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FEMALE AND MALE SIZE, STRENGTH AND PERFORMANCE: A REVIEW OF CURRENT LITERATURE

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SAN DIEGO, CALIFORNIA 92152

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The increase in female personnel utilization aboard ship has initiated a need to examine gender based differences in anthropometrics, biomechanics, psychophysical performance, physiological attributes and the relationship of these factors to the design of shipboard equipment and fittings. Literature in this area was examined by Ayoub et al (1978). The purpose of the present report was to update and extend the baseline established by Ayoub et al (1978) by examining current work. Specifically, this report seeks to:

- consolidate current performance and anthropometric articles into an updated data base,

20. Continued.

- identify the presence and degree of overlap between the sexes in performance and anthropometric variables,
- relate gender based differences to potential effects on performance levels,
- identify "gaps" in the anthropometric an ormance literature that warrant further investigation.

To accomplish this, a survey of the relevant scientific literature was conducted which focused on male/female differences in basic anthropometrics and performance. The review covered the published literature as well as technical notes and reports that have a limited distribution.

The results of a critical review of the obtained literature indicated that several general and specific needs exist which must be addressed in order to increase the utility of this data base for system design applications. The lack of standardized methodologies and the potential discrepancy between laboratory data and job performance were noted. Gaps were noted in the literature concerning gender differences in: psychomotor skills, vigilance, cold tolerance and dynamic anthropometry/biomechanics.

More work is recommended to examine the effectiveness of compensatory physical training programs where female performance is found to be below criteria. Additionally, the positive aspects of gender based performance differences need to be further examined and exploited in equipment design and task and function allocations. Gender differences in visual system biases and their potential application to monitoring and detection tasks are noted.

Articles examined in this update are classified by a matrix of topic areas to provide cross referencing. Abstracts of the current literature are also included.

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REPORT NO. 342-1

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ABSTRACT

The increase in female personnel utilization aboard ship has initiated a need to examine gender based differences in anthropometrics, biomechanics, psychophysical performance, physiological attributes and the relationship of these factors to the design of shipboard equipment and fittings. Literature in this area was examined by Ayoub et. al. (1978). The purpose of the present report was to update and extend the baseline established by Ayoub et. al. (1978) by examining current work. Specifically, this report seeks to:

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1.0 INTRODUCTION

The 1970's brought many demographic shifts in the make-up of the work force in the United States. Not the least of these shifts was the dramatic increase in numbers of women employed in "non-traditional" occupations. During the past decade, women have entered diverse and non-conventional careers as construction workers, law enforcement officers, and heavy machine operators. The late 1970's saw a growing research effort for defining the role of women in the space program (Brown, J.W., 1979). This trend toward expanded female work roles is likely to continue to grow into the 1980's.

This demographic shift in the composition of the civilian work force has been paralleled in the military sector. While increasing cultural acceptance has played a significant role in increased female enlistment, there have also been compelling practical reasons. Since the mid 1970's, the number of military-aged males in the United States has been consistently declining. Current Pentagon estimates hold that the number of eligible men might drop by as much as 25% by 1992 (Marcinick, 1980). This population shift has been accompanied by the abolition of the draft in 1973. These two factors have forced the armed services to re-examine the utilization of women in non-traditional areas.

The role of women in the armed forces has expanded from traditional clerical and nursing positions to include almost all non-combatant military jobs. The Navy has, in turn, expanded its assignment of women to include permanent shipboard duty assignments on non-combatant ships.

In a recent instruction from the Secretary of the Navy (Secretary of the Navy, 1979), it was stated that, "It is the policy of the Department of the Navy that women members, officers and enlisted, will be assigned to billets commensurate with their capabilities to the maximum extent practicable." The only restriction placed on female personnel utilization is that women may not be permanently assigned to a combatant vessel. Women may serve temporary duty on any ship in the Navy, provided that it is not expected to have a combat mission during the period of temporary duty. This expansion of the role of women aboard ship has led to female personnel being assigned to over twenty Naval ships to date.

The introduction of women into a workplace designed for use by males has been shown to cause human engineering-related deficiencies in workplace layout (Ketcham-Wiedle and Bittner, 1977). The influx of women into shipboard billets has therefore raised questions about the adequacy of shipboard equipment design for female use. Ship fittings and equipment were designed with only the male user in mind. No consideration was given to human engineering standards that would accommodate both males and females in ship systems.

Gender based human engineering problems can arise from male/female differences in anthropometrics, biomechanics, psychophysical performance, physiological attributes and the relationship of these factors to the design of shipboard equipment and fittings. The above cited increase in female personnel utilization therefore initiates a need to examine current literature which concerns these gender related issues. These articles also need to be consolidated into an accessible data base.

1.1 PURPOSE

An exhaustive review of the gender based human performance literature entitled: Classification, Summary, Relevance and Application of Male/Female Differences in Performance, was performed by Ayoub et. al. (1978). The purpose of the present report is to update the data base established by Ayoub et. al. The focus of this report is on literature published after the Ayoub paper, however, some citations covered in that earlier review are covered here where needed to establish the context of current work. Specifically, this report seeks to:

- consolidate current performance and anthropometric articles into an updated data base,
- identify the presence and degree of overlap between the sexes in performance and anthropometric variables,
- relate gender based differences to potential effects on performance levels,
- identify "gaps" in the anthropometric and performance literature that warrant further investigation.

2.0 METHOD

2.1 INFORMATION SOURCES

A survey of the relevant scientific literature was conducted which focused on male/female differences in basic anthropometrics and performance. The review covered the published literature as well as technical notes and reports that have a limited distribution. The Topside and Bayside libraries of the Naval Ocean Systems Center (NOSC) were used for their periodical and book holdings, technical notes and reports housed there and for interlibrary loan sources. Two computer data base searches were made to locate additional sources:

1. Medline, Off-line Bibliographic Citation of the National Library of Medicine

2. National Technical Information Service, U.S. Department of Commerce

In addition to the computer searches, manual searches of abstract sources were conducted at San Diego State University's Love Library. These sources included:

1. Science Citation Index

2. Index Medicus

The computer searches yielded titles with author(s) while the manual searches yielded abstracts as well as author(s) and title. The title, and when available the abstract, would usually indicate whether an article was appropriate for review. If the article appeared relevant, it was obtained through the NOSC Topside Library.

The references cited in an article often reveal potential new sources of relevant information. Promising articles cited in reference lists were therefore also obtained through the NOSC library.

