane potential depolarized and hyperpolarized eventually reaching 0 mV after seven seconds. In Fig. 4B simultaneous recordings of EEG and membrane potential are presented. Prior to the aortic transection, the resting membrane potential of the cell was - 70 mV. However, after the aortic transection, EEG activity increased momentarily and then decreased to isoelectric (Fig. 4B, upper panel). After the transection, membrane potential hyperpolarized slightly then depolarized and eventually reached 0 mV (Fig. 4B, lower panel). The elapsed time to loss of consciousness was determined to be 18 ± 6 sec (n = 3).

DISCUSSION

Measurements of membrane potential of neocortex cells of the rat during normal oxygen and anoxic conditions were recorded with microelectrodes. Most of the impaled cells displayed "flat" activity recordings, while a smaller number of cells exhibited "spike" activity. In the present study, the resting membrane potential of cells examined ranged from -20 to -90 mV. Cells which exhibited spike activity possessed membrane potentials between -50 and -60 mV. However, the length of recording of cells with spike activity was no longer than ten seconds. Therefore, only cells which exhibited long flat membrane potential recordings were subjected to anoxia (aortic transection to cause cerebral ischemia). After an aortic transection, recordings of membrane potential of neocortex cells showed varying results. Generally, after transection, membrane potential hyperpolarized and than depolarized.

The initial hyperpolarization of membrane potential after the aortic transection is may be due to the outward movement of potassium which has been noted in the rat cortex (Hansen, 1985), rat hippocampus (Fujiwara et al., 1987; Leblond and Krnjevic, 1989) and the guinea pig hippocampus (Hansen et al. 1982). However, measurements of membrane potential of neurons of the cat during hypoxia have yielded varying results. Several authors have reported a rapid depolarization of membrane potential to anoxia of spinal neurons of the cat (Kolmodin and Skoglund, 1959; Collewijn and van Harreveld, 1966; Eccles et al., 1966). Other authors have reported an absence of change in membrane potential when motorneurons were subjected to anoxia (Nelson and Frank, 1963).

At present, the cause of the initial changes in membrane potential during cerebral ischemia remains unknown. Many questions still need to be asked and answered. Continuing research in the field of loss of consciousness due to cerebral ischemia will provide the needed information which scientists can use to better understand the phenomena of gravity-induced loss of consciousness.

RECOMMENDATIONS

1) The use of microelectrodes to measure membrane potentials of neocortex cells of the rat subjected to cerebral ischemia via an aortic transection appears to be an appropriate method for examining the initial effects of loss of consciousness (LOC). Further studies with this technique using the "bench-top" model of LOC will add to our knowledge concerning cerebral ischemia which can be applied to gravity-induced loss of consciousness (G-LOC). However, it is recommended that the four-artery occlusion technique (Pulsinelli and Brierley, 1979; Pulsinelli and Buchan, 1988) for inducing cerebral ischemia res... ing in LOC be substituted for the aortic transection method. With the four-artery occlusion technique, the investigator can induce multiple episodes of LOC without having to sacrifice the animal. This technique would allow measurement of membrane potentials after subsequent episodes of LOC with the same animal. The aortic transection method allows only one measurement of membrane potential, then, the animal is sacrificed in order to induce LOC. However, it may be of interest to perform an aortic transection after multiple occlusions to verify the multiple occlusion data collected

2) The feasibility of implementation of the microelectrode technique for measuring membrane potentials of neocortex cells of the rat while under high sustained G forces (SAC) appears to be a high risk undertaking at the present level of technical advances. This recommendation is suggested for the following reasons: **A)** the microelectrodes are very delicate and the likelihood that a microelectrode could be mounted in a rat brain and cemented with dental acrylic and and the rat placed in a restraining holder without being broken is very slim. **B)** The microelctrodes are fab·icated from glass tubing and are filled with KCL. At the present time, it is unknown how well glass (and the liquid inside the pipette) will withstand high sustained G forces. And, **C)** Since the animal is subjected to very high sustained +Gz (25 to 30 G), it is probable that the brain of the rat will move during the this maneuver (P. Werchan, pers. comm.) and the microelectrode (which is making an intracellular recording) would move out of the cell which it had impaled.

3) It is recommended that metal oxygen electrodes be used to monitor tissue oxygen levels in both the "bench-top" cerebral ischemia model of LOC (via the four-artery occlusion technique) and with rats subjected to high sustained +Gz (G-LOC) with the small animal centrifuge (the techniques I learned with handling microelectrodes will be an added advantage for working with the metal oxygen electrodes, also during my summer research I have learned and employed some of the techniques necessary for the proposed recommendation). This recommendation is made from the following observations. Present dogma is that G-LOC occurs due to a critical reduction of cerebral blood circulation caused by the increased G force (Burton, 1988). However, at the present time, nothing is known about the tissue oxygen level of the rat cortex or sub-cortical regions (i.e., hippocampus) just prior, during and after G-LOC. Analyses of high energy phosphates of brains of rats which have been exposed to high sustained +Gz, with the small animal centrifige, suggest that a shift from aerobic metabolism to anaerobic metabolism does occur prior to or during G-LOC (Werchan and Shahed, in preparation). These data suggest that tissue oxygen levels are depleted (due to reduced cerebral blood flow) during high sustained +Gz. However, the time correlation between oxygen depletion and onset of anaerobic metabolism is not known. The use of metal oxygen electrodes have some advantages over glass microelectrodes. First, the metal oxygen electrodes are placed extracellularly, therefore, the movement of the brain in the rat is not as crucial as would be the case for glass microelectrodes. Secondly, the metal electrodes are more durable and would better withstand handling of the animal after implacement. The metal electrodes would definitely withstand high sustained G exposure. Thirdly, use of the metal oxygen electrodes would allow measurements to be made on the same animal after multiple centrifuge runs on the same day. Or measurements could be made on the same animal after a long period of recovery subsequent to centrifuge experiment (weeks). This would allow an examination of the effects of multiple G exposures on tissue oxygen levels.

ACKNOWLEDGMENTS

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I wish to thank Dr. Paul Werchan for his assistance, encouragement, advice and friendship during this project. I thank Doug Coffey, Charlie Kuhnel, and Judy Barber for their technical assistance during all phases of the project. Lastly, I wish to thank Drs. Lew Lutton and Randy Glickman for the use of equipment which made my task much easier.

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Table 1. Observed m mbrane potentials of neocortex cells of the rat brain

Category (mV)	Mean Membrane Potential (mV)	Spike Activity[1] Present	N[2]
- 20 to - 49	- 35 ± 9	1	26
- 50 to - 59	- 52 ± 3	4	11
- 60 to - 90	- 73 ± 9	0	46

[1] number of cells with spike activity

[2] total number of impaled cells

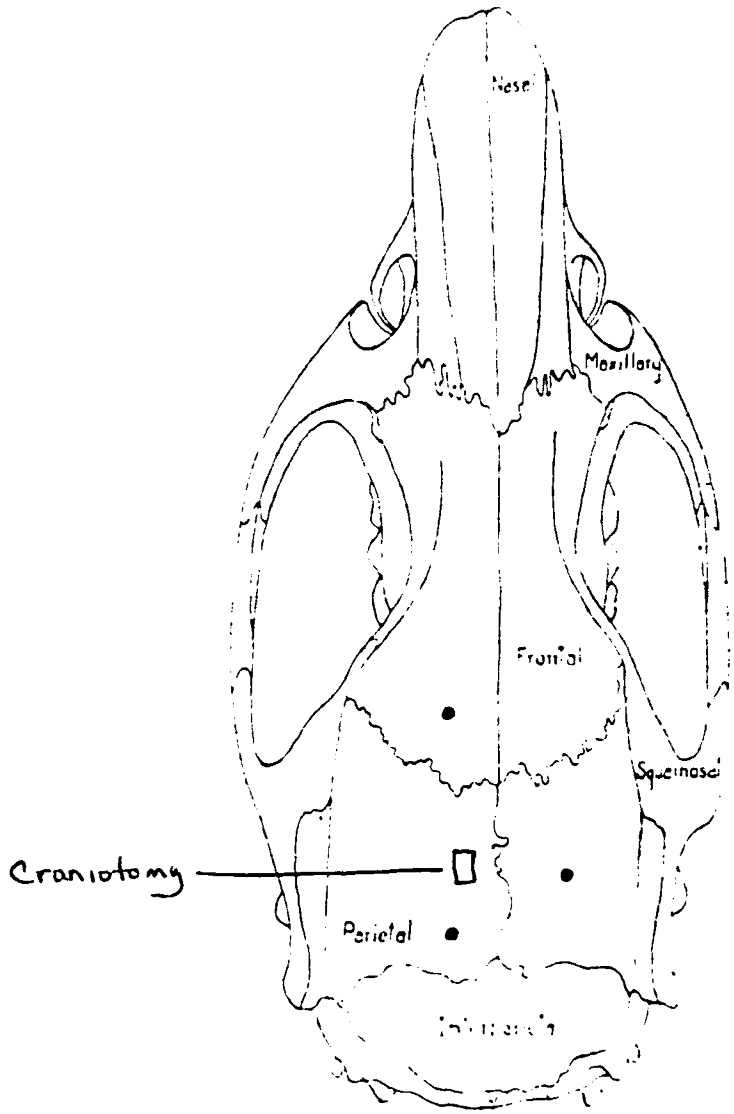
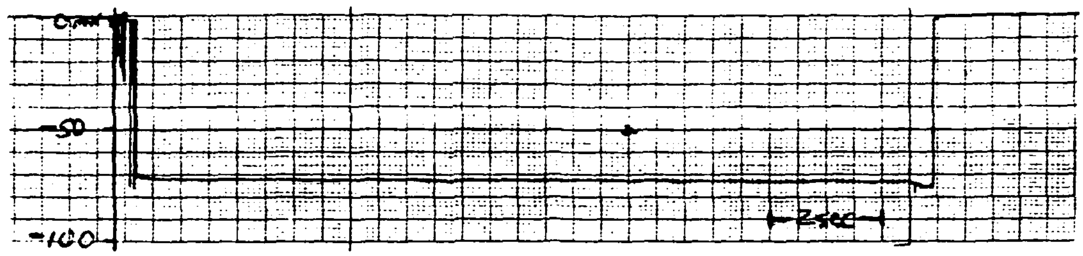


Figure 1. Location of the craniotomy within the left parietal bone of the rat skull. The dura mater was punctured and removed to allow passage of microelectrodes. Location of EEG electrodes are shown by solid circles.



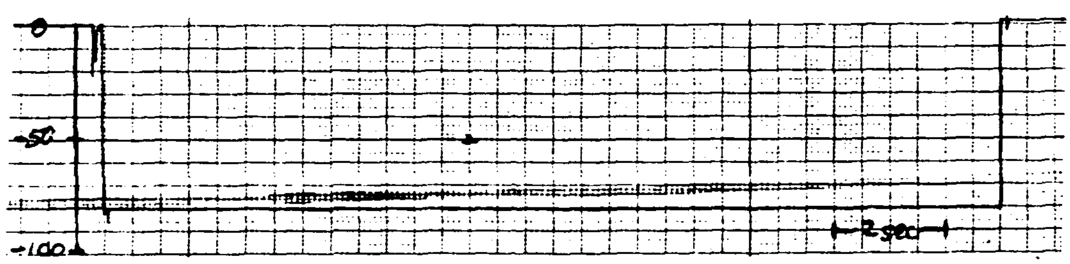


Figure 2. Traces of membrane potential recordings from two neocortex cells of the rat brain. A) A recording of a cell with a resting membrane potential of - 72 mV. B) A recording of a cell with a resting membrane potential of - 80 mV. Note the rapid response of the micropipette as it enters and is removed from the cell.

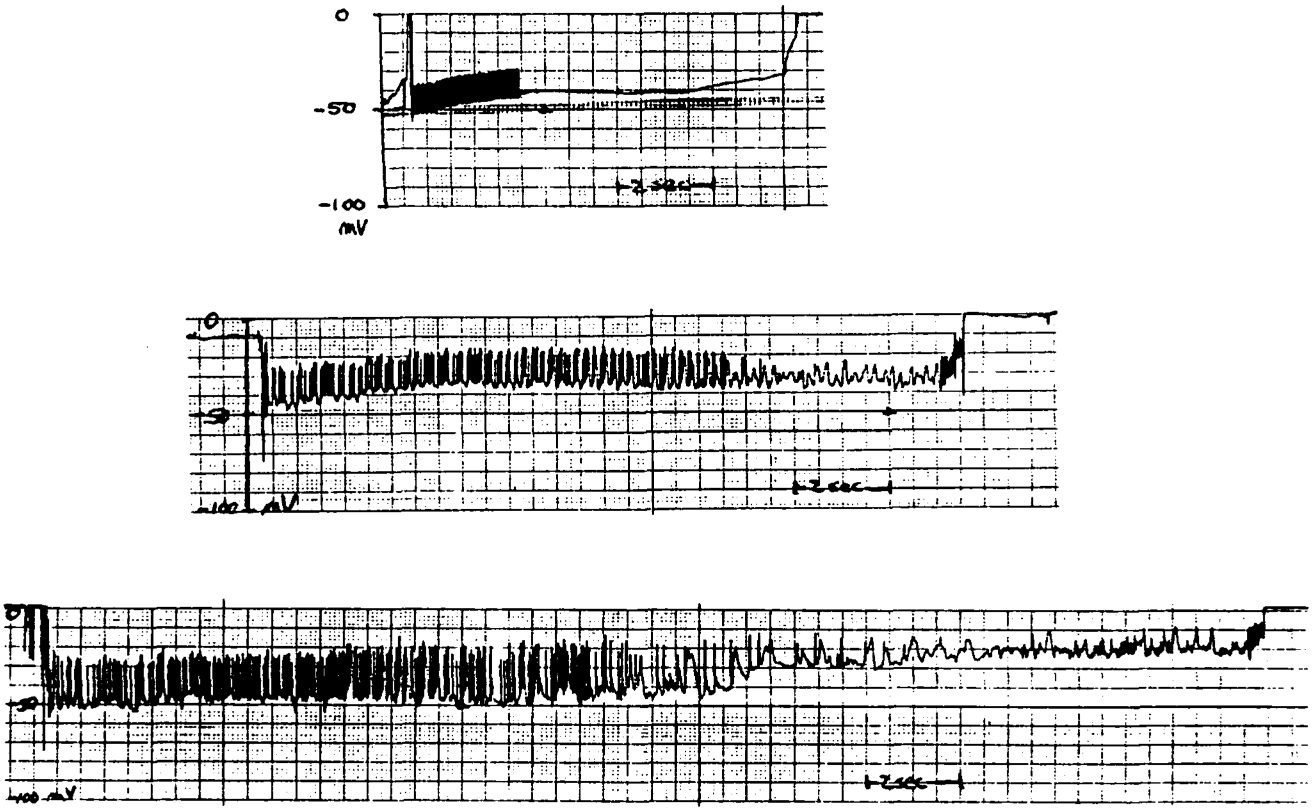
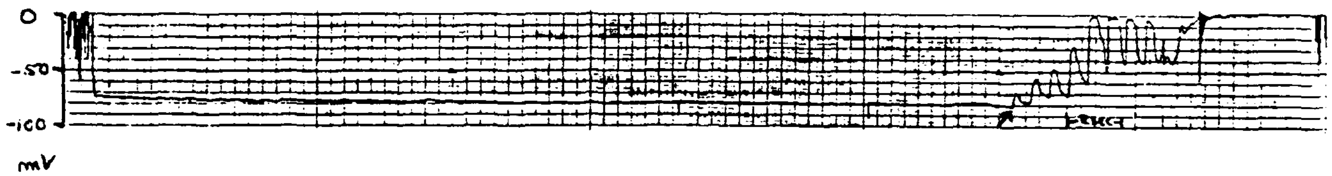


Figure 3. Spike activity recorded from neocortex cells of the rat brain.

A



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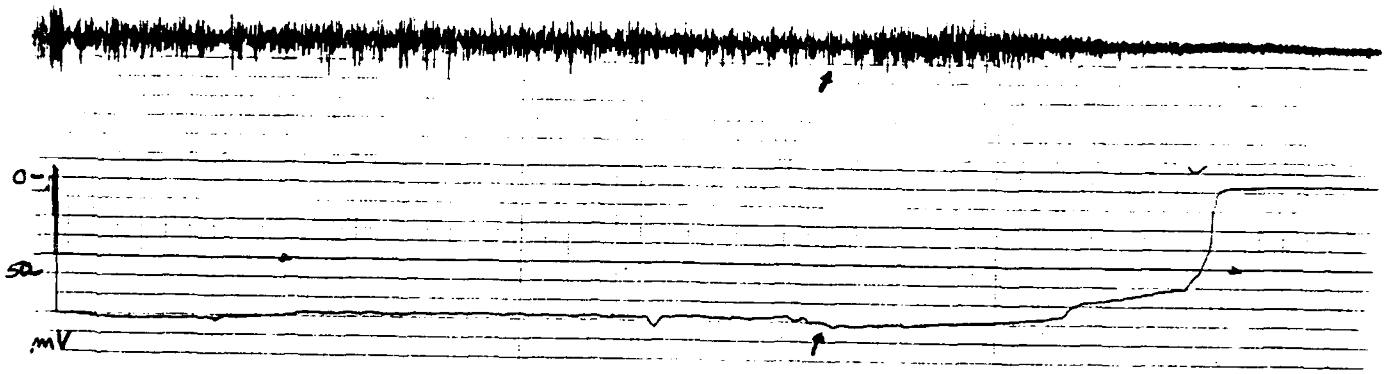

Figure 4. A) Recording of a membrane potential of a neocortex cell of the rat before and after an aortic transection. The resting membrane potential of the cell is - 80 mV prior to the transection. However, membrane potential falls to 0 mV shortly after the aortic transection is performed. Note the increase in EEG activity after the transection, and then, the EEG recording becomes isoelectric. B) Tracings of EEG (upper panel) prior to and during an aortic transection. After the transection, membrane potential became slightly hyperpolarized and then depolarized eventually reaching 0 mV.

PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM SUBMAXIMAL EXERCISE TESTING IN AEROBICALLY FIT AND NONFIT SUBJECTS

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ABSTRACT

Aerobic physical fitness as determined by the body's maximal capacity to utilize oxygen (VO_{2max}) during demanding work is an important determinant of a person's ability to perform many military job tasks. The need to easily and accurately estimate this important factor on a periodic basis is becoming evident as dissatisfaction with the present 1.5 mi run mounts. This paper reviews prior studies of a test which uses heart rate response to known workloads on a cycle ergometer to predict VO_{2max}. This test, as revised by scientists at the USAF Armstrong Laboratories at Brooks AFB, Texas, was validated on 20 male subjects by comparing the test results with laboratory measurements of VO_{2max} obtained by analysis of expired air during maximal treadmill exercise. The cycle ergometry prediction underestimated the measured VO_{2max} in all subjects, but there was a correlation of 0.93 between the estimated and measured values. Both estimated and measured VO_{2max} were significantly higher in the group of trained runners than in the inactive subjects.

INTRODUCTION

Positive health is characterized by more than an absence of disease; functional capacity, one aspect of which is aerobic capacity (the body's ability to do heavy sustained work) is another important aspect. Aerobic capacity is measured by determining the body's maximal rate of oxygen consumption, which is dependent on the cardiovascular system's ability to deliver blood to working muscles and the cellular ability to take up and utilize this oxygen in energy production. Maximal oxygen uptake (VO_{2max}) is both the most important indicator of physiological fitness and is positively correlated with cardiovascular health(1,2).

Measurement of VO_{2max} is a laboratory procedure involving maximal treadmill or cycle ergometer exercise with analysis of expired air and requires a considerable amount of time and expensive equipment. Methods of easily and accurately estimating this important parameter would be valuable adjuncts to health and fitness evaluations(2,3). There are a number of methods of estimating VO_{2max} in common usage; heart rate response to a standard submaximal exercise on a cycle ergometer, treadmill, or stepping bench or box is perhaps the most widely used method(3). This prediction method is based on the assumption that there is essentially a linear relationship between heart rate(HR) and VO2 or workload.

Distance run in a specified time(4), or conversely time required to run a set distance is another commonly used method of predicting VO_{2max} from submaximal physical performance. This method is based on the known oxygen requirement for running at a given speed, ignoring the HR response. This test involves almost as much risk as a maximal treadmill test, and the run results are also confounded by such factors as climate, running efficiency, motivation, and pacing skill.

SIGNIFICANCE

The level of aerobic fitness is an important factor in the ability of military personnel to carry out duties required of them both in peacetime and during times of emergency or actual combat conditions. Many Air Force personnel fill sedentary "desk jobs" during normal peacetime operations, but during war, many of them may be called on to perform tasks which require much higher levels of energy expendature than they are accoustomed to. Other personnel, such as firefighters and crash crews, have jobs which are mostly sedentary, but which may periodically require extremely heavy workloads under unfavorable environmental conditions(5).

The aerobic fitness level of personnel entering the military services may be low to begin with, and the sedentary nature of many jobs after the completion of basic training is not conducive to the attainment or maintenance of satisfactory levels of VO_{2max}. Some method is needed to easily and accurately assess the aerobic fitness of Air Force personnel on a periodic basis without imposing a health risk on the individuals tested. The present 1.5 mi run test performed annually requires a near maximal effort by young low-fit individuals, and may pose a danger to middle-aged and older personnel who are not accoustomed to such exertion.

The interaction between aerobic capacity and acceleration tolerance is of great interest to organizations and individuals responsible for safety in high performance combat and other aircraft. There is widespread belief within the aviation medicine hierarchy that there is an inverse relationship between aerobic capacity and positive G-tolerance (+Gz). Despite considerable interest in this issue, there is only limited and somewhat controversal research evidence in support of this hypothesis.

There also exists concern that enhanced aerobic capacity may increase a pilot's susceptibility to an inappropriate chrono-tropic and/or dysrhythmic response to +Gz stress. These concerns certainly point to the need for an accurate, easily conducted test to predict the aerobic capacity or VO_{2max} in the Air Force pilot population.

BACKGROUND

Cooper(6,7) found a correlation of .90 between distance run or walked in 12 min and VO_{2max} in 115 Air Force men aged 17-52 years. The 1.5 mile run was adopted as the official fitness test for all USAF personnel in 1970 despite the fact that it may provide estimates which differ by as much as 40% from the true measured VO_{2max}. Getchell et al.(8) found a similar r of .91 between the time to run 1.5 miles and VO_{2max} expressed as ml/kg/min in 21 trained young women. The correlation, however, was only .46 when the VO2 was expressed as l/min indicating that weight was an important factor in this relationship in women.

Harrison, et al.(9) found a correlation of .95 between measured VO_{2max} and VO_{2max} predicted from the time to run 2 km. The prediction overestimated VO_{2max} by 1% and 92% of the variance between the methods was accounted for by the run time.

A submaximal exercise test during which heart rate response to steady-state exercise is measured has been used to estimate VO_{2max} since the mid 1950's(10). Astrand and Ryhming constructed a nomogram for calculation of VO_{2max} from submaximal steady-state HR response to either cycling or step test work. The test is based on the attainment of a steady-state HR of 125-170 during the last 3 min of the 6 min test. The nomogram was constructed using data from 58 well-trained male and female subjects, aged 18-30 yr and the prediction had a SEE of ~.28 l/min. The nomogram was revised in 1960 to account for differences in mechanical efficiency at lower workloads and in VO2 at a given workload between men and women(11).

This test is relatively accurate and does not suffer from many of the drawbacks of the running tests. Other similar cycle ergometer and stepping protocols have been devised and tested, and variations of the Astrand-Ryhming(A-R) test have been made, but it remains probably the most commonly used standardized submaximal test which allows estimation of VO_{2max}.

Margaria, et al(12) proposed a similar prediction method in which VO_{2max} could be obtained from the HR response to 2 submaximal stepping workloads. However this prediction is based on the same premise as that of Astrand and Ryhming that HR and VO_{2max} are linearly related throughout the entire range of values. Harrison and others(9) also studied the validity of the Margaria step test prediction method of estimating VO_{2max}. They found a correlation of .95 between the measured and predicted values using a modification of the stepping rate of the original test. The prediction underestimated the measured value by 6%, but accounted for 91% of the variance in the regression.

Maritz and associates(13) criticized the A-R method and tested a prediction method in which 4 sets of HR and VO2 values were plotted at 4 workloads and an individual regression line is calculated for each subject and used to extrapolate to VO_{2max}. They found a systematic underprediction of the A-R method of about 10% and a greater accuracy of their prediction when compared to measured values. Rowell and others(14) found that the multiple HR extrapolation method of Maritz et al. was no more accurate than the A-R prediction for estimating VO_{2max}.

Respiratory quotient (RQ) was used by Issekutz and others (15) to predict VO_{2max} during submaximal work. This method was based on a linear relationship found between log(RQ - 0.75) and VO2. DeVries and Klafs(16) found that the Issekutz prediction overestimated VO_{2max} by 9%, but the correlation coefficient between the two was only .50. Rowell, et al(14) found that the VO_{2max} prediction proposed by Issekutz was unreliable for individuals. However, extrapolation for mean RQ difference values from 3 VO2 levels at and above 2.75 l/min gave an estimation of VO_{2max} which was close to the measured values. Measurement of RQ requires special equipment for analyzing the oxygen and carbon dioxide content of expired air, thus its use does not seem practical as a prediction method except in a laboratory setting.

Fox(17) developed a VO_{2max} prediction technique similar to that of Astand and Ryhming based on HR response to a single submaximal cycle workload (150 W). The subjects were 87 untrained college aged males and the correlation was .76 between predicted and measured VO_{2max} with a SEE of .246 l/min. The nomogram for predicting VO_{2max} from HR responses to bench stepping exercise developed by Margaria, et al(12) requires an estimation of the maximal HR and therefore has an inherent age correction factor. The nomogram was validated on male and female subjects aged 9-47 yr with a difference of 1.08 ml/kg/min between measured and predicted VO_{2max}.

The A-R test is not without drawbacks and sources of error, but it may have been criticized for deficiencies which the procedure originally was not intended to be capable of taking into consideration(17). These include lack of an age correction which would extend its use beyond the original validation group which consisted of young, fairly well-trained subjects; lack of valid prediction at the upper range of VO2 where the relation with heart rate may become nonlinear; lack of a mechanism which would allow for adjustment of the exercising HR during the test if it did not reach acceptable levels, variability of submaximal HR due to such factors as temperature, meal ingestion, emotions, illness, dehydration, and fatigue. Most of the latter mentioned factors can be easily controlled for and an age correction factor has been developed(11,19), but the lack of linearity of the HR-VO2 relationship remains a source of error when a single or even dual HR determination is used as the basis for the prediction.

Glassford and associates(20) compared the Astrand-Ryhming (A-R) submaximal HR prediction to maximal oxygen uptake determined during cycling and treadmill exercise. They found that the prediction underestimated the treadmill VO_{2max} by 1.1% and overestimated the cycle ergometer VO_{2max} by 6.3%. The correlations between predicted and measured values were .75 for the treadmill and .63 for the cycle. Teraslinna, et al.(21) compared the A-R prediction with measured VO_{2max} on a progressive cycling protocol. They found that the prediction overestimated the measured value by 7.6% with a correlation of .92 when the age correction factor was applied.

DeVries and Klafs(16) found that the A-R prediction underestimated the VO_{2max} as measured during an intermittent cycle ergometer test protocol. The difference was 7.2% and the correlation .74 between the tests with a SEE of .36 l/min. Amor and others(22) found that the A-R prediction overestimated the VO_{2max} of British servicemen as determined by both treadmill and cycle ergometer testing. They found that the mean error was only 0.7%, but that the correlations were .63 for the cycle ergometer and .58 for the treadmill.

Siconolfi and others(23,24) in two studies found that the A-R method overpredicted VO_{2max} in subjects ranging from 19 to 70 years of age. In one study the difference was 5.5% and an r=.86 and SEE of .25 l/min; in the other investigation, the difference was 3% with an r=.92 and SEE of .29 l/min.

Other investigators have not found the A-R prediction to be as valid a method as the previously mentioned studies. Rowell and associates(14) found that the A-R prediction underestimated VO_{2max} by only 6% in athletes, but by 26.5% in nontrained sedentary individuals. After training, the method underestimated VO_{2max} by 13.7% in the previously sedentary subjects. Davies(25) made the same type of attempt to study the validity of the A-R prediction of VO_{2max} and found that the nomogram underestimated the measured value by 26% in tests where the HR was <140 and 20% in those in which HR was 140-160. Fitchett(26) found that the A-R nomogram significantly underpredicted VO2max despite the 2 values being significantly correlated (r=.84).

Other methods of estimating VO_{2max} from submaximal exercise information involves the use of multiple regression techniques with several variables measured. Kline, et al. (27) used such a method with a 1 mile walk, age, body weight, and gender as the criteron variables and attained a correlation of .93 and SEE of .325 l/min. Mastropaolo(28) found an r=.93 and a SEE=.172 l/min for respiration exchange ratio (RER), workload, diastolic blood pressure (DBP), expired volume, and expired CO2 as multiple regression variables. Jessup, et al.(29) used age, height, weight, DBP, leg length, 12-minute run time, and A-R predicted VO_{2max} and obtained an r=.81 and SEE of .188 l/min. Hermiston and Faulkner(30) found an r=.90 for VO_{2max} from fat-free weight, submaximal treadmill heart rate, RER, age, expired CO2, and tidal volume measurements. Ribisl and Kachadorian(31) used age, 2 mile run time, and body weight to predict VO_{2max} in middle-age men with an r=.95 and SEE of 1.97 ml/kg/min.

PURPOSE

The purpose of this investigation was to determine the validity of a modification of the A-R submaximal HR method of prediction of VO_{2max} in trained runners and nontrained men.

SUBJECTS

Subjects for the study were 20 adult male volunteers 26-45 years of age, 11 of whom were aerobically trained runners and 9 were relatively sedentary. The trained group consisted of men who ran 20 to 50 mi per week. The sedentary group consisted of subjects who were minimally engaged in physical activity, most of which consisted of weight lifting or walking. The subjects are characterized by group in Table 1.

The subjects were recruited from among members of the Brooks AFB running club and by an announcement in the base bulletin. Each subject was briefed as to the purpose and requirements of the study and was given the opportunity to read the protocol and ask questions about the various tests. A written informed consent was obtained prior to conducting any procedures. The study was approved by the Committee for Human Experimentation at Brooks AFB, Texas, and by the Air Force Surgeon General's office.

METHODS

The subjects were screened for inclusion in the high or low aerobic capacity groups by exercise history and by a modification of the A-R submaximal HR cycles ergometer test. The A-R test has been modified by Myhre(32) to include specific criteria for determining the initial workload and for increasing workload during the early minutes of the test in order to increase the HR to desired steady-state levels during the last minutes of the test(33). The tests were conducted on a calibrated Monarch cycle ergometer in a quiet, air conditioned room with the temperature maintained at 23°C. HR was determined using an Exersentry monitor and cycling speed was kept at 50 rpm in cadence with an electronic metronome.

An interactive computer program was used during the cycle ergometer test to determine the initial workload based on age, weight, sex, resting HR, and habitual physical activity level(33). The computer also determined the adjustments in workload during the early minutes of the test based on HR values entered each minute and then computed the predicted VO_{2max} after making a correction for age(11,19).

Body composition was determined from underwater weighing and residual volume estimated using a He dilution technique. Percent fat was calculated from density using the formula of Brozek et al.(34). Blood volume was estimated in some of the subjects from analyses of blood samples for carboxy-hemoglobin content before and after a carbon monoxide rebreathing procedure (35).

Maximal oxygen uptake was measured by indirect calorimetry during a continuous progressive running protocol. The initial level running speed was set to require approximately 75% of VO_{2max} as estimated from the cycle ergometer prediction. Each stage was 2 min in duration with the grade increased 2.5% for each subsequent stage. This protocol is designed to elicit VO_{2max} in 10-12 min (36-38). Expired air was collected in 250 l meteorologic balloons and the volume was determined in a balanced Tissot spirometer. A 100 ml sample was drawn from each balloon and triplicate measures of O2 and CO2 concentration were made using a calibrated mass spectrometer.

DATA ANALYSES

The data were analyzed using linear regression techniques to determine relationships between the predicted and measured VO_{2max} values for each group separately and for the entire group of 20 subjects. Correlation coefficients and standard errors of estimation were computed. T-tests were used to determine the significance of differences between the two groups of subjects.

RESULTS

There was not a significant difference between the 2 groups in age, but the runners weighed significantly less and were less fat than the inactive subjects. VO_{2max}, measured or predicted was significantly higher in the runners as would be expected.

The cycle ergometry test using the modified A-R protocol and nomogram systematically underestimated VO_{2max} in all of the subjects in this study. The error was greater in the more inactive subjects than in the trained runners as is shown in Table 1 and Fig. 1.

There is a linear relation between the VO_{2max} values obtained by the 2 methods as can be seen in Fig. 1. The correlation coefficient was 0.935, but the standard error of estimate was 5.05ml/kg/min. The mean difference between the methods was 14.5ml/kg/min for all subjects, with a difference of 10.7ml/kg/min for the runners and 12.8 ml/kg/min for the inactive group.

DISCUSSION AND CONCLUSION

The cycle ergometry submaximal heart rate method of aerobic capacity estimation based on the A-R nomogram appears to be a valid predictor, with reservations. The method under-predicts treadmill measured VO_{2max} by about 20%, but highly fit subjects by the predicted method have high measured values and inactive persons tend to have lower measured values..

The correlation of 0.93 between the predicted and measured values is similar to that found by some other investigators (21,23,24). The standard error of the estimate found (5.05) is similar to that found by Amor, et al.(22).

Although individual values may be subject to considerable error for what ever reason, the concept of using a submaximal test based on a heart rate determined prediction of aerobic capacity is valid. The test may be able to be made more precise by better controlling for variables which may affect heart rate response to submaximal exercise. Some subjects may respond better to a repeated test, conducted under more controlled conditions or by a more experienced test administrator.

The elimination of emotionally driven elevations in heart rate will also tend to reduce the error, but it must be recognized that some persons simply have an exagerated heart rate response to exercise unrelated to level of aerobic capacity or state of physical training. These types of conditions might be partially corrected for by the introduction of other variables in the prediction, such as a physical activity index, rating of perceived exertion, or other factors. More study is need on this topic, to include data on additional persons in the middle capacity levels, women, and older persons.

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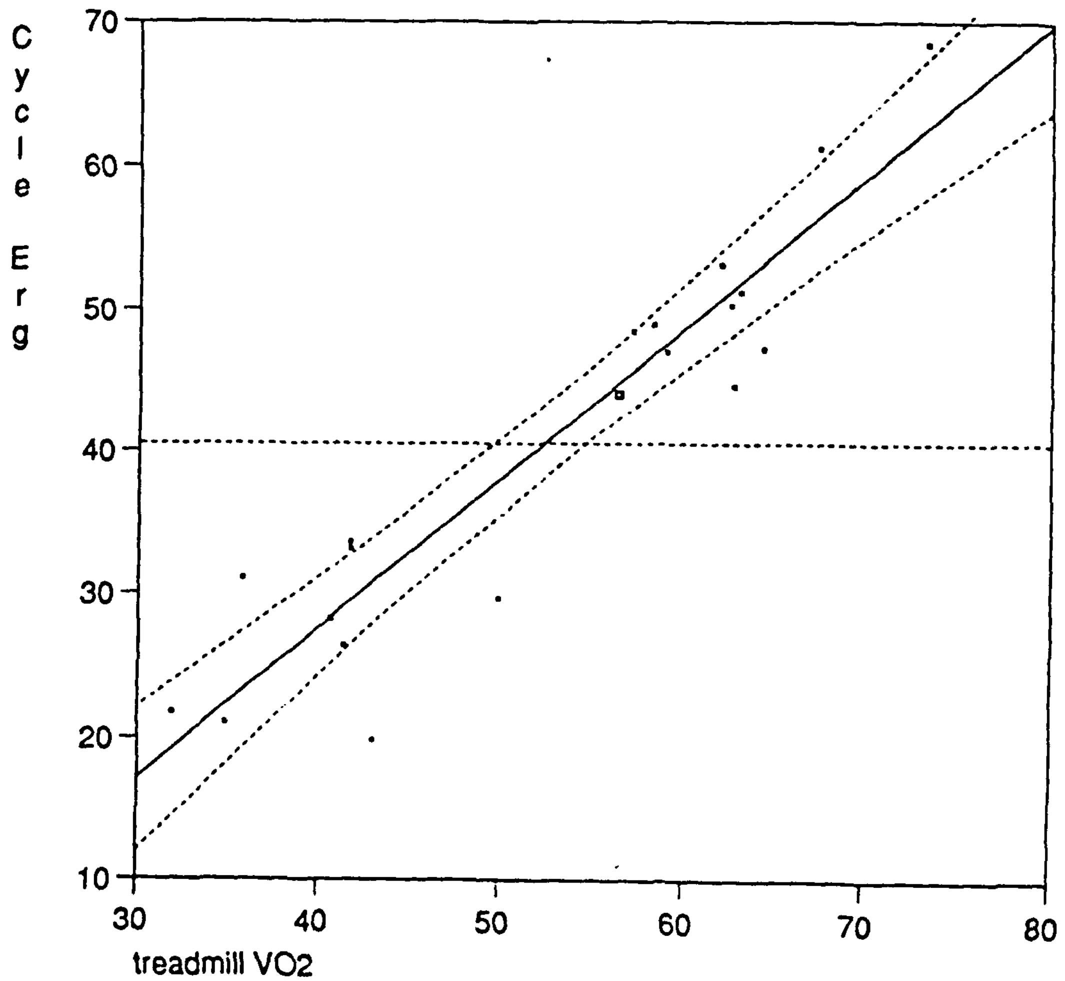
TABLE 1
Characteristics of Subjects

Group	n	Age	Wt(kg)	%Fat	CE	Mea	L/min
Runners	11	37.6 ±6.0	72.0 ±5.4	11.8 ±4.3	51.5 ±7.4	62.2 ±4.9	4.48 ±.41
Inactive	11	35.8 ±5.4	80.9 ±10.5	20.9 ±5.0	27.3 ±5.3	40.1 ±5.2	3.25 ±.43

CE=VO2max, ml/kg/min - cycle egrometry
Mea=VO2max, ml/kg/min - measured
L/min=VO2max, liters per minute



A COMPARISON OF THERMOREGULATORY RESPONSES AND WORK PERFORMANCE IN SUBJECTS WEARING STANDARD CHEMICAL DEFENSE AND CWU-77P ENSEMBLES

Richard A. Hengst, Ph.D.

Abstract

Two chemical defense ensemble configurations were tested for human subject performance under heat stress conditions (40°C; 20% relative humidity). The CDE+BDU is the configuration currently issued by the U.S. Air Force while the CWU-77P represents alternate design concepts currently under consideration for protective clothing. Physiological parameters of Heart rate, skin temperature, rectal temperature (Tre), sweat production and clothing temperatures were measured while subjects walked at a constant rate of 1.34 m/sec (5% grade). Subjective perception of thermal comfort and perceived exertion were also evaluated. Experiments were terminated when Tre increased 1.5°C above starting values. CWU-77P allowed for 62% longer performance periods under heat stress conditions. Reasons for this improvement appear to be a lower mean skin temperature and higher evaporation rates through suit cloth. This appears to allow slower rates of heat storage and rise in core temperature thus prolonging activity times. No other physiological parameters could account for these differences. Subjects rated both suits equally in regards to thermal comfort or perception of work load imposed by the protective clothing.

INTRODUCTION

Chemical defense ensembles (CDE's) are designed to protect wearers from skin contact with toxic aerosol and liquid agents (2). These garments restrict both efficient movement and heat dissipation either of which impedes task performance. CDE's reduce both dry and wet heat loss to the environment thereby elevating suit temperature and humidity

(1,2,3,6). Thermal stress is especially accentuated in hot environmental conditions since suit microclimate conditions interfere with physiological heat dissipation processes (6). Previous investigations have shown that even moderate activity in protective clothing elevates core temperatures in warm or hot environments (2). Progressive elevation of core temperatures above 39.5 causes prolonged recovery, impaired performance, fatigue, heat exhaustion, muscle weakness, neurological damage, and possibly death (5, 6, 7). It is important to know more about physical performance in CDE's under ambient conditions in which these suits present the greatest stresses: hot environments. This has become especially so since the likelihood of CDE use under desert conditions remains high. Therefore, it is important to evaluate which CDE design causes the least thermal stress if personnel are to function at maximum efficiency and safety.

Compromises must be made between toxic agent protection and thermal stress of the protective gear. Design factors that decrease toxic agent penetration tend to increase thermal stress and restrict movement. Heat generated from activity adds additional heat load to that normally imposed by such clothing (6,7,8). High ambient temperatures can make it difficult to dissipate heat accumulation within the body and suit microclimate. However, heat loss can still occur if evaporative heat loss is possible. Suit microclimates saturation reduces skin surface evaporation and, therefore, heat dissipation.

Previous attempts at resolving conflict between protection and thermal stress have included intermittent work-rest cycles of various lengths (the current Air Force procedure) (2, 6), continuous cooling, and cooling during rest cycles (3,4). At high ambient temperatures, core temperature may not decrease sufficiently during rest periods when cooling is not available (2). Thus, it is prudent to examine new designs in CDE's which maximize physiological cooling potential under heat stress conditions.

STATEMENT OF THE PROBLEM

For this study, two CDE's were selected for evaluation. The first is the standard two piece CDE currently issued to military personnel. This standard CDE is normally worn under the battle dress uniform or BDU, and uses a relatively thick layer of charcoal, uniformly distributed. The CWU-77P was chosen for purposes of comparison since it is lighter in weight, one-piece, and uses micropellets of charcoal enclosed in fabric. The purpose of this study is to compare physiological responses in subjects exposed to identical work and environmentally stressful conditions.

METHODS AND MATERIALS

Subject Population

Protocols for this study were approved by the Human Subjects Institutional Review Committee. A subject pool of eleven volunteers were recruited from among Air Force personnel. It is believed they represent a reasonable profile of personnel currently serving in the Air Force. Each underwent extensive physical examinations before participating in experiments. Physical characteristics of the group are shown in Table 1.

Table 1

Physical Characteristics of Subject Population

n = 11 (1 F, 10 M)

Characteristic	Mean	(S.D.)	Range
Age (y)	34.5	(5.7)	24 - 41
Height (cm)	175.6	(3.3)	172.5 - 180.0
Weight (Kg)	81.1	(8.7)	60.0 - 98.0

Experimental Design

All subjects participated in both sets of CDE tests. Subjects participated in heat acclimatization exercises prior to beginning trials. During experiments subjects walked on a treadmill for the time it took rectal temperature (Tre) to rise 1.5°C above the starting value. Treadmill conditions were a constant speed of 1.3 m/sec with a 5% grade; this imposed a moderately hard work load. Environmental chamber conditions approximated desert heat stress conditions of 40°C and 20% relative humidity. A 15 minute rest period followed the treadmill exercise during which physiological variables were monitored.

Physiological variables measured included heart rate (HR), rectal temperature (Tre) as an approximation of core temperature, skin temperatures measured at chest, forearm, thigh and calf. In addition, skin temperature transducer modules included heat flux transducers which measured heat transfer rates for these same chest, forearm, thigh and calf sites. Skin temperatures were also used to continuously calculate mean skin temperature and heat storage for each individual.

Information on clothing heat transfer and temperature were measured by placing thermistor/heat flux transducers (HFT's) on CDE's at points immediately above chest, forearm, thigh and calf skin sites.

Experimental variables mentioned above were automatically recorded every thirty seconds by a Macintosh II computer for the duration of each experiment.

Sweat losses were determined by body weight measurements for clothed and unclothed subjects before and after experiments. Total sweat production and sweat evaporation were determined for each individual for both suits.

Subject perception of performance was solicited every 5 minutes throughout the test by means of personal rating of effort and thermal stress. Such performance was rated on the standardized Perceived Exertion Scale (RPE) and Thermal Comfort Scale (TC) by subjects.

Mean skin heat flux (HFTskin), clothing heat flux (HFcloth) and clothing temperature (Tcloth) were directly calculated from the original data acquisition computer files.

For safety, subjects were continuously monitored for heart rate and rectal temperature. No subjects exceeded the maximum heart rate allowed of 180 beats per minute or a Tre of 39.0°C.

Statistical Analysis

Means, standard deviations and standard errors were calculated for each variable for each suit. The data presented here are primarily descriptive since the rates presented occur at different rates over time. This would result in comparison of data at different physiological stages rather than over time which is the purpose of the experimental series. All error bars represented in Figures are labeled as to type of variability expressed.

RESULTS

Mean times for subjects to increase Tre by 1.5°C over starting values are shown in Table 2.

TABLE 2

Sweat production and Evaporation
in CDE+BDU and CWU-77P Uniforms

	CDE+BDU	CWU-77P
Time (min)	34.7 ±5.8	53.2 ±10.7
Sweat Prod. (ml)	1423.6 ±424.6	1900.9 ±505.6
Evaporation (ml)	433.2 ±132.5	867.3 ±181.6
Sweat/min (ml/min)	41.0	35.7
Evap/min (ml/min)	12.5	16.3

Individuals wearing CWU-77P garb lasted 62% longer than those wearing the standard CDE+BDU currently in use by the Air Force. CDE+BDU subjects averaged 34.73 min of exercise compared with 53.18 minutes for CWU-77P under the same environmental and exercise conditions. Mean rectal temperatures of the CWU-77P group were lower than those of the CDE+BDU group (Figure 1). Mean skin temperatures of both groups were initially similar but the CDE+BDU group's temperature rose significantly higher than that of the CWU-77P group (Figure 2). Mean heart rate of the CWU-77P group remained below that of CDE+BDU subjects throughout the experiments (Figure 3). Mean heat flux of the skin was initially similar in both groups and followed similar patterns of increase over time with CDE+BDU values eventually increasing faster than that of CWU-77P values. Mean temperatures of CWU-77P clothing were initially much higher but steadily decreased over time while CDE+BDU clothing temperatures steadily increased throughout the experiments (Figure 5). The CWU-77P showed the greater sweat production, higher sweat evaporation, and greater percent sweat evaporation of the two uniforms tested (Table 2). In thermal comfort, subjects made no distinction between suits (Figure

Figure 1
Mean Rectal Temperatures of Subjects Performing Constant Exercise

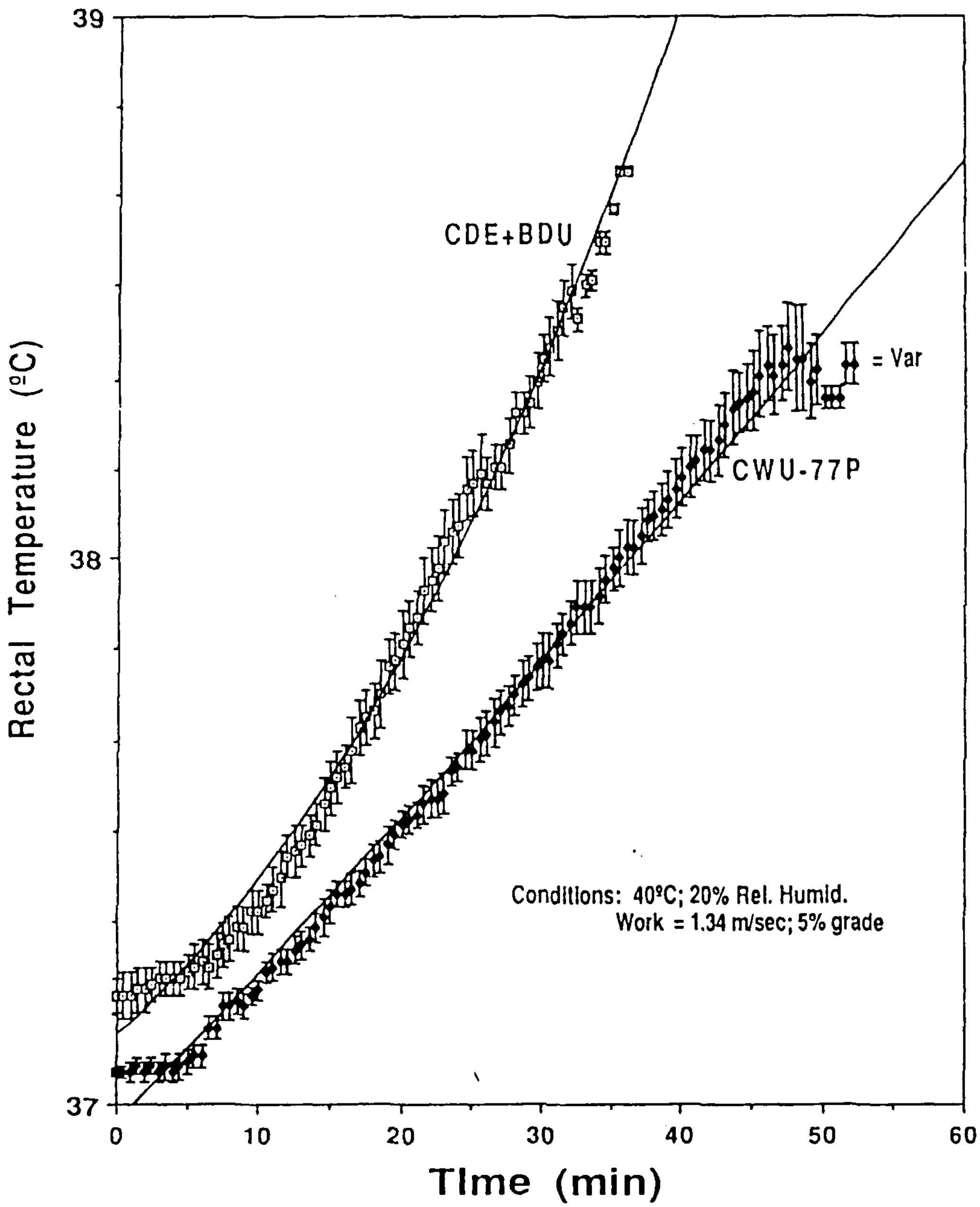


Figure 2
Mean Skin Temperatures of Exercising Subjects

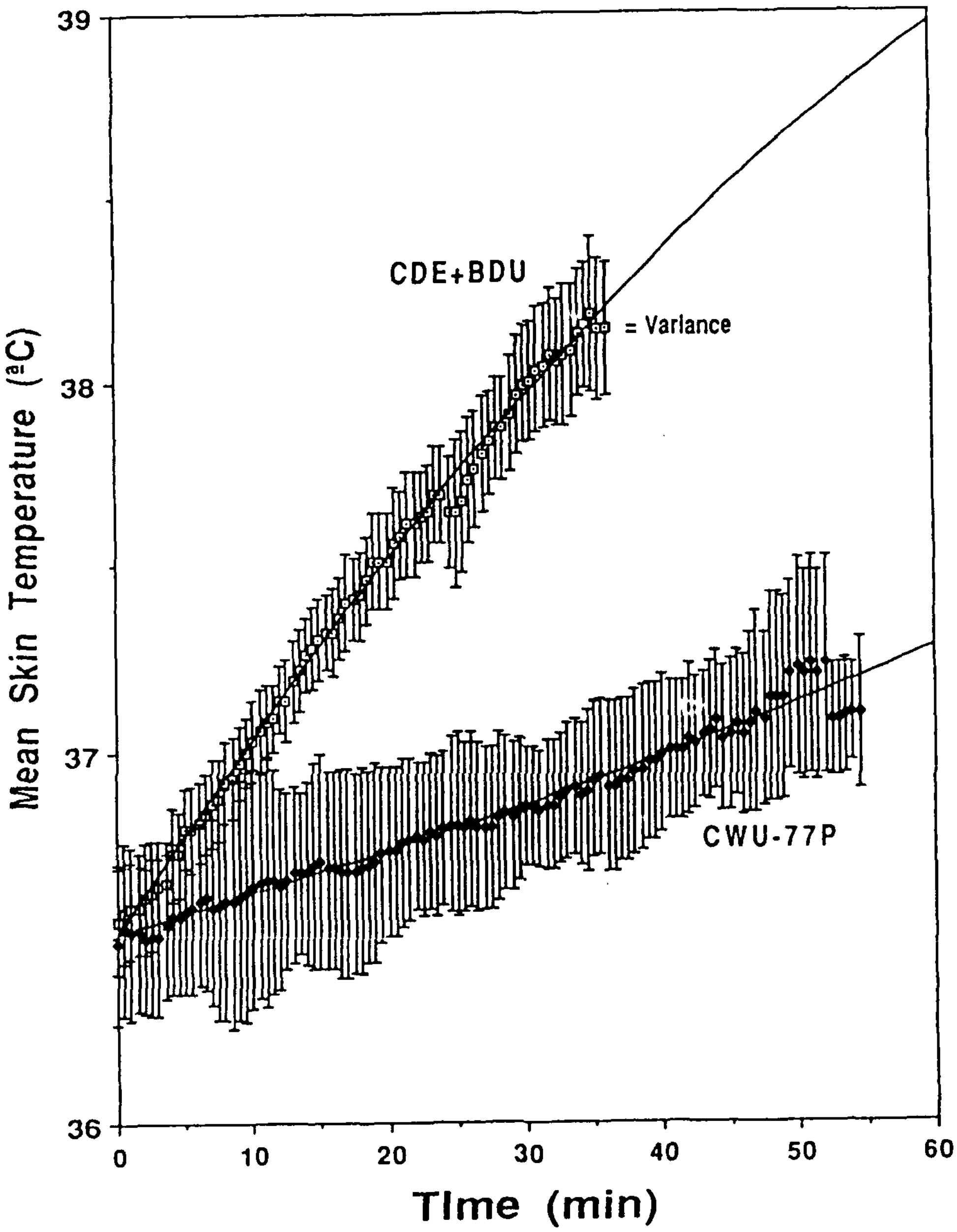


Figure 3
Heart Rates of Exercising Subjects

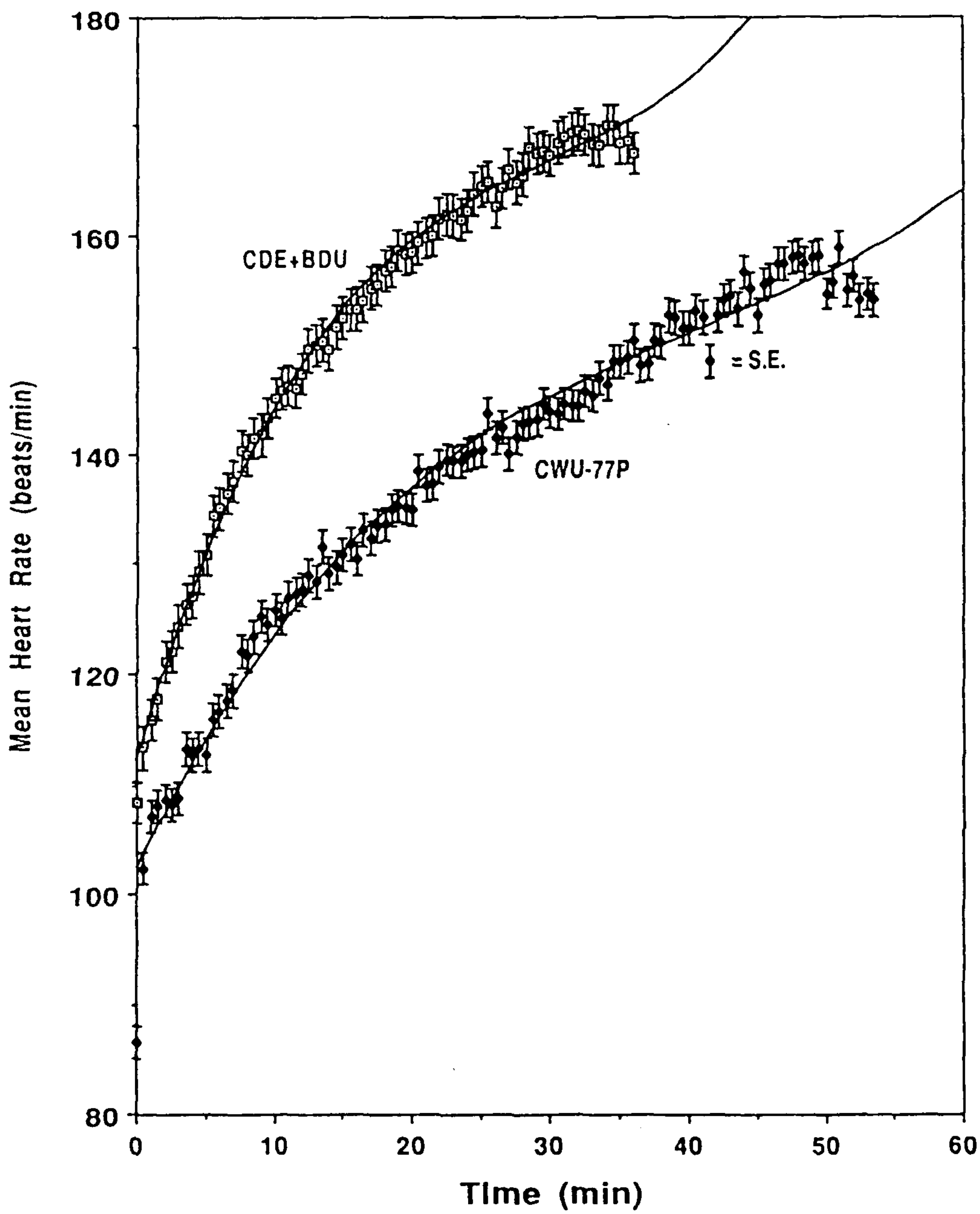


Figure 4
Mean Skin Heat Flux of Exercising Subjects

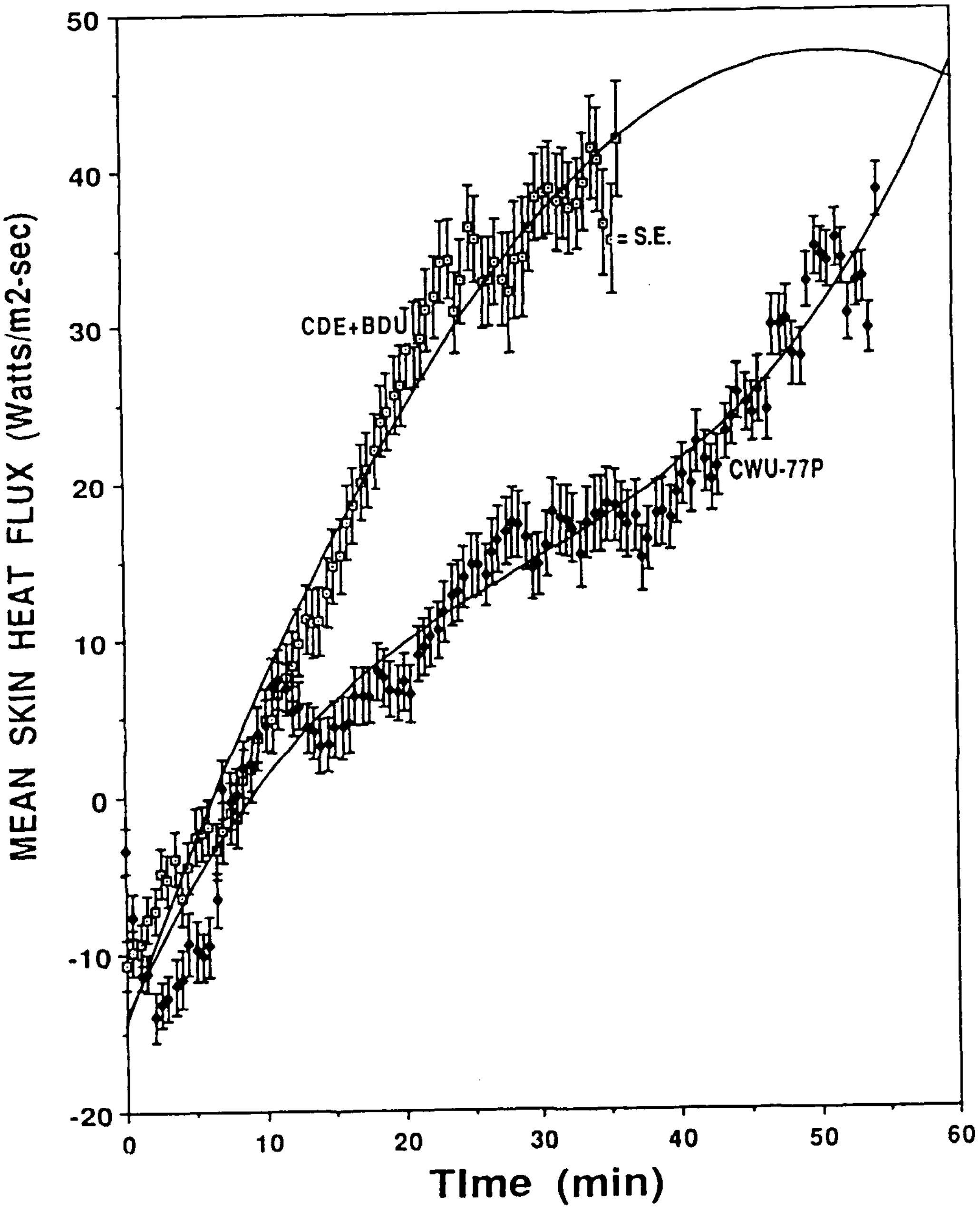
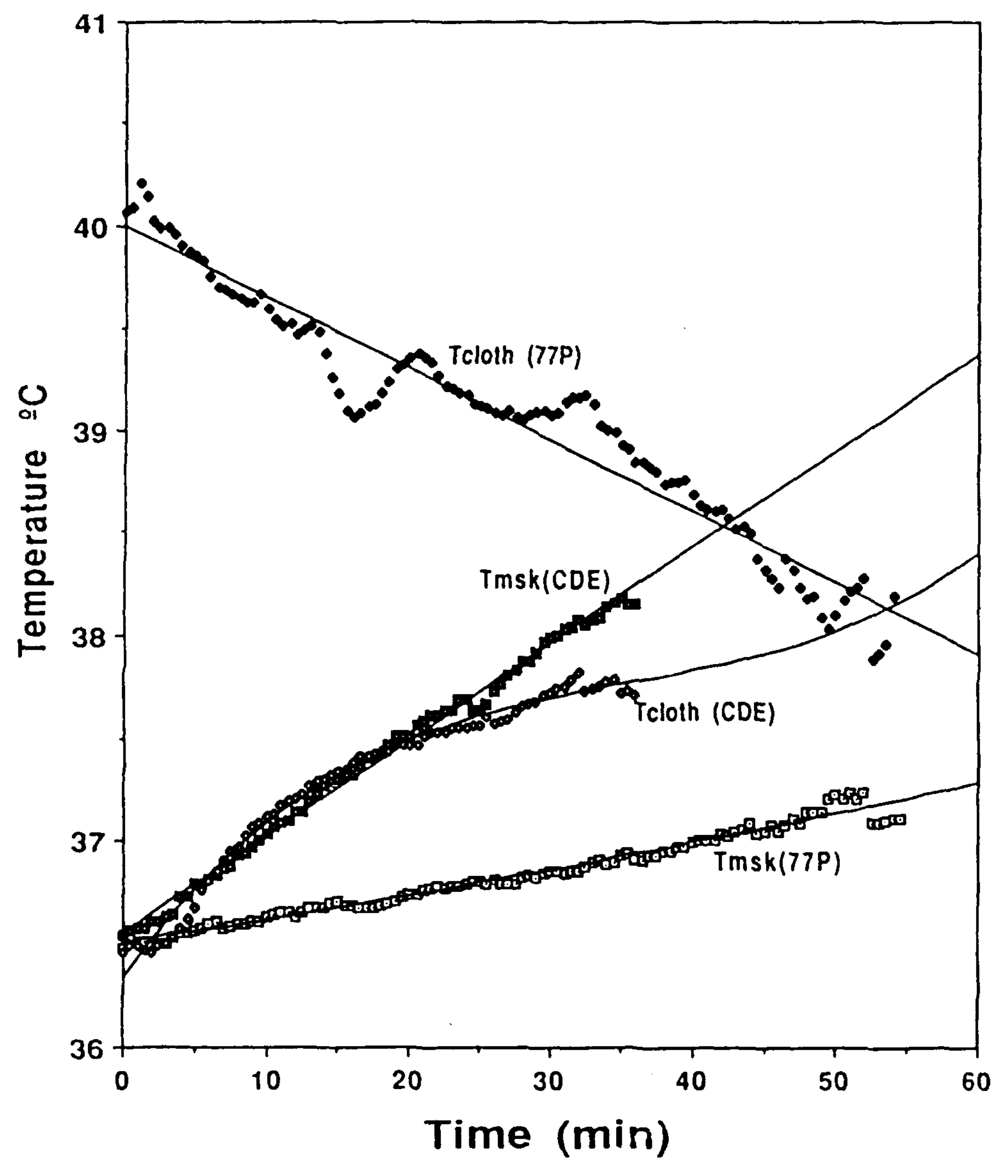


Figure 5
Mean Skin and Clothing Temperatures



6) . In a similar manner, subjects rated their perceived exertion to be virtually identical in both suits at similar stages of each experiment (Figure 7).

Discussion

Individuals wearing the CWU-77P uniforms were walked for a significantly longer period of time than those wearing standard issue CDE+BDU. Since the experimental design utilized a stock 1.5°C increase in Tre for both experiments, it indicates an overall lower heat stress exists for the subjects. This is supported by the descriptive data shown in the various Figures. Rectal temperature and, therefore, heat storage rose at a slower rate for the CWU-77P (Figure 1 & Figure 8). It is clear from the differential rate of Tre rise that the slightly lower initial temperature of the CWU-77P group (and subsequently lower Tre's) cannot account for all of the observed differences in physiological parameters. For example, mean skin temperature, an indicator of surface cooling (Figure 2), was initially identical for both groups but CWU-77P maintained a cooler temperature despite simultaneously having higher cloth temperatures. This indicates that some surface cooling is occurring in the CWU-77P group which is not occurring for CDE+BDU. Evaporative cooling is supported by the data for sweat production and evaporation. CWU-77P wearers produce and evaporate more sweat. This must be considered in view of the fact that these individuals also were exercising for an extended period and thus had more time in which to produce this greater sweat volume. A per-minute sweat rate is shown in Table 2. It is clear that mean per-minute sweat production is lower in CWU-77P wearers yet evaporation is higher. This lends credence to the idea that CWU-77P suits permit greater vapor loss and presumably more cooling capabilities.

Differences in heart rate (Figure 3) are probably affected more by

Figure 6
Thermal Comfort of Chemical Defense Clothing Types

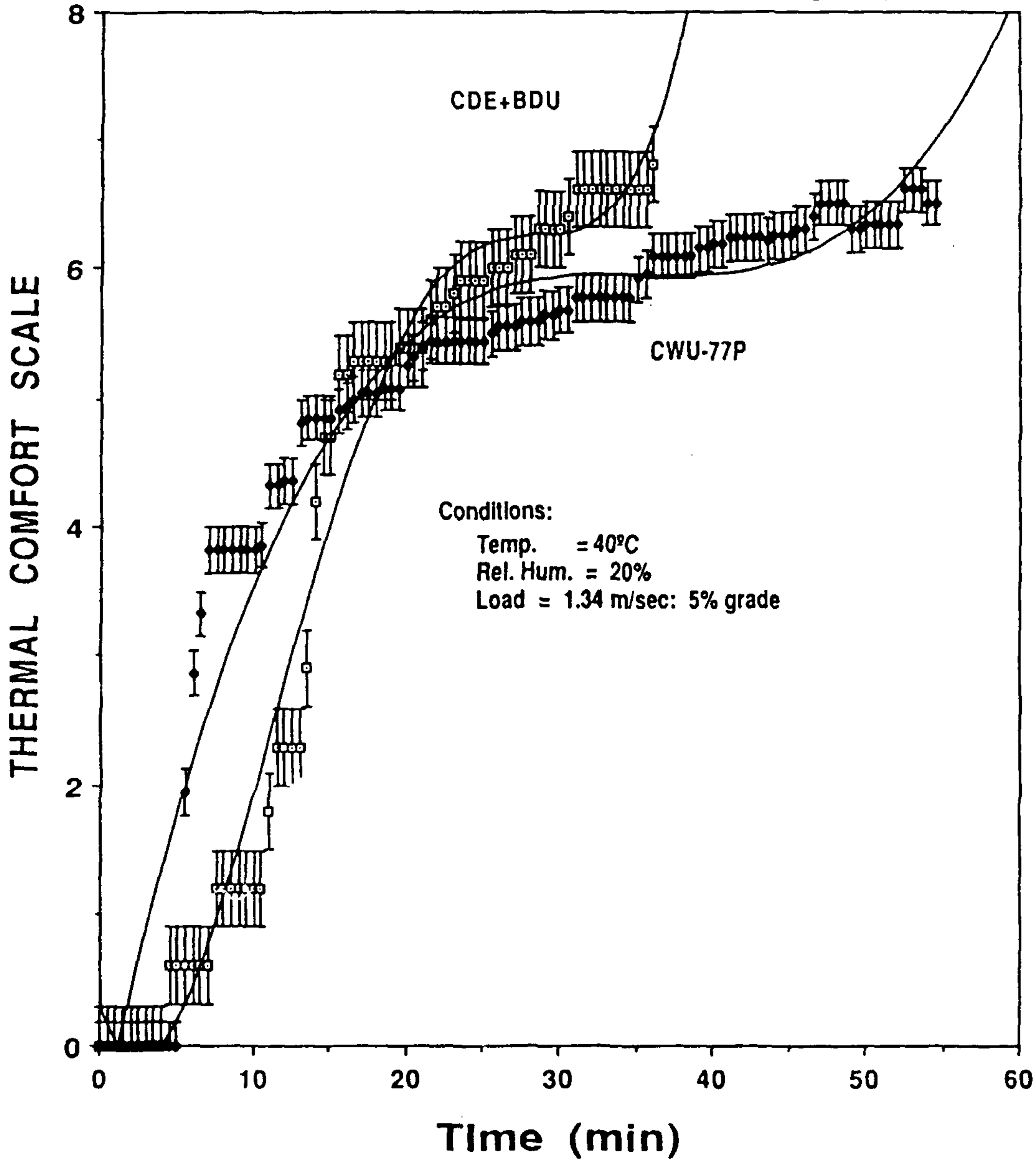


Figure 7
Perceived Exertion Index of Exercising Subjects Wearing CDE+BDU and CWU-77P Protective Clothing

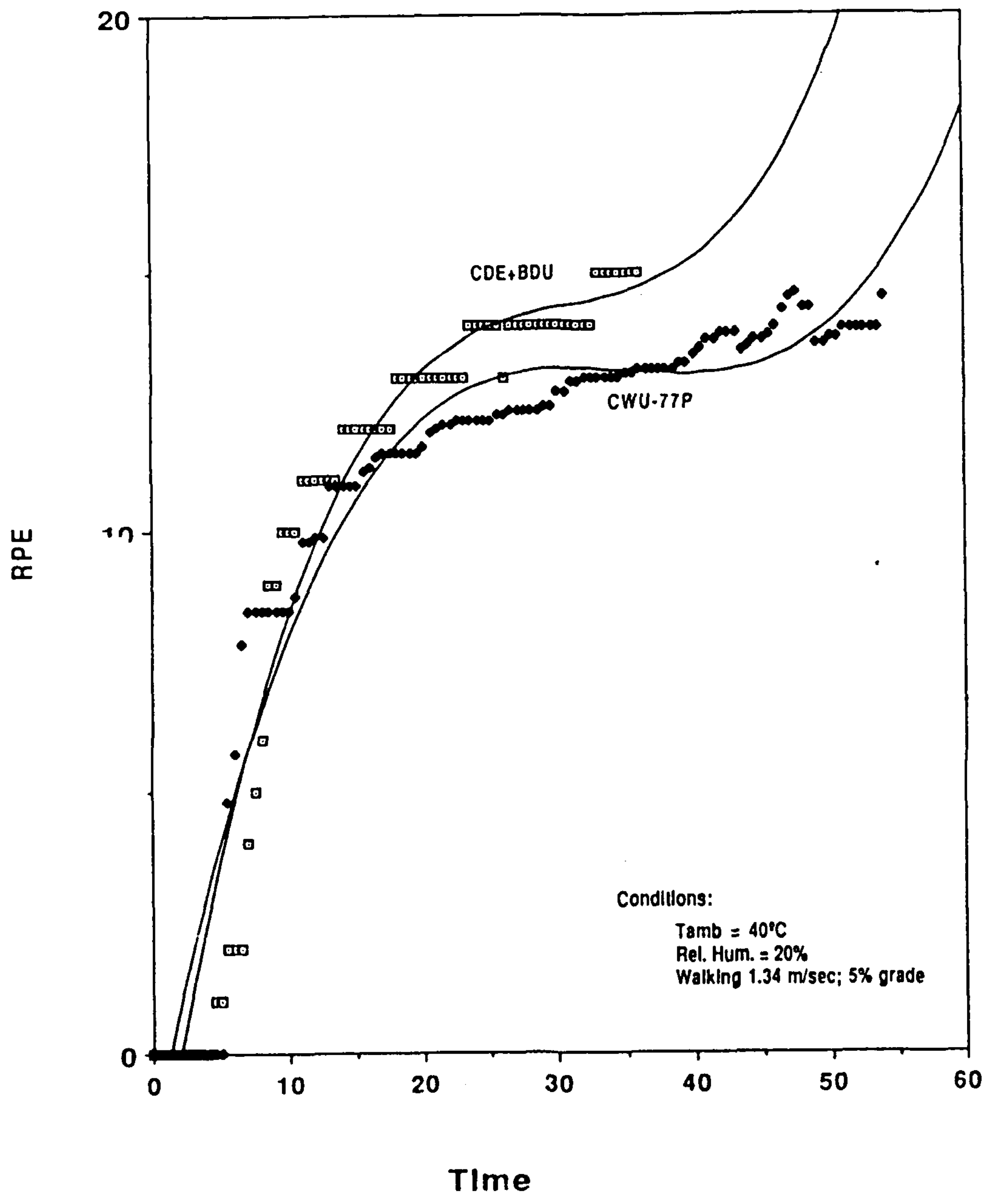
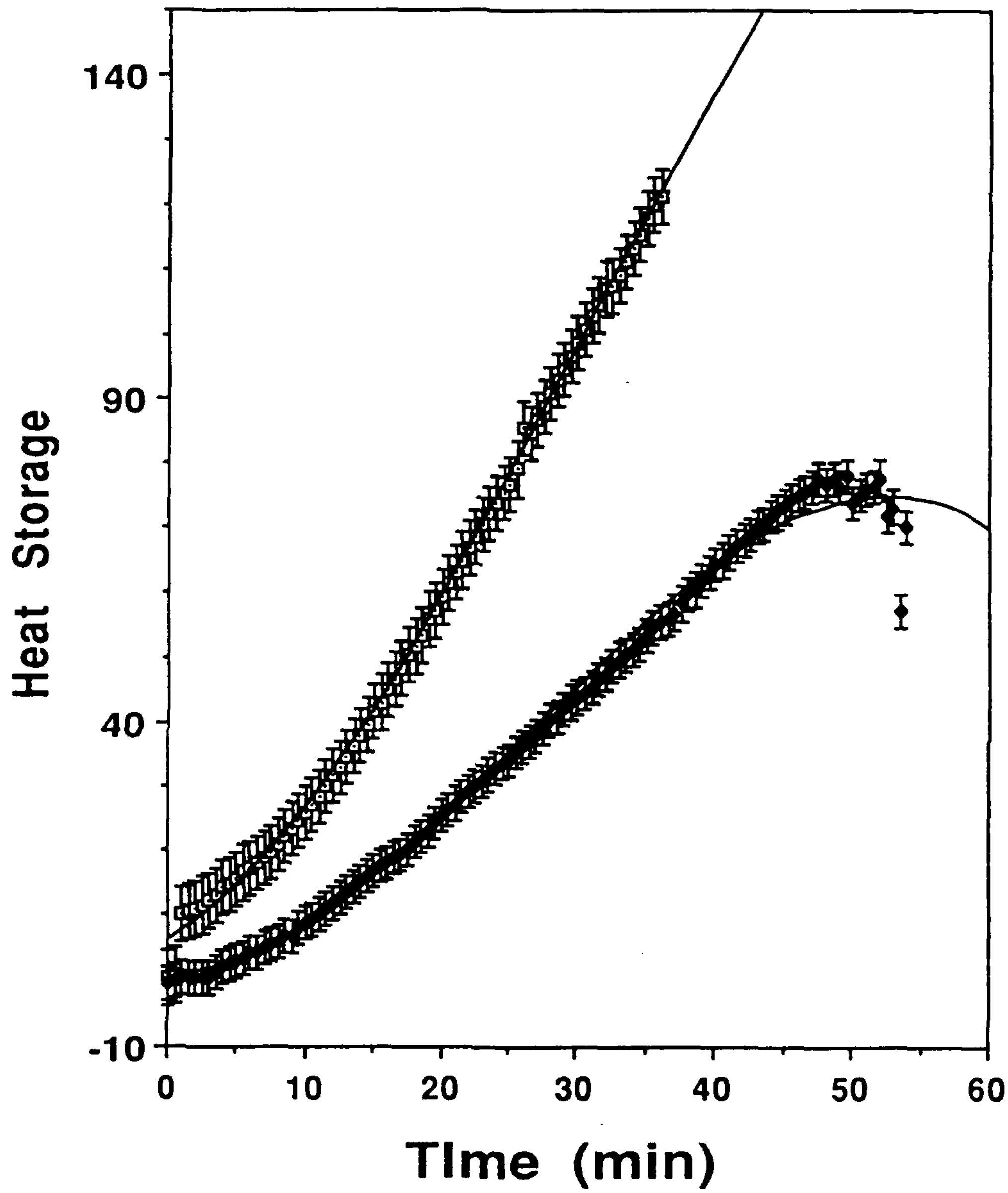


Figure 8
Heat Storage of During Exercise
in CDE+BDU and CWU-77P



Tre differences than by suit differences. This is apparent when heart rate is expressed as a function of Tre; CWU-77P heart rate is somewhat lower for much of the experiment but not significantly so. The most significant difference between suits very likely lies in the greater porosity of the CWU-77P which allows for greater evaporation of sweat. This is supported by the patterns seen in Figure 5. The mean skin temperature rises throughout the experiment for both groups. CDE+BDU cloth temperature rise parallels that of Tmsk but in the case of the CWU-77P skin temperature rises as cloth temperature falls. This could happen under constant ambient temperature only if sweat evaporation were cooling the cloth. This is further supported by the higher per-minute evaporation rate seen in the CWU-77P (Table 2).