2.2 EVALUATION CRITERIA

Upon receiving the report, the amount and quality of new information added to the existing literature was determined by subjecting the article to a series of conditional requirements. Articles were sought which were published since 1978 because they would not be included in the baseline established by Ayoub (1978). Articles found which were published before 1978 and weren't included in the Ayoub paper, were also reviewed to determine if they were appropriate for inclusion in this update.

Obviously, priority was given to articles that considered both male and female data, so that direct comparisons could be made between the sexes. Articles that furnished needed data on only one or the other genders were also included if appropriate.

Articles were evaluated for their relevance to workplace, clothing and equipment design. Data which focused on male/female performance in both laboratory and field settings were reviewed for inclusion. Particular consideration was given to adequacy of sample size and descriptions of populations sampled in anthropometric studies.

If an article furnished new, relevant information to the literature according to the considerations noted above, the report was abstracted to include methods, results, and summary application. If the article was of interest but furnished little new information, the report was abstracted with just the summary application. The resulting set of abstracts can be seen in Appendix II of this report.

2.3 CLASSIFICATION MATRIX

Articles abstracted were classified by a matrix of topic areas. By organizing the literature pertinent to male/female differences in performance into a classification matrix, the reader is provided with a quick access cross index to the abstracted sources. The classification matrix covers the following areas:

- Basic Scope
  - Male
  - Female
  - Research
  - Review
- Anthropometrics
- Biomechanics
- Sensory/Motor
- Environmental Influences
- Human Engineering
  - Clothing/Tools
  - Manual Materials Handling
  - Workplace design

2.3.1 Basic Scope

The scope of an article refers to the populations included (male, female or both), and whether the article concerns new research or presents a review of prior work.

2.3.2 Anthropometrics

Anthropometry is the comparative study of human body measurements. Included here are structural body dimensions taken with the subject's body in a fixed (static) position and functional body d mensions that reflect the range of body movement (dynamic). Static measures include height, leg length, etc., while reach envelope is characteristic of dynamic anthropometric measures.

Anthropometric data is typically presented in terms of mean values and percentile ranks. The data are arranged in discrete 1% sets ranging from the first (smallest) to the 99th (largest) percentile. A specific percentile value will reflect the percentage of data that falls below that particular value in the ordered array. The 50th percentile value represents the median of the data set. The 5th to 95th percentile range describes the data that falls within approximately two standard deviations above or below the mean value in the variable's distribution. Percentiles are used extensively in anthropometric surveys as reference markers when two or more surveys are compared to determine the degree of overlap between the populations sampled.

2.3.3 Biomechanics

Biomechanics concern the force production capabilities of males and females. Biomechanical data cover static and dynamic measures. Static strength is the ability to exert isometric muscle force or to push, pull or lift in a single explosive effort. Dynamic strength measures the ability to perform repeated or continuous movements. Similar to anthropometric data, these strength measures are commonly presented as mean pounds of force and as percentile ranks.

2.3.4 Sensory/Motor

Psychosensory studies usually involve visual and/or auditory detection thresholds, frequency sensitivity and the like. Tracking, hand-eye coordination and control dynamics are topics of psychomotor investigations. Studies concerning vigilance performance may fall somewhere between the psychosensory and psychomotor catagories depending on emphases and tasks chosen for experimental evaluation. Therefore, for the purposes of this review, articles involving vigilance performance are also subsumed under this heading.

2.3.5 Environmental Influences

Environmental influences encompass the performance effects of adaptation to environmental stressors (e.g. thermoregulatory mechanisms), and in women, the effects of the menstrual cycle on these adaptive functions.

2 3.6 Human Engineering

This final category concerns applications oriented research in: tool/clothing design, manual materials handling and workplace design.

2.4 ORGANIZATION

The remainder of this report presents an updated literature review which follows the classification matrix categories listed in section 2.3. The emphasis is on consolidation of the current data base and the identification of areas where results are in conflict, or data is lacking. Following the review abstracted articles are cross referenced by data categories in the classification matrix presented in Appendix I. The actual abstracts are located in Appendix II.

3.0 REVIEW AND EVALUATION

3.1 ANTHROPOMETRICS

Within the last twelve years, there have been two large-scale anthropometric surveys of military women. These include the survey of United States Air Force women in 1968 (Clauser et. al., 1972) and the survey of the United States Army women in 1977 (Laubach et. al., 1977, Churchill et. al., 1977, White, 1979). Surveys of military males include the United States Air Force male personnel in 1963 (Churchill, Kitka & Churchill, 1977), United States Air Force Flying personnel (Clauser et. al., 1967), United States Army males in 1965 and 1966 (White and Churchill, 1971) and United States Army men in 1977 (McConville et. al., 1977). The 1977 United States Army surveys represent the only pair of studies in which both military males and females were measured at the same time and place, by the same investigators and with the same tools and techniques. Table 1 displays forty-one static and dynamic anthropometric measurements taken on the USAF women, U.S. Army women, the U.S. Army men and American Airlines stewardess trainees (Snow, 1975). The measurements included in Table 1 are typical of those that are found in the majority of the surveys cited in this report. The mean age of the group surveyed is also listed in Table 1.

Civilian anthropometric surveys include the Health Examination Survey performed in 1962 (Stoudt et. al., 1970) and the anthropometric survey of American Airlines stewardess trainees shown in Table 1 (Snow and Reynolds, 1975; Reynolds and Allgood, 1975). Both of these surveys have deficiencies which limit their application to military design problems. The Health Examination survey measured weight and ten measures of height, one measure of body breadth, two skinfolds and three body circumferences. The lack of adequate characterization of body size and proportions of the civilian population greatly limits the utility of this study. The airline stewardess

Table 1

COMPARATIVE ANTHROPOMETRIC DATA

Measurement	Airline Stewardesses	USAF Women	US Army Women	US Army Men
Static				
Ankle Circumference	7.93* .40** 422 ***	8.30 .51 1905	8.16 .49 1331	8.55 .56 287
Biacromial Breadth	13.79 .58 422	14.11 .65 1905	14.06 .63 255	15.53 .78 287
Biceps Circumference	9.18 .53 422	10.08 .90 1905	10.19 1.01 255	11.48 1.09 287
Bust Circumference	33.71 1.56 221	35.33 2.24 1905	34.73 2.53 1331	XXXX
Buttock-Knee Length	22.62 .92 423	22.61 1.04 1905	22.78 1.21 1331	23.93 1.[illegible]1 287
Calf Circumference	12.68 .64 422	13.44 .88 1905	13.82 .99 1331	14.10 1.10 287
Chest Circumference-Inspiration	29.38 1.28 406	29.26 1.92 1905	29.46 1.98 1331	36.58 2.60 287
Eye Height-Sitting	29.92 1.08 423	29.02 1.20 1905	28.99 1.36 1331	30.48 1.34 287
Hip Circumference	35.46 1.31 422	37.51 2.37 1905	37.61 2.51 1331	37.46 2.38 287
Neck Circumference	11.76 .46 421	13.29 .66 1905	12.74 .62 1331	XXXX
Popliteal Height	17.12 .83 422	16.16 .73 1905	16.41 .93 1331	17.43 1.07 287

* Mean in inches ** Standard deviation in inches *** Sample size

Table 1 (continued).