Subject perceptions of effort needed to walk in the suits were virtually identical. The same was true for thermal comfort. Although skin temperatures were lower in the CWU-77P, subjects rated both suits as similar under heat stress conditions.

Conclusions

The newer design CWU-77P allows for distinctly extended periods of activity when compared with the standard issue CDE+BDU clothing under heat stress conditions. Reasons for this increased performance period include lower mean skin temperatures and better evaporative cooling of the suit. As a result, core temperatures rose more slowly and fall more rapidly during rest periods. Neither suit is superior in effort needed to perform tasks (walking) or in comfort. It is important that additional testing to confirm the suits' qualities as protection against toxic aerosols be done. Future designs of CDE suits should maximize evaporative qualities of fabric if heat stress is considered a major factor, particularly if non-physiological cooling is not feasible for active personnel. It is clear that such alternatives do exist at present and warrant further development and testing.

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WHITE-NOISE ANALYSIS OF CAROTID BARORECEPTOR FUNCTION

by
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Georgia Institute of Technology

Abstract

A feasibility study was performed on an adult male New Zealand White rabbit to determine whether it is possible to "white-noise" modulate blood pressure in the vicinity of the carotid baroreceptors. Pressure variations were induced by varying the flow rate of IV fluid injected into the carotid artery approximately 1 centimeter below the baroreceptors. Equal volumes of blood were periodically removed from the femoral vein. The resulting modulations of carotid blood pressure were random. However, the pressure data has not been analyzed yet to verify that the power spectrum was flat over the desired range of frequencies, DC to 5 Hz.

Background

The "white-noise" method for characterizing nonlinear biological systems has been successfully demonstrated in catfish retina studies (Marmarelis and Naka, 1973), in human

ERG studies (Koblasz, et al, 1980) and in a variety of other vertebrate studies (Marmarelis, 1976). Similar nonlinear characterization schemes have been demonstrated using random square wave stimuli (Yasui and Koblasz, 1984) and random pulse sequences (Fricker and Sanders, 1975).

Recently, a white-noise protocol has been demonstrated in a study of aortic baroreceptor function using in vivo rabbit preparations (Masaru, et. al., 1990). The aortic pressure was modulated by electrically stimulating the right ventricle using pacing electrodes triggered at a constant frequency of 400 beats per minute. The pacing was sustained for variable durations of greater than 1 second per burst, and the interval between bursts was varied to produce aortic pressure fluctuations with a flat power spectrum up to .5 Hz.

The aortic pressure was measured using a high-fidelity micromanometer (Millar MPC-500), and the baroreceptor response was measured using Ag/AgCl bipolar electrodes positioned at the distal end of the (desheathed) left aortic depressor nerve. Linear transfer functions were calculated using these stimulus/response data. The resulting math model characterized the combination of aortic wall mechanics followed by neural transduction and encoding mechanisms.

Methods

An adult male New Zealand White rabbit (3.8 kg) was anesthetized with Ketamine (100 mg IM) and α-Chloralose (50 mg/kg IV, followed by a maintenance dose of 20 mg/kg per hour). Pancuronium bromide (.1 mg/kg IV) was also given to reduce muscle activity.

The equipment described below was used to produce white-noise modulations of volume flux into the isolated left common carotid artery of the rabbit.

1. The electrical circuit in figure 1 was used to generate a pseudo-random square wave signal with a flat power spectrum ($\pm$ 3dB) over the range of DC-50 Hz.

2. The pseudo-random signal was then applied to a stepping motor driver circuit shown in figure 2.

3. The stepping motor was connected to a linear hydraulic valve, as depicted in figure 3.

4. A reservoir containing 100 ml of IV fluid was mounted approximately four feet above the hydraulic valve, and the reservoir fluid was pressure-dropped through IV tubing into the hydraulic valve inlet port.

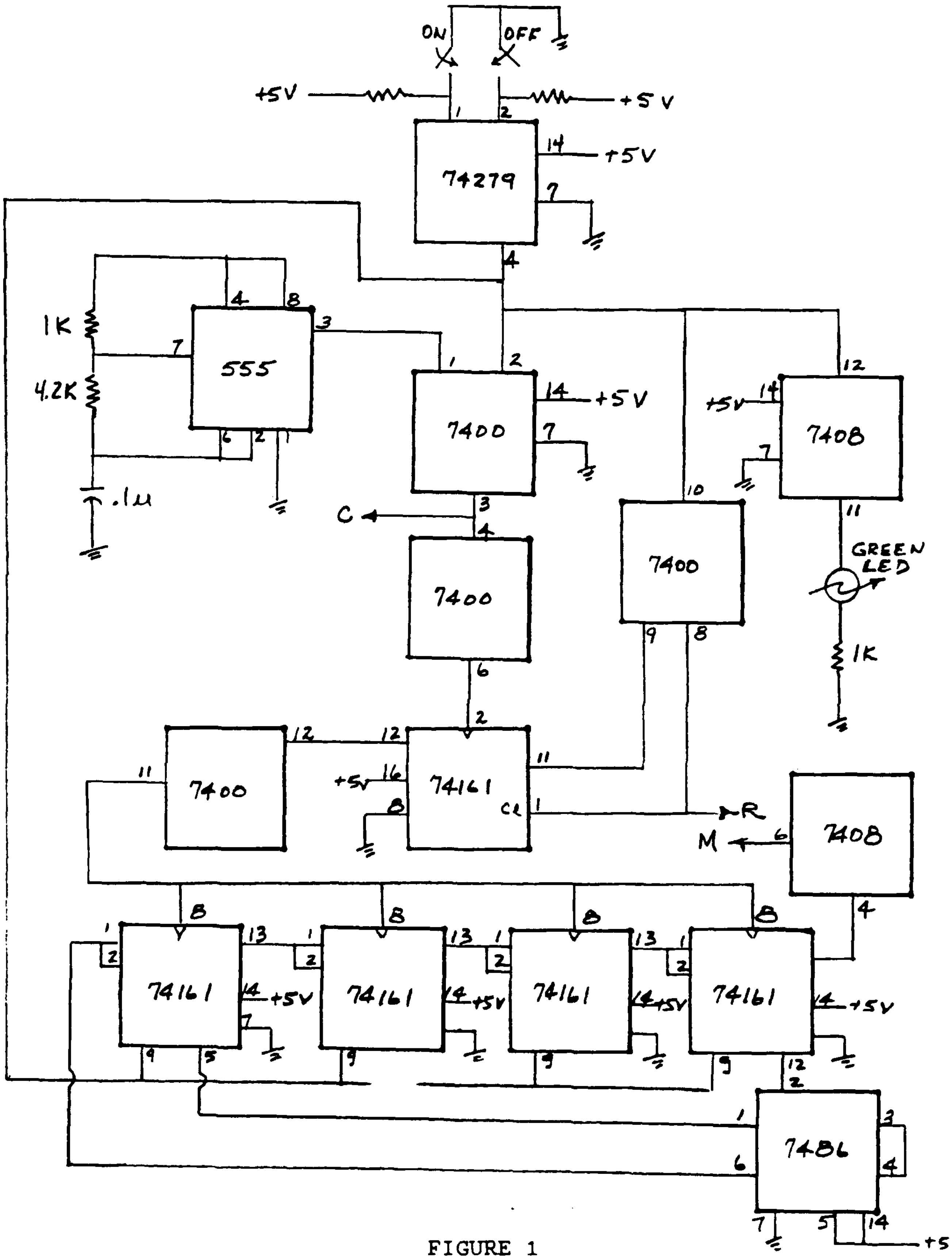

FIGURE 1
Pseudo-random square wave generator circuit

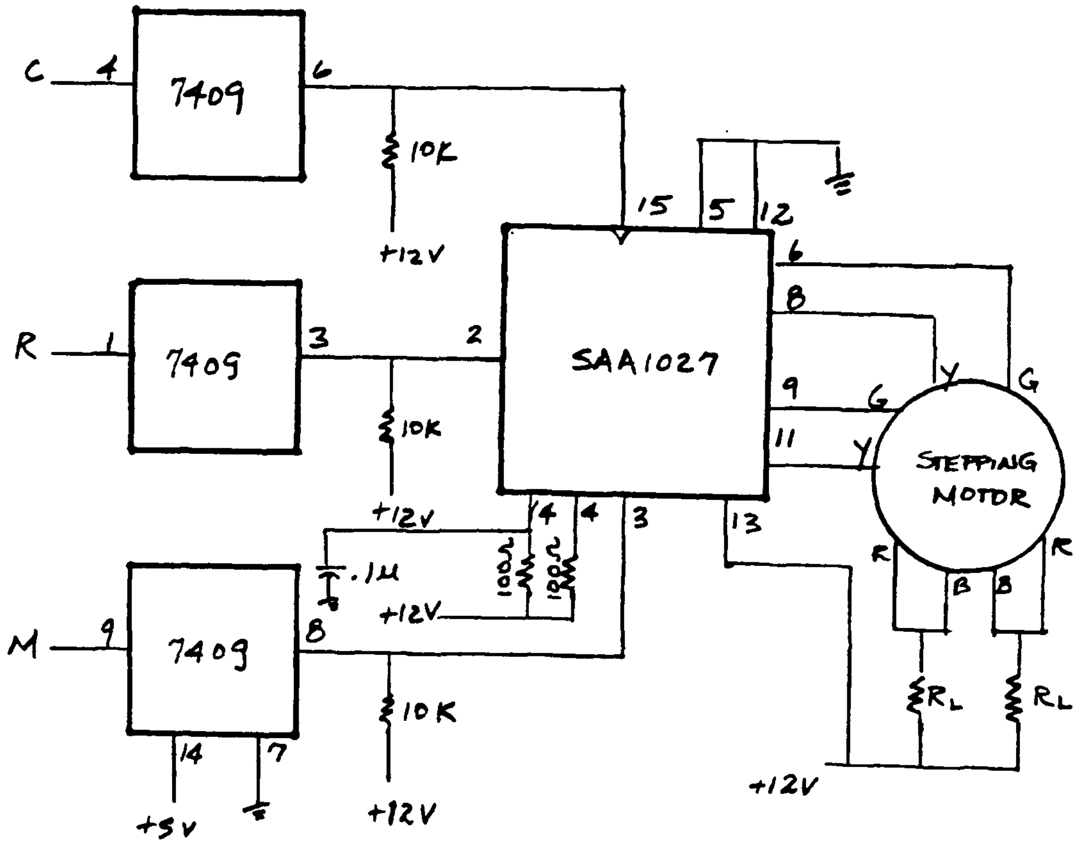

FIGURE 2
Stepping motor driver circuit

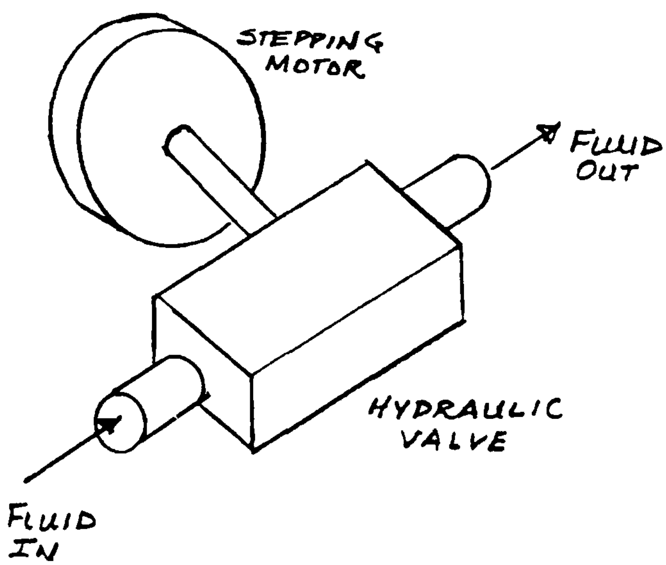

FIGURE 3
Linear hydraulic valve

5. Rotations of the stepping motor changed the opening/closing of the hydraulic valve, producing flow rate variations which are characterized in figure 4. Hence, white-noise modulations of the stepping motor produced proportional variations in the flow rate.

The resulting pressure changes in the left common carotid artery were measured using a Millar SPC330 pressure transducer. EKG was also measured using disk electrodes positioned on each thigh.

Discussion

The data collected in this feasibility study will be analyzed during the next two months by students at the Georgia Institute of Technology. The proposed analytical methods are described below.

1. The power spectrum of the carotid pressure variations will be calculated using FFT and Rectangular Window algorithms on 1 minute segments of data. The same statistics will be calculated for "integrated pressure"--average carotid pressure during the previous three cardiac cycles.

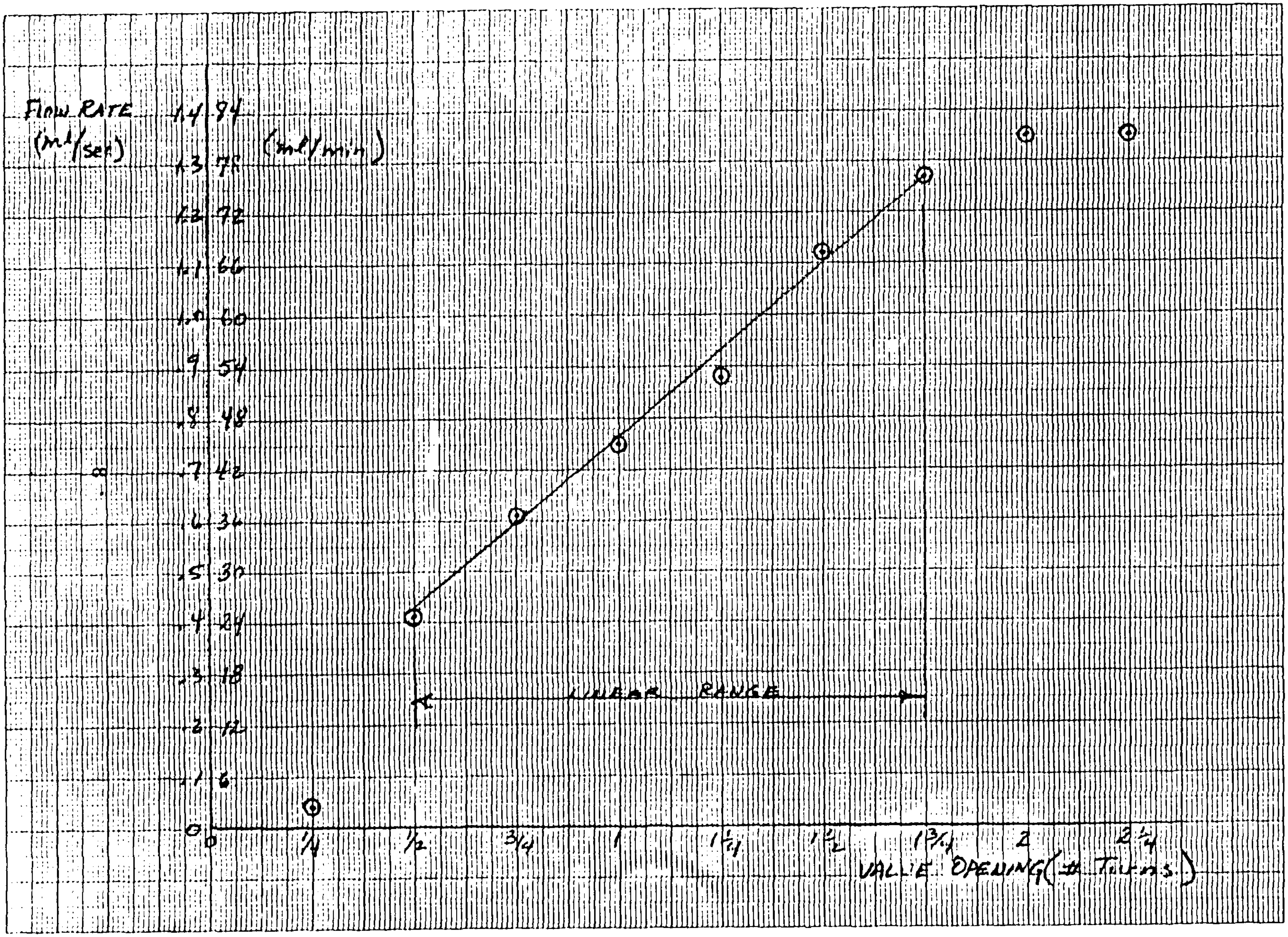
FLOW RATE (ml/sec)
(ml/min)
1.4 84
1.3 78
1.2 72
1.1 66
1.0 60
.9 54
.8 48
.7 42
.6 36
.5 30
.4 24
.3 18
.2 12
.1 6
0
0
1/4
1/2
3/4
1
1 1/4
1 1/2
1 3/4
2
2 1/4
LINEAR RANGE
VALVE OPENING (# Turns)

FIGURE 4

2. The relationship between the hydraulic valve position and the resulting carotid pressure will be determined by calculating the h1 Wiener kernel (Marmarelis, 1976) for the motor+valve assembly and then using the h1 kernel to predict the Bode plots of gain and phase versus frequency.

3. The relationship between the carotid pressure and the resulting R-R interval will be determined by calculating h1 and h2 Wiener kernels-- cross-correlations between the carotid pressure (stimulus) and the R-R interval (response). Linear and 2nd-order nonlinear characteristics will be revealed and compared with the dynamics reported by Andresen (1978).

4. The accuracy of the linear model and the significance of higher-order nonlinearities will be revealed and compared with the results reported by Brown (1978).

5. The compilation of all results will be compared with the nonlinear model proposed by Masaru (1990).

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THE EFFECT OF HYPERBARIC OXYGENATION ON MUSCLE REGENERATION FOLLOWING TOXIN INDUCED NECROSIS

Dr. Arnold Nelson, Summer Faculty Researcher

Abstract

Skeletal muscle's viability and its capacity to recover from injury are tied to the amount of oxygen present in the tissue. Hyperbaric oxygenation therapy (HBO) has been shown to reduce the amount of muscle necrosis and thus maintain viability during acute conditions of ischemia and compartmental syndrome. It is not known, however, if HBO will continue to slow the rate of necrosis under more chronic conditions or if it will accelerate the recovery from a necrotic condition. The purpose of this project was to determine if the rate of muscle regeneration or recovery from a chemical toxin induced muscle necrosis can be accelerated by HBO.

Introduction

When a person spends an extended amount of time living in an untamed outdoor environment such as those encountered in wartime activity or maneuvers, they are at a greater risk of being attacked by a venomous animal. In addition to the possibility of death from such an attack, envenomation can cause serious injury to the body since most venoms exhibit vasoconstrictive, thrombotic, hemolytic, neurotoxic, and necrotizing activity. Interestingly, the tissue pathology arising from these deleterious activities of venoms is quite similar to that which is seen in cases of tissue ischemia and compartment syndrome. Since compartment syndrome and ischemic based myonecrosis respond well to hyperbaric oxygenation therapy (HBO) (1), it would appear that HBO would be indicated for the treatment of evenomation. Unfortunately, little research has been done on the use of HBO and evenomation, and that which has been done is open to question. For instance, there are clinical studies (such as Workman et al (2) with pit viper evenomation and Svendsen (3) with brown recluse spider evenomation) which suffer from the lack of a control group, and there are controlled studies (such as Stolpe et al (4) with pit viper evenomation) which are inconclusive due to lack of venom and antivenin dose/response knowledge for the animal model used. Therefore an ideal research project concerning the efficacy of HBO on evenomation induced myonecrosis would entail using a control group and a venom with characterized myonecrotic activity. The cardiotoxin purified from the venom of Naja mocambique mocambique has been used in research involving muscle regeneration (5). This toxin when applied directly to mouse muscle at a 10 uM concentration will induce myonecrosis without causing death or destroying the muscle's innervation (5). Also, the myonecrotic activity is at a low enough level that muscle regeneration to a normal condition is complete two months post-administration (5). Thus it appears that this toxin would be a good choice as the toxic agent for research concerning the efficacy of HBO on venom induced myonecrosis.

Therefore, it was the purpose of this research project to evaluate the effect of HBO on the recovery of skeletal muscle following a toxin induced myonecrosis. It was hypothesized that HBO would help the muscle regenerate quicker than it would under non-treated conditions.

Experimental design and methods

Animals. Thirty-six adult male rabbits served as the experimental model. The rabbits were divided into four groups of nine rabbits each.

Evenomation Procedures. To create the toxin injury, the rabbits were anesthetized with ketamine HCL (35 mg/kg I.M.) and xylazine (5 mg/kg I.M.). The right gastrocnemius was then injected with pure cardiotoxin, 10 uM Naja mocambique mocambique cardiotoxin (Sigma Chemical Co., St. Louis MO) in 0.9% NaCl solution. The muscles were injected in ten sites each with 0.1 ml of the cardiotoxin solution. Six rabbits randomly selected from each group were injected each until all rabbits had been injected.

Experimental treatments. Each group of nine rabbits was randomly assigned to one of four treatments. The animals in three of the groups were subjected to HBO treatments, while the other group served as the control. Group 1's HBO treatment was similar to the protocols shown by Nylander (2) and Strauss et al (3) to be effective in the acute treatment of crush injuries. For the long term care, the protocol was adjusted so that it simulated the general treatment protocol currently used by USAF Al/AOH to treat the majority of medical problems seen in human patients. Specifically, the treatment protocol consisted of 90 minutes of breathing 100% oxygen at a pressure of 2.4 ATA (45 fsw). The descent to 2.4 ATA took five minutes, and the ascent to normabaria following the treatment lasted 15 minutes. Thus, the animals were in the hyperbaric chamber a total of 110 minutes each treatment period. Temperature within the hyperbaric chamber was maintained near 22° C by venting a continuous flow of 100% O_2 through the chamber. This venting procedure also prevented the build-up of expired CO_2. The venting flow rate was set at a flow which ensured that the oxygen content, as determined by a polargraphic oxygen analyzer, of the vented gases was greater than 95%. The treatments were initiated 6 hours post-operative and continue twice daily five days a week thereafter. The twice daily sessions will consist of one A.M. session and one P.M. session with a minimum four hour interval between sessions. Group 2 received the same treatment protocol as Group 1 with one modification. Instead of breathing 100% O_2, Group 2 breathed a mixture of 8.5% O_2 and 91.5% N_2 (a mixture which is comparable to breathing normabaric atmospheric air.) Group 3 also received the same treatment protocol as Groups 1 & 2, except in their case they were expose to 100% O_2 at 1 ATA.Finally, Group 4 experienced the same chamber protocol, but in their case the rabbits breathed normabaric atmospheric air (1 ATA, 21% O_2, 0.03% CO_2, 79% N_2).

As indicated above, the groups receiving HBO received these treatments 5 days per week.The treatments for each group proceeded as outlined above for a period of 4 weeks (or 20 HBO treatment days), at which time the animals were euthanatized in the order which they were injected (six animals per day and the poisoned muscle harvested for analysis.

Tissue Harvest. As mentioned above, crushed muscle was harvested for analysis following 4 weeks of treatment. The muscle harvest occurred 12-16 hours following the last treatment session (i.e. harvesting began in the morning of the day immediately following the 20th day of treatments). The animals were anesthetized with ketamine (35 mg/kg I.M.) and xylazine (5 mg/kg I.M.) and the muscle exposed. Prior to the harvest of the crushed muscle for morphological and biochemical analysis, the muscle's twitch and fused tetanus tensions was recorded. The muscle was freed from the surrounding connective tissue, and the gastrocnemius portion of the Achilles tendon severed and attached to the lever arm of a force transducer. The muscle was held at its normal resting length by securing the lower hindlimb via steel pins placed through the knee and ankle joints. The muscle was then stimulated directly via platinum electrodes placed on each side of the muscle nerve.Both twitch and a fused tetanic tension were recorded via the force transducer to an oscilloscope. To obtain a muscle twitch, the muscle was stimulated by a single 10 V square wave pulse 2.4 msec in duration. Following the twitch, the muscle was allowed to recover for 1 minute, after which maximal tetanic tension was recorded. Maximal tetanic tension was elicited using a 1 train/sec for 500 msec with 100 impulses/train stimulation regime. Again, the muscle recovered for one minute, and then the muscle removed. Upon removal, the muscle was trimmed of connective tissue, weighed, and a portion belly cut out and placed in 10% formalin buffer. The rest of the muscle was quick frozen in isopentane cooled to below -80^{o} C and stored at -75^{o} C. These procedures were then repeated with the contralateral left gastrocnemius muscle. Following the removal of the contralateral muscle, the soleus, diaphragm, heart, trachea, sciatic nerve, and liver were removed and frozen for analysis in conjunction with other projects.

Tissue analysis. The formalin fixed muscle pieces were to be paraffin embedded, sectioned, and stained with hematoxylin and eosin (H&E) (6) to determine muscle pathology and with Masson trichrome (6) to highlight intra-muscular collagen by the pathology personnel of AL/OEV. Additional muscle pieces were designated for analyses to determine enzymatic activity. The enzymes to be assayed and the procedures used were as follows: citrate synthase, Srere (7); adenylate kinase, Bergmeyer (8); glyceraldehyde 3-phosphate dehydrogenase, Lowry and Passonneau (9); hexokinase, Uyeda and Racker (10); and glucose 6-phosphate dehydrogenase, Wagner et al (11).

Statistics. An analysis of variance was used to compare the differences between the right and left muscles within and between groups.

Results

The gastrocnemius muscle weights for the poisoned limb (right) and the nonpoisoned limb (left) for each treatment group are shown below in Table 1. AS can be seen in Table 1 there was no difference in muscle weights between legs or across groups. Due to the magnitude of the tensions for the majority of the muscles exceeding the resolution capabilities of the available force transducers, the muscle tension measurements were discarded and are not presented here. Visual inspection of the muscles found no evidence of muscle necrosis. This observation, however, can not be verified by the histochemical stains and enzyme analyses as these procedures can not be completed in time to make the deadline for this report.

Table 1. Gastrocnemius muscle weights.

Treatment	Left	Right
2.4 ATA 100% O_2	10.1 ± 1.1	10.0 ± 1.0
2.4 ATA 8.5% O_2	9.7 ± 1.2	9.8 ± 1.1
1 ATA 100% O_2	10.3 ± 0.6	10.1 ± 0.4
1 ATA 21% O_2	10.2 ± 0.7	10.5 ± 0.5

Values are means ± S.D.

Discussion

The above data derived from the excised gastrocnemius muscles indicates that the experiment did not accomplish its intended goal. Apparently, the desired toxin-induced muscle necrosis did not take place to the extent which was desired, if it took place at all. There are at least three possible reasons for the low necrosis. First, previous work (5) using the naja mocambique toxin was done in mice, and therfore it is possible that the rabbit physiology differs enough that the sucessful dosage in mice is not concentrated enough for the rabbit model. It is also possible that the dosage was adequate, but that the recovery rate from the toxin is much more rapid in the rabbit than it is in the mouse. Finally, it is possible that the toxin used had become inactive or denatured thus losing its necrotic capabilities.

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FINAL REPORT

1991 USAF-RDL SUMMER FACULTY RESEARCH PROGRAM

GRADUATE STUDENT RESEARCH PROGRAM

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Conducted by the

Research and Development Laboratories

FINAL REPORT

Bioeffects of Microwave Radiation on Mammalian Cells

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Bioeffects of Microwave Radiation on Amino Acid Metabolism by Mammalian Cells

by

Donald K. Robinson

Abstract

In this study we sought to determine if microwave radiation (2450 MHz, 30 minutes) has an effect on the amino acid composition of the growth media. Three separate cell lines were used: RAW mouse macrophage cells; C3H mouse embryo cells and 3T3 mouse embryo cells. The effects of microwave and sham treatment on cell number or cell density were also evaluated in order to determine if the effects are the result of changes in cell metabolism of amino acids or due to changes in cell number. In addition, studies were performed on all three cell lines using two cell densities; a standard density and a 1:10 dilution. The changes in amino acid profiles were determined by thin-layer chromatography 24 hours post microwave and sham exposure. Two amino acid antagonists were used to amplify the effects of microwave radiation. The amino acid bands were found to be less intense in the microwave treated pairs of two of three cell lines examined. In addition, the bands were also less dense in the microwave exposed groups that had been diluted 1:10 and in the groups that contained the amino acid antagonists. The cell number did not appear to differ significantly, thereby indicating that the changes are due to an effect on metabolism rather than on cell number.

I. INTRODUCTION:

During the past decade, there has been an increase in the number of radar and radio transmitters in use in the civilian and in the military sectors of our society. There has also been an increase in the interest in the possible health effects of microwave and radiofrequency radiation. A wide range of studies on the bioeffects of microwave radiation have been performed, however, the results have varied. Some of these studies have been negative (1,2,3), others have been positive. Microwave exposure has been reported to cause changes in chromosome number (4) and structures (5), formation of cataracts in humans (6), promotion of malignant tumor formation in rats (7), and increases in tumor production and leukemias (8). Further studies need to be made because not all results have been reproducible and because of questionable controls and experimental designs (1). It is very important to control the increased temperatures associated with microwave radiation. Failure to adequately control temperature can cause thermal effects to be mistaken for bioeffects of microwave radiation. In this study, we sought to confirm our previous findings by expanding the studies to include two other mammalian cell lines. We were also interested in learning if there was any relationship between the bioeffects of microwave radiation and the density of the mammalian cell suspension sample. High density samples are initially under stress and may be more susceptible to the stress of microwave exposure. Additionally, we wanted to investigate whether L-citrulline or N-methyl-L-arginine could amplify the effects of microwave radiation on the amino acid metabolism of RAW 264.7 cells. Both of these reagents are antagonists to L-arginine utilization by mammalian cells. RAW 264.7 cells exposed to microwave radiation have shown an increased utilization of L-arginine 24 hours and 48 hours past exposure.

In these experiments, temperatures in the microwaved samples and sham controls were maintained at 37$\pm$ 0.1oC with a computer-controlled feedback system. Therefore, the results obtained could not be caused by temperature effects resulting from microwave radiation. Additionally, we determined the cell numbers after sham/microwave treatment to determine if the effects of microwave radiation was due to cell metabolism of amino acids or if it was due to cell numbers. We used thin layer chromatography last summer and the results were quantitated by high performance amino acid analysis. The TLC experiments are easy to perform, inexpensive, fast and changes in amino acid profiles can be easily seen and interpreted.

II. OBJECTIVES OF THE RESEARCH EFFORT:

The objectives of this research effort are as follows:

A. Determine the effects of microwave radiation on the metabolism of amino acids in three different mammalian cell lines: RAW 264.7 mouse macrophage, 3T3 mouse embryo, and C3H mouse embryo.

B. Determine the effects of microwave radiation on the metabolism of amino acids in mammalian culture medium by RAW 264.7 mouse macrophage cells that were treated with N-methyl-L-arginine.

C. Determine the effects of microwave radiation on the metabolism of amino acids in mammalian culture medium by RAW 264.7 mouse macrophage cells that were treated with L-citrulline.

D. Determine if microwave radiation has an effect on cell number or if the effect is on cellular metabolism of amino acids. This determination will be made by examining the difference in cell density immediately post exposure and 24 hours post exposure.

E. Determine the effects of microwave radiation on amino acid concentrations using two separate cell densities i.e. cell densities that are approximately 10-fold less than the original density. This study will determine if cell density can possibly amplify the bioeffects of microwave radiation.

III.

METHODS

Experimental Design

The study protocol utilized RAW 264.7 cells at a cell density of 3.6×10^6 cells per ml of RPMI mammalian culture medium; C3H cells at a cell density of 2.3×10^5 cells per ml of RPMI mammalian culture medium; and 3T3 cells at a density of 7.6×10^5 cells per ml of Dulbecco's modified Eagles medium containing 4.5 g/L of glucose and 10% calf serum.

For each cell line, 2.2ml aliquots were transferred to sterile culture tubes for microwave radiation (2450 MHz, continuous wave, mean specific absorption rate of 103.5 ± 4.2 W/Kg) REF or sham treatment for 30 minutes. After microwave exposure or sham treatment, each culture tube was moderately vortexed and a 0.2 ml aliquot of cell suspension was transferred to a corresponding "prime" labeled tube which contained 1.8 ml of culture medium. Both sets (original and diluted) of cell suspensions were allowed to grow for 24 hours in an incubator at 37°C. Next, the culture tubes were vortexed and a 0.1 ml aliquot was removed for counting with a coulter cell counter. The cell cultures were centrifuged to pellet the cells and the supernates were removed for further analyses. Additional studies with RAW 264.7 cells similar to those above were also performed except that L-citrulline or N-methyl-L-arginine was added, before treatment, to both the microwave treated and the sham treated cell cultures. A 0.5 ml aliquot of L-citrulline, 2mg/ml, in PBS, Ph 7.2 or N-methyl-L-arginine, 2mg/ml, in PBS, PH7.2 was added to 0.5 ml of cell suspension to give a final concentration of 1 mg/ml. A 0.5 ml volume of PBS, PH 7.2, was added to 0.5 ml preparations that did not contain L-citrulline or N-methyl-L-arginine prior to sham or microwave exposure. After 24 hours of growth, both the microwave treated and the sham treated cell cultures were centrifuged and the supernates were removed for further analyses. All of the supernates were stored in the freezer until analyzed.

Thin Layer Chromatography (TLC)

Seven microliters of each supernate were applied to a pre-coated, thin-layer chromatographic plate. Sigma cell type 100 cellulose on polyester, 20x20 cm., (sigma T-6890), were used for the studies. The plates were sprayed with 0.2% ninhydrin in ethanol.

Cell Density

Cell densities were determined using a coulter cell counter, model ZBL, Hialeah, Florida.

RESULTS

Effects of Microwave radiation on Amino Acid concentrations in 3 different mammalian cell lines

RAW 264.7 Cells

The chromatograms of the five sham treated and five microwaved treated samples displayed very similar banding patterns. THere were three distinct amino acid banding regions. The banding regions of the microwave treated group were less intense than the bands in the sham treated group.

3T3 Cells

The chromatogram of the five sham treated and five microwave treated samples displayed two distinct bands per sample. The bands of each group were similar however, the bands of the microwaved group were less intense than the five sham treated samples.

C3H Cells

The chromatogram of the five sham treated and five microwave treated samples displayed three very intense bands per sample. The banding regions for the samples of each group were very similar. No discernible differences in the band intensities were observed.

Effects of microwave radiation on the amino acid metabolism of RAW 264.7 cells treated with L-Citrulline

The chromatograms of the sham treated and microwave treated samples showed four, distinct, bands for each sample. The intensities of the bands in the sham treated samples were significantly greater than the band intensities of the microwave treated samples.

Effects of microwave radiation on the amino acid metabolism of RAW 264.7 Cells treated with N-methyl-L-arginine

The chromatograms of the sham treated and microwave treated samples displayed four, distinct, bands for each sample. The band intensities of the sham treated samples were significantly greater than the band intensities of the microwave treated samples.

The difference in cell density immediately post exposure and 24 hours post exposure

RAW 264.7 Mouse Macrophage cells

Table 1 shows the number of cells per ml for both the undiluted and diluted, sham(s) treated and microwave (m) treated samples. Table 2 shows the average number of cells per ml for the (5) sham treated and the (5) microwave treated samples in both the undiluted and diluted group. The averages were calculated by eliminating the highest and the lowest counts in the sham treated and microwave treated groups and averaging the remaining three counts. The percent change (% ▲) of each group was calculated from entries (2) and (3). Approximately 30% of both undiluted (s/m) treated cells died 24hours post (s/m) treatment. Approximately 26% of the diluted (s/m) treated cells died 24 hours post (s/m) treatment.

3T3 Mouse embryo cells

Table 3 shows the individual sample counts/ml for the undiluted and diluted cell suspensions. Table 4 displays the average densities of both the (s/m) treated groups. There was a 35% decrease in cell density 24 hours post (s/m) treatment for the (s) treated, undiluted cells. The (m) treated, undiluted cells showed a 21% decrease 24 hours post (s/m) treatment. The diluted, (s) treated cells increased in density 24 hours post (s/m) treatment by 40% and the diluted (m) treated cells showed a 13% rise in density during this time.

C3H mouse embryo cells

Table 5 exhibits the number of cells per ml for the individual, (s/m) treated, samples in both the diluted and undiluted groups. Table 6 displays the cell averages for the (s/m) treated samples in each group. The decreases in average cell densities for the undiluted group were 43% for the (s) treated and 40% for the (m) treated cells. The diluted (s) treated cells showed a 35% decline and the (m) treated cells had a 28% decline in average cell density.

<u>The effects of microwave radiation on amino acid metabolism of</u>

mammalian cells that are approximately 10-fold less dense than their original density.

RAW 264.7 cells

The chromatogram of the five sham treated and five microwave treated samples displayed two distinct amino acid bands per sample. The bands of each group were very similar. the intensities of the bands of the microwave treated group were a fraction of a shade lighter than the band intensities of the sham treated group.

3T3 cells

The chromatogram of the five sham treated and five microwave treated samples displayed two banding regions per sample. The bands of the microwaved group were found to be less intense than the bands of the sham treated group.

DISCUSSION

Microwave radiation resulted in decreased amino acid concentrations of the growth media in two of the three mammalian cell lines; RAW and 3T3 cells. The effects of microwave radiation within the two cell groups were found to take place even when the cells were diluted post exposure. This implies that the effects of microwave radiation is independent of cell density and is not due to the effects of cell stress.

In this study, the RAW 264.7 mouse macrophage and 3T3 mouse embryo cells employed the same growth media. The C3H mouse embryo cells were grown in a different media containing higher concentrations of various constituents. It could be that the higher concentrations of the constituents in the growth media may have masked the effects of microwave radiation.

The amino acid antagonists, L-citrulline and N-methlyl-L-arginine, did not amplify the cells. The amino acid patterns were similar to those found in microwave treated RAW 264.7 cells that did not contain antagonist. The effects of microwave radiation nevertheless were apparent in the cells in that the amino acid concentrations like those in cells without antagonists, were found to be lower than those in the sham treated cells.

In this study, we determined if microwave radiation had an effect on the cell number or cell density compared to the cell number or cell density compared to the sham treated. There were no apparent differences in cell numbers between the microwave and sham treated groups of RAW and C3H cells or in the changes in cell numbers 24 hours post exposure for the microwave treated and the sham treated. There were, however, some differences in the number of 3T3 cells of the microwave and sham treated groups. However, the variabilities (s.d) in the cell numbers for both the microwave and sham treated groups suggest that the microwave treated groups suggest that the microwave treated group may not actually differ from that of the sham treated group. The effects of microwave radiation using this cell line needs to be repeated and appropriate analysis needs to be performed on the results.

TABLE 1

RAW 264.7 MOUSE MACROPHAGE

NUMBER OF CELLS/ml

SAMPLE # (ml)	BEFORE (s/m) ($X10^6$)	AFTER (s/m) ($X10^6$)	AFTER 24hrs ($X10^6$)
1S 2.2	3.8	3.7	3.1
2M "	3.5	3.4	3.1
3M "	3.8	3.7	3.2
4S "	3.4	3.7	3.1
5S "	3.9	3.8	2.5
6M "	3.6	3.7	2.4
7M "	3.7	3.7	2.3
8S "	3.7	3.6	2.2
9S "	3.7	3.6	2.0
10M "	3.6	3.7	2.2
(1:10) $1S^1$ 2.0	-	3.5 ($X 10^5$)	2.4 ($X10^5$)
$2M^1$ "	-	3.6	2.2
$3M^1$ "	-	3.9	1.4
$4S^1$ "	-	4.0	1.3
$5S^1$ "	-	3.8	3.2
$6M^1$ "	-	4.2	3.0
$7M^1$ "	-	4.0	3.8
$8S^1$ "	-	3.9	3.0
$9S^1$ "	-	3.8	3.8
$10M^1$ "	-	3.9	3.2

TABLE 2

RAW CELLS

SHAM(S)/MICROWAVE (M) TREATMENT	AVERAGE NUMBER OF CELLS/ml (1) BEFORE (s/m) TREATMENT	(2) AFTER (s/m) TREATMENT	(3) AFTER 24hrs TREATMENT	%▲ (3) VS (2)
	($X10^6$)	($X10^6$)	($X10^6$)	
S	3.7± 0.06	3.6± 0.06	2.6± 0.46	-28
M	3.6± 0.06	3.7± 0.0	2.6± 0.43	-30
		($X10^5$)	($X10^5$)	
S^1 (1:10)		3.8± 0.06	2.9± 0.42	-24
M^1 (1:10)		3.9± 0.06	2.8± 0.53	-28

TABLE 3

NIH/3T3 (CONTACT-INHIBITED NIH SWISS MOUSE EMBRYO)

NUMBER OF CELLS/ml

SAMPLE # (ml)	BEFORE (s/m) ($X10^5$)	AFTER (s/m) ($X10^5$)	AFTER 24hrs ($X10^5$)
1S 2.2	7.9	6.5	6.1
2M "	7.0	7.0	7.3
3M "	6.0	6.7	6.1
4S "	8.6	11.0	7.2
5S "	8.0	13.0	7.0
6M "	7.3	12.0	6.8
7M "	9.2	13	6.9
8S "	5.6	11	6.0
9S "	7.2	7.6	4.4
10M "	8.3	7.0	8.7
(1:10)			
$1S^1$ 2.0	-	11 ($X 10^4$)	0.8($X10^5$)
$2M^1$ "	-	10	1.2
$3M^1$ "	-	10	3.2
$4S^1$ "	-	7.7	1.0
$5S^1$ "	-	10	1.5
$6M^1$ "	-	8.5	1.4
$7M^1$ "	-	9.1	1.8
$8S^1$ "	-	8.0	1.7
$9S^1$ "	-	6.6	1.1
$10M^1$ "	-	6.9	1.4

TABLE 4

<u>3T3 CELLS</u>

SHAM(S)/MICROWAVE (M) TREATMENT	AVERAGE NUMBER OF CELLS/ml (1) BEFORE (s/m) TREATMENT	(2) AFTER (s/m) TREATMENT	(3) AFTER 24hrs TREATMENT	%▲ (3) VS (2)
	(X10^5)	(X10^5)	(X10^5)	
S	7.7± 0.44	9.9± 2.0	6.4± 0.55	-35
M	7.5± 2.8	8.7± 2.8	7.0± 0.26	-21
		(X10^4)	(X10^5)	
S^1 (1:10)		8.6± 1.3	1.2± 0.26	+40
M^1 (1:10)		9.2± 0.75	1.5± 0.23	+63

TABLE 5

C3H/IOT1/2, CLONE 8 (MOUSE EMBRYO)

CONTACT - SENSITIVE FIBROBLASTS

NUMBER OF CELLS/ml

SAMPLE # (ml)		BEFORE (s/m) ($X10^5$)	AFTER (s/m) ($X10^5$)	AFTER 24hrs ($X10^5$)
1S	2.2	3.2	2.6	1.1
2M	"	4.4	3.1	1.5
3M	"	2.0	2.3	1.4
4S	"	2.1	2.0	1.3
5S	"	1.8	1.5	0.9
6M	"	1.9	1.9	1.2
7M	"	2.5	2.3	1.3
8S	"	2.8	2.4	1.4
9S	"	2.3	3.0	1.7
10M	"	1.7	1.8	1.1
(1:10)				
$1S^1$	2.0	-	1.2 ($X 10^5$)	10 ($X10^4$)
$2M^1$	"	-	1.4	13
$3M^1$	"	-	1.0	7.6
$4S^1$	"	-	1.1	6.5
$5S^1$	"	-	0.5	5.3
$6M^1$	"	-	0.9	7.4
$7M^1$	"	-	1.1	6.7
$8S^1$	"	-	1.0	7.3
$9S^1$	"	-	1.5	7.7
$10M^1$	"	-	0.7	5.6

TABLE 6

C3H CELLS

SHAM(S)/MICROWAVE (M) TREATMENT	AVERAGE NUMBER OF CELLS/ml (1) BEFORE (s/m) TREATMENT	(2) AFTER (s/m) TREATMENT	(3) AFTER 24hrs TREATMENT	%Δ (3) VS (2)
	$(X10^5)$	$(X10^5)$	$(X10^5)$	
S	2.4± 0.36	2.3± 0.3	1.3± 0.15	-43
M	2.1± 0.32	2.2± 0.23	1.3± 0.1	-40
		$(X10^5)$	$(X10^4)$	
S^1 (1:10)		1.1± 0.1	7.2± 0.61	-35
M^1 (1:10)		1.0± 0.1	7.2± 0.47	-28

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EVOKED ELECTRICAL ACTIVITY IN THE HAMSTER SUPRACHIASMATIC NUCLEUS MONITORED OPTICALLY WITH VOLTAGE-SENSITIVE DYES

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ABSTRACT

The optimal conditions for monitoring the spatial/temporal patterns of neural activity evoked in the hamster suprachiasmatic nucleus (SCN) using optical recording techniques were determined. A specialized computer-based data acquisition and graphic display system developed by the Principal Investigator at The University of Texas at San Antonio (UTSA) allowed evoked electrical activity in an *in vitro* slice preparation of the SCN to be directly visualized and quantitatively analyzed following electrical stimulation of the transected optical nerve. In most preparations, a single 0.5 ms shock to the optical nerve evoked widespread neuronal activity that could be detected from both ipsilateral and contralateral SCN's after staining with the voltage-sensitive dye RH155. Control experiments demonstrated that the recorded optical signals were not seriously distorted by either the stimulus artifact or by changes in intrinsic light scattering. The feasibility of using multiple-site optical recording techniques to study evoked activity in the hamster SCN was clearly demonstrated.

INTRODUCTION

Most life forms, including man, exhibit cyclical changes in behavior and physiological processes that have a period of about 24 hours. In multicellular organisms such diurnal rhythms are driven by neuronal circuitry that functions as a 'circadian pacemaker'. There is now good evidence that for rodent species (and probably for other mammalian species as well) the circadian pacemaker is contained within the suprachiasmatic nucleus (SCN) of the anterior hypothalamus (e.g. Shibata, et. al., 1982; Groos & Hendriks, 1982; Moore, 1983; More & Card, 1986; Gillette & Reppert, 1987; Shibata & Moore, 1988).

An important attribute of the circadian pacemaker is its ability to be entrained by environmental cues, primarily diurnal fluctuations in light and temperature (e.g. Aschoff, 1954). In nocturnal rodents, the sensitivity of the circadian pacemaker to light entrainment is particularly acute (e.g. Pittendrigh & Daan, 1976) and is mediated by visual afferent input from the optic nerves (Pickard, 1982). It is clear from single-unit and field-electrode studies of the SCN, *in vivo* and *in vitro,* that SCN neurons receive a direct synaptic input from optic nerve fibers (e.g. Groos, 1979; Green & Gillette, 1982; Shibata & Moore, 1988). How this afferent input alters the electrical and/or biochemical activity of units SCN to affect entrainment of the 'oscillator' is still largely unresolved, however.

To obtain further information about the about neural control of the SCN by the retino-hypothalamic tract, we decided to monitor evoked neural activity in the SCN using multiple-site optical recording techniques. The primary advantage of this approach over more conventional electrophysiological approaches (e.g. microelectrode and EEG recording) is that optical recording allows activity to monitored simultaneously from a relatively large number of contiguous anatomical sites thus providing a more global view of the synaptically driven input/output interrelations (e.g. Senseman et al., 1990).

OBJECTIVES OF THE RESEARCH EFFORT

The basic feasibility of using of optical recording techniques to monitor evoked activity in the SCN was established in a recent study of the mouse SCN by Obaid et al. (1991). The primary objective of our experiments was to determine the optimal conditions for optical recording from the hamster SCN in order for our results to be directly collated with extensive behavioral, biochemical and electrophysiological studies of the hamster SCN being performed by M. Rea and his associates at the Amstrong Laboratory, Brooks AFB. In particular, we wanted to determine the following parameters:

1. Optimal Staining Parameters
2. Optimal Objective Magnification
3. Optimal Stimulation Parameters
4. Optimal Recording Protocol

METHODS

Experimental Preparation

Hamster weighing 40 - 60 gms were maintained on a 14:10 LD cycle. Between 4 - 6 hrs after lights on, animals were surgically anesthetized with halothane and decapitated. After removal from the cranium, the isolated brain was momentarily chilled in cold oxygenated saline. The anterior hypothalamus containing the SCN's, optic chiasm and optic nerves was dissected free and affixed to the stage of an oscillating tissue slicer (model OTS-3000, Frederick Haer Inc) with cyanoacrylate adhesive. A single 400 um thick slice was cut along the rostral-caudal axis moving in a rostral direction. The slice was incubated at room temperature in oxygenated saline for 30 min and then stained for 60 - 90 min with a saline solution containing 1.0 mg/ml of the voltage-sensitive dye, RH 155 (Nippon Kankoh-Shikiso Kenykyusho Co., Okayama, Japan). At the end of the staining period, excessive dye was removed fresh saline and the slice allowed to incubated for an additional 30 min.

After the staining/incubation period, the slice was removed from the incubation chamber and pinned to a Sylgard layer that formed the bottom of simple experimental chamber. The tissue was perfused continuously with oxygenated (95% O_2/5% CO_2) saline at room temperature with the following ionic composition (in mM): NaCl, 125; KCl, 5; $MgSO_4$, 2; $CaCl_2$, 3; NaH_2PO_4, 1.25; $NaHCO_3$, 25.5 and d-glucose, 10.

Electrical Stimulation

Neural responses were evoked in the SCN slice using a plastic 'suction' electrode attached to the right optical nerve. Under low power magnification, the end of the transected optical nerve was positioned at the opening of the electrode. A gentle suction was then applied using a 1 cc syringe to draw the distal end of the nerve into the electrode. Electrical pulses were delivered by means of a Ag/$AgCl_2$ wire inserted into the lumen of the suction electrode and a Ag/$AgCl_2$ wire in the bath (indifferent electrode). Pulse durations were varied between 0.1 and 1.0 ms and pulse intensities between 0.01 mA and 1.5 mA.

Optical Recording

The experimental chamber was mounted on the stage of a large binocular microscope (Zeiss UEM) that served as an optical platform. Brightfield illumination of the preparation was accomplished using a 12 volt, 100 watt tungsten-halogen lamp 'over-driven' to 9 amps by a regulated DC power supply (Lambda model LK 351-PM). The light was collimated and passed through various heat and bandpass interference filters before being brought to a focus on the preparation via the microscope's substage condenser. Microscope objective lens of various magnifications were used to project a real image of the preparation on to the surface of a 12 x 12 silicon photo-diode array (MD 144-O, Centronic Electro-Optics, Inc, Newbury Park, CA) that was mounted on the microscope's trinocular tube. Additional details concerning the data acquisition system can be found in Cohen & Lesher (1986).

Video Imaging

Conventional procedures were followed for the acquisition, processing and storage of high-resolution video images of the experimental preparation (512 x 512 pixels, 256 grey levels). Video images were obtained by replacing the photodiode array on the microscope's trinocular tube with a TV camera optimized for video microscopy (Hammamatsu model C2400). To increase the camera's field of view, we substituted a microscope objective with a lower magnification (2.5X) than the one use for optical recording. Improved video contrast was achieved by illuminating the preparation with a pair of fiber optical light guides, positioned tangentially to the microscope's optical axis, to produce a 'pseudo d...field' image. The TV camera's video output was fed to a Panasonic (Model TQ-2025F) Optical Disc Memory Recorder (ODMR) which provided archival storage of the image data. Selected video images were subsequently digitized ('frame grabbed') with a commercially available image processor system (Imaging Technology Inc., Series 151) and the digitized image file transferred to a graphics workstation. Further details concerning the combined display of diode array-recorded optical signal data and video-recorded image data can be found in Senseman et al. (1990).

RESULTS

Approximately 50 MBytes of experimental data were collected during the 10 week SFRP. An initial qualitative analysis of these data has been completed while a more rigorous quantitative analysis is still in progress. Fig. 1 shows the results obtained in a typical trial in a 'page display' format. In this presentation format, the optical signals recorded by each of the array's 124 active photodiode elements are displayed in their relative position within the image field. The approximate location of the two SCN's has been indicated with dotted lines. In this experiment, the suction electrode used for stimulation was attached to the right optic nerve.

Two selected traces from this display (detectors 13 & 42) are shown in Fig. 2, at higher magnification. Detector 13 was located over the stimulated (right) optic nerve while detector 42 was located over the contralateral (left) SCN. Whereas detector 13 shows only a single fast response, the signal recorded by detector 42 shows a multiphasic response with an initial fast transient recorded coincident with the 'spike' in detector 13 followed by a much larger depolarizing transient and later broad depolarization.

Based on neuroanatomical and neurophysiological considerations, we believe the initial transient in both records represents evoked afferent of the retino-hypothalamic tract (pre-synaptic response). The large transient that occurs 10-20 ms later in detector 42 would therefore represent the synaptic activation of the SCN neurons by these incoming visual fibers. The later, broad depolarization seen in detector 42 is presumably due to recurrent excitation within the SCN itself.

Optimal Staining Parameters

Optimal staining can be defined as the amount of tissue staining with a voltage-sensitive dye (e.g. RH155) that produces optical signals with maximal amplitude with a minimal amount of pharmacological and/or photodynamic damage to the preparation. The degree of staining can be controlled by varying (1) the concentration of the dye in the staining solution and/or (2) the duration of the staining period. Up to a certain point, the amplitude of optical signals can be increased by increasing the degree of tissue staining. However, at higher levels of tissue staining, optical signals will tend to get progressively smaller as more and more of the transmitted light is absorbed by the tissue. We observed the largest optical signals when the *in vitro* preparation was stained for 60 min. using a dye concentration of 0.5 mg/ml.

Optimal Objective Magnification

The magnification of the objective lens will directly determine the area monitored during the recording trial. Objective magnification will also directly affect the signal-to-noise ratio of the optical response in an inverse fashion since higher power objectives acquire less light than low power ones and since the SN ratio is directly related to light intensity. While the largest optical signals were recorded using a Wild 7.0 X objective, only 8-10 of the array's 124 photodiode elements were positioned directly over the paired SCN's.

Our attempts to use moderately high powered objectives (20 - 40X) to increase the number of diode elements over the SCN's were not successful for two reasons. First, at higher powers $\geq$20X, it proved extremely difficult to form a real image of the preparation on the surface of the photodiode array due primarily to scattered light that 'blurred' the image. Secondly, the blurred image also decreased our ability to visually identify surface landmarks need later to map the location of the array on to a video image of the preparation.

The best compromise in lens magnification was determined to be in the range of 10 to 16 X. At this range, each diode element monitored a 'patch' of hypothalamus of about 100 um x 100 um with roughly 10 to 20 elements positioned over each of the two SCN's. In future experiments using a new 24 X 24 silicon photodiode array, the number of array elements monitoring the SCN's will be increased by a factor of 4.

Optimal Stimulation Parameters

Selection of optimal stimulation parameters was guided by previous electrophysiological studies by K. Hart and M. Rea (unpublished, personal communication). In studies in which a field electrode was used to monitor activity in the SCN evoked by stimulation of the optical nerve using a suction electrode, these workers found that input/output curve (i.e. amplitude of the evoked response as a function of the applied stimulating current) reached a maximum at approximately 0.5 mA using a 200 usec duration current pulse.

The relatively short duration of the current pulse (200 usec) selected by these workers was due, in part, to the fact that stimulating pulse tended to contaminate the evoked response monitored by the field electrode. This is not a problem, however, with optical recording since it is insensitive to the snock artifact. For this reason we selected a 500 usec pulse duration for our experiments. At this duration, we also observed maximal optical response to be generated with current pulses between 0.4 and 0.6 mA.

CONCLUSIONS

The ability of multiple-site optical recording techniques to simultaneously monitor evoked electrical activity over a relatively wide anatomical area was used to good advantage in these experiments. The results obtained strongly suggest that both pre- and post-synaptic activity can be measured from a relatively large number of SCN areas simultaneously. Using such optical recording techniques, it should be possible to monitor and analyze changes in evoked SCN activity as a function of the circadian cycle. Such changes may provide clues as to the underlying neurophysiological mechanisms responsible for the light entrainment of the SCN.

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FIG. 1 **Optical recording of evoked electrical activity in the hamster suprachiasmatic nucleus of the hypothalamous shown as a 'page display'**

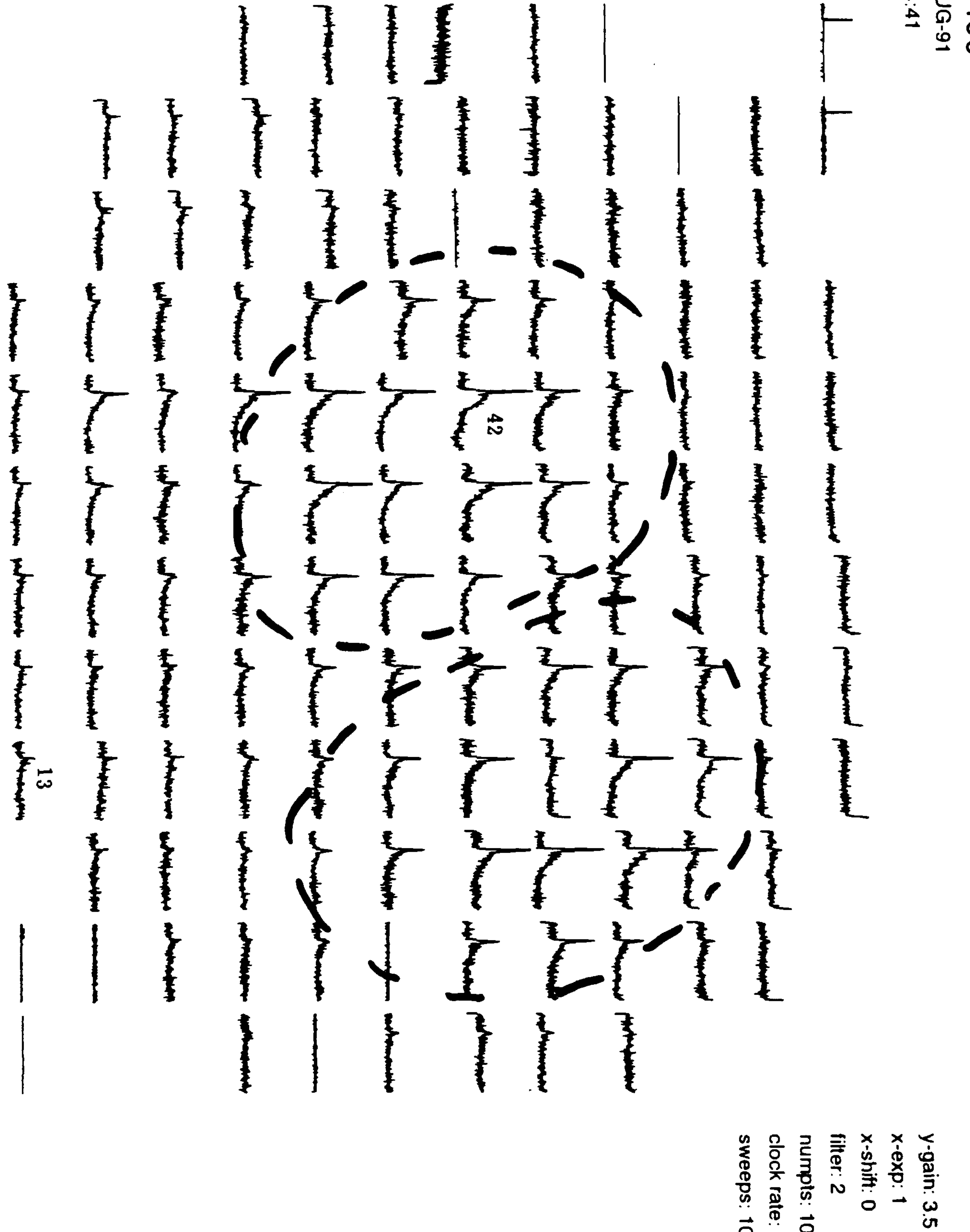
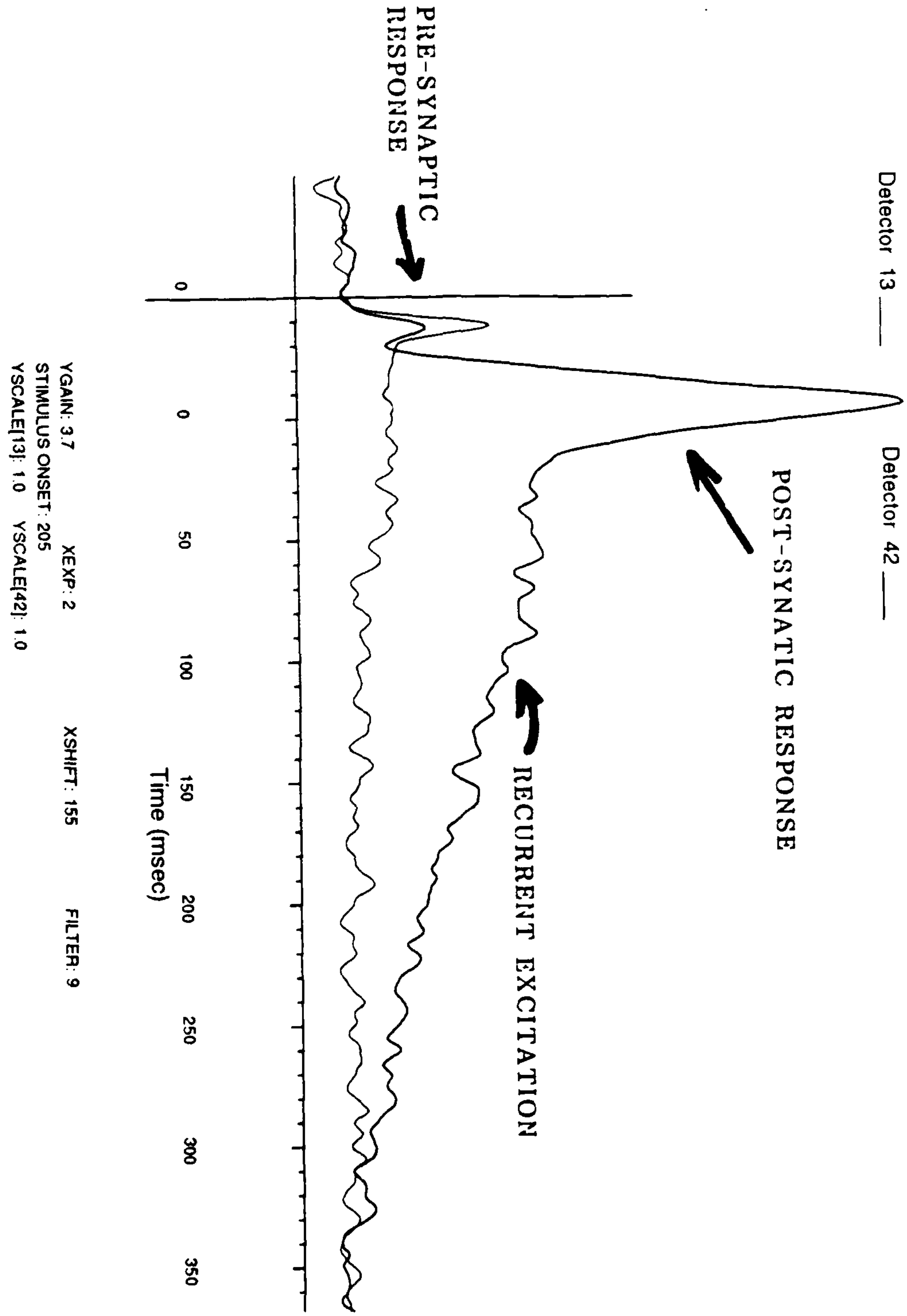


FIG. 2 **Magnified view of traces 13 and 14 in Fig. 1**



1991 USAF-RDL SUMMER FACULTY RESEARCH PROGRAM/

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FINAL REPORT

Development of an Enhanced Hydraulic Cardiovascular Model/Test Apparatus for In-Vitro Simulations in Altered-g Environments.

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ABSTRACT

This report concerns the design of a mechanical/hydraulic model which can be used to study cardiovascular system responses to low, high and very high gravitational fields. The model will require lumped element equivalents of major circulation components including the heart, the aorta, the lungs, and major systemic vascular beds. A design tool (compliance box) for determining the parameter values of the mechanical elements required to hemodynamically model the body parts is evaluated and tentatively found to be successful. The mechanical model is considered a good substitute for the actual body part if the input impedance and compliance are properly scaled and modeled. The statistical design of experiments (Full Factorial Analysis) is introduced and used as a tool for developing the design equations of the lumped elements. A variety of transducer systems for measuring flow velocity and pressure in the model are considered and it is found that the hot film anemometer is an excellent choice for velocity and remote pressure transducers connected to the flow system via short lengths of copper tubing are suitable for pressure measurements.

ACKNOWLEDGEMENTS

My thanks are extended to the Air Force Office of Scientific Research for sponsorship of this project and to the people at Research and Development Laboratories for handling the administrative details of the program.

This, my second summer experience at Brooks AFB was rewarding and enriching because of the efforts of many individuals. First among them are Dr. Ricky Latham and Curtis White who provided needed resources, technical consultation and encouragement. Sgt. Rick Owens was especially effective in handling day-to-day administrative details and Ron Mendenhal provided invaluable technician support in the instrumentation/data acquisition phases of the project. Thanks to all.

I. INTRODUCTION

The mission of the Laboratory for Aerospace Cardiovascular Research (LACR) at Brooks Air Force Base is to support clinical medicine decision-making by providing information on the cardiovascular system's response to altered gravitational fields and g-protective environments. Research is being performed in both acutely instrumented humans and chronically instrumented baboons. These in-vivo models provide information on the global response of the cardiosystem as a whole, but the researcher's ability to study a specific parameter change effect is very limited because the cardiovascular system is strongly dynamic and interdependent. For example, one cannot alter peripheral resistance without changing heart rate and the mean blood pressure. In order to better study fundamental cause and effect cardiovascular mechanisms in altered-g environments an independently controllable model needs to be developed. An in-vitro mechanical/hydraulic model that can be subjected to various g-fields would satisfy this need.

A long term goal of LACR is the design, construction and evaluation of a lumped parameter mechanical model of the cardiovascular system. It will consist of multiple compartments simulating the thorax, abdomen and peripheral vascular beds. These compartments will contain fluid analogs of major vessels, organs, and peripheral resistances. Each element will have adjustable impedance/compliance characteristics and it is expected that pressures and flows (and perhaps vessel diameters) will be monitored at the inlets.

The author first became involved with this project during the USAFOSR 1990 Summer Research Program. The focus of that work was on uncertainty analysis, data analysis techniques and experiment design and the results are presented in reference 1. The objectives of the 1991 summer continuation of this work are given below.

II. OBJECTIVES OF THE 1991 RESEARCH EFFORT

The objectives for the USAFOSR 1991 Summer Researc^h Pr\u0306gram are listed in priority order below:

1. Investigate the suitability of a complianc^ \u0306ox as a design tool for developing lumped element equivalents for cardiovascular system components.

2. Introduce and use the concepts of statistical design of experiments into the model development process.

3. Determine the suitability of Omega pressure transducers as substitutes for catheter transducers in the model. Calibrate both types.

4. Design and construct calibration and probe holder/traverse systems for the hot film anemometer for use in measuring velocity and flow in the model. Calibrate probes.

5. Compare an Ultrasonic Doppler Velocity Probe with the hot film anemometer for use in measuring velocity profiles in pulsatile flows. Calibrate probe.

6. Explore the suitability of using ultrasonic crystals to measure radial dimension changes in elastic tubes with pulsatile flow. G selection/design/repair of a suitable pulsatile pump for use in the "heart" of the model.

III. DEVELOPMENT

Guido Avangolini, et al. (2,3) examine the problem of choosing lumped element models to simulate systemic vascular beds. They find that the five-element modified Windkessel model exhibits very close adherence to physical reality while a three-element model provides reliable results in parameter estimation problems. The mechanical/hydraulic model chosen for our study is shown in Figure 1a. It is essentially a three-element model with adjustable resistance and capacitance. The model consists of a plexiglass box with a sealable lid, inlet and outlet bulkhead fittings with a compliant tube and fluid resistor clamped between them. The simulated blood flow pulses into the compliant tube through one of the bulkhead fittings, through the fluid resistor and out of the box through the opposing bulkhead fitting. The effective capacitance is adjustable in two ways. Tubes of different elastic properties and/or various air pocket sizes may be used alone or in combination to get a continuously adjustable range of capacitance. Resistance to flow may be varied in two ways. The fluid resistor can be changed or the box can be pressurized to cause the compliant tube to partially collapse. Also, by placing an open-celled foam in the box along with a viscous fluid it is possible to simulate some viscoelastic behavior. Figures 1b and 1c show the hot film anemometer probe holder and the plexiglass portal used to introduce the pressure measuring catheter. Velocity and pressure are measured continuously at both the inlet and outlet of the model. Analysis of the velocity (flow) and pressure data allows the computation of the input impedance of the system. Adjusting the parameters of the compliance box until its input impedance and compliance match those of the human cardiovascular system component to be simulated should result in a successful mechanical/hydraulic model.

There are, of course, a very large number of combinations of parameter values which could be examined in this impedance/compliance matching process. To examine them all would be resource wasteful and fortunately there are procedures available for such problems which maximize information obtained while keeping resource consumption to a minimum. The method used in this project is based on the statistical design of experiments. (4) Experimental design consists of purposeful changes of the inputs to a process in order to observe the corresponding changes in the responses. Generally the technique can be used to: (1) gain an understanding of the relationship between input factors and responses; (2) determine the settings of the input factors which optimize the response; and (3) build a mathematical model relating the response to the input factors. Full factorial, Plackett-Burman, Shainin, Taguchi and CCD are examples of experimental design techniques and each has its advantages and disadvantages. Our initial work involves two levels each of 3 factors (resistance, capacitance, and flow rate). For such problems the full factorial approach is best. (4) The following summarizes the test procedure used. A, B and C correspond to input factors fluid resistance, air pocket size (capacitance) and flow rate respectively. There are eight different runs and the orthogonal array below shows the combinations of values for the input factors for each run. Five repetitions are used to get a 95% confidence level and the order of testing within each set of eight runs is random.

Factor				Repetitions-Order of Runs				
RUN 3	A	B	C	Y_1	Y_2	Y_3	Y_4	Y_5
1	-	-	-	6	5	8	2	4
2	-	-	+	7	4	2	5	2
3	-	+	-	3	2	5	3	6
4	-	+	+	8	8	1	4	1
5	+	-	-	4	6	6	1	8
6	+	-	+	2	7	3	7	5
7	+	+	-	5	1	7	6	6
8	+	+	+	1	3	4	8	3

A: + = Large resistance; - = small resistance

B: + = Large air pocket; - = no air pocket

C: + = 8 L/min; - = 4 L/min

The response variables of interest are the inlet pressure and flow rate. Since both of these are time varying and contain information at frequencies up to 100 to 200 Hz if turbulence is present, rapid response transducers are necessary for measuring them. A hot film anemometer is chosen to measure the velocity (the flow rate is computed from the velocity data and the tube diameter) and two candidates are available for the pressure measurements. The first is a solid state piezoresistive pressure transducer from Omega (Series Px236) and the second is a standard Millar catheter pressure transducer. The compliance box is fitted with probe and transducer holders designed to allow velocity measurement from the center to the outer wall of the tubing and static pressure in the immediate neighborhood of the plane of the velocity measurements at both the inlet and outlet.

Although not of immediate interest in the mechanical model it will be desirable to be able to measure the velocity profiles and tube dimension changes in the same radial plane in the near future. Due to the bulkiness of the present hot film anemometer probe holder and the difficulties associated with traversing the tube without one it is likely that the Doppler velocity crystal will be used instead of the hot film to get the velocity profiles. The time changing radius of the tube can be measured using two ultrasonic crystals placed diametrically opposite to each other on the tube outer surface wall. The results for preliminary efforts to use these crystals are given below.

The success or failure of developing a suitable mechanical cardiovascular model depends on finding a suitable pump to simulate the heart. Four candidate pumps are examined: (1) a constant speed reciprocating bellows pump, (2) an aortic balloon cardiac assist pump, (3) a controllable linear actuator "superpump" and (4) a custom designed linear actuator/bellows pump.

IV. RESULTS

The steady flow resistance of the compliance box is found by establishing a constant pressure drop across it and measuring the corresponding flow rate. Pressure drops of 35, 60, and 90 mm Hg are used and it is found that the resistance levels are independent of flow rate over this range. Three levels of resistance are available using a modified kidney dialysis module with three effective aperture areas; these are 0.35, 0.60 and 1.15 mm Hg Sec/cc. The uncertainty is $\pm$0.05 mm Hg Sec/cc and the corresponding flow rate ranges are 6 to 16.3, 3.5 to 9 and 1.8 to 4.7 L/min respectively.

The results of the experiments carried out using the protocol developed with the full factorial analysis are not yet available. The data are available in analog form on FM Tape but conversion to digital form is necessary for analysis. It is expected that the conversion and analysis will be performed during October, 1991.

Some preliminary analyses of the input and output pressure wave forms for a heart rate of 1.56Hz and flow rates of 1.1 and 2.94 L/min suggest that the use of the compliance box as a design tool will be successful. Fast Fourier Transforms show changes in magnitude, phase angle and power spectra consistent with expected results.

The compliance of the bicycle innertube is found to be approximately constant (.003± .0005 cc/mmHg) over the range in transmural pressure from 50 to 175 mm/Hg. (See Figure 2) Our latex tube (Penrose drain tube), on the other hand, showed a nearly linear increase in compliance (from .012 to .012 ±.001 cc/mmHg) for a transmural pressure range from 50 to 95 mm/Hg.

The Omega pressure transducers, Px 236, give output data that are virtually the same as the catheter pressure transducers. While a detailed spectral analysis of the pressure data from the two transducer types has not yet been done, signals superimposed on a CRT are indistinguishable. Initial concern that the tubing connecting the pressure measurement site to the actual transducer might filter the signal seems to be unwarranted. This is probably due to the rigid nature of the copper tubing.

The hot film anemometer works well as a velocity measurement tool provided that calibration is done in the same fluid as is used in the flow circuit. A circular grooved plexiglass platter/turntable is an effective calibrator when care is taken to prevent lint or other foreign substances from depositing on the hot film probe. During some of our calibration runs an unknown substance precipitated out of our test fluid (plain distilled water, we thought). Calibration data from these runs were not used.

A twenty-five micron filter is used in the flow circuit to eliminate any substances which might deposit on the probe. The ultrasonic Doppler probe requires a seeded fluid and a mixture of 7.5 gm of corn starch per liter of distilled water works well. The starch particles are small enough to pass through the filter and yet large enough to reflect ultrasonic signals.

The Doppler output signals are generally similar to the hot film ones but they do contain substantial noise. After spectral analysis it will be possible to recommend a low pass filter to use with the Doppler in order to filter out this unwanted noise.

Only one or two runs using the dimension crystals were made. It is therefore premature to report on the efficacy of using them for measuring vessel dimensional changes although our preliminary work looks promising.

The constant speed variable stroke bellows pump is suitable for preliminary checks of input impedance sensitivity to parameter changes in the compliance modules. However, since its speed is constant, the output pressure wave form cannot be tailored to match that in the heart. The aortic balloon assist pump has adjustable systolic/diastolic components but adjustment is sensitive and difficult. None of our attempts to duplicate aortic pressure wave forms were successful. The super pump (electrically driven linear actuator) is still a candidate for the heart pump in the mechanical model but it is likely that the pump head will have to be replaced with a bellows type system and a more sophisticated motion profile/control will be needed. Our work shows some promising results although the existing system has limited frequency response. A more powerful motor and low mass bellows type pump should solve the problem.