Measurement	Airline Stewardesses	USAF Women	US Army Women	US Army Men
Shoulder Circumference	37.61 1.27 422	39.53 2.02 1905	39.52 2.15 1331	43.67 2.42 287
Sitting Height	34.27 1.11 419	33.70 1.25 1905	33.49 1.41 1331	35.17 1.43 287
Stature	65.45 1.91 422	63.82 2.36 1905	64.16 2.57 1331	68.53 2.68 287
Suprasternal Height	52.99 1.71 422	51.97 2.09 1905	52.21 2.22 255	58.18 2.40 287
Waist Circumference	24.50 1.10 394	26.46 2.16 1905	27.86 2.72 1331	30.97 3.17 287
Weight	116.42* 9.39* 422	127.28* 16.59* 1905	132.22* 19.16* 1331	156.02* 24.22* 287
<u>Head/Hand/Foot</u>				
Bizygomatic Breadth	5.07 .17 423	5.08 .23 1905	5.20 .21 216	5.42 .21 102
Foot Breadth	3.4/ .18 422	3.49 .20 1905	3.49 .20 1331	3.90 .22 286
Foot Length	9.40 .41 422	XXXX	9.57 .49 1331	10.53 .52 286
Hand Breadth	2.90 .13 423	XXXX	3.08 .15 1331	3.51 .17 287
Hand Length	6.82 .31 423	7.24 .38 1905	6.87 .35 1331	7.66 .28 287
Head Length	7.29 .25 417	7.25 .27 1905	7.37 .26 1331	7.66 .28 287

* Weight in pounds

Table 1 (Continued).

Measurement	Airline Stewardesses	USAF Women	US Army Women	US Army Men
Head Breadth	5.73 .20 418	5.71 .23 1905	5.75 .21 1331	5.93 .21 287
<u>Skinfold Measurements</u>				
Subscapular Skinfold	.36 .09 407	.51 .19 1905	.55 .24 255	XXXX
Suprailiac Skinfold	.39 .14 376	.78 .28 1905	.66 .28 255	XXXX
Triceps Skinfold	.57 .13 421	.75 .21 1905	.69 .20 255	XXXX
<u>Dynamic or Workspace Measurements</u>				
Functional Arm Reach	31.03* 1.28 422	29.19 1.53 1905	28.02 1.78 300	31.40 1.62 106
Functional Arm Reach, Extended	XXXX	33.01 1.92 1905	32.73 2.29 300	36.17 2.36 106
Functional Leg Length	XXXX	XXXX	42.88 2.28 300	46.67 2.06 106
Overhead Reach, Breadth	XXXX	XXXX	13.69 .76 300	15.16 .81 106
Overhead Reach, Height	XXXX	78.44 3.37 1905	78.42 3.56 300	84.69 3.71 106

* Functional arm reach is measured to the tip of the middle finger instead of the tip of the index finger touching the thumb as is the case in the other three surveys.

Table 1 (continued).

Measurement	Airline Stewardesses	USAF Women	US Army Women	US Army Men
Overhead Reach, Sitting	52.33 1.87 423	XXXX	50.80 2.60 300	53.89 2.30 106
Bent Torso Height	XXXX	XXXX	49.64 3.10 300	54.05 2.86 106
Bent Torso Breadth	XXXX	XXXX	15.79 .80 300	17.61 .88 106
Kneeling Height	XXXX	XXXX	48.05 1.87 300	50.86 1.79 106
Kneeling Leg Length	XXXX	XXXX	25.52 1.37 300	27.31 1.43 106
Bent Knee Height, Supine	XXXX	XXXX	17.91 1.06 300	19.31 1.06 106
Horizontal Length, Knees Bent	XXXX	XXXX	59.42 2.81 300	63.46 2.84 106
Weight, Clothed	XXXX	XXXX	135.86* 17.68* 300	159.10* 21.83* 106
Stature, Clothed	XXXX	XXXX	65.81 2.62 300	70.06 2.46 106
Age	22.08 1.64 406	23.43 6.45 1905	23.1 5.4 1331	XXXX

* Weight in pounds

trainees are highly selected in terms of height, weight and body proportions and therefore do not reflect the dimensions of military females. Table 1 illustrates the disparity between the stewardess trainees and the military women.

A comparison of some of the measures shown in Table 1 reveals that men are generally larger than women on all dimensions, with the exception of hip circumference. On the average, chest circumference for U.S. Army men was 1.85 inches larger than U.S. Army women (bust circumference) and 1.25 inches larger than USAF women. Waist circumference was 3.11 inches larger for men when compared to U.S. Army women. When compared to USAF women, the male waist circumference was 4.5 inches larger. Hip circumference for all three military surveys was almost equal (variation of 0.1 of an inch). The face and hand breadth ranges for the 5th through 95th percentiles do not overlap at all. The results of functional measurements correspond to the findings for structural measures. Generally, the 50th and 95th percentiles of female functional measurements approximate the 5th and 50th percentile values for male measures. These data indicate that there are proportional as well as absolute differences between males and females.

A more complete comparison of these and other military anthropometric surveys was recently undertaken by White (1979) and White and DeSantis (1978). These reports also found men larger in all body measurements except hip circumference. Differences were found to be slightly greater at the 95th percentile rank than the 5th percentile. In conclusion, White states that:

> "...the contrasts in body size and also proportions bewtween army men and women discussed here are of significance, both in the design and sizing of clothing, and in the human engineering of equipment intended for use by both men and women." (White, 1979).

The proportional differences between the sexes were underlined in a report by Robinette et. al. (1979). In this study, male and female subjects from the 1977 U.S. Army survey were matched for height and weight. Dimensions based on the primary sex characteristics such as hip circumference, biceps circumference, and shoulder circumference were significantly different between male and female matched groups. Major differences were also found in hand and foot sizes, indicating that even using samples that are matched on stature and weight, female dimensions at the distal appendages are much smaller than the male dimensions.