V. CONCLUSIONS/RECOMMENDATIONS

Work on the compliance box as a design tool should continue. The flexibility of the box and ease with which parameter changes can be made make it an excellent choice for determining the design parameter values of the mechanical/hydraulic models of the various parts of the cardiovascular system. The introduction of open celled foam and viscous liquids surrounding the vessel should allow the simple introduction of viscoelasticity to the modules.

It is tentatively recommended that the hot film anemometer and the Omega pressure transducers be used to measure velocity and pressure pending the outcome of spectral analysis of our data. The catheter pressure transducers may be used, of course, but the Omega ones are simpler and easier to use. Further development work is needed before a final recommendation for the "heart pump" can be made. The electric linear actuator with bellows pump head shows promise and is the most likely candidate.

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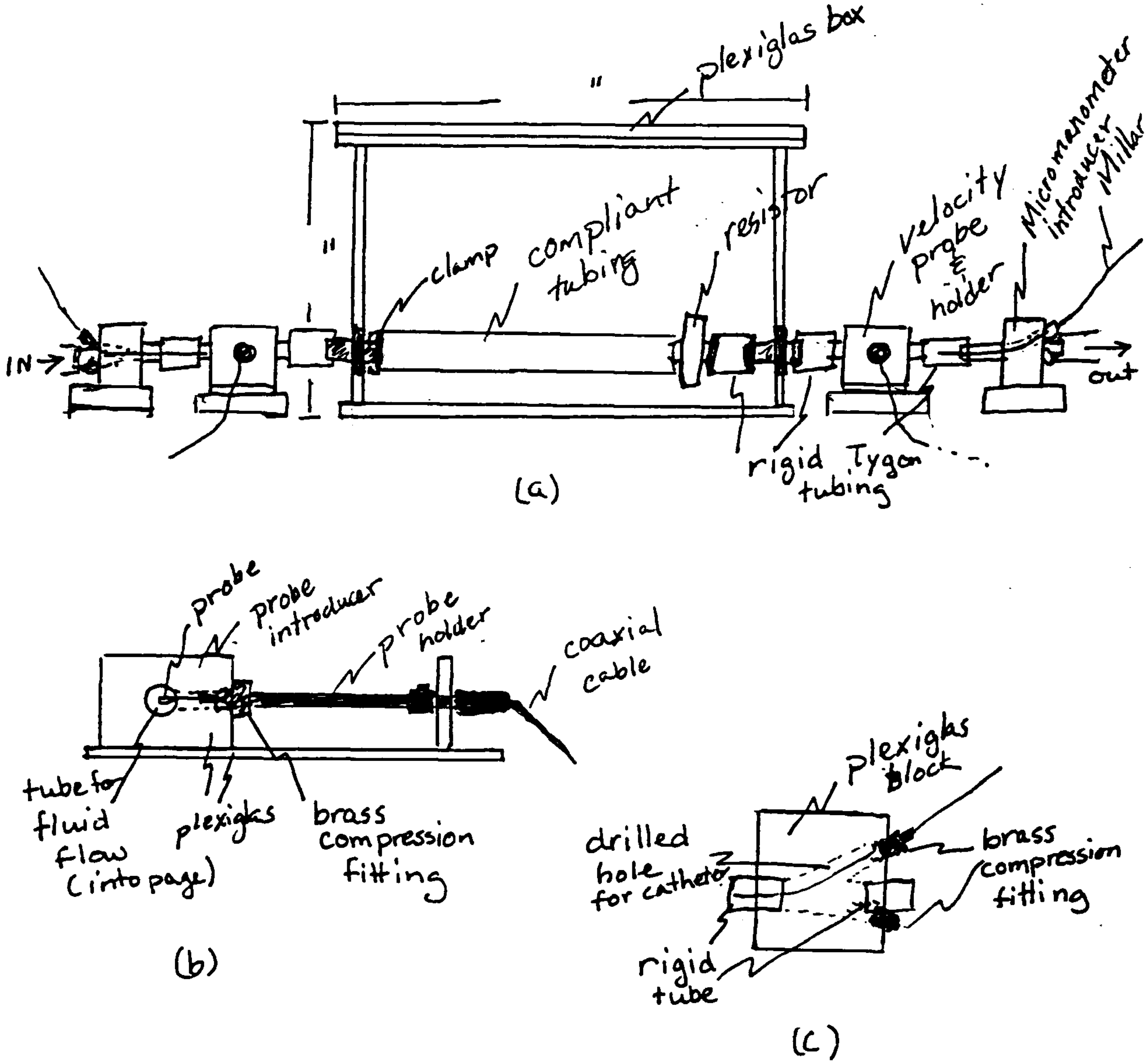


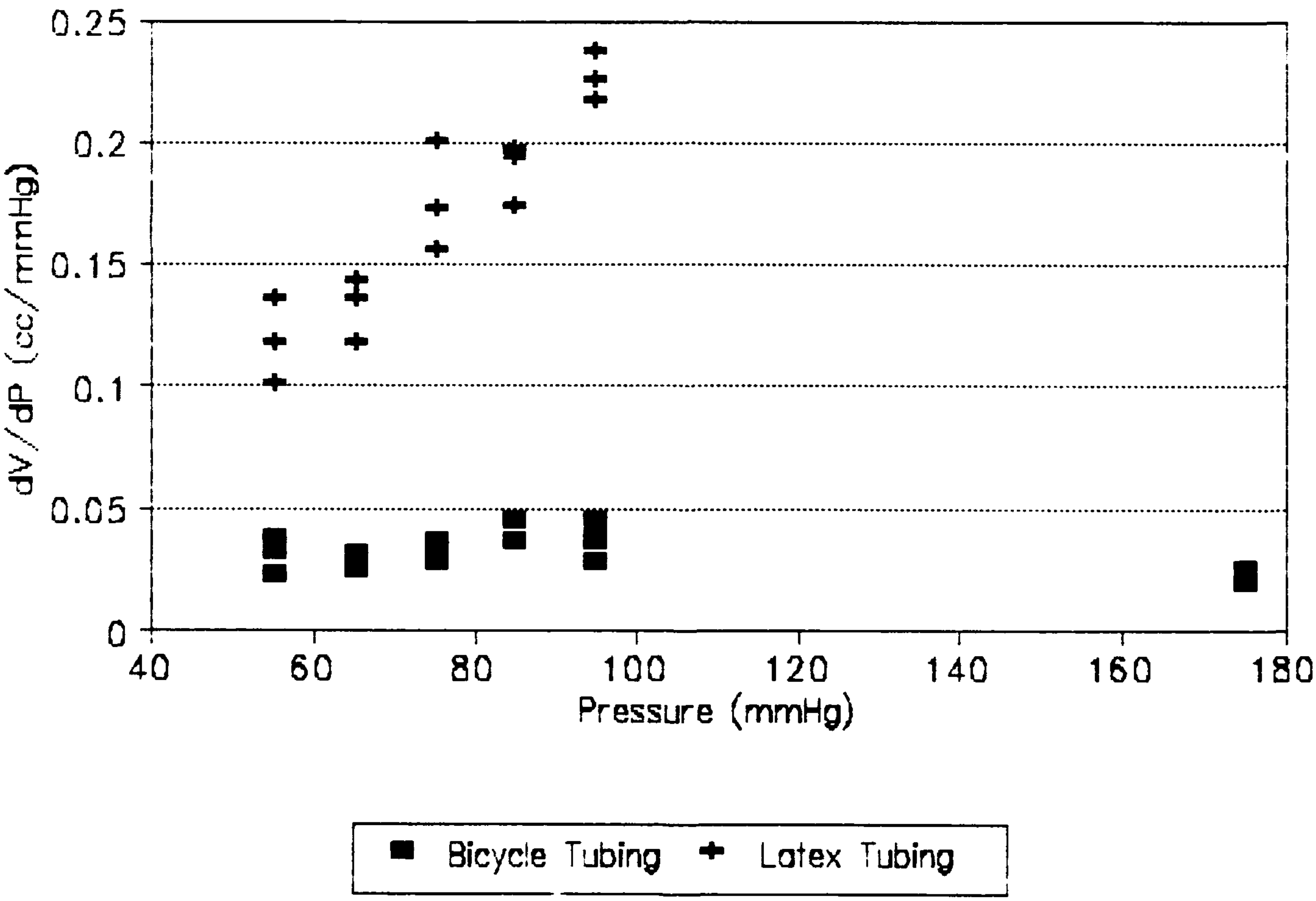
Figure 1 : Compliant system

(a) system with monitoring equipment

(b) hot film anemometer (velocity)

(c) Millar micromanometer & Introducer

Figure 2. Compliance Testing:
Bicycle and Latex Tubing



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FINAL REPORT

AN INVESTIGATION OF THE CHECKMARK PATTERN AND THE EFFECTS OF MEASUREMENT ERROR AND COLLINEARITY IN COVARIATES IN THE AIR FORCE HEALTH STUDY

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Date: September 30, 1991

An Investigation of the Checkmark Pattern and the Effects of Measurement Error and Collinearity in Covariates in the Air Force Health Study

by

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ABSTRACT

The scientists working with the Air Force Health Study data observed a pattern between the prevalence of diabetes and dioxin exposure in the Comparison group as well as in the Ranch Hand group. Under this pattern, the Ranch Hand rate of disease is less than the Comparison rate among subjects with low current dioxin levels (less than 10 parts per trillion (ppt)), and greater than the Comparison rate in Ranch Hands with high current dioxin level (greater than 33 ppt). A similar pattern was observed regarding the association between the mean triglyceride and dioxin. A statistical model is derived that explains this pattern. It is likely that some variables in this study are subject to measurement errors. The effect of measurement errors in covariates on the estimates of various parameters is assessed and quantified. The assessment and diagnosis of collinearity among covariates while fitting logistic regression model, not yet available in packaged programs, has been implemented in a SAS program given in the Appendix.

ACKNOWLEDGEMENT

I would like to thank the Air Force Systems Command and the Air Force office of Scientific Research for sponsoring this research. I would also like to thank the Research and Development Laboratories for administering the Summer Research Faculty Program.

My special thanks are due Dr. Joel E. Michalek and his staff at the Brooks Air Force Base for providing me with all the necessary facilities to carry out this research. I also wish to thank Dr. Danna Flanders for discussions and sharing his ideas on some aspects of this research.

I. INTRODUCTION

The scientists working with the Air Force Health Study (AFHS) data observed a pattern between some end points and dioxin exposure among the Comparisons and the Ranch Hand veterans. For example, for the continuous variable triglyceride, the Ranch Hand mean in men having low dioxin levels (below 10 ppt) is less than the Comparison mean, the Ranch Hand mean in men having intermediate dioxin levels (between 15 and 33 ppt) is about the same as the Comparison mean, and in men having higher dioxin levels (above 33 ppt), the Ranch Hand mean is greater than the Comparison mean. A similar pattern was observed for the relationship between the prevalence of diabetes and dioxin exposure. This pattern has been called the "checkmark" pattern, and needed a statistical model to explain it. When both the variables involved are continuous, the checkmark pattern has been modelled in this report based on the bivariate normal distribution. When the end point is categorical, such as the presence or absence of diabetes, this pattern has again been modelled by using logistic regression. These models are presented in Section 3. The observed values are compared with the predicted values obtained from these models with favorable results.

The presence of measurement errors in covariates generally affects the estimates of the parameters of interest. In certain instances, measurement errors are unavoidable even though proper precautionary measures are taken. In this report, the effect of measurement errors in covariates on the estimates based on the logistic regression model has been studied and quantified. Specifically, in the AFHS, dioxin measurements on Vietnam veterans are subject to measurement errors with a coefficient of variation (CV) of 0.2. Effect of this error on the estimates of the coefficients in a logistic model relating the prevalence of diabetes to dioxin is assessed utilizing some algorithms developed by Stefanski and Carroll (1985). A Statistical Analysis System (SAS) program has been written to assess this effect. The program is given in the Appendix 1.

It is well known that the presence of collinearity among covariates in multiple linear regression renders computations unstable and produces estimates with larger variance. Similar problems arise in the case of logistic regression. Diagnostic tools for detecting and remedying the effects of multicollinearily for multiple regression are well developed and implemented in the common statistical packages. However, such tools for the logistic regression are not yet available. Recently Marx and Smith (1989) have proposed some methods for detecting multicollinearily among covariates for logistic regression and implemented these in a SAS program. This program has been modified and rewritten to implement the diagnostic tools proposed by Marx and Smith for AFHS data. The program appears in the Appendix 2.

II. OBJECTIVES OF RESEARCH EFFORTS

There are three major objectives of this research:

1) To explain the observed checkmark pattern between the mean triglyceride and dioxin, and between diabetes prevalence and dioxin among the Comparisons and the Ranch Hands.
2) To assess and quantify the effects of measurement error in covariates on the estimates of the parameters of interest.
3) To implement the methods and enhance the program of Marx and Smith (1989) for detecting multicollinearity among covariates in logistic regression and propose remedial measures.

III. APPROACH

A. Models for the checkmark pattern:

Case 1: Both variables continuous:

Suppose that the two variables of interest whose association is being assessed are continuous. Let these be denoted by a bivariate random vector (x,y). For the Ranch Hand application, we may take x = ln(dioxin), y = ln(triglyceride). Here, x and y are the natural logarithms of the dioxin and triglyceride measurements, respectively. This is so because the distributions of ln(dioxin) and ln(triglyceride) are known to be normal. We assume that (x,y) has a bivariate normal distribution with the joint probability density function (pdf)

$$f(x,y) = \frac{1}{2\pi\sigma_x\sigma_y\sqrt{1-\rho^2}} \exp\{-\frac{1}{2(1-\rho^2)} [(x-\mu_x)^2/\sigma_x^2 - 2\rho(x-\mu_x)(y-\mu_y)/\sigma_x\sigma_y + (y-\mu_y)^2/\sigma_y^2]\} \qquad (1)$$

where μ_x, σ_x and μ_y, σ_y are the means and the standard deviations of x and y respectively, ρ is the correlation coefficient between x and y. To study the checkmark pattern, we divide the range of x into k intervals $(a_{i-1}, a_i]$, $i = 1,2,...,k$ as follows:

$a_0 \quad a_1 \quad a_2 \quad \cdots \quad a_{k-1} \quad a_k$

with $a_0 = -\infty$ and $a_k = +\infty$, and find $E(y \mid x \epsilon (a_{i-1}, a_i])$ for $i = 1,2,...,k$. This provides the relationship between the mean of y and x in each subinterval of ln(dioxin) and explains the observed pattern. For this, we need the joint pdf of $(x,y) \mid x\epsilon (a_{i-1}, a_i]$ given by

$$\underset{x\epsilon (a_{i-1},a_i]}{f(x,y)} = \frac{1}{2\pi\sigma_x\sigma_y D_i\sqrt{1-\rho^2}} \exp\{-\frac{1}{2(1-\rho^2)} [(x-\mu_x)^2/\sigma_x^2 - 2\rho(x-\mu_x)(y-\mu_y)/\sigma_x\sigma_y + (y-\mu_y)^2/\sigma_y^2]\} \qquad (2)$$

where $D_i = \Phi[(a_i-\mu_x)/\sigma_x] - \Phi[(a_{i-1}-\mu_x)/\sigma_x]$, and $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution. Hence

$$E(y \mid x\epsilon (a_{i-1},a_i]) = \mu_y + \frac{\rho\sigma_y}{D\sqrt{2\pi}} (e^{-(a_{i-1}-\mu_x)^2/2\sigma_x^2} - e^{-(a_i-\mu_x)^2/2\sigma_x^2}) \qquad (3)$$

The predicted mean of triglycerides over the ith interval of the dioxin distribution can be obtained by substituting estimates of the parameters involved in (3).

The following table shows the fit by model (3) of the checkmark pattern observed in the Ranch Hand data:

Table 1

Fit of the Checkmark Pattern for Triglycerides vs Dioxin

	Mean of ln(Triglyceride)	
Group	Observed	Expected
Comparison	4.753	4.787
Low (Rand Hand)	4.651	4.636
Medium (Ranch Hand)	4.956	4.841
High (Ranch Hand)	4.907	4.981

From this table it is clear that the fit provided by Model (3) is remarkable.

Case 2: When one of the variables is categorical:

Assume that the response variable is categorical such as presence or absence of a disease, say diabetes. Let the independent variable be denoted by x (say ln(dioxin). Suppose that the range of x is divided in k intervals, as earlier. Let p_i denote the proportion of subjects in the ith interval who have diabetes. Let x_i denote the average level of ln(dioxin) for the subjects in this group. We also assume that the logit of the proportion of the diabetic subjects is linear in terms of the logarithm of the level of dioxin over the k intervals. This gives

$$E\{\ln[p_i/(1-p_i)] \mid x \epsilon (a_{i-1}, a_i]\} = \alpha + \beta x_i, \qquad i = 1,2,\ldots,k, \qquad (4)$$

Since, the distribution of ln(dioxin) is normal (for the AFHS data, it is normal with $\mu_X = 2.67, \sigma_X = 1.34$) the pdf of $x \mid x \epsilon (a_{i-1}, a_i]$ is

$$\underset{x \mid x \epsilon (a_{i-1}, a_i]}{f(x)} = \frac{1}{D_i \sigma_X \sqrt{2\pi}} \exp[-(x-\mu_X)^2 / 2\sigma_X^2], \qquad a_{i-1} < x \leq a_i$$

Unconditioning (4) with respect to the restricted distribution of x in $(a_{i-1}, a_i]$, we have

$$E\{(\ln[p_i/(1-p_i)]\} = \alpha + \beta\mu_X + \frac{\beta\sigma x}{D_i\sqrt{2\pi}} [e^{-(a_{i-1}-\mu_X)^2/2\sigma_X^2} - e^{-(a_i-\mu_X)^2/2\sigma_X^2}]. \qquad (5)$$

If there is a reason to believe that the relation between the ln $[p_i/(1-p_i)]$ and x_i is curvilinear, one mav fit a quadratic model given by

$$E\{\ln[p_i/(1-p_i)] \mid x \epsilon (a_{i-1}, a_i]\} = \alpha + \beta_1 x_i + \beta_2 x_i^2, \qquad i = 1,2,\ldots,k \qquad (6)$$

Again, unconditioning (6) with respect to the distribution of x over $(a_{i-1}, a_i]$, we get

$$E\{\ln[p_i/(1-p_i)]\} = \alpha + \beta_1\mu_x + \beta_2\mu_x^2 + \frac{(2\mu_x\sigma_x)\beta_2}{D_i\sqrt{2\pi}}(e^{-A^2_{i-1}/2} - e^{-A^2_i/2})$$

$$+ \frac{\beta_2\sigma_x^2}{D_i\sqrt{2\pi}}\{\sqrt{\pi/2}\,[\mathrm{erf}(A_i) - \mathrm{erf}(A_{i-1})]$$

$$- \sqrt{2}\,[A_i e^{-A_i^2} - A_{i-1} e^{-A_{i-1}^2}]\} \qquad (7)$$

where $A_i = (a_i-\mu_x)/\sigma_x$. The results of fitting (5) and (7) for the AFHS data are given in the following table:

Table 2

Fit of the Checkmark Pattern for the Prevalence of Diabetes vs. Dioxin using Logistic Regression

Groups*	Observed (%)	Expected (%) Model (4)	Model (6)
Background Comparisons	8.2	8.2	8.2
Unknown Ranch Hands	5.5	4.6	4.6
Low Ranch Hands	8.3	7.8	18.9
High Ranch Hands	16.6	11.0	50.3

*For Background Comparisons ppt$\leq$10, Unknown RH ppt $\leq$10, Low RH 15$<$ppt$\leq$33.3, High RH ppt$>$33.3.

From the above table it is clear that the linear logistic model gives a better fit than the quadratic logistic model, although, none of these fits are very close. The poor fits by these models may be a result of the inadequacy of the logistic models (4) and (6) to describe the underlying relationship.

B. Effect of Measurement Error in Covariates on the Estimates of Beta Coefficient in Logistic Regression (Stefanski and Carroll (1985)). Suppose that independent observations (y_i, x_i) are available where x_i are fixed p-vector predictors and y_i are Bernoulli random variables (which takes on a value 1 if some disease is present 0 otherwise) with

$$P(y_i = 1 \mid x_i) = F(x_i\beta) = (1 + \exp(-x_i\beta))^{-1} \qquad i = 1,2,\ldots,n.$$

When covariates are measured with error, the usual logistic regression estimates of β is asymptotically biased (see Clark (1982), Michalek and Tripathi (1980)). As a consequence of bias, there is generally a tendency to underestimate the disease probability for high-risk cases and overestimate for low-risk cases. Also, bias creates a problem with hypothesis testing in the sense that the usual asymptotic tests for individual regression coefficients can have levels different than expected. Thus, there is a clear need to incorporate a measurement-error model and study the effect this model has on the asymptotic bias of the usual logistic regression estimator.

Consider the following model for the measurement error:

$$X_i = x_i + \sigma v_i, \text{ with } v_i = \Sigma^{1/2} \epsilon_i \tag{8}$$

Where $\Sigma^{1/2}$ is the square root of a symmetric positive semi- definite matrix Σ, scaled so that $|\Sigma| = 1$, and ϵ_i, $i = 1,2,...,n$, are independent and identically distributed random vectors with zero mean vector and identity covariance matrix. Also, ϵ_i is independent of y_i, $i = 1,2,...,n$. Let $V = \sigma^2 \Sigma$ be the covariance matrix of the error in (8). Let $\hat{V}$ be a consistent estimate of V.

<u>Effect of Measurement Errors</u>.

To study the effect of measurement error on the estimate of β, we maximize the likelihood function

$$L_n(\beta) = n^{-1} [\sum_i \{y_i \ln F(c_i\beta) + (1-y_i) \ln F(-c_i\beta)\} \tag{9}$$

with respect to β.

This yields the likelihood equations

$$\sum_i (y_i - F(c_i\beta)) c_i = 0 \tag{10}$$

when $c_i = x_i, i = 1,2,....,n$. Let $\hat{\beta}$ be the solution of (10). It can be shown that under some general conditions (see Stefanski and Carroll (1985) Theorem 1) we can write $\hat{\beta}$, up to first order of approximation, as

$$\hat{\beta} \approx \beta_0 + n^{-1/2} S_n^{-1} (\beta_0) Z_n + \sigma^2 S_n^{-1} (\beta_0) (J_{n,1} + J_{n,2}) \beta_0 \tag{11}$$

where β_0 is the true value of β,

$$S_n(\gamma) = n^{-1} \sum_i F^{(1)}(x_i\gamma)\, x_i x_i'$$

$$Z_n = n^{-1/2} \sum_i (y_i - F(x_i\beta_0))x_i$$

$$J_{n,1} = -(2n)^{-1} \sum_i F^{(2)}(x_i\beta_0)x_i\beta_0{}' \Sigma$$

$$J_{n,2} = -n^{-1} \sum_i F^{(1)}(x_i\beta_0)\Sigma,$$

$F^{(1)}(\cdot)$ and $F^{(2)}(\cdot)$ are the first and the second derivatives of $F(\cdot)$ with respect to its argument. It can be shown that with $\lambda = \sqrt{n}\,\sigma^2$, asymptotically,

$$\sqrt{n}(\hat{\beta} - \beta_0) \approx N(\lambda S_n^{-1}(\beta_0)(J_{n,1} + J_{n,2})\beta_0, S_n^{-1}(\beta_0))$$

when n is large and σ is small. Thus $\hat{\beta}$ is clearly a biased estimator of β_0. Also, the tests regarding β_0 or its components based on $\hat{\beta}$ or its components will have bias in their asymptotic levels in the presence of substantial measurement errors in the covariates. This is because the standard error of $\hat{\beta}$ is overestimated in the presence of measurement errors.

Accounting for Measurement Errors:

Next, we investigate how to account for the measurement errors in adjusting the data so that the estimates of β_0 based on the corrected data will be less biased. We present four methods of correcting data, the first three of these are due to Stefanski and Carroll and the fourth one is due to Clark (1982):

Method (i): This method of correcting data is based on the expansion (11) and is distribution free in the sense that only moment assumptions are made about the measurement errors. The corrected data are

$$X_{i,c} = X_i + \hat{\sigma}^2 (I - \hat{\sigma}^2 \hat{B}_n')^{-1} \hat{B}_n' X_i, \qquad i = 1,2,\ldots,n \qquad (12)$$

with $\hat{B}_n = S_n^{-1}(\hat{\beta})(J_{n,1} + J_{n,2})$.

Let the estimates based on $X_{i,c}$ be denoted by $\hat{\beta}_c$. This estimator has smaller bias than that based on x_i. The next two methods are based on normal measurement error. For the methods (ii) and (iii) given below, we assume that ϵ_i's are normally distributed.

Method (ii): Under the above assumption, we correct the data as

$$X_{i,f} = X_i + (y_i - F(X_i\hat{\beta}))\hat{\sigma}^2 \hat{\Sigma} \hat{\beta}$$

and denoted the estimator obtained by maximizing (9) as $\hat{\beta}_f$.

Method (iii): This correction of data is based on the fact that when errors are normal, given $\sigma^2 \Sigma$ and β_0, a sufficient statistic for estimating x_i is given by

$$X_{i,s} = X_i + \hat{\sigma}^2 (y_i - 1/2) \hat{\Sigma} \hat{\beta}$$

and denoted the corresponding estimator of β as $\hat{\beta}_s$.

Method (iv): If, in addition to the errors being normal, we also assume that the covariates x_i also have a normal distribution such that $E(x_i \mid X_i) = X_i - \sigma^2 \Sigma \Sigma_X^{-1} (X_i - \mu)$ where Σ_X and μ are the covariance matrix and the mean vector of X_i. Let Σ_X and μ be the covariance matrix and the mean vector of the observed data, then the correction suggested by Clark is

$$X_{i,n} = X_i - \hat{\sigma}^2 \hat{\Sigma} \hat{\Sigma}_X (X_i - \hat{\mu})$$

Denote the estimator obtained by using $X_{i,n}$ as $\hat{\beta}_n$.

A logistic model with y_i as indicator of diabetes, and ln(dioxin), PBF (percent body fat), and AGEBASE (age at baseline) as covariates was fitted to AFHS data. Denote the estimator as β. Since, measurement errors may have occurred in measuring the covariates, logistic regression models were run with the same y_i, but with covariates corrected for errors as in (i) - (iv). The errors in the estimates are given below in Table 3.

Table 3

Errors in the Beta Coefficients of logistic Regression when covariates are Subject to Measurement

	$\hat{\beta}_c-\beta$	$\hat{\beta}_f-\beta$	$\hat{\beta}_s-\beta$	$\hat{\beta}_n-\beta$
ln (dioxin)	-.0096	-.0051	.0054	.0042
PBF	.0003	.0002	-.0001	-.0001
AGEBASE	.0003	.0001	-.0001	-.0001

From this table it is clear that the estimates obtained by accounting for the measurement errors are not very far apart from the estimates that do not account for this error. Thus, the conclusion for the AFHS data is that the measurement errors in covariates do not present any serious bias in the estimates. A computer program that generates the estimates in Table 3, is given in Appendix 1.

C. Assessment of Multicollinearily in the Logistic Regression

Consider a disease of interest, say diabetes, and denote, as above,

$$y_i = \begin{cases} 1 & \text{if ith subject has diabetes} \\ 0 & \text{otherwise} \end{cases}$$

for $i = 1,2,\ldots,n$. Also let x_i' denote the row vector of covariates for subject i. Let $\pi_i = P(y_i = 1 \mid x_i)$ and logit $(\pi_i) = \ln(\pi_i/(1-\pi_i)) = x_i\beta$ where β is a $(p+1)$-vector of unknown coefficients. Then the logistic model is given by

$$\text{logit}\,(\pi) = X\beta$$

where π is a n x 1 vector of π_i, and X is a n x (p+1) matrix of covariates. Let $V = \text{diag}\,(\pi_i(1-\pi_i))$, be a n x n diagonal matrix. Estimation of β is carried out by an iterative maximum likelihood scheme expressed as

$$\beta_t = \beta_{t-1}, + (X' V_{t-1} X)^{-1} (y-\pi_{t-1})$$

where y is a n-vector of y_i, and t denotes the iteration step until a specified convergence is achieved. The estimated information matrix $\Phi = X' V_{t-1} X$ for β plays an important-role in this iteration process. Estimation and prediction problems due to multicollinearity among covariates similar to those in ordinary regression can arise in logistic regression as well. In view of the above, an ill-conditioned information matrix can result in estimators with undesirable asymptotic properties such as large variances associated with the parameter estimates, extreme sensitivity to small perturbations of the X data and low power for parameter tests. Marx (1988) suggested that the diagnostic for multicollinearity in X's should be oriented toward the spectral decomposition of $X'VX$ and not $X'X$. In order to have a standard for comparison, suppose that $S = V^{1/2}X$ is scaled and centered so that the information matrix Φ is in correlation form, and denote the new matrix by Φ. Let λ_{max} be the largest eigen value of Φ^* and λ_i be the ith largest eigen value of Φ^* such that

$$\lambda_1 < \lambda_2 < ...... < \lambda_{max}$$

Then the condition number is defined as $\Psi_i = (\lambda_{max}/\lambda_i)^{1/2}$

Another diagnostic tool commonly used in multiple regression is variance inflation factor (VIF). Marx proposed weighted variance inflation factor (WVIF), obtained similarly as the VIF, by the diagonal elements of the inverse of the information matrix Φ^*. Multicollinearity is assumed to be present if for any variable its WVIF > 10 and its condition number > 30.

As recommended by Marx (1988), it is also informative to determine what proportion of variance of each coefficient is attributed to each near dependency in the information matrix. Define ρ_{ij} as the proportion of weighted variance inflation associated to the jth estimated coefficient, attributed to ith eigen value of Φ^*. A matrix of these proportions can be constructed. A small eigen value (relative to the largest) responsible for at least two large proportions, say ρ_{ij} and ρ_{ij}' suggest that weighted multicollinearity is damaging desirable properties of the logistic regression. If a large WVIF is present, then the analyst should consider deletion of one of the variables responsible for a large ρ_{ij} (associated with a small eigen value).

For the AFHS data, these diagnostics were performed for a logistic regression model relating the prevalence of diabetes to continuous covariate ln(dioxin), PBF, and AGEBASE on 1051 subjects. The WVIFS and ρ_{ij}'s are given below:

Table 4

Weight Variance Inflation Factor

Variable	WVIF
Intercept	49.10
Ln(dioxin)	1.69
PBF	26.71
AGEBASE	8.15

Table 5

Weighted Variance Proportion Decomposition

Eigen Value	Condition Number	Intercept	LN(DIOXIN)	PBF	AGEBASE
3.27	1.00	0.002	0.030	0.003	0.010
0.54	2.45	0.002	0.904	0.005	0.010
0.17	4.41	0.004	0.003	0.074	0.462
0.01	15.94	0.993	0.062	0.918	0.518

As suggested by Marx and Smith, when a variable with small eigen value is contributing to large ρ_{ij}; and ρ_{ij}', then either one of the variables should be excluded from the model or an alternative method of fitting such as logistic ridge estimation should be utilized. For the analysis of the AFHS data in Table 5, the variable corresponding to the eigen value .01 has two large weighted variance proportions, .993 with the intercept term, and .918 with the PBF. Since, we do not wish to exclude the intercept term from the model, PBF should either be excluded or logistic ridge estimation should be attempted.

RECOMMENDATIONS:

1) Since, the model for the checkmark pattern when both variables are continuous, is providing an excellent fit, it is recommended to use this model. When, one of the variables is discrete, the linear logistic model provides a better fit than the quadratic model, although, neither provides a close fit, In

this case, it is recommended that some tests of fit be carried out to arrive at a better model which may better explain the underlying pattern.

2) The effects of measurement errors in the covariates do no seem to be too serious, hence, the analyses based on logistic regression that do not account for measurement errors will give estimates which do not have serious bias.

3) In the diagnostic checks for multicollinearity among covariates in logistic regression, PBF seems to be a candidate to be excluded from the model. However, if it is necessary to keep PBF in the model, an alternative estimation procedure such as logistic ridge regression may be employed.

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APPENDIX 1

PROGRAM TO ASSESS THE EFFECTS OF MEASUREMENT ERROR IN COVARIATES IN LOGISTIC REGRESSION ON THE ESTIMATES OF THE COEFFICIENTS

```
/* THIS CODE IS USED TO COMPUTE THE STEFANSKI AND CARROL BIAS */
/*   AS WORKED OUT ON 26 JUNE 1991 WITH RAM TRIPATHI       */

LIBNAME BBB  [MICHALEK] ;
DATA TEMP1;
SET BBB.ADXENDO;

IF GRPI = 1 AND COMPDBI LE 2 AND PSEADIAB NE 'PRE' AND
  REPORT NE 'GNQ' AND PPTR NE.;

DEPDIAB = .;
IF COMPDBI = 2 THEN DEPDIAB = 1;
IF COMPDBI = 1 THEN DEPDIAB = 2;
DEP = COMPDBI-1;

CLOGPPT = LOG(PPTR + .1)/LOG(2);
AGEPPT = CLOGPPT*AGEBASE;
PBFPPT = CLOGPPT*PBF;

/***** MULTIVARIATE SITUATION *****/

PROC CORR DATA = TEMP1 NOPRINT COV OUTP = COVAR;
VAR CLOGPPT PBF AGEBASE;

PROC LOGIST DATA = TEMP1;
MODEL DEPDIAB = CLOGPPT AGEBASE PBF AGEPPT PBFPPT;
TITLE GIVES ADJUSTED BETAHATS FROM RAW DATA;

PROC LOGIST DATA = TEMP1;
MODEL DEPDIAB = CLOGPPT AGEBASE PBF PBFPPT;
TITLE GIVES ADJUSTED BETAHATS FROM RAW DATA;

PROC LOGIST DATA = TEMP1;
MODEL DEPDIAB = CLOGPPT AGEBASE PBF AGEPPT;
TITLE GIVES ADJUSTED BETAHATS FROM RAW DATA;

PROC LOGISTIC DATA = TEMP1;
MODEL DEPDIAB = CLOGPPT PBF AGEBASE;
OUTPUT OUT = LOGIST P = PHAT XBETA = XBETA;
TITLE *** GIVES BETAHAT AND XBETA FOR BETAC, THIS IS THE ONE WE WANT ***;
```

```
DATA LOGIST;
SET LOGIST;
F1=XBETA*PHAT*(1-PHAT);
F2=PHAT*(1-PHAT)*(1+(XBETA**2)*(1-2*PHAT));
/*
CPPT=CLOGPPT+(DEP-PHAT)*638.59119*.0/23;
CPBF=PBF+(DEP-PHAT)*(5.1087E-6)*.1713;
CAGE=AGEBASE+(DEP-PHAT)*306.52377*.0317;
*/
PROC IML;
USE COVAR;
          READ ALL WHERE (_TYPE_= 'COV')INTO COV(|COLNAME-COLS|);
USE LOGIST:
READ ALL VAR{CLOGPPT PBF AGEBASE} INTO x (|ROWNAME=CASE5 COLNAME=COLS1|);
READ ALL VAR{F1} INTO F1 (|ROWNAME=CASE5 COLNAME=COLS|);
READ ALL VAR{F2} INTO F2 (|ROWNAME=CASE5 COLNAME=COLS|);
READ ALL VAR{PHAT} INTO P (|ROWNAME=CASE5 COLNAME=COLS|);
READ ALL VAR{DEPDIAB} INTO Y (|ROWNAME=CASE5 COLNAME=COLS2|);

PRESIG={.125 0 0, 0 0.000000001 0, 0 0 0.06};
DETP=DET (PRESIG);
DETL=(LOG(DETP))/3;
DP=EXP(DETL);
SIGMASQ=DP;
SIGMA=(1/DP)#PRESIG;
DETS=DET(SIGMA);
BETAHAT={0.0723,0.1713,0.0317);

M=SIGMA*INV(COV);

PD=DIAG(P);
S=X'*(PD*X);

U=J(NROW(X),1,1);
F2D=DIAG(F2);
AA=(F2D*X)';
BB=BETAHAT'@U;
J1=AA*BB*SIGMA;
J1=-.5#J1:
SUMF1=F1(|+,|);
J2=-SUMF1#SIGMA;
J=J1+J2;
BN=INV(S)*J;
BETAC=BETAHAT-SIGMASQ#BN*BETAHAT;
UNIT=J(NROW(X),1,1);
YS=SIGMASQ#(Y-.5#UNIT);
XS=X-YS*(SIGMA*BETAHAT)';
STEF38=Y || XS;
```

```
X34 = X + SIGMASQ#(Y-P*(SIGMA*BETAHAT)‘;

COLSF = COLS2 ¦¦ COLS1;

MATRIX34 = Y ¦¦ X34;
CREATE DATA34 FROM MATRIX34 (¦COLNAME = COLSF ROWNAME = CASE5¦);
APEND FROM MATRIX34(¦ROWNAME = CASE5¦);
CREATE STEF38D FROM STEF38 (¦COLNAME = COLSF ROWNAME = CASE5¦);
APPEND FROM STEF38D (¦ROWNAME = CASE5¦);
XC = X-SIGMAS#X*M‘;
CLARK = Y ¦¦ XC;
CREATE CLARKD FROM CLARK (¦COLNAME = COLSF ROWNAME = CASE5¦);
APPEND FROM CLARK(¦ROWNAME = CASE5¦);

PRINT ‘BETAHAT‘,,BETAHAT;
PRINT ‘CORRECTED BETA‘,,BETAC;
PRINT ‘SIGMA MATRIX‘,,SIGMA;
PRINT ‘DETERMINANT OF PRESIGMA‘,,DETP;
PRINT ‘DETERMINANT OF SIGMA‘,,DETS;

PROC LOGIST DATA = CLARKD;
MODEL DEPDIAB = CLOGPPT AGEBASE PBF;
TITLE *** GIVES CLARKS BETAN ***;

PROC LOGIST DATA = STEF38D;
MODEL DEPDIAB = CLOGPPT AGEBASE PBF;
TITLE *** GIVES CORRECTED BETAS FROM (3.8) ***;

PROC LOGIST DATA = DATA34;
MODEL DEPDIAB = CLOGPPT PBF AGEBASE;
TITLE *** GIVES BETAF FROM CORRECTION (3.4) ***;
```

APPENDIX 2
PROGRAM TO ASSESS MULTICOLLINEARITY
IN LOGISTIC REGRESSION

```
LIBNAME BBB BASE '[MICHALEK]';
DATA TEMP;
SET BBB.ADXENDO;
LOGPPT = LOG(PPTR + .1);
DEPDIAB = COMPDBI-1;

IF GRPI EQ 1 AND COMPDBI LE 2 AND
   PSEADIAB NE 'PRE' AND REPORT NE 'GNQ' AND PPTR NE.;

PROC LOGIST DATA = TEMP OUTEST = BETAS COVOUT ;
MODEL DEPDIAB =  PBF AGEBASE / COVB;
OUTPUT OUT = PRED P = PHAT LOWER = LCL UPPER = UPL;
RUN;

PROC PRINT DATA = BETAS;
TITLE 'PARAMETER ESTIMATES AND COVARIANCE MATIRX';
RUN;

PROC PRINT DATA = PRED;
TITLE 'PREDICTED PROBABILITIES AND 95% CONFIDENCE LIMITS';
RUN;
*/
PROC IML;
RESET NOLOG NONAME;

USE TEMP;
/*READ ALL VAR{LI TEMP CELL} INTO X (|COLNAME = XNAMES|);*/
READ ALL VAR{PBF AGEBASE} INTO X (|COLNAME = XNAMES|);
READ ALL VAR{DEPDIAB} INTO Y (|COLNAME = YNAME|);
CLOSE TEMP;
USE PRED VAR{PHAT};   /*VECTOR OF PROBABILITIES FROM PROC LOGIST*/
READ ALL VAR{PHAT};
CLOSE PRED;

N = NROW(X);
ONES = J(N,1,1);
X = ONES||X;
K = NCOL(X);
ONE = J(K,1,1);
Q = ONES-PHAT;
PQ = PHAT#Q;   /*DIAGONAL MATRIX OF BERNOULLI VARIANCES*/
V = DIAG(PQ);
RV = SQRT(V);
```

```
S=RV*X;
SUM=S(|+,|);MEAN=SUM/N;
S=S-J(N,1)*MEAN;
SS=SQRT((S#S)(|+,|));
S=S/(J(N,1)*SS);
SPS=S='*S; /*CENTERED AND SCALED INFORMATION MATRIX*/

R1={" "};
NAMES='INTCPT'||XNAMES;
PRINT "CORRELATION MATRIX OF WEIGHTED REGRESSORS",,, SPS
(|ROWNAME=NAMES COLNAME=NAMES|),,,,;

*
THE CONSTRUCTION OF THE VARIANCE INFLATION FACTORS FOLLOW;
VIF=INV(SPS);VIF=DIAG(VIF);VIF=VIF*ONE;
PRINT 'WGHTD VARIANCE INFLATION FACTORS'
VIF(|COLNAME=R1 ROWNAME=NAMES|),,,,;
CALL EIGEN(L,M,SPS);
RL=SQRT(L);
RLMAX=RL(|1,1,|);
CI=RLMAX/RL;

/*THE CONSTRUCTION OF VARIANCE PROPORTION DECOMPOSITIONS FOLLOW;*/

VPD=J(K,K,0);DIAGL=DIAG(L);IDIAGL=INV(DIAGL);
START;
 DO ROW=1 TO K;
  DO COL=1 TO K;
    VEC=M(|ROW,*|);
    VPD(|COL, ROW|)=(M(|ROW,COL|)##2)/L(|COL,1|)/(VEC*IDAGL*VEC');
   END;
  END;
 FINISH;
RUN;

VPD=L||CI||VPD;
NAMES={"EVALUE" "CONDNMBR" "INTCPT"}||XNAMES;
PRINT "WGTD VARIANCE PROPORTION DECOMPOSITION",,, VPD(|COLNAME=NAMES|);
RUN;
```

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FINAL REPORT

TEMPERATURE EFFECTS ON ERYTHROCYTE SEDIMENTATION RATES, CELL VOLUMES AND VISCOSITIES IN MAMMALIAN BLOOD.