Martz (1980) investigated the measurements taken during anthropometric surveys to identify redundant measurements. Different measures of the same body part were identified and collected into groups signifying that body part. Factor analysis by groups was then performed to identify intragroup relationships. If many variables loaded heavily on one factor, the variable with the highest correlation with that factor was selected to represent that group. This process extracted a critical subset of measurements from the initial anthropometric dimensions that would collectively account for the measurements not included. The reduction in the number of measurements employed in a survey can save time and be cost effective without the loss of pertinent information.

3.1.1 Static Dimensions

Structural body dimensions are taken with the individual in a static or fixed position. The clothing worn by the subject is of a brief and fixed nature. Men usually wear swimming or gym trunks while women wear swimming suits (two-piece). The measurements are taken with several types of equipment. The following pieces of equipment were used in the U.S. Army survey of men and women in 1977:

- anthropometers, Siber Hegner #101
- spreading calipers, Siber Hegner #106
- sliding calipers, Siber Hegner #104
- 2-meter steel tapes, K&E Tip-Top Wyteface
- headboard and special guage
- footboard and block
- medical scales
- Lange skinfold calipers

All of these instruments are standard for use in large anthropometric surveys. With the exception of different types of measuring tape, the same instruments were used in the measurement of the USAF women.

A total of 137 static anthropometric dimensions were taken in the USAF survey of 1905 women (Clauser et. al., 1972). The measurements included 5 measures of weight and fat thickness, 30 meausres of body height and length, 26 measures of body girths, 15 measures of body breadths and depths, and 12 measures of body surface distance. In addition, 30 measures of the head and face were taken as well as 3 of the hand and 2 of the feet.

The anthropometric survey of the U.S. Army women (Churchill et. al., 1977; Laubach et. al., 1977) was conducted on 1331 subjects and included a basic set of 69 measurements designated as core measurements. An additional set of measurements were taken on a smaller sample of women and included 28 traditional anthropometric measurements and 31 measurements of the face and head.

The survey of U.S. Army men was taken to complement the survey taken on the U.S. Army women. The measurements included 44 of the 69 core measures, 13 of the 28 traditional anthropometric measurements and the 31 measurements of the face and head. The sample size for the Army men was 287 subjects.

The anthropometry of the hand has been extensively studied by Garrett on United States Air Force men and women (Garrett, 1970; 1971). Thirty-four measurements were taken on the hand in a straight-hand position and ten measurements were taken with the hand in a relaxed position. The results for men and women are compared in a later publication so the differences between the sexes can easily be discerned (Garrett, 1971). Static hand measurements were also included in the 1977 survey of U.S. Army men and women.

3.1.2 Dynamic Dimensions

Dynamic or functional anthropometric measurements represent body positions that result from motion. The functional body measurements taken in the anthropometric surveys describe ranges of leg, arm, and hand movements.

Functional arm reach, functional arm reach (extended), and overhead reach height were all measured on the USAF women and U.S. Army men and women. Eleven other functional dimensions were measured on the U.S. Army samples. All fourteen functional dimensions appear in Table 1.

Kennedy (1978) measured the reach capability (sitting) of 30 men and 30 women at 15° intervals in both vertical and horizontal dimensions. Maximum and minimum values were established for each measurement. Kennedy found that major factors affecting reach capability were arm length, torso size, and movements of the shoulder, elbow, and waist. The reach capability of women was primarily inhibited by shorter arm length and larger fatty tissue layers which restricted mobility. Women were found to have greater angular reach to the rear, indicating greater shoulder mobility in women.

Although the data presented in this report were taken from seated operators only, it is probably safe to infer that sex-related differences in reach capabilities would be at least as great in standing operators. Data from the 1977 Army anthropometry survey lends some support to this inference. Although measures and methods differed in these surveys from those of Kennedy (1978), the trends in the data were similar, as can be seen in Table '.

Stoudt (1973) correlated certain static anthropometric measurements with functional arm reach and found that stature, elbow-fingertip length and shoulder-elbow height were highly correlated with functional reach. These structural measurements can serve as predictors for functional arm reach when coupled with regression analysis.

Garrett (1971) measured the hands of U.S. Air Force males in seventeen functional positions. This report presents the results in a tabular format along with a graphic illustration of the measurement. This study exhausts the various positions the human hand can take while working. It is unfortunate though, that corresponding functional data for women is not available.

3.1.3 Evaluation

The data base formed by the 1968 USAF survey and the 1977 US Army survey survey include sufficient structural dimensions, measured on an adequate sample size, to be useful for most military clothing design and many equipment and workspace design applications. This data, however, has only been collected on Air Force and Army populations. Cross validation studies with a modest, representative sample of Naval personnel should probably preceed any large scale Naval design efforts based on this data base.

Although many functional dimensions are represented in these surveys, additional functional anthropometric data will probably be needed for specific design problems. For example, the reach dimensions described in the Army survey are of limited use to the designer because they describe a specific reach to a single point rather than characterizing the reach envelope by 15° intervals as Kennedy (1978) did in his recent study. A step toward filling this gap would be provided by a study using the method of Kennedy (1978) on a large sample of military males and females in standing positions. While exhaustive data exists on male and female structural hand anthropometry (Garrett, 1971), functional hand data only exists for men. This gap too must be filled to provide a more complete data base for use by designers.

Data which describes various subsets of the American civilian population is all but non-existant. Aside from the population specific survey of American Airline stewardess trainees (Snow, 1975) and the incomplete information provided by the Health Examination survey (Stoudt et. al., 1970), no data exists which approaches generalizable applicability for use in the design of civil systems.

3.2 BIOMECHANICS

Muscular strength increases in men and women until approximately 30 years of age. After thirty, strength tapers off at varying rates according to muscle groups involved and the sex of the individual. The strength of women generally peaks at the age of thirty and then decreases thereafter while the strength of men peaks in the middle to late twenties. The rate of decrease is faster in women than in men (Roebuck et. al., 1975). Overall, at age 50, women have only half the strength of their male cohorts while at age 30, women have two-thirds the strength of men.

Strength differences which occur between the sexes have much of their origin in the physiological differences of men and women. Physiological variables such as the fitness of the cardiovascular system, heart rate, sweat rate, vital capacity, aerobic power, stature, and weight contribute to the overall strength differences found between the sexes (Macnab et. al., 1969). Printy (1979) provides an overview of exercise physiology and its relationship to strength differences in men and women.

Body build is related to strength and working capacity. Significant, but generally low, correlations are found between strength and body circumferences, lengths, and weights. Correlations between anthropometric dimensions, physiological variables and strength values are usually too low to have practical predictive value (Laubach, 1976 a and b).

Strength values are in general valid only for the circumstances under which they are obtained. Laubach, Kroemer, and Thordsen (1972) concluded in their article concerning static strength measurements in air raft that "...if data are desired on forces exertable in other locations or directions, i.e., under other conditions, than those previously investigated, the information generally has to be gathered experimentally rather than computed from other force data."