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Date:	July 30, 1991

TEMPERATURE EFFECTS OF ESR. CELL VOLUMES AND VISCOSITIES: FINAL REPORT

Professor W. Drost-Hansen

ABSTRACT

Erythrocyte sedimentation rates and erythrocyte and platelet volumes of blood from 13 different species of mammals have been found to change abruptly near 46 - 46°C. The often dramatic drop in sed rates for temperatures above 45° reflect a histologically proven change in shape of the red cells from biconcave disks to nearly spherical. This change in morphology prevents rouleaux formation and thus lowers the sed rate. Furthermore, the viscosity of blood plasma increases rapidly and abruptly above the critical temperature of 45°C thus further lowering the sed rate. Finally, even resuspended erythrocytes in the absence of the plasma proteins show markedly reduced settling rates above 45°C. Abrupt changes are also seen in some parameters near 30°C; these and the 45°C anomalies reflect the effects of structural changes in the vicinal water associated with both the cells and the biopolymers in solution. This interpretation is further supported by notable thermal anomalies seen in the viscosities of a variety of polymers in aqueous solution, including both synthetic model polymers and naturally occurring biopolymers (such as BSA and fibrinogen.)

INTRODUCTION

Adding EDTA or citrate to whole, freshly drawn blood prevents clotting; the erythrocytes stay suspended in the plasma for varying lengths of time until they slowly settle (hindered settling). The rate of settling may be observed for periods of time up to several hours. The distance settled in one hour at 25°C (room temperature) is the quantity used clinically as "the sed rate" (ESR) (Maile, 1977). In normal, healthy individuals, the ESR is anywhere from a few mm to 10mm. Notably larger values (say,>15-20mm) suggest some type of pathology. The ESR has been in use for almost 70 years and is probably still the most frequently performed, clinical lab test in the world; a vast literature exists on the subject.

The initial objective of our research was to measure the effects of temperature of the sed rate; very little attention has been paid to this aspect in the past. Two years ago, the suggestion was also made that the temperature coefficient of the ESR ($d[ESR]/dT$) may contain some diagnostically significant information presently missed.

To facilitate making measurements at closely spaced temperature intervals, a Linear Temperature Gradient incubator (TGI - i.e., a "polythermostat") has previously been developed by the Senior Author and his collaborators (Drost-Hansen, 1981). A number of commercial models of the TGI have been available for some time; however, these units are mostly designed for studies on systems requiring agitation, such as bacterial growth, cell cultures, enzyme reactions and adsorption studies. The TGI unit employed in the present study is "homemade" and allows for arranging two sets of 30 standard-sized sample tubes in rigid, vertical positions making it highly useful for sedimentation studies.

As with the commercial, more sophisticated models, the principle is the same: a heavy, rectangular aluminum bar (8 x 20 x 150 cm, weighing about 100 kg) is carefully insulated in a support box. One end of the bar is provided with electric heating elements and a thermoregulator to maintain any preselected, constant temperature. The heat is dissipated by conduction through the bar; at the cold end a plastic chamber serves as a reservoir for a circulating cold liquid, the temperature of which is kept constant. As lateral heat losses from the bar are kept to a minimum, an essentially linear temperature gradient is set up in the bar. Along the length of the bar are two sets of 30 "wells", equidistantly spaced. Each well is large enough to accommodate a standard culture tube (15cm long and 18mm diameter). The long term stability (constancy) of the TGI has proven highly satisfactory: except possibly for wells #30 and #1, temperature fluctuations in any well over a period of days(or weeks) have been within 0.1^{o}C., or less. Considering that a thermal gradient about 0.4^{o}C exists across each well, fluctuations of $\pm$ 0.1^{o}C in any one well are insignificant.

Hematology parameters were determined with a Baker System 9000 Cell Counter which is calibrated for both human and animal blood samples. In repeat experiments, the reproducibility was found to be excellent, usually with 1% in cell numbers (both RBC and platelets) and better than 1% in cell volume measurements.

In the present study standard Wintrobe tubes were placed directly in the wells of the TGI using rubber stoppers assuring as nearly vertical positioning as practical. In separate experiments with the Wintrobe tubes, the rate of temperature equilibration was determined: after about 15 minutes the temperature of the blood has essentially reached the equilibrium temperature. As most sedimentation experiments were carried out over periods of two to four hours, the initial lack of equilibration (at the higher temperatures) is not significant. For sedimentation and all volume measurements using the TGI, EDTA was used as anticoagulant. A 0.25 molar stock solution of disodium EDTA was added to the freshly drawn blood; 1ml EDTA stock solution per 50 ml blood - i.e., a 2% dilution of the whole blood.

SEDIMENTATION RATE DATA

Figures 1-8 shows some typical sed rates as a function of temperature. In ALL cases studied so far, the rate of settling decreases abruptly above 45 ($\pm$1)^{o}C. In some cases, anomalies are seen also near 30($\pm$1)^{o}C. (This latter feature is sometimes brought out more clearly in graphs of the logarithm of the sed rate versus temperature - i.e., a quick and dirty approximation to an Arrhenius graph). To date, sed rate measurements have been made on blood from the following mammals: humans, chimpanzee, baboon, dog, cat, horse, cow, goat, sheep, rabbit, pig, llama, and killer whale; plus blood from one bird, the emu (!)

The dynamics of the erythrocyte sedimentation process is extremely complicated. Little progress has been reported on the construction of suitable models for the process. Among the many difficulties is the tendency for RBC rouleaux formation - a process notably influenced by the presence in the blood of large, usually asymmetric, macromolecules such as fibrinogen (and, via this mechanism reflecting possible pathological conditions in the subject). The rouleaux formation is primarily responsible for the enhanced settling rate (compared to isolated, resuspended erythrocytes).

It is generally accepted that exposure to high temperatures leads to changes in the shape of the erythrocytes. Thus, Whittam (1964) quotes Ponder to the effect that heating red cells "causes profound morphological changes of which perhaps the most striking is the irreversible change to spherical form on heating a few minutes at 48^{o}C. If indeed this morphological change should occur as well as the result of exposure for 30 (or more) minutes to temperature of 45^{o}C (and above), then it is hardly surprising that the sed rate should drop abruptly near this critical temperature as the change from the normal, bi-concave disk shape to spherical will prevent the rouleaux formation normally responsible for large sed rates.

The obvious next question is: what causes the abrupt change in RBC morphology at 45-48^{o}C? (i.e., the change from bi-concave disk to near spherical). The answer is that it is likely to be

Fig. 1

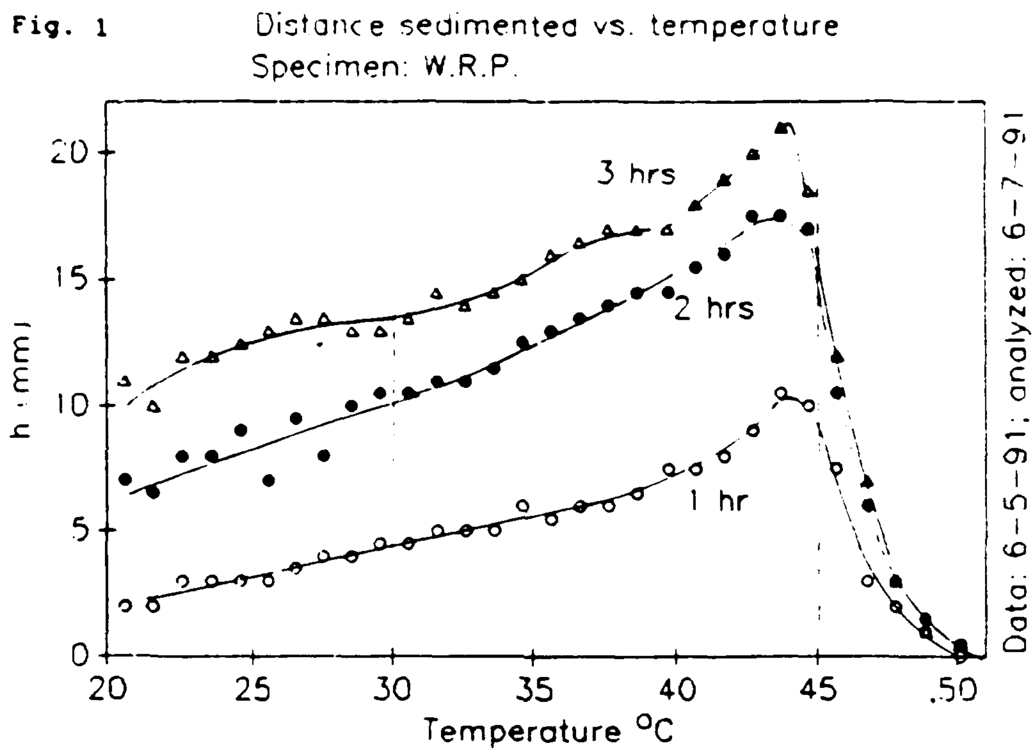

Distance sedimented vs. temperature
Specimen: W.R.P.
3 hrs
2 hrs
1 hr
h (mm)
Temperature °C
Data: 6-5-91; analyzed: 6-7-91

Fig. 2

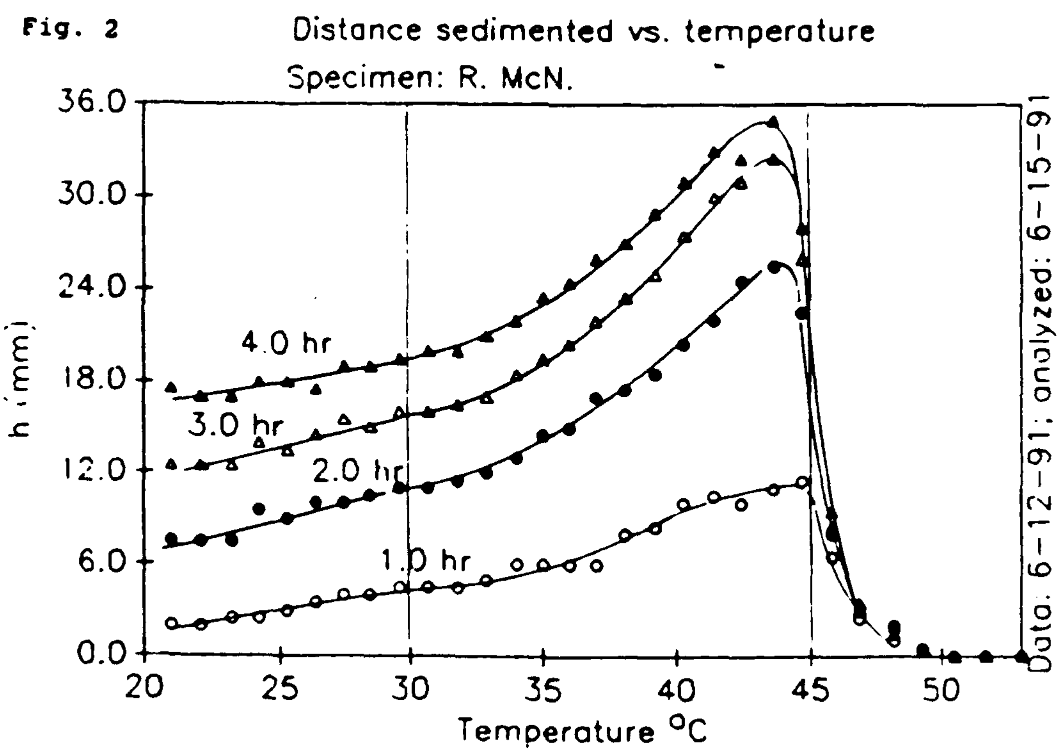

Distance sedimented vs. temperature
Specimen: R. McN.
4.0 hr
3.0 hr
2.0 hr
1.0 hr
h (mm)
Temperature °C
Data: 6-12-91; analyzed: 6-15-91

Fig. 3

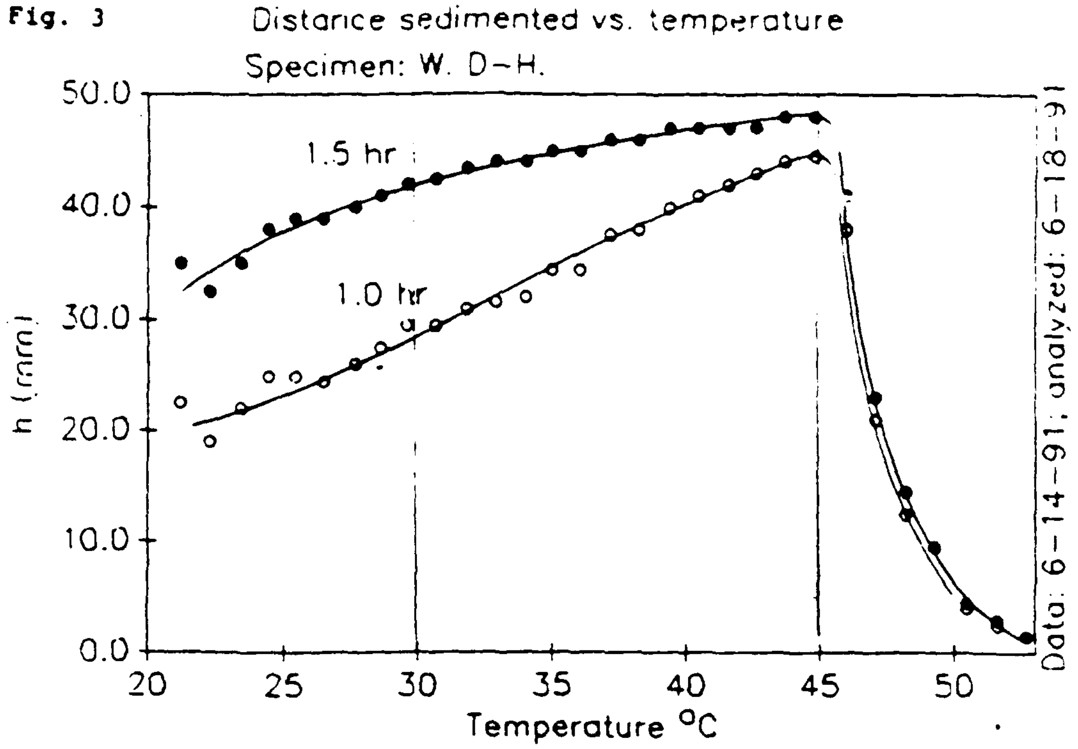

Distance sedimented vs. temperature
Specimen: W. D-H.
1.5 hr
1.0 hr
h (mm)
50.0
40.0
30.0
20.0
10.0
0.0
20
25
30
35
40
45
50
Temperature °C
Data: 6-14-91; analyzed: 6-18-91

Fig. 4

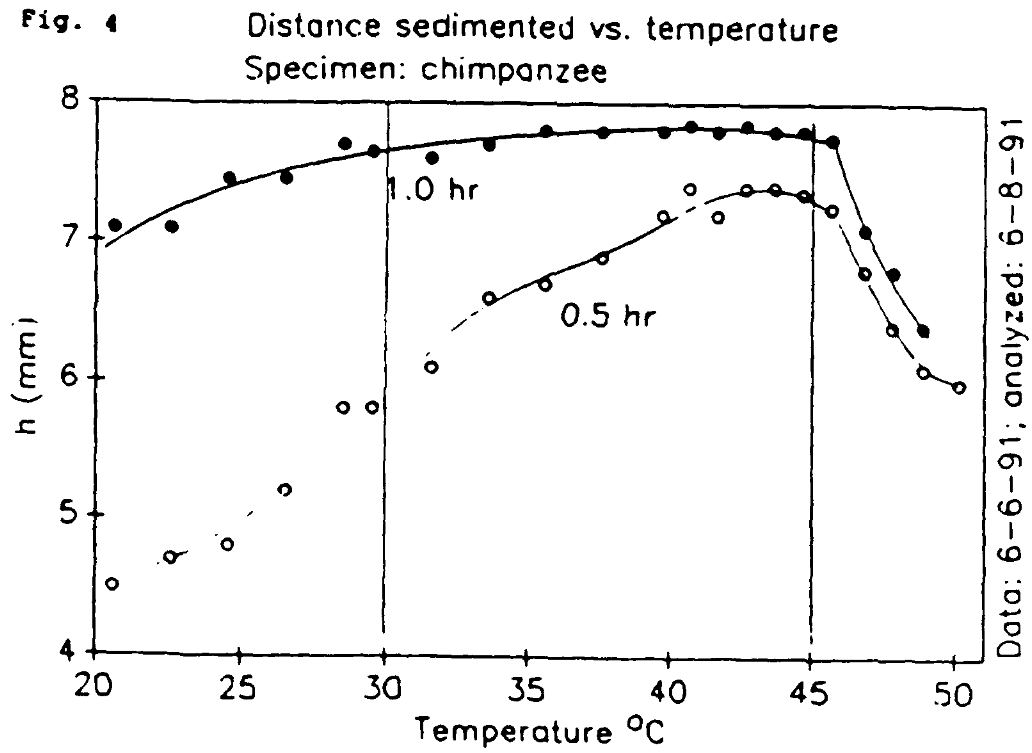

Distance sedimented vs. temperature
Specimen: chimpanzee
1.0 hr
0.5 hr
h (mm)
8
7
6
5
4
20
25
30
35
40
45
50
Temperature °C
Data: 6-6-91; analyzed: 6-8-91

Fig. 5 Distance sedimented vs. temperature

Specimen: baboon

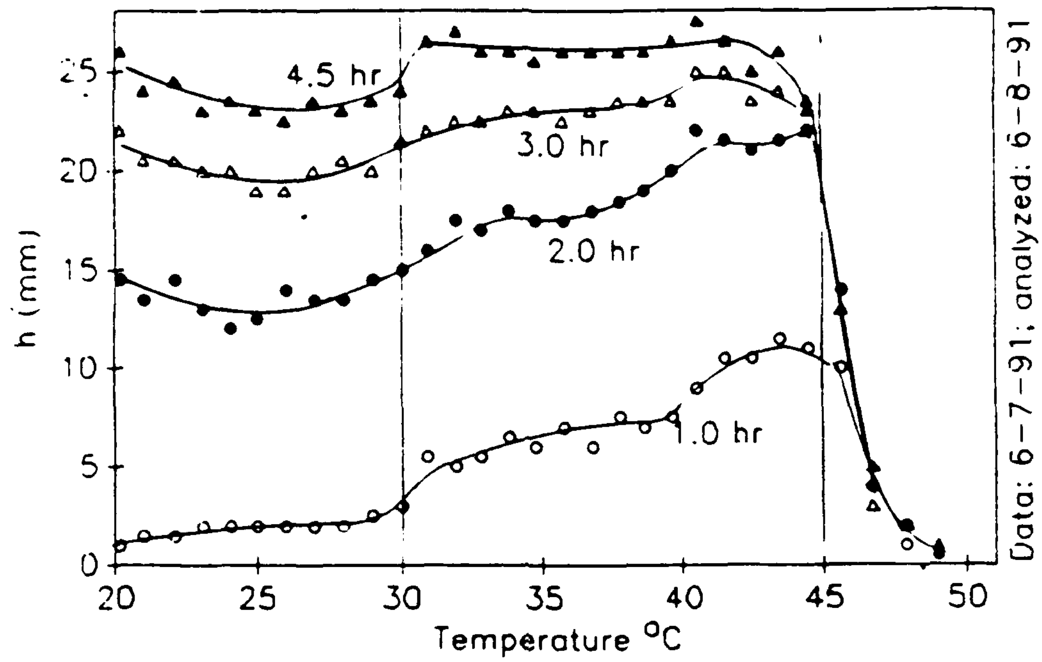


Fig. 6 Distance sedimented vs. temperature

Specimen: pig

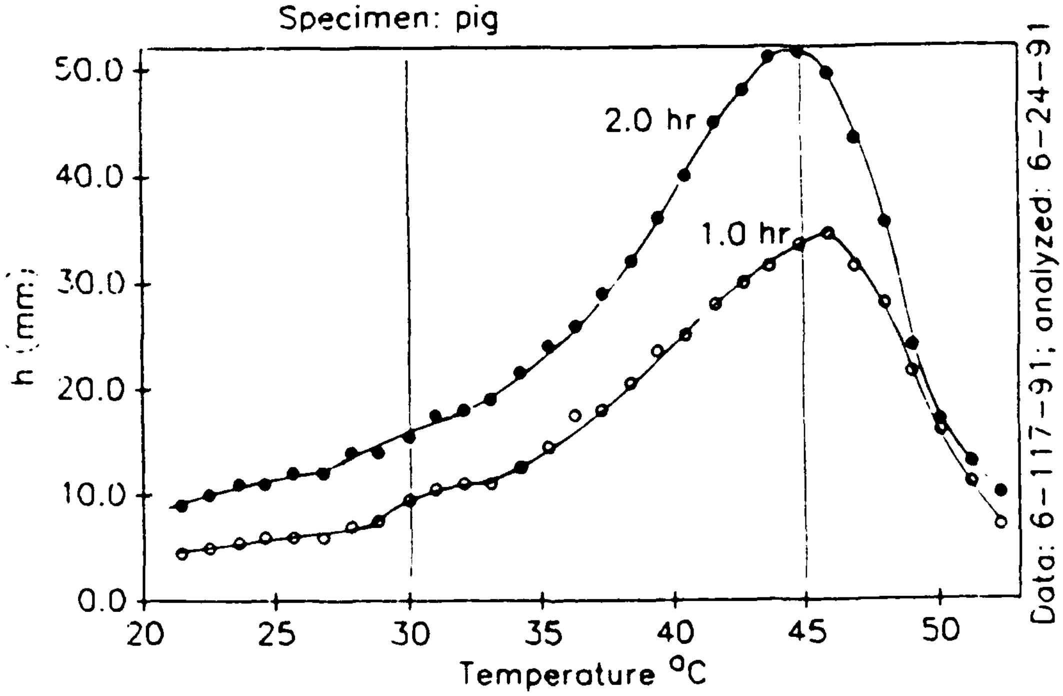


Fig. 7

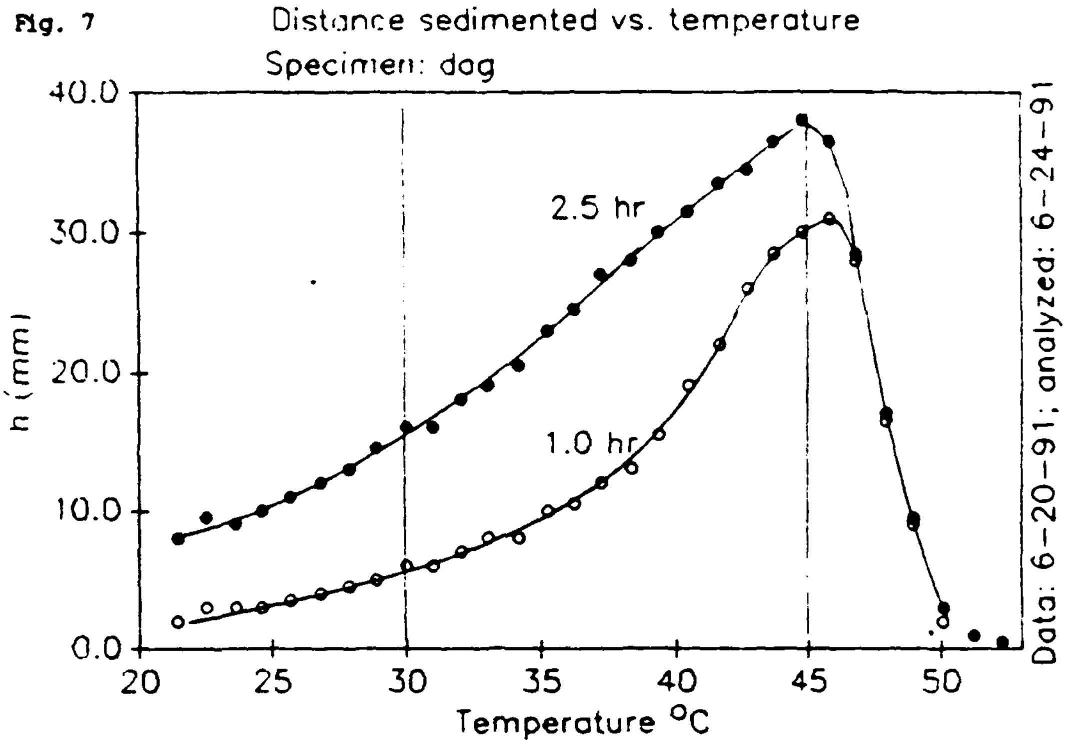
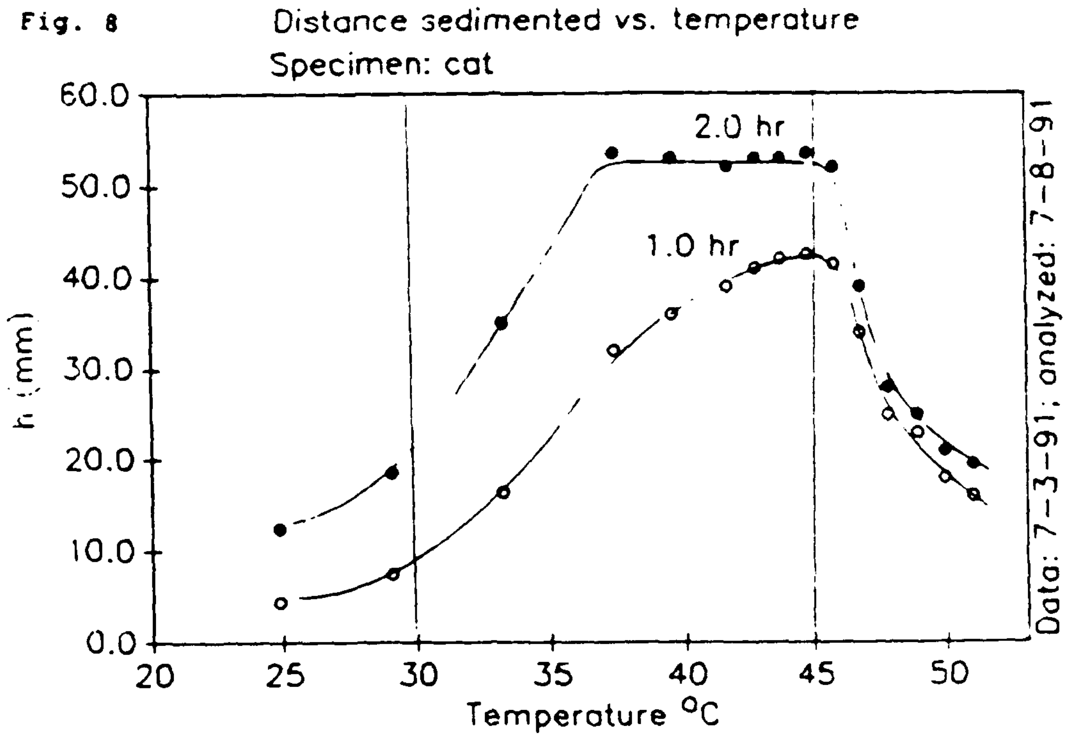

Distance sedimented vs. temperature
Specimen: dog
2.5 hr
1.0 hr
h (mm)
40.0
30.0
20.0
10.0
0.0
20
25
30
35
40
45
50
Temperature °C
Data: 6-20-91; analyzed: 6-24-91

Fig. 8


Distance sedimented vs. temperature
Specimen: cat
2.0 hr
1.0 hr
h (mm)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
20
25
30
35
40
45
50
Temperature °C
Data: 7-3-91; analyzed: 7-8-91

the vicinal water. Thus, if the vicinal water contributes to the stability of the RBC shape via the vicinal hydration of some structural elements (for instance the microtubles, intermediate filaments or microtrabecular network) destabilization is likely to occur near 44-45°C when the vicinal water changes form one type of structure to whatever structure is stable above this critical temperature range. Furthermore, the rheological character of the RBC interior will change as the temperature is raised past the transition temperature range: the viscosity of all the polymers studied so far changes, often abruptly, at or near the vicinal water transition temperatures (see below).

MEAN CELL VOLUMES (RBC AND PLATELETS)

In most attempts to develop theories of hindered settling, the point of departure is the Stokes fall of a single, rigid, spherical particle (far removed from the confining surfaces and neighboring particles) in a Newtonian fluid: $v = 2\pi r^2 \Delta\rho / 9\eta$. The conceptual gap between the model assumptions and the nature of real-life whole blood is staggering. Nonetheless, because of the r^2 dependence of the Stokes fall velocity it was of interest to measure the volumes of the erythrocytes as a function of temperature over the same range as used for the settling rate measurements. Figures 9-12 show some typical results of the volume measurements. In humans, a large anomaly is seen near 45°C and similar anomalies are seen in the blood from variety of other mammals, but not observed with some (such as cat, goat, etc. see Figures (13-19). It should be noted that temperatures above 45°C are highly "unphysiological" as this temperature is (almost invariably) the thermal death limit for all mammals (and birds) (Drost-Hansen, 1971).

The experimental approach used for the erythrocyte volume measurements also allows determinations of the (apparent) platelet volumes. Some typical results of such measurements are shown in Figures 20, 21, and 22. The trends in the data are remarkably reproducible; however, the a ual numerical values are subject to much uncertainty because of possible interference from spurious small particle fragments as well as platelet aggregation. We have observed platelet aggregation to increase dramatically at 45 to 46°C.