3.2.1 Static Strength

Static or isometric strength is defined as the single maximum force exerted by the subject in a fixed position (Laubach, 1978). During the contraction phase, the length of the involved muscle does not change. There is no limb motion accompanying the force production (Kroemer, 1969).

Laubach (1976a) reviewed the literature concerning the muscle strength of men and women. The results appeared in the NASA Anthropometric Source Book, Volume I. In 1976, Laubach (1976b) recruited 31 women from the University of Dayton, Dayton, Ohio (n=28) and from the Aerospace Medical Research Laboratory (n=3) for a muscular strength study. The results were then compared to two other studies on males (push forces - Kroemer, 1969; upper and lower extremity cable tension strengths - Laubach and McConville, 1969). Laubach's report agreed with prior findings that "overall" female strength was about two-thirds that of men, although the range of this figure was from 35% - 86%. Strength in the lower extremities was found to be 71.9% that of men while strength in the upper extremities was 59.5% of men's. A large discrepency was found in grip strength, where female values were approximately one-half the male values.

A second major survey of static strength in women completed since the Ayoub (1978) literature review is the U.S. Army survey of Army women (Churchill et. al., 1977). Nine isometric strength tests were made twice on 349 female subjects, yielding both mean and peak strength values. A comparable sample of Army men (n=102) served as subjects for the same series of tests to provide comparative strength values. Table 2 displays the results for the nine isometric strength tests. The values are reported in kilograms as are the mean and standard deviation of each test. Table 3 gives the 5th and 95th percentiles for each strength test. This illustrates the variation within each sex and between the two sexes. In seven cases, involving the Standing Two-Handed Pull: 100 cm level (2 cases), Standing Two-Handed Push: 150 cm level (4 cases), and the Seated-Centerline Two-Handed Pull: 38 cm level (1 case), the 95th percentile value for women is less than the 5th percentile value for men. The significance of these findings is that the male and female distributions for these strength measurements do not overlap. One explanation for these

Table 2. Isometric Strength Values of U.S. Army Women and Men.

Strength Measure	Mean Force 1	Mean Force 2	Peak Force 1	Peak Force 2
Standing Two-Handed Pull: 38 cm Level	56.6(15.2)* 102.7(20.6)**	58.3(15.1) 103.9(19.1)	63.1(15.9) 111.2(20.8)	65.1(15.2) 113.9(18.1)
Standing Two-Handed Pull: 50 cm Level	55.7(16.3) 102.2(18.2)	58.8(16.0) 103.2(18.1)	62.2(16.8) 112.1(19.5)	65.3(16.4) 112.7(18.7)
Standing Two-Handed Pull: 100 cm Level	31.0(8.1) 66.6(14.7)	30.7(8.1) 66.0(15.0)	34.6(8.5) 72.4(15.0)	34.6(8.6) 72.4(15.9)
Standing Two-Handed Push: 150 cm Level	25.9(7.1) 67.2(17.9)	26.0(7.3) 68.8(19.8)	29.6(7.8) 74.5(19.1)	29.9(7.9) 75.9(20.5)
Standing One-Handed Pull: 100 cm Level	19.0(5.8) 41.6(13.1)	18.8(6.1) 42.3(12.8)	22.2(6.4) 47.6(14.9)	22.1(6.8) 48.9(14.4)
Seated-Centerline One-Handed Pull: 45 cm Level	22.6(9.0) 45.4(13.1)	23.1(9.1) 47.6(14.2)	26.7(10.2) 52.0(15.0)	27.1(10.1) 53.2(15.2)
Seated-At Side One-Handed Pull: 45 cm Level	21.4(7.2) 39.3(11.9)	21.8(7.1) 42.3(11.4)	25.1(8.2) 45.3(13.1)	25.6(7.9) 47.9(12.2)
Seated-Centerline Two-Handed Pull: 38 cm Level	47.6(16.0) 89.7(20.1)	49.2(16.4) 90.5(18.4)	53.7(16.7) 98.2(20.3)	55.5(17.2) 100.0(18.5)
Seated-Centerline Two-Handed Pull: 50 cm Level	39.8(13.0) 77.5(17.5)	40.8(13.2) 77.8(16.1)	45.2(13.9) 85.3(18.9)	45.9(14.3) 87.1(18.2)

*Mean (Standard Deviation) for U.S. Army Women (kilograms)

**Mean (Standard Deviation) for U.S. Army Men (kilograms)

Table 3. Percentile Values of Isometric Strength Tests of U.S. Army Women and Men.

Strength Measure*	Mean Force 1		Mean Force 2		Peak Force 1		Peak Force 2	
	5th	95th	5th	95th	5th	95th	5th	95th
Standing Two-Handed Pull:	32.3	83.0	33.8	83.4	37.6	90.3	40.5	90.6
38 cm Level	70.3	138.1	75.2	137.4	76.5	146.4	86.1	146.6
Standing Two-Handed Pull:	29.4	83.0	33.3	85.7	34.6	89.6	38.2	92.3
50 cm Level	74.5	134.[illegible]	77.3	136.8	82.8	147.0	84.7	145.8
Standing Two-Handed Pull:	18.8	45.2	18.9	45.1	21.9	49.4	22.2	50.3
100 cm Level	45.3	94.9	43.6	93.1	51.4	100.2	48.1	100.8
Standing Two-Handed Push:	15.3	38.1	15.6	38.7	18.3	43.1	19.2	43.8
150 cm Level	41.7	99.8	40.8	103.7	48.0	108.4	48.2	111.6
Standing One-Handed Pull:	10.4	28.9	10.5	28.7	13.3	32.4	13.4	32.9
100 cm Level	21.7	63.8	21.9	64.0	26.4	73.8	26.2	72.8
Seated-Centerline One-Handed Pull:	10.8	39.7	10.3	40.0	12.9	45.7	13.0	45.9
45 cm Level	21.3	66.4	23.2	69.2	27.1	74.7	27.9	77.3
Seated-Side One-Handed Pull:	11.1	34.4	10.8	34.0	13.7	40.3	13.6	39.5
45 cm Level	20.4	57.7	24.4	61.5	24.4	66.5	27.8	67.2
Seated-Centerline Two-Handed Pull:	23.3	75.8	24.6	[illegible]8.6	28.0	83.3	29.0	65.8
38 cm Level	59.3	124.5	60.7	119.5	68.0	135.0	71.3	131.6
Seated-Centerline Two-Handed Pull:	20.0	62.8	20.8	64.4	24.2	67.8	24.1	71.1
50 cm Level	49.8	107.3	53.5	107.3	57.4	119.5	60.7	121.2

*Measurement recorded in kilograms.

results is that the upper body strength of women ranges from 35% to 79% of the strength of men with an average mean percentage of 55.8% (Laubach, 1978). Two of the tests (Standing Two-Handled Pull: 100 cm level and Standing Two-Handed Push: 150 cm level) focus upon the upper extremities with the placement of the handle in such a position to minimize the input of the leg and back muscles.

Table 4 compares the results of handgrip strength tests from five different sources. The mean, standard deviation (except Konz, 1978) and sample size (except Garrett, 1971) were given for grip strength. As one can see, there is a wide range of means reported with the grip strength of women being considerably lower than the grip strength of men. The great variation in sample size and the methodological differences of these studies may account for this wide range of variation. A number of studies have shown little correlation between grip strength and other measures of body strength (Laubach, Kroemer and Thordsen, 1972).

3.2.2 Dynamic Strength

Dynamic strength involves the same forces measured as static strength, but the movements are repeated in a continuous manner. Measurement of dynamic strength does not imply a large surge of strength as in static strength, but is measured as a function of endurance such as how long a subject can repeatedly lift a specific item or how far an individual can run. Dynamic strength combines the ability of the subject to exert the force required to overcome a given resistant force with the ability of the subject's cardiovascular system to deliver sufficient quantities of oxygen and nutrients to the muscles and remove the toxic byproducts of muscular activity.

Investigators have followed two basic approaches for analyzing the dynamic strength required for a task. If the task only involves several movements as in lifting or carrying, then the task

Table 4. Grip Strength Values for Men and Women.

	Mean	Standard Deviation	Sample Size
Women USAF (Clauser et al., 1972)	29.89*	5.70	1905
Women (Nordgren, 1972)	29.80	6.0	23
Women (Laubach, 1976)	26.4	3.8	31
Women (Konz, 1978)	27.4	***	8
Women (Asmussen & Heeboll-Nielson, 1961)	37.5	5.9	250
Men USA (Garrett, 1971)	48.12	8.51	***
Men (Backlund & Nordgren, 1968)	55.0	8.6	23
Men (Laubach & McConvolle, 1969)	50.4	8.8	77
Men (Konz, 1978)	55.0	***	8
Men (Asmussen & Heeboll-Nielson, 1961)	55.9	9.0	360

*Values are expressed in kilopounds. (1 kilopound = 2.2 pounds).

can be recreated in a controlled environment to measure the strengths. The other approach involves several basic tests of dynamic strength (pull-ups, sit-ups, lifts) and extrapolating the subject's ability to perform the task from the laboratory tests.

Manual materials handling in industry is an area of job evaluation where the first approach is appropriate for measuring dynamic strength. Snook (1970), Snook and Ciriello (1974), and Shannon (1980b) have conducted surveys of manual material handlers in civilian and military situations. The results of these investigations are discussed in the manual materials handling section of this report, 3.5.2.

Maximal and submaximal work capacity differences in men and women were investigated by employing three different experimental tests of work capacity (Macnab et. al., 1969). Treadmill walking, bicycle ergometer pedalling, and progressive step testing comprised the battery of tests administered to twenty-four men and twenty-four women. Results indicated that the male scores in all the tests exceeded the female scores beyond the 0.01 level of significance. Men had a greater work capacity than women.

Bernaurer and Bonanno (1975) investigated the use of a field test battery (including dynamic strength) to predict the success of an individual in the completion of pole climbing school. Static strength (static arm strength and grip strength) and dynamic strength (dynamic arm strength, sit-ups, pull-ups, sit-ups + five pounds) were both found to be significant predictors of successful pole climbing performance. Pull-ups were found to be the most effective predictor of successful performance.

Wardle and Gloss (1977) employed treadmill walking at different workloads (light, medium, heavy, very heavy) to investigate how much strenuous work women could complete. Eight females served as subjects in this study. The results indicated that women could complete 100% of the light work, 95% of the medium work, 97.5% of the heavy work, and 92.1% of the very heavy work. The correlation between heart rate and energy expenditure was found to be significant.

Hanson and Nedde (1974) exposed eight sedentary females to an eight month physical training program. The subjects' work capacity was evaluated before and after this regimine with a bicycle ergonometer and treadmill walking task. Results indicated greatly increased work capacity as evidenced by declines in oxygen utilization, carbon dioxide production and heart rate. The authors concluded that the trainability of non-athletic females does not differ from their male counterparts. Similar results were found by Wilmore (1974). In this study, significant increases in dynamic strength were found in males and females as a result of a ten week physical training program. Women exhibited the greatest relative increase in bench press and leg strength.

3.2.3 Correlation of Static and Dynamic Strength

The relationship between static and dynamic strength is quite important to the designers of workspaces. Design engineers would like to be able to reliably predict the performance of individuals on tasks involving dynamic strength from a measurement of static strength. Isometric strength is easily measured in laboratory situations and since there is no motion involved, the investigator avoids the complicated physics that accompany movement (Kroemer, 1969). The chosen experimental task however, may have limited application to the "real" world of occupational tasks. Laubach (1978) includes a review of the literature concerning the correlation of static and dynamic strength. Basically, the conclusions are split as to the reliability of predictions of dynamic strength from measures of static strength. Over the total body, the correlation appears to be relatively low, but for specific muscle groups, the correlation can be as high as 0.83. This correlation coefficient was computed for static and dynamic strengths of the right elbow flexor muscles (Carlson, 1970). The study done by Bernauer and Bonanno (1975) on the relationship of performance on a field test battery and actual pole climbing combined both static and dynamic strength measures. The relationship of static arm strength and dynamic arm strength yielded a correlation coefficient of 0.63 while static strength correlated with sit-ups to a higher degree (r=0.71). Grip strength and dynamic arm strength were found to be related to a significant degree as demonstrated by the correlation coefficient of 0.74. The sample size for this part of the study was 20 individuals, half male and half female. Grip strength was found to be ineffective for discriminating between successful and unsuccessful completion of pole climbing school while dynamic arm strength was one of the most discriminating indicators of successful performance.

3.2.4 Predictive Models

A lifting capacity predictive model was developed by Mital, et. al. (1978) based on various operator and task variables using a balanced incomplete block factorial design. The dependent variable was the maximum acceptable weight of lift plus body weight. Body weight was added to the weight lifted since during any lifting activity, a person also lifts a part of his or her body. The independent variables were sex, weight, arm strength, age, shoulder height, back strength, abdominal strength, and dynamic endurance. These eight variables explained 85% of the variance in the data. The sex code explained half of this total variance. The model predicts the combined weight (body weight plus acceptable weight lift). The maximum acceptable weight of lift can thus be determined for an individual by subtracting body weight from the predicted value.