Fig. 9 Mean erythrocyte volume vs. temperature
Specimen: W.R.P. Incubation: 4 hours

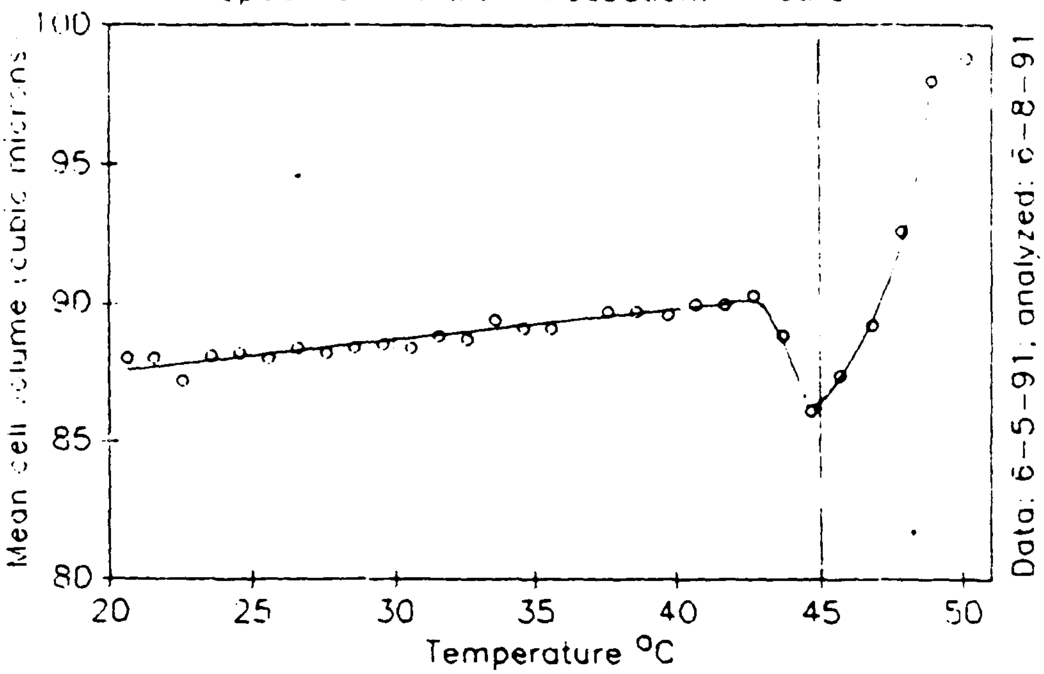


Fig. 10 Mean erythrocyte volume vs. temperature
Specimen: R. McN. Incubation: 4.5 hours

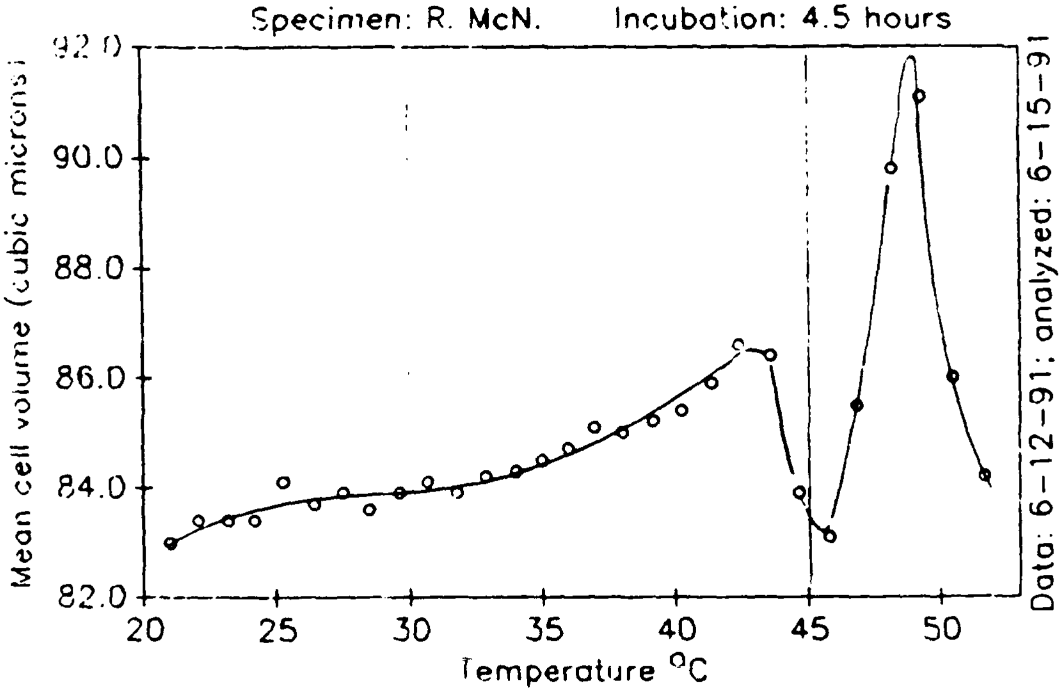


Fig. 11 Mean erythrocyte volume vs. temperature Specimen: W. D-H. Incubation: 2.0 hours

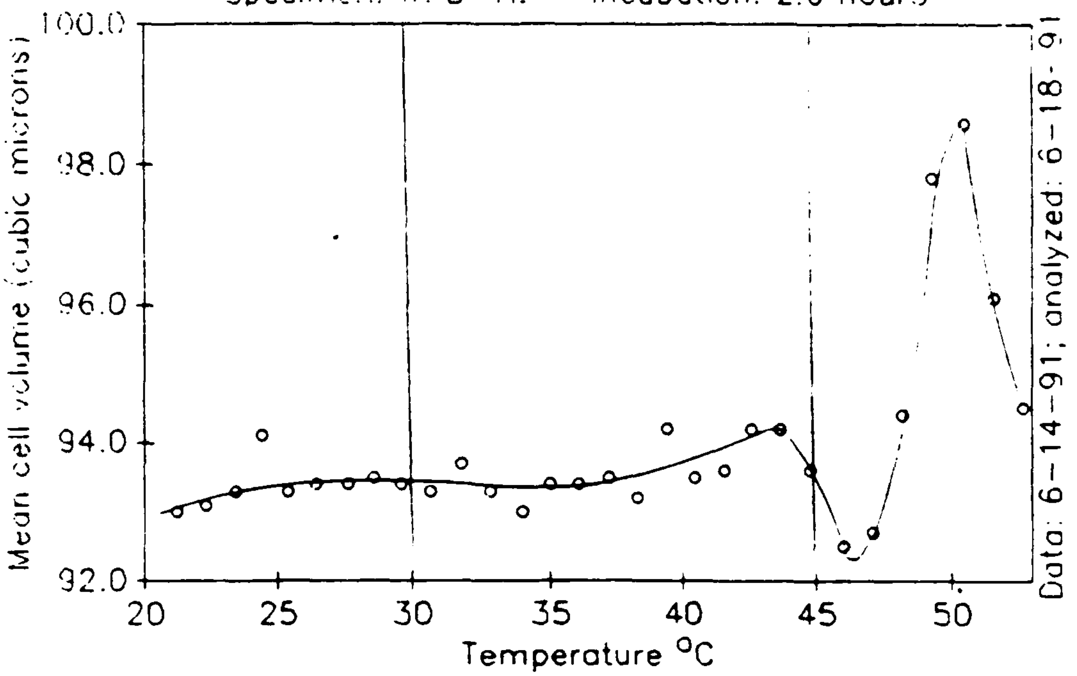


Fig. 12 Mean erythrocyte volume vs. temperature Specimen: pig Incubation: 2 hours

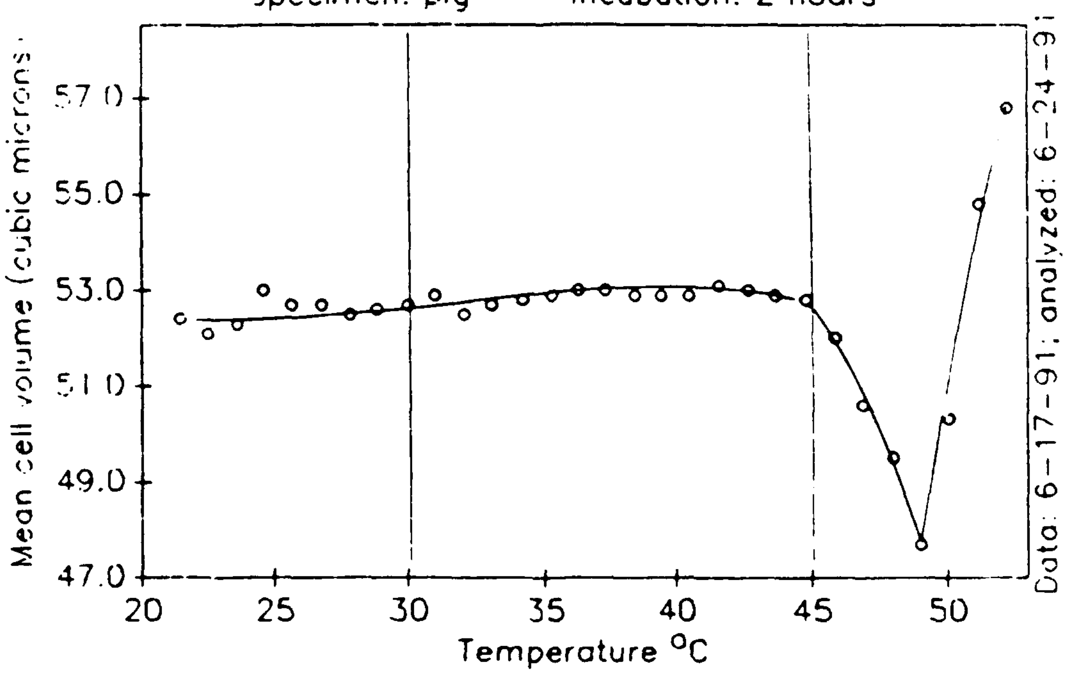


Fig. 13

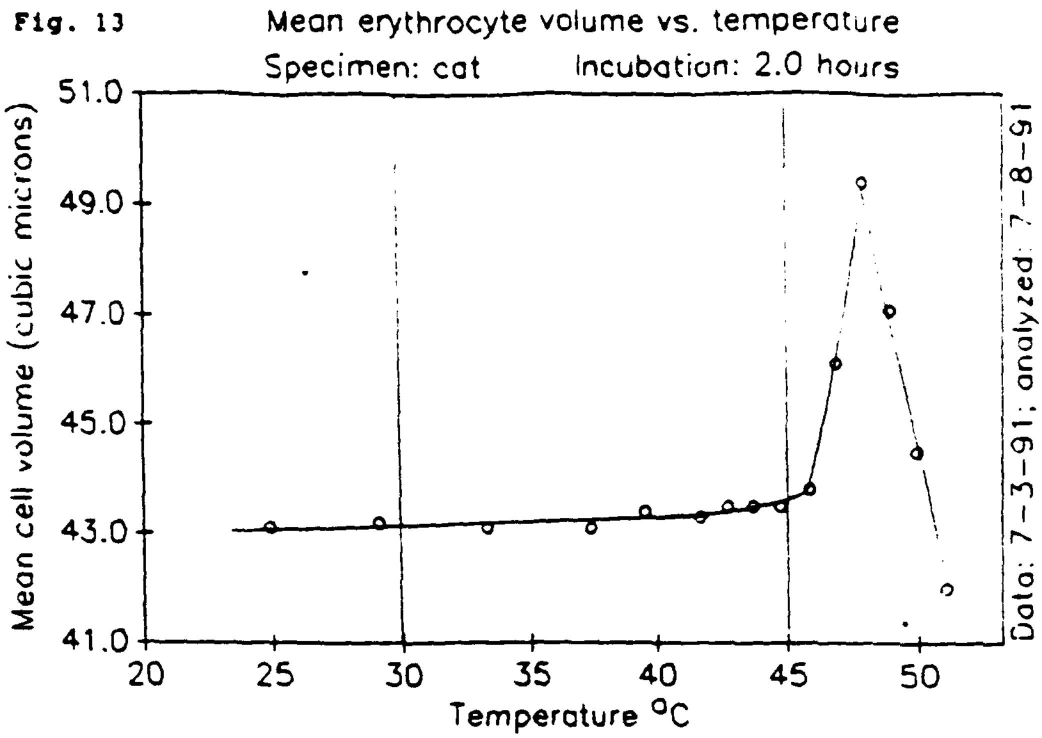

Mean erythrocyte volume vs. temperature
Specimen: cat Incubation: 2.0 hours
Mean cell volume (cubic microns)
51.0
49.0
47.0
45.0
43.0
41.0
20
25
30
35
40
45
50
Temperature °C
Data: 7-3-91; analyzed: 7-8-91

Fig. 14

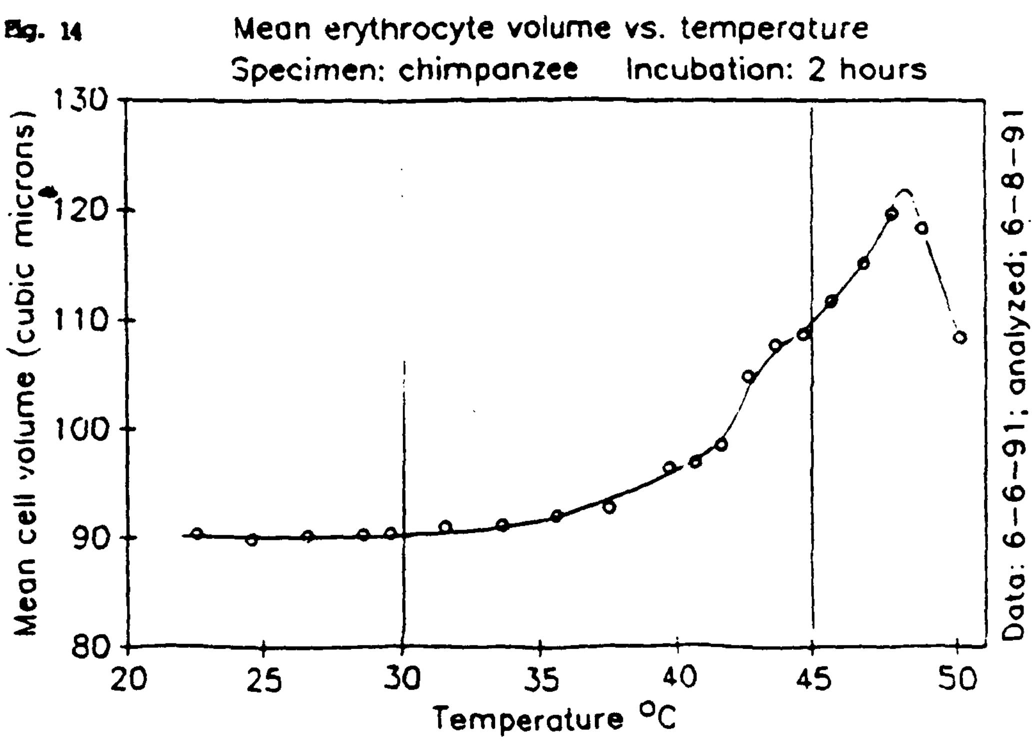

Mean erythrocyte volume vs. temperature
Specimen: chimpanzee Incubation: 2 hours
Mean cell volume (cubic microns)
130
120
110
100
90
80
20
25
30
35
40
45
50
Temperature °C
Data: 6-6-91; analyzed; 6-8-91

Fig. 15 Mean erythrocyte volume vs. temperature
Specimen: baboon Incubation: 4 hours

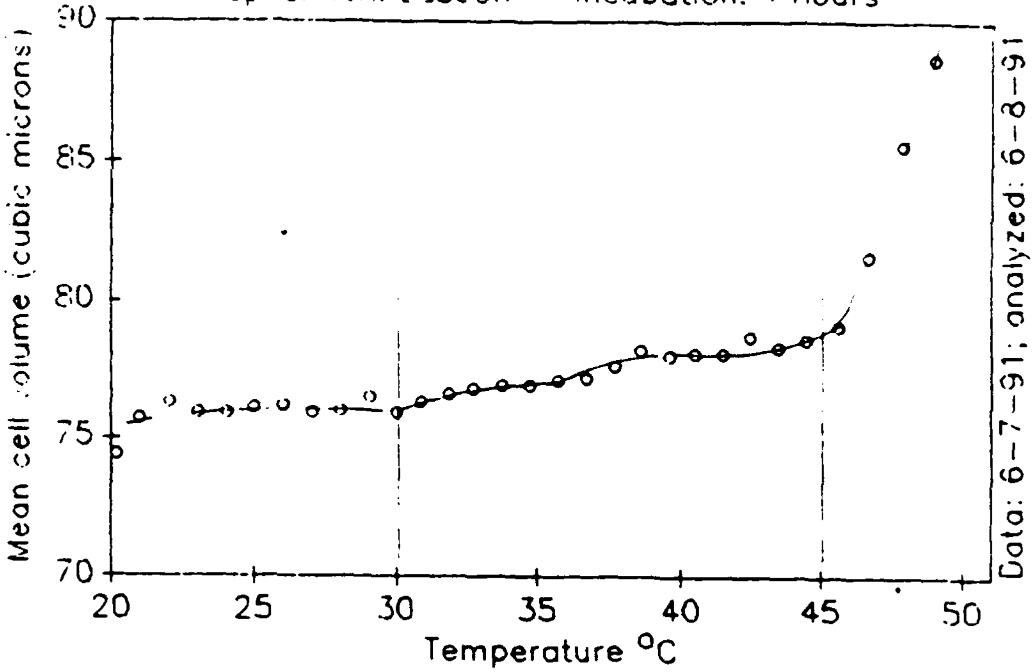


Fig. 16 Mean erythrocyte volume vs. temperature
Specimen: cow Incubation: 2.0 hours

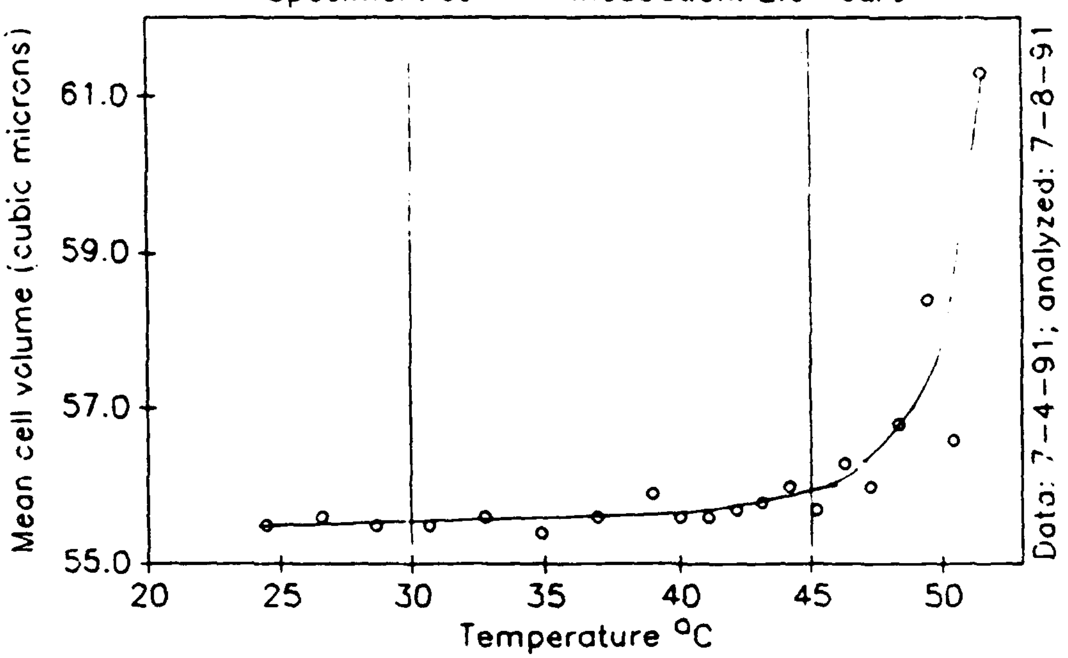


Fig. 17 Mean erythrocyte volume vs. temperature

Specimen: goat Incubation: 2.0 hours

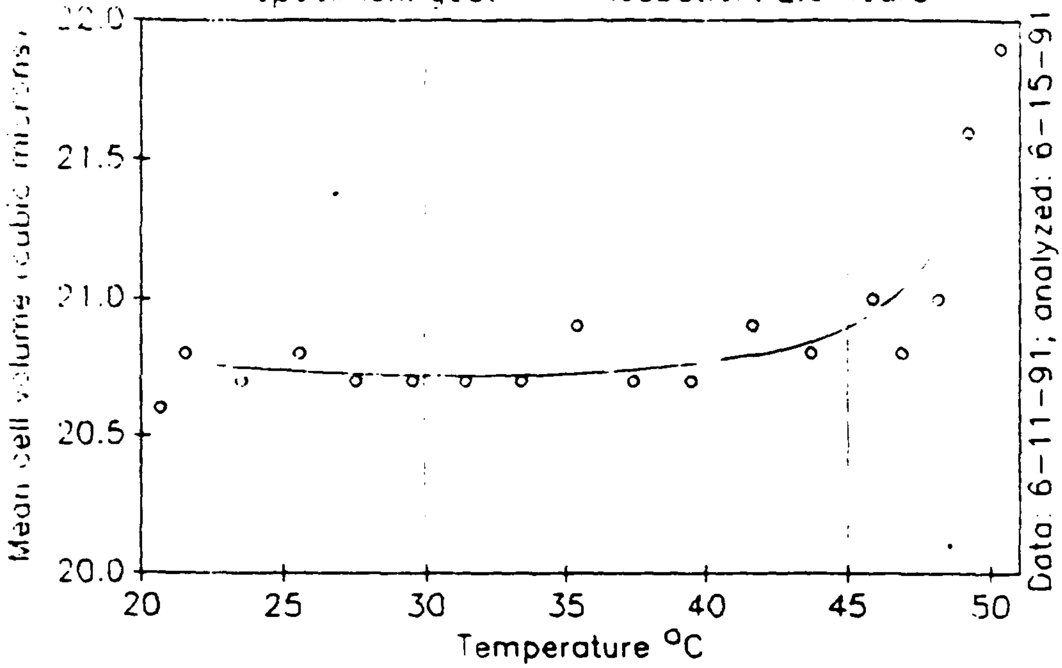


Fig. 18 Mean erythrocyte volume vs. temperature

Specimen: sheep Incubation: 3.0 hours

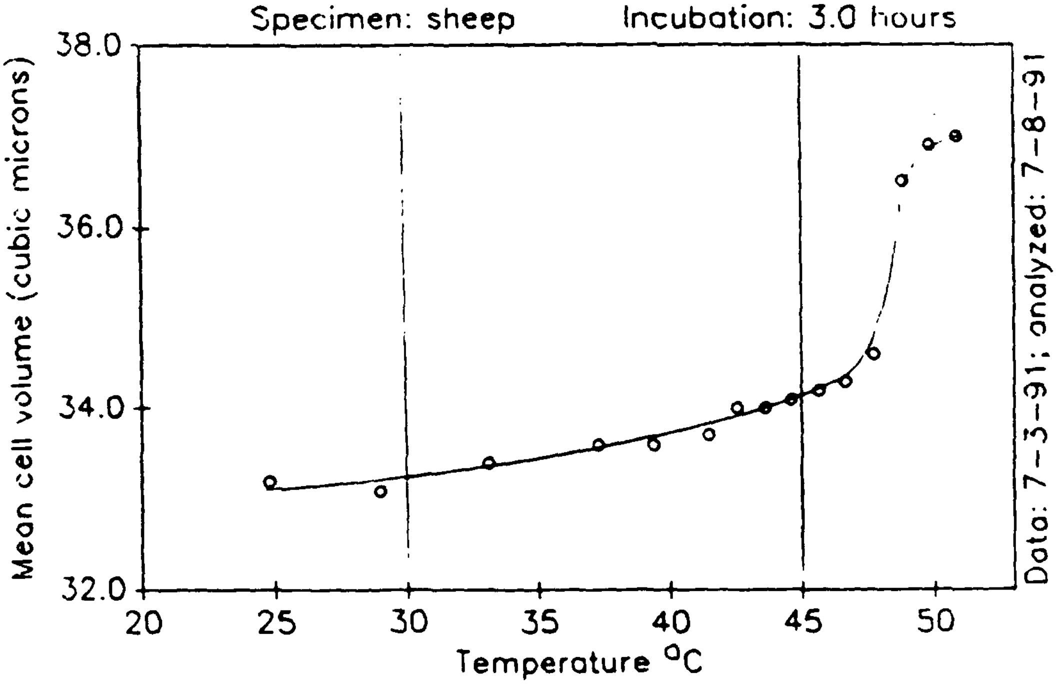


Fig. 19

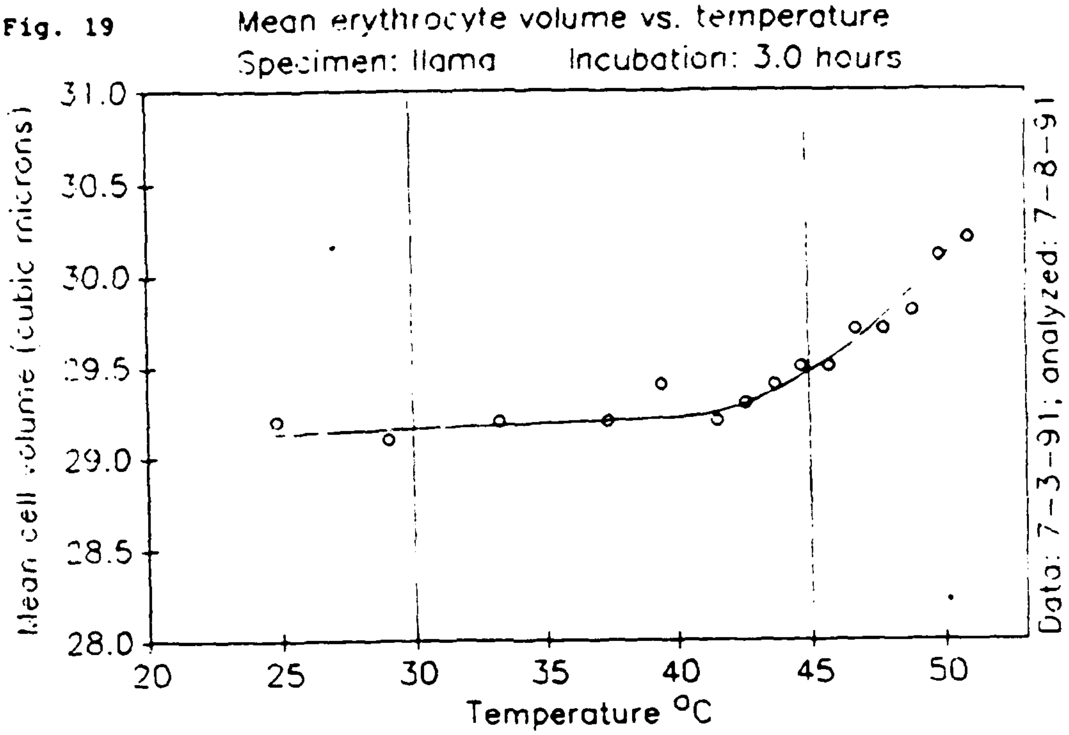

Mean erythrocyte volume vs. temperature
Specimen: llama Incubation: 3.0 hours
Mean cell volume (cubic microns)
31.0
30.5
30.0
29.5
29.0
28.5
28.0
20
25
30
35
40
45
50
Temperature °C
Data: 7-3-91; analyzed: 7-8-91

Fig. 20

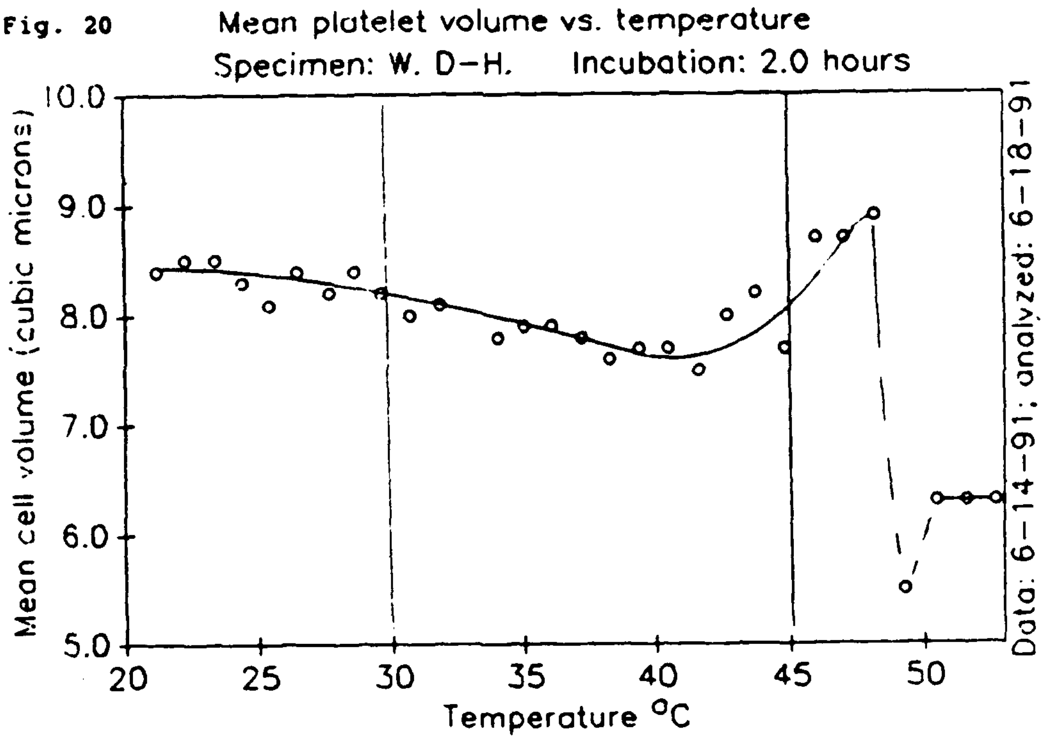

Mean platelet volume vs. temperature
Specimen: W. D-H. Incubation: 2.0 hours
Mean cell volume (cubic microns)
10.0
9.0
8.0
7.0
6.0
5.0
20
25
30
35
40
45
50
Temperature °C
Data: 6-14-91; analyzed: 6-18-91

Fig. 21 Mean platelet volume vs. temperature
Specimen: chimpanzee Incubation: 2 hours

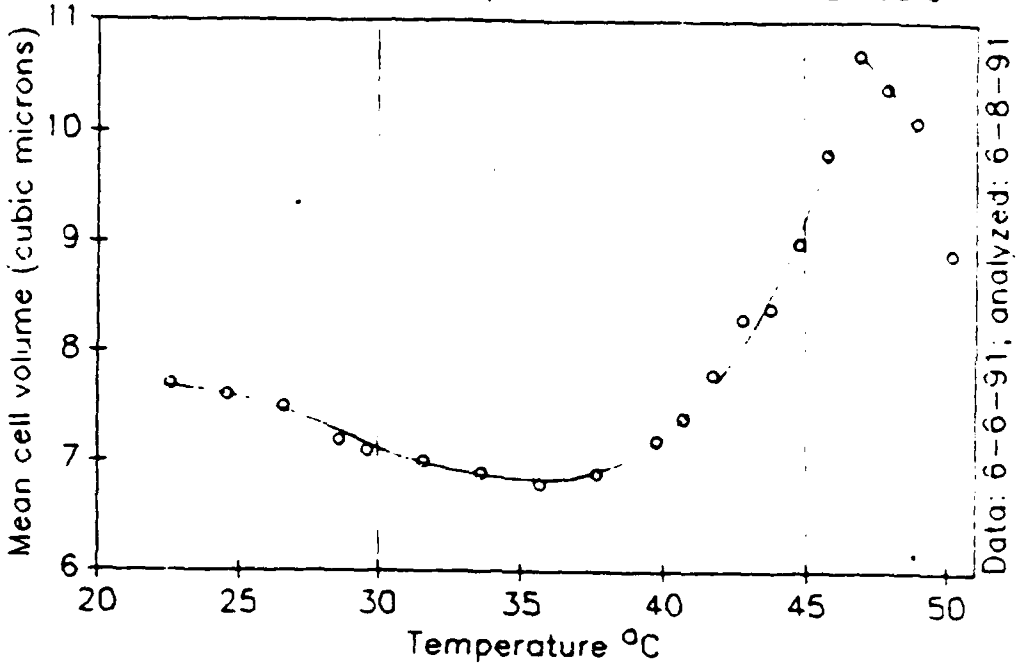
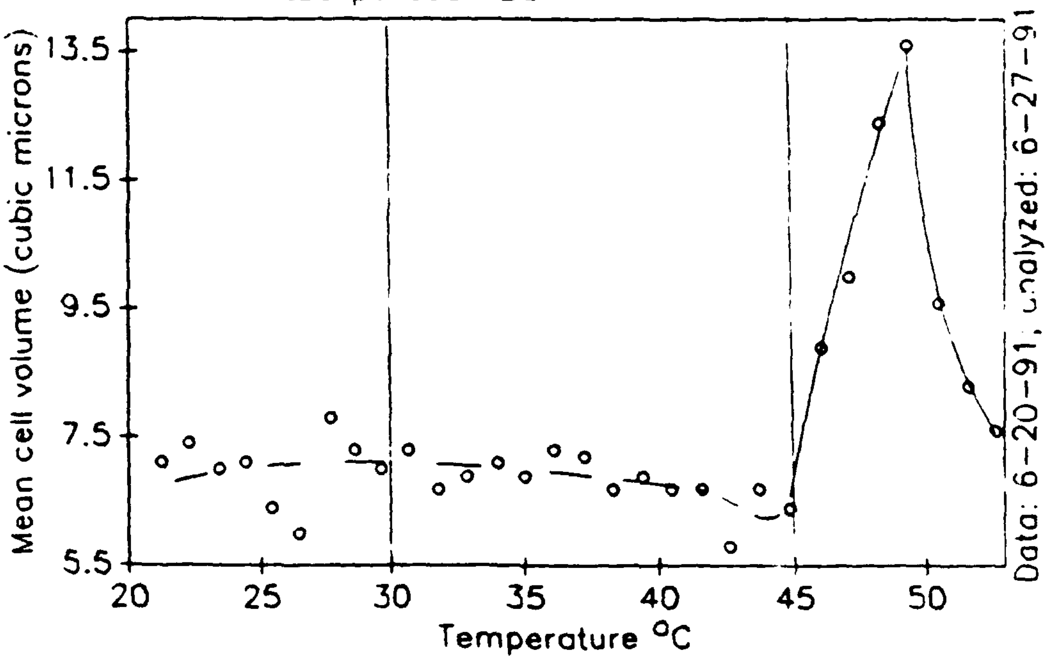


Fig. 22 Mean platelet volume vs. temperature
Specimen: dog Incubation: 17.0 hours
Resuspended RBC



DYNAMICS OF SEDIMENTATION

We are investigating the possible mechanisms involved in the dramatic changes in the sed rate of the erythrocytes in whole blood near 45°C. The main question is: besides the likely change in extent of rouleaux formation, does the 45°C drop in sed rate reflect a sudden increase in the viscosity of the blood plasma - presumable reflecting dramatic changes in viscosities of aqueous protein solutions - or does the change in sed rate reflect some intrinsic feature of the erythrocytes themselves? The answer is rather surprising: both aspects are found to contribute!

Erythrocytes were isolated from whole blood by centrifuging and repeated washings (3 washings with lactate-Ringers solution) and redispersed in the isotonic solution. Figures 23, 24, 25 and 26 show the settling of the isolated erythrocytes as a function of temperature. The rate of settling is far lower than in whole blood; this is presumably due to the removal of the proteins responsible for the rouleaux formation which is the primary mechanism responsible for the high rate of settling of the red cells. However, once again it is seen that the rate of settling drops notably at or just above 45°C. Thus, some aspect of the erythrocytes themselves appear to cause a change near the transition.

Viscosity measurements have been carried out on both the blood plasma isolated from the centrifuged cells as well as on a blood serum obtained from the same donors. The viscosity measurements were made with a Brookfield, Model LVTDV-II viscometer at various shear rates, using the parallel plate measuring technique (see the graphs for the RPM used in each case).

VISCOSITY DATA

Figures 27, 28, 29 and 30 show some of the data obtained for the viscosities of the plasma. An anomaly is frequently seen near 30°C and a <u>large</u> increase in viscosity is observed somewhere above 45°C - but not necessarily right at this temperature. The increase in viscosity is often a factor of ten (or more): no wonder, then, that the rate of settling of the erythrocytes drops off quite dramatically at higher temperatures. (Recall, however, that even the absence of the plasma proteins, the rate of settling of the isolated erythrocytes is notably slowed down above 45°C.

Fig. 23 Distance sedimented vs. temperature
Specimen: R. McN. RBC suspension

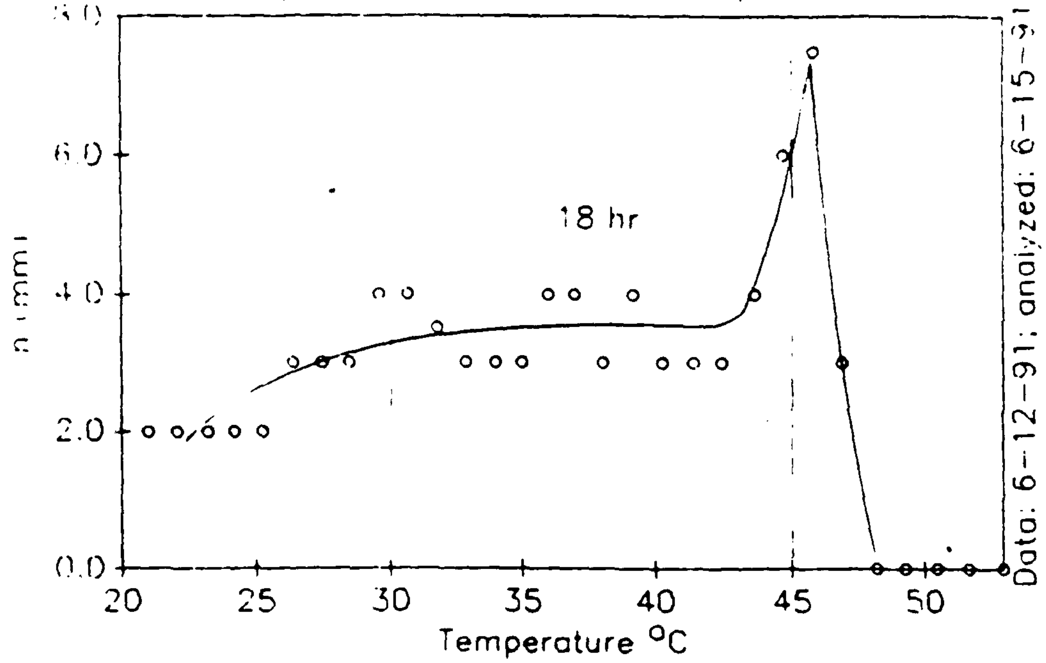


Fig. 24 Distance sedimented vs. temperature
Specimen: W. D-H. Resuspended RBC

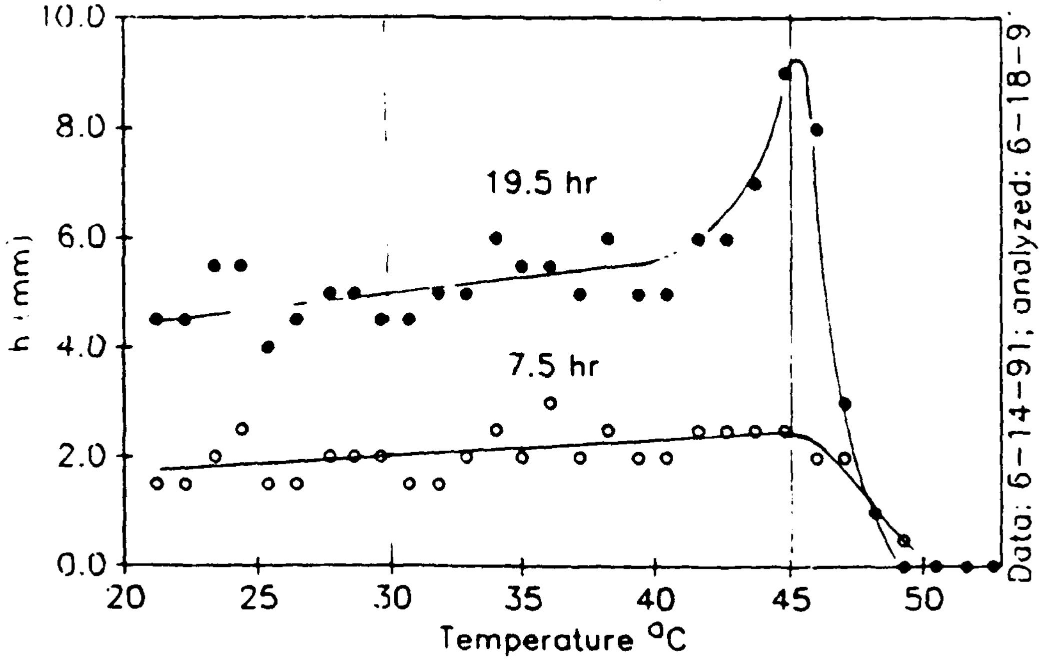


Fig. 25

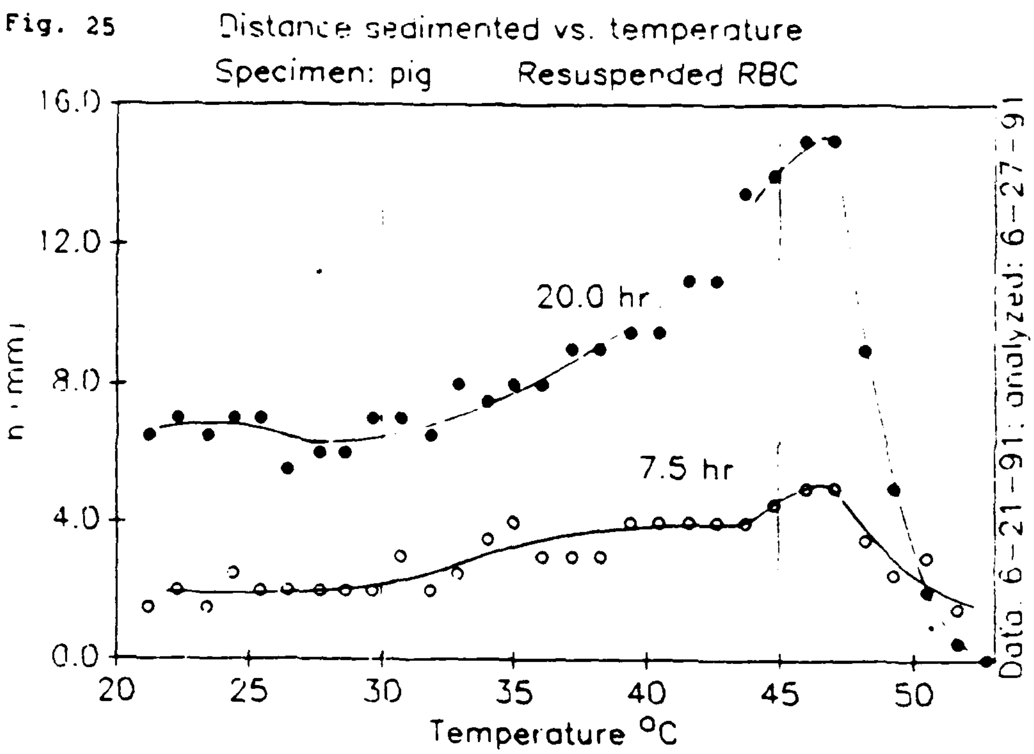

Distance sedimented vs. temperature
Specimen: pig Resuspended RBC
16.0
12.0
8.0
4.0
0.0
20
25
30
35
40
45
50
Temperature °C
h (mm)
20.0 hr
7.5 hr
Data: 6-21-91; analyzed: 6-27-91