A factor analysis was utilized by Shannon (1980a) to construct a biomechanical model using a group of independent variables (weight of lift, time between lifts, time of measure (morning or afternoon), height range of lift, and sex). The dependent variables were 15 reactive forces and torques on the joints and links of the body. Eight males and eight females comprised the sample.

This analysis sorted out the interdependence between the 15 dependent variables and reduced the size of subsequent analyses. Results indicated that five factors adequately accounted for angular displacement and resultant forces in the x and y planes from both a force platform and inertial force at the hands (as measured by stroboscopic photography).

3.2.5 Evaluation

The strength differences between men and women were covered in four research reports (Macnab et. al., 1969; Bernauer and Bonanno, 1975; Laubach, 1976; Churchill et. al., 1977). All of these articles found significant differences in strength for the two sexes. The Churchill (1977) report was the only study that sampled from a population that is analagous to the women of the Navy. Figure 1. from the Laubach study is included in this report to summarize the results of studies on strength differences for men and women. Wardle and Glass (1977) investigated the work capacity of women only and found that women were capable of completing very heavy work as measured by treadmill walking. Three comprehensive review articles of sex differences in strength capacities were presented (Laubach, 1976; Laubach, 1978; Printy, 1979).

The most apparent limitation in the applicability of currently available biomechanical data involves its task and population specificity. Methodological variations between studies also tend to restrict the utility of some data. The wide range of values reported across studies (as typified by the grip strength results shown in Table 4), may largely be a result of non-standardized biomechanical methodologies, and population specific force production capabilities.

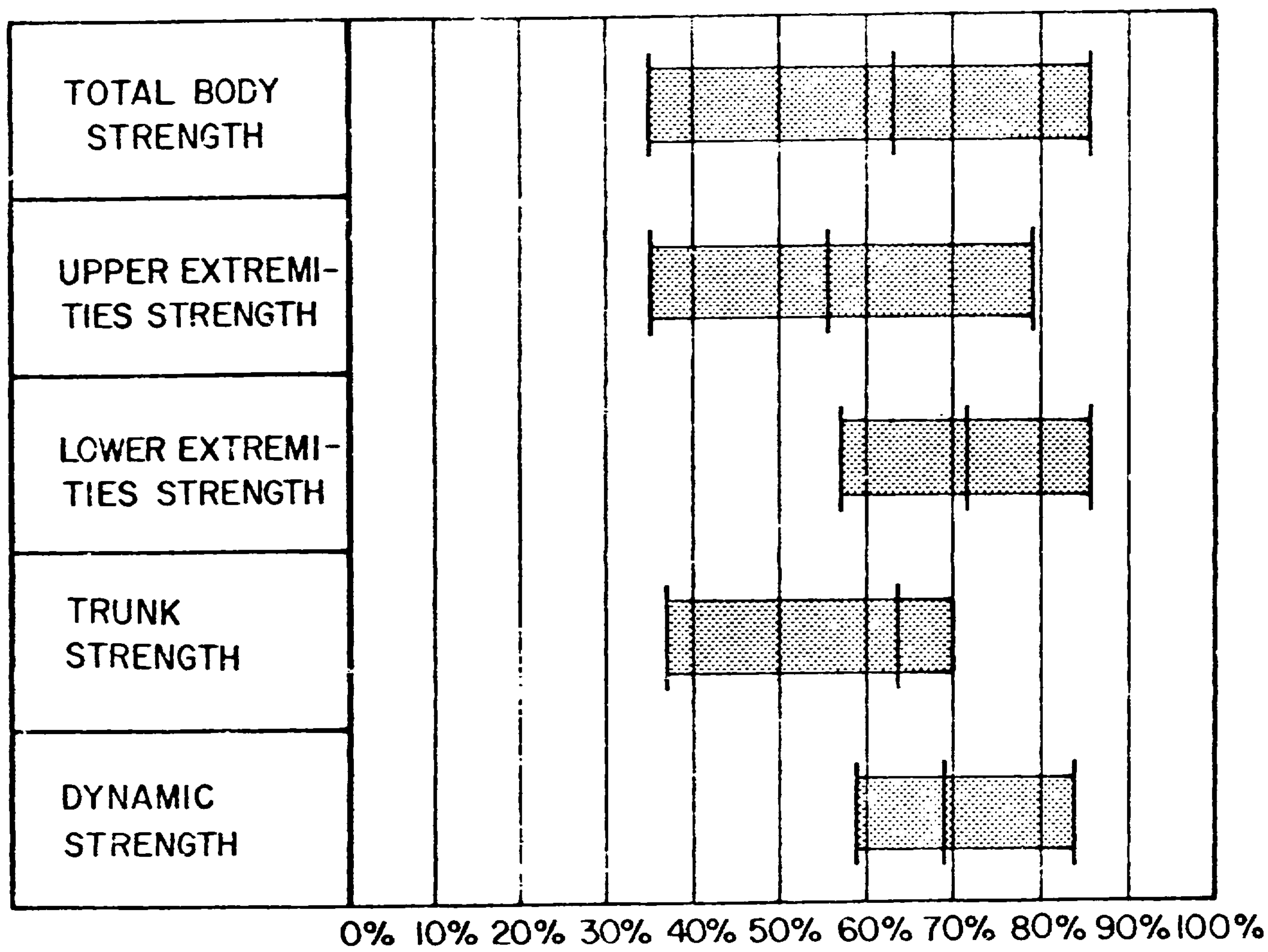

Figure 1. The range and average mean percentage differences in muscle strength characteristics between women and men.

A less tangible problem involves the potential equivocation between work capacity and work performance. In other words, laboratory derived data on maximal capabilities may not sufficiently predict self-paced worker performance. This may be especially true in dynamic, repetitive tasks.

More work is needed to formulate biomechanical models that reliably predict worker performance in a variety of physical tasks. Correlations between static and dynamic strength measures are also in need of further examination to extend the utility of biomechanical data for design applications.

3.3 SENSORY/MOTOR

3.3.1 Vision and Audition

Sex differences in vision and audition have been demonstrated in a number of recent studies (McGuinness 1972; 1974; 1976; McGuinness and Lewis 1976; Braybn and McGuinness 1979). Studies of audition revealed that women were more sensitive to loud noises than men (McGuinness, 1974). Threshold data from male subjects were negatively correlated with loudness estimation while female threshold data showed a positive correlation with loudness estimates. The author suggests that hereditary sensitivity rather than cultural response bias was responsible for these sex differences in hearing.

McGuinness (1976) tested sex differences in four visual perception tasks. Experimental tests included acuity, threshold for four field positions, visual persistence and a measure of comfortable brightness. Subjects also completed five personality questionnaires. Results indicated that males had better acuity than females. Females demonstrated greater visual persistence under darkened conditions, while no sex differences in persistence were found in lighted conditions. Females tolerated brighter levels of illumination than males. Additionally, correlations between this data and data gained from the same subjects who participated in an earlier study on auditory preferences (McGuinness 1974) showed a significant positive relationship between comfortable levels of illumination and sound volume.

Sex differences were also found in three areas of visual persistence (McGuinness and Lewis, 1976). In this Ganzfeld experiment, males showed less loss of sensation to red and green light than females. Females held the sensation of red significantly longer than green, while there was no difference for males. Males had a far greater persistence of color overall and a greater variety of visual experience (colors fading in and out, complementary colors to stimulus colors) than females. Females were found to be generally more responsive to colors from the long wave region of the spectrum.

Braybn and McGuinness (1979) found sex differences in visual perception as a result of spatial frequency and stimulus orientation. Females demonstrated superior resolution for the three lowest frequency stimulus gratings (.4, .6, .8 cycles/deg) while males' resolution was best for the highest frequency gratings (8.0, 9.0, 10.0 cycles/deg). This effect was more pronounced for vertical and oblique orientations than it was for horizontal orientations.

The authors apply these findings to potential implications for pattern recognition. It is suggested that females, with primary sensitivity to low frequency information, may take an "integrative" approach to pattern analysis while males may take a "segragative" approach, attending primarily to high frequency information and isolating objects of interest from the field. Further investigation is needed to explain the finding that the sex difference exhibited in the frequency domain was considerably weaker for horizontal gratings.

3.3.2 Motor Skills

Kipnis and Kidder (1977) found that men and women demonstrated higher levels of task learning ability of two psychomotor tasks (pursuit rotor and labyrinth) when they believed the majority of their sex performed well on the tasks they were learning and there were no evaluative comments made on their performance. Women were found to put more time in on practice than men and to perform best in a practice situation rather than a test situation. The report focused on men's and women's perception of achievement, performance evaluation, and methods of self-evaluation rather than the actual performance differences.

Considerable differences between men and women were found for mechanical aptitude. Polit, Nuttal, and King (1979) determined in their review of women in industrial careers that men scored higher than women on tests of mechanical comprehension, mechanical aptitude, and mechanical assembly. The authors concluded that women have had a limited opportunity to acquire mechanical skills.

3.3.3 Vigilance

The sex differences of vigilance performance were investigated by Waag, Halcomb, and Tyler (1973) and Thackray, Touchstone, and Bailey (1978). Waag et. al. (1973) found that there were significant sex differences for monitoring a simple visual vigilance task. Females detected fewer signals and tripped more alarms. In a review of medical literature for the employment of women in the Canadian military Haakonson (1978) found no sex differences in vigilance performance on a simple motor task.

Thackray et. al. (1978) found no significant main effects for sex in monitoring a simulated radar task. Though the results are seemingly in conflict with those of Waag et. al. (1979), the two experiments were found by Thackray to have different procedural requirements. The simple vigilance task utilized by Waag et. al. and the radar task employed by Thackray et. al. share a requirement for basic alertness. However, the radar task also requires scanning for successful task performance. There may be other skills and abilities that set the two tasks apart.

3.3.4 Evaluation

The research reviewed here reveals consistent differences in visual biases between males and females. Gender specific biases are shown in wavelength (for persistence) frequency (for resolution) and amplitude preferences. The effects of stimulus orientation on resolution are not adequately explained by the current data.

Future research is needed which explores the relationship between gender based visual system differences and pattern recognition theory. Braybn and McGuinness (1979) suggest several hypothesis in this area which merit a closer look. Performance oriented research in this area should focus on exploiting male/female visual system differences to determine optimal modes of information display for tracking, detection and discrimination tasks for males and females.

The paucity of research which addresses sex differences in motor skills does not allow even the most general conclusions to be drawn. More work is called for in all areas of gender based psychomotor experimentation.

The conflicting results reported by Waag et. al. (1973) and Thackray et. al. (1978) in their studies of vigilance performance suggest a need for clarifying research. Experimentation is needed to isolate the specific task variables which led to decreased female vigilance performance in the Waag et. al. investigation, while ro sex differences were found in the task employed by Thackray et. al.

3.4 ENVIRONMENTAL INFLUENCES

The environment an individual works in plays a crucial role in determining the performance of that individual for a given task. Under particular consideration in this report are the environments that women aboard ship might encounter in different working situations, i.e. extreme thermal conditions, vibration and motion. As of this writing, articles concerning sex differences in the areas of motion and vibration have not been found. The subjects for experiments dealing with the effects of motion and vibration aboard ship have soley been male. Therefore, the remainder of this section will focus on sex differences in thermoregulation.

Morphological differences exhibited by men and women greatly affect the ability of the two sexes to produce and dissipate heat. Women have smaller body sizes and have a greater percentage of their total body weight as body fat when compared to men. The body surface area or the surface area-to-mass ratio is larger for women (Burse, 1979). These two morphological conditions of females cause a double disadvantage for cold adaptation. Fatty tissue is not metabolically active so that when women perform hard muscular work, they have less fat-free "active" body mass to draw upon. The body fat of women is distributed evenly over the body (except for the extremities) providing greater body insulation when vasoconstricted. The greater surface area combined with the distribution of body fat gives the female a relatively larger peripheral heat sink when compared to the male.

3.4.1 Cold Stress

The smaller muscle mass of women places tham at a disadvantage in extreme cold since the muscles serve as "generators" of body heat. The layer of subcutaneous fat does retard core cooling in women more than in men, but does not protect the extremities such as the hands and feet in a cold stress situation. Women have approximately 25% more fat on their legs than men affording the women an advantage for swimming in cold water (Burse, 1979).

Le Blanc et. al. (1978) examined the response of men and women to local cooling with the cold hand test and the cold face test. At the beginning of the tests, males and females had the same responses, but at the end of the tests, women had significantly lower blood pressure values than the men. The difference persisted during the two minute recovery period following the test. The authors concluded that the cardiovascular functions of the female subjects were depressed following exposure to the cold environment.

3.4.2 Heat Stress

The larger surface area-to-mass ratio of women proves to be an advantage under hot environmental conditions. The ratio of evaporatively cooled surface to metabolically active tissue in females is larger than in males (Burse, 1979). The subcutaneous