Fig. 26

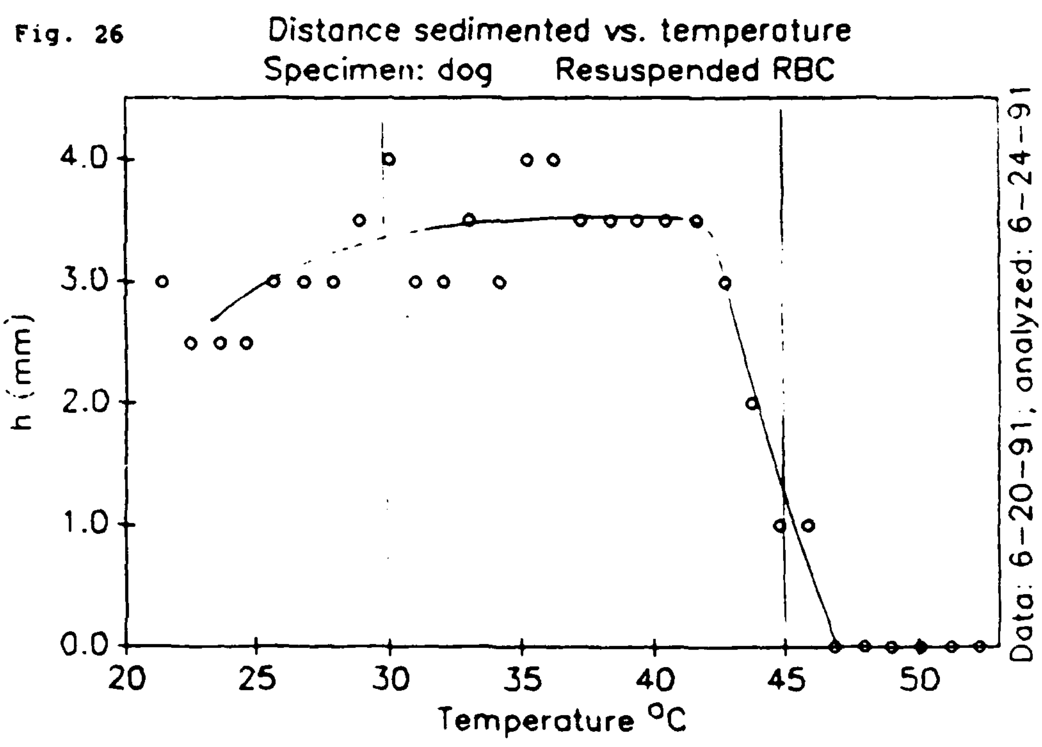

Distance sedimented vs. temperature
Specimen: dog Resuspended RBC
4.0
3.0
2.0
1.0
0.0
20
25
30
35
40
45
50
Temperature °C
h (mm)
Data: 6-20-91; analyzed: 6-24-91

Fig. 27

Apparent viscosity vs. temperature
Specimen: R. McN. Fluid: plasma

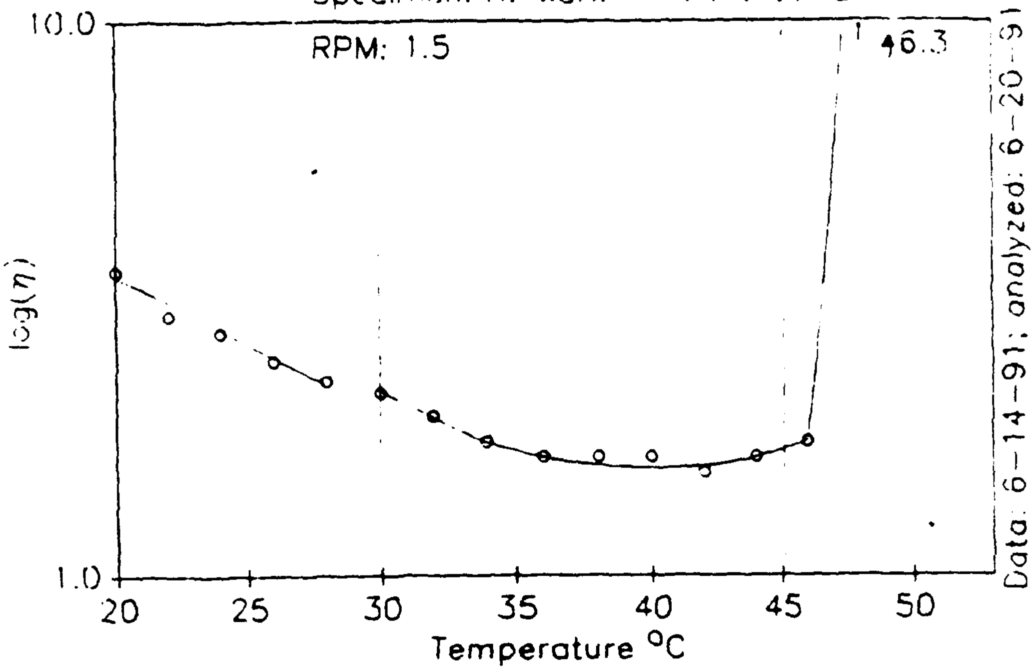


Fig. 28

Apparent viscosity vs. temperature
Specimen: W. D-H. Fluid: plasma

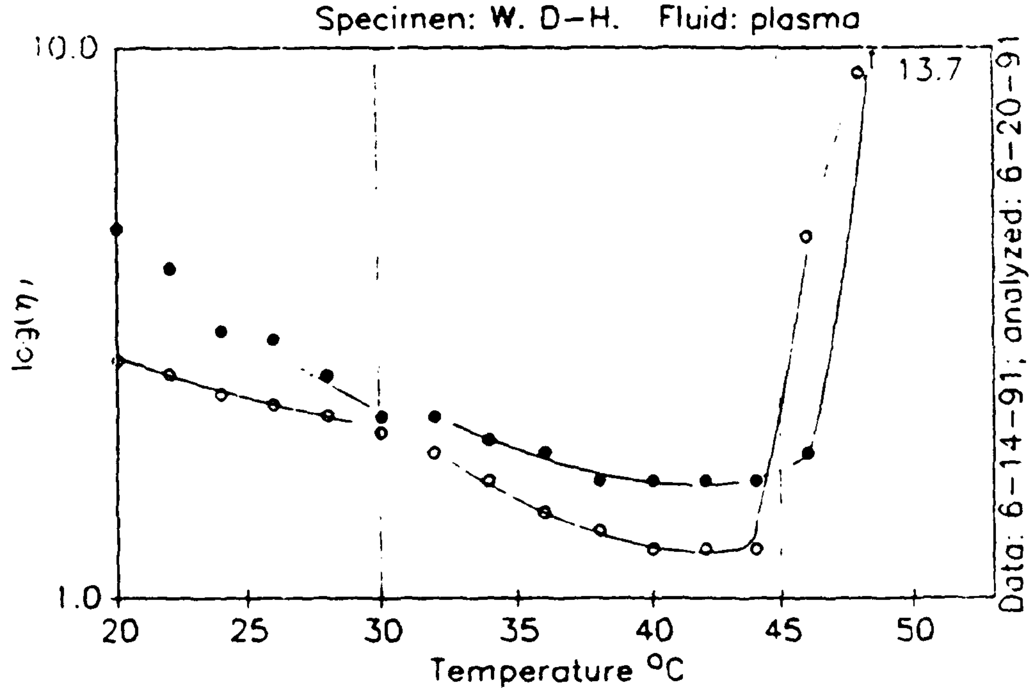


Fig. 29 Apparent viscosity vs. temperature
Specimen: pig Fluid: plasma

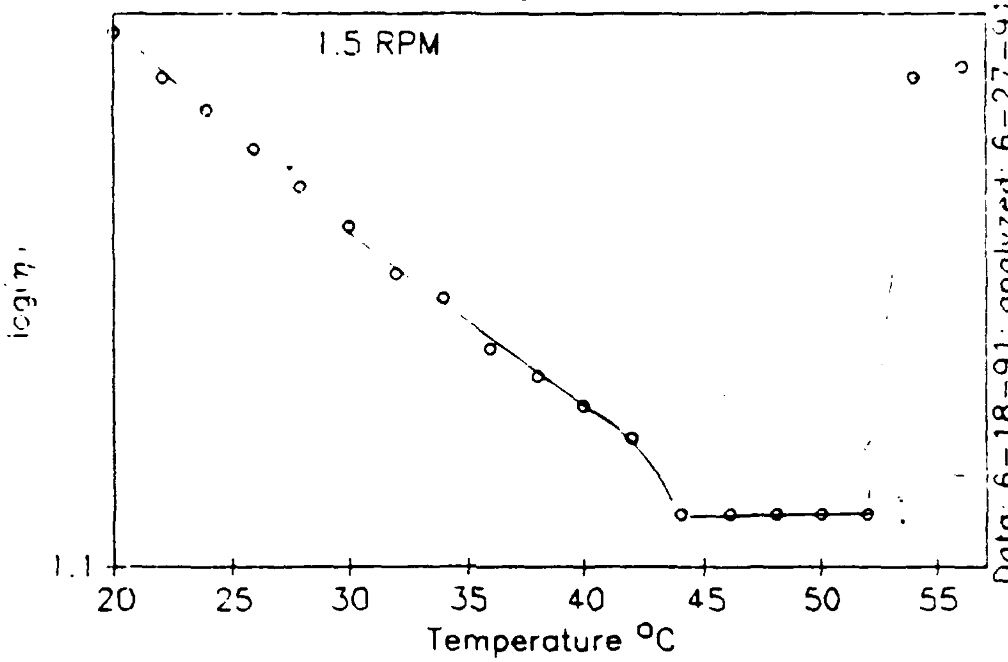


Fig. 30 Apparent viscosity vs. temperature
Specimen: dog Fluid: plasma

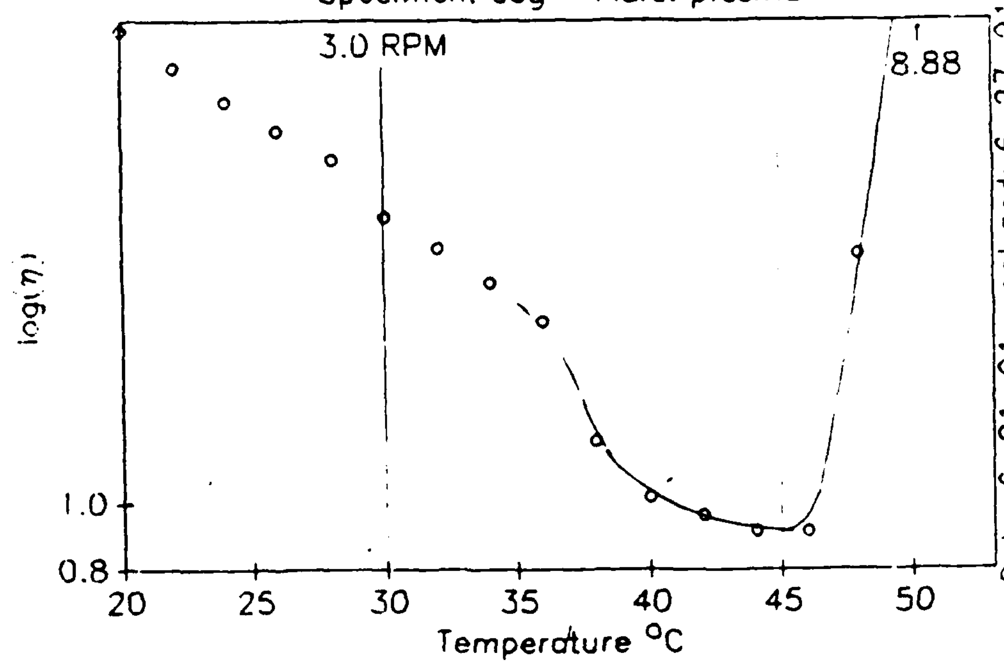


Fig. 31

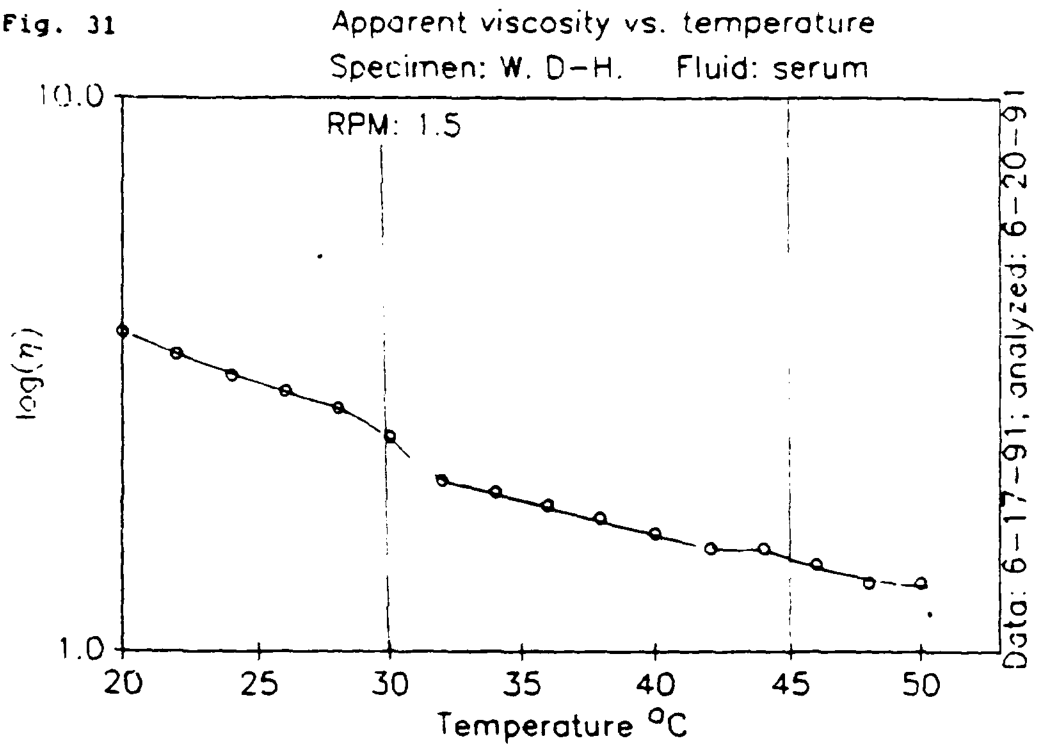
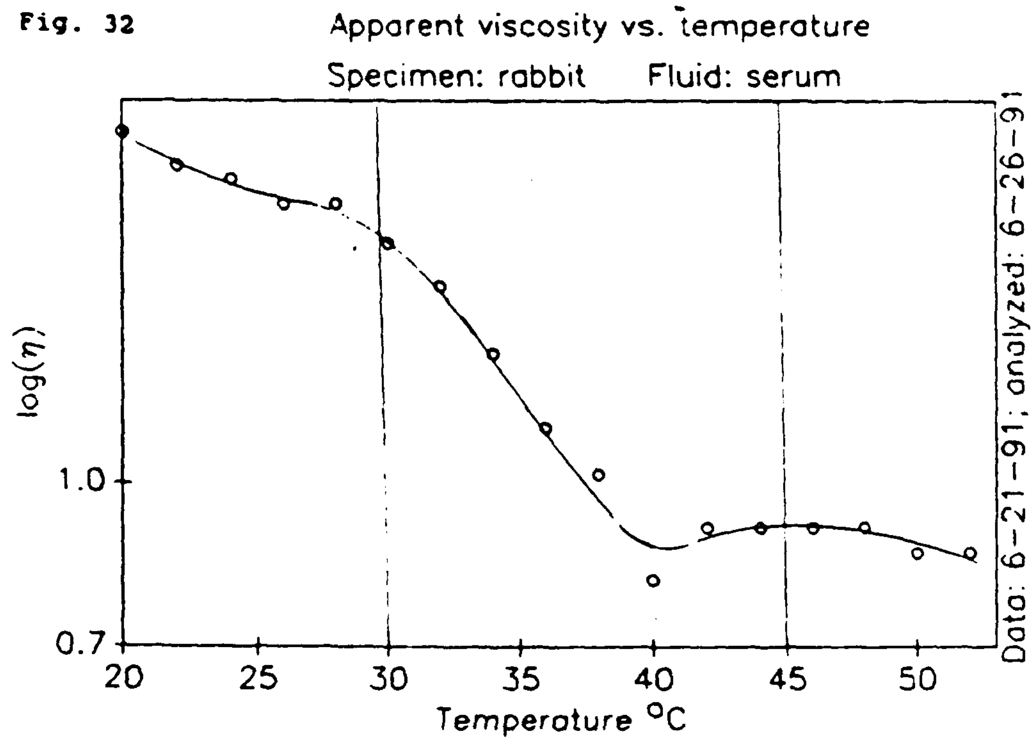

Apparent viscosity vs. temperature
Specimen: W. D-H.   Fluid: serum
RPM: 1.5
10.0
1.0
log(η)
20
25
30
35
40
45
50
Temperature °C
Data: 6-17-91; analyzed: 6-20-91

Fig. 32


Apparent viscosity vs. temperature
Specimen: rabbit   Fluid: serum
log(η)
1.0
0.7
20
25
30
35
40
45
50
Temperature °C
Data: 6-21-91; analyzed: 6-26-91

Figures 31 and 32 show typical viscosity data for blood serum. In these cases no dramatic increase occurs above 45^{o}C. This suggest that the protein responsible for the increase in the viscosity of the plasma (and thus likely in part responsible for the reduction of the settling rate of the erythrocytes) is the fibrinogen which is removed in the clotting process. In separable measurements, we have confirmed that the viscosity of fibrinogen solutions (0.3%) increases dramatically above 45^{o}C; Figures 33 and 34. Note in Figure 27 - 34, that anomalies are sometimes seen at 30^{o}C, and if not, at 45^{o}C, and sometimes at both temperatures. The anomalies are of considerable interest as they occur right at the "Drost-Hansen thermal transition temperatures" (Drost-Hansen, 1977, 1987, 1979, 1991a, 1991b, Etzler and Drost-Hansen 1983. Clegg and Drost-Hansen 1991) suggesting a role for vicinal water: in this case the vicinal water of hydration of the plasma or serum proteins. In this connection we have also measured viscosities of some more well-defined aqueous polymers. Thus, Figures 35, 36, and 37 show, respectively, the results obtained on 5% polyvinyl pyrrolidone (MW 40 000 Dalton) and 5% dextran (MW 67 000 Dalton and 82 200 Dalton). In all cases thermal anomalies are seen at or near the vicinal water transition temperatures. Likewise, Figures 38 and 39 show the viscosity of 5% BSA; again the thermal anomalies are seen. Together with the other lines of evidence previously published, it now appears ALL polymers in aqueous solution are vicinally hydrated and that these vicinal hydration structures must be taken into account in all studies of such solutions, both in model systems and all living cells. Indeed these findings must ultimately be considered in all areas of cell physiology, biophysics and molecular biology.

CONCLUSION

In blood form all mammals tested (humans, chimpanzee, baboon, dog, cat horse, cow, goat, sheep, rabbit, pig, llama, and killer whale) the erythrocyte sedimentation rate in whole blood drops abruptly at temperatures above 45 (- 46)^{o}C. In suspensions of erythrocytes in protein-free isotonic solution, the sed rate is much lower but also drops sharply above this critical

Fig. 33

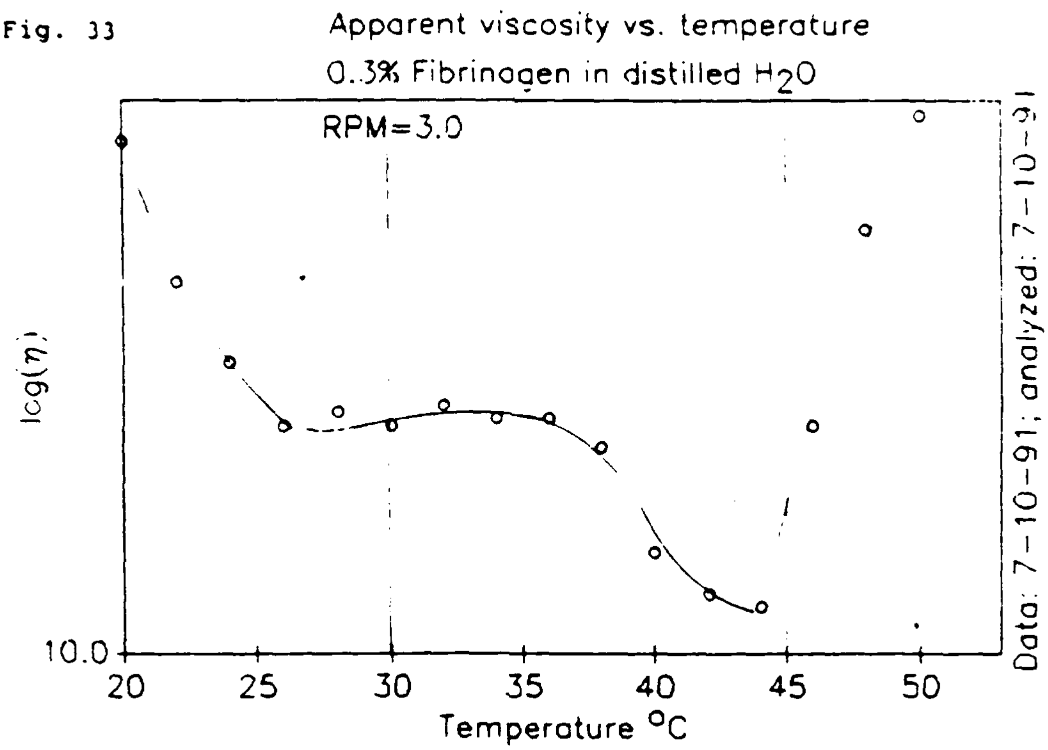

Apparent viscosity vs. temperature
0.3% Fibrinogen in distilled H_2O
RPM=3.0
log(η)
10.0
20
25
30
35
40
45
50
Temperature °C
Data: 7-10-91; analyzed: 7-10-91

Fig. 34

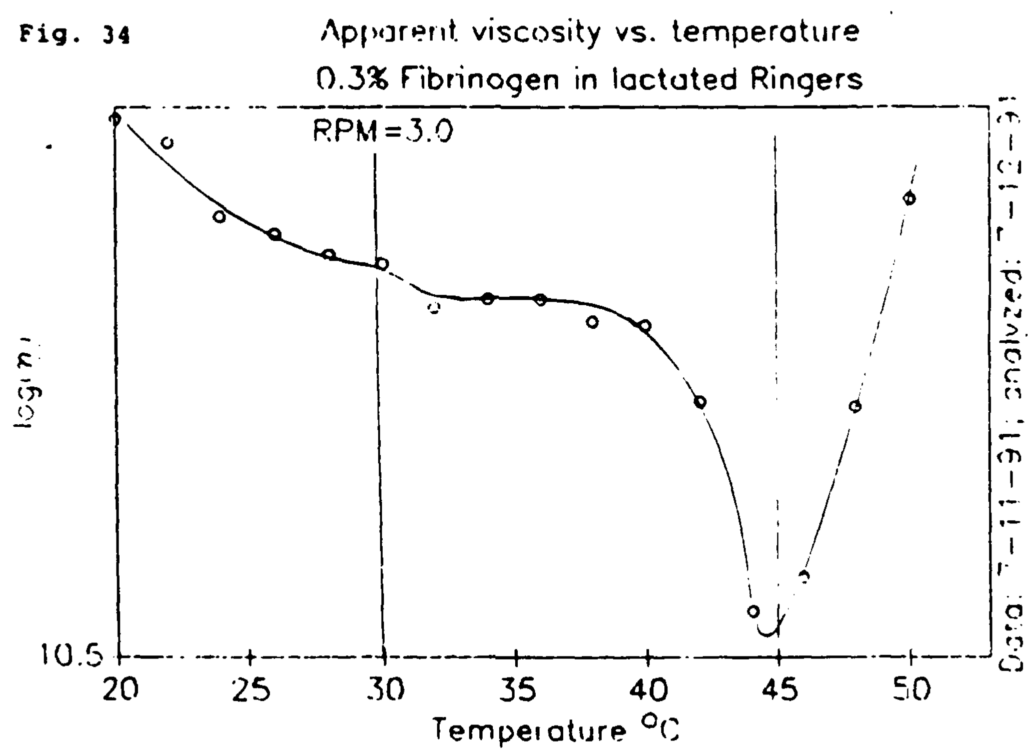

Apparent viscosity vs. temperature
0.3% Fibrinogen in lactated Ringers
RPM=3.0
10.5
20
25
30
35
40
45
50
Temperature °C

Fig. 35 Apparent viscosity vs. temperature

5% Polyvinyl pyrrolidone in distilled H_2O

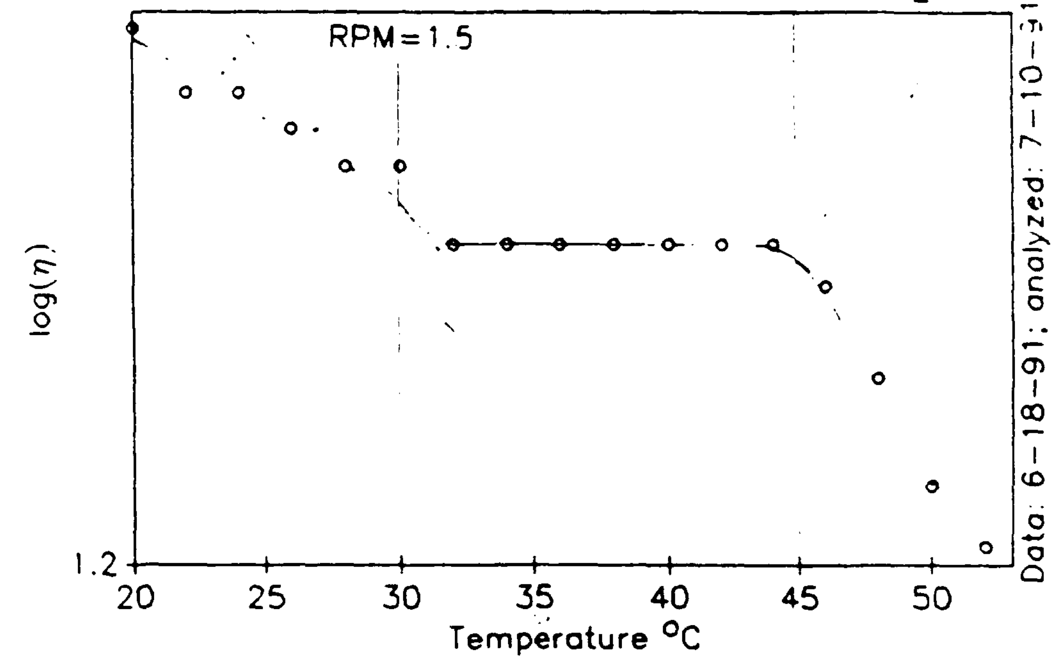


Fig. 36 Apparent viscosity vs. temperature

5% dextran MW: 67,000 D

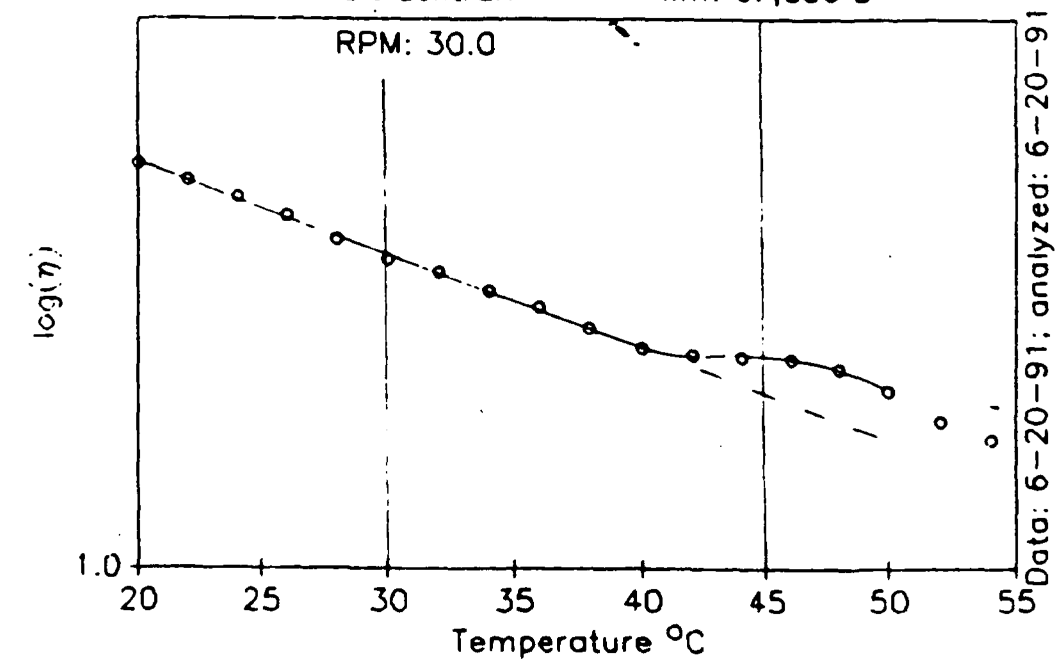


Fig. 37

Apparent viscosity vs. temperature

5% Dextran MW: 82,200 u

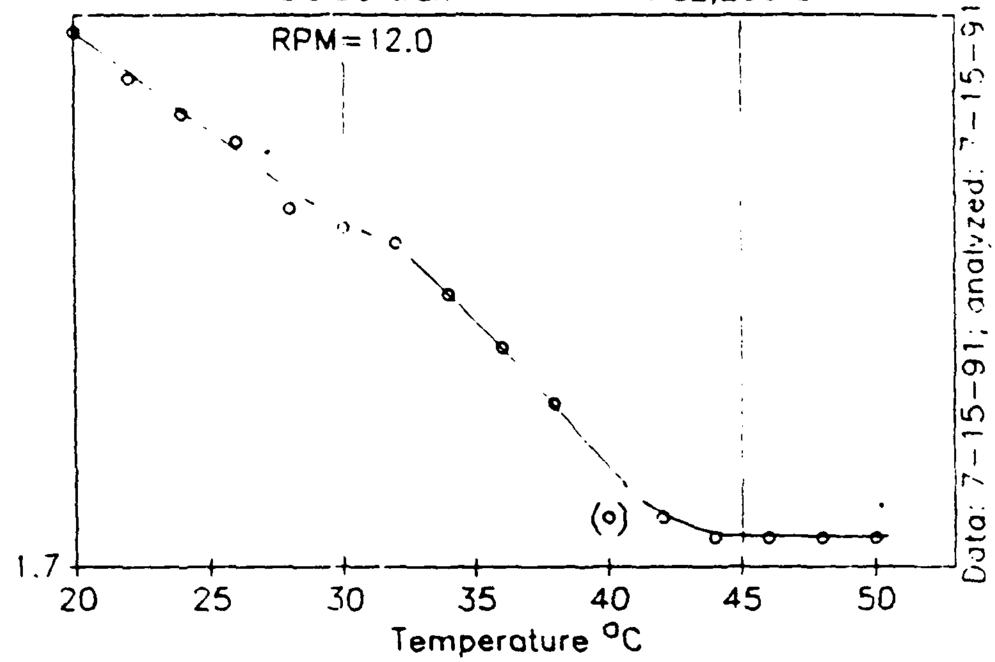


Fig. 38

Apparent viscosity vs. temperature

5% BSA in doubly distilled H_2O

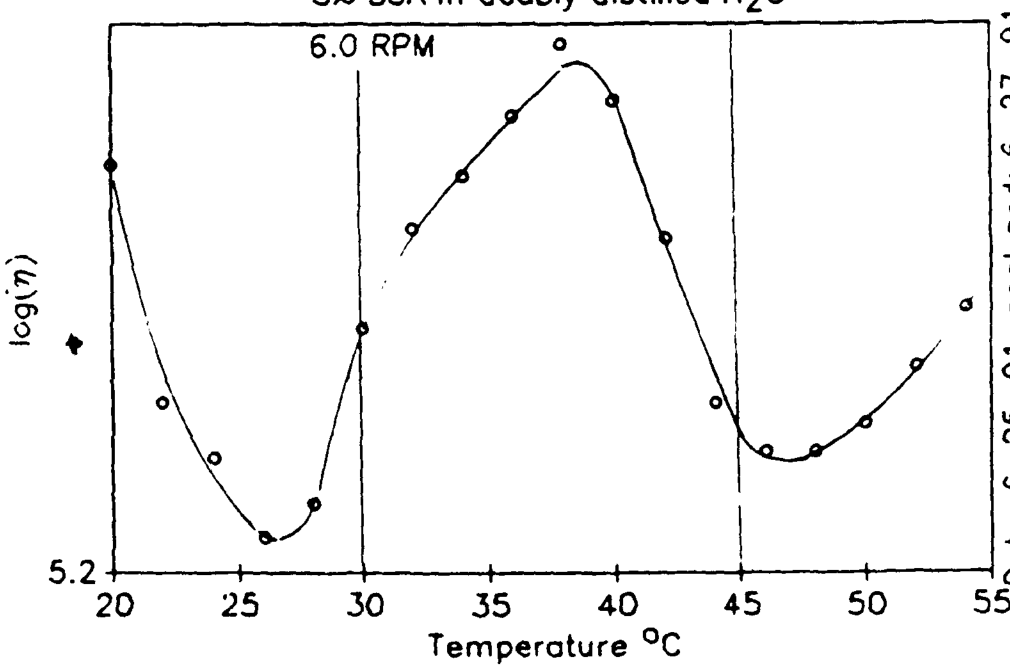
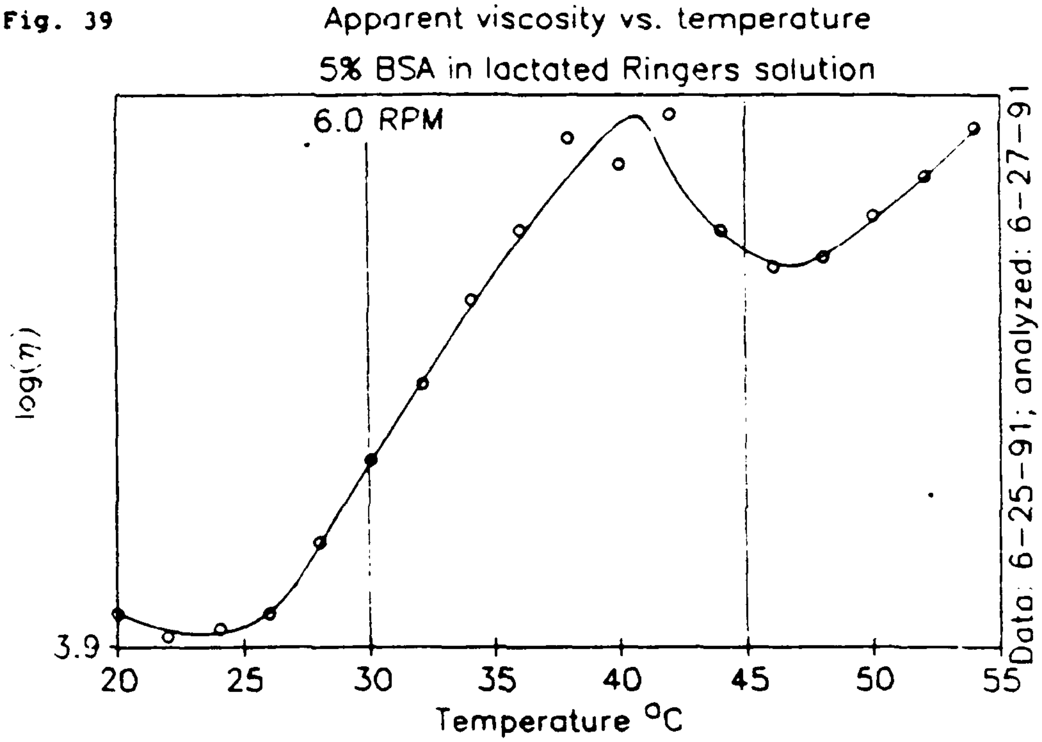


Fig. 39


Apparent viscosity vs. temperature
5% BSA in lactated Ringers solution
6.0 RPM
log(η)
3.9
20
25
30
35
40
45
50
55
Temperature °C
Data: 6-25-91; analyzed: 6-27-91

temperature range. The latter observation suggests that some intrinsic property of the erythrocytes themselves senses that the temperature has passed one of the critical structural transition temperatures of vicinal water (which certainly includes the cell-associated water.) Furthermore, in whole blood, histological examinations have shown that erythrocytes undergo profound morphological changes near 45^{o}C, changing from the normal biconcave disk form to more nearly spherical - thus preventing the rouleaux information which is critical for high sed rates. Other histological examinations have shown that above 45-47^{o}C there is a dramatic, almost grotesque, tendency for platelets to aggregate. Finally, we have shown that the viscosity of plasma increases dramatically above 45^{o}C which in turn must surely strongly reduce the sed rate. It is of interest to note also that no similar increase in viscosity with temperature is seen in the serum from blood of the identically same donors, suggesting that the abrupt viscosity increase in the whole blood plasma is due to fibrinogen. Consistent with this finding is our observation that the viscosity of aqueous fibrinogen solutions (0.3%) also increases abruptly above 45^{o}C. Measurements have also been made on aqueous solutions of Bovine Serum Albumin, dextrans (2 different molecular weights) and polyvinyl pyrrolidone. All the solutions have shown distinct thermal anomalies near 30 and/or 45^{o}C, strongly suggesting that ALL polymers in aqueous solutions are vicinally hydrated and displaying the characteristic thermal responses: i.e., structural transitions at one or more of the "Drost-Hansen thermal transition" temperatures, T_k,(namely, near 15, 30, 45, 60^{o}C.) In short, the properties of blood is notably affected by - and some times completely controlled by - vicinal water, as are indeed practically ALL living systems (and all polymers in aqueous solution as well.)

W. Drost-Hansen

Miami, Florida

July 1991

FINAL NOTE:

A vast amount of data have been accumulated this summer (as well as in the summer of 1989) and it is our intent to publish these results in a series of four or five papers, variously co-authored with Drs. J.H. Cissik, W.R. Patterson, Mr. J.P. Lafferty, IV, and Mr. R.R. McNeer. I wish to express my sincerest thanks to Drs. Cissik and Patterson, as Director and Deputy Director, respectively, of the Clinical Investigation Directorate of Wilford Hall USAF Medical Center (Lackland AFB, San Antonio, TX) who have been instrumental in making this study possible, as well as the Summer Faculty Research Program of the US Air Force Office of Scientific Research.

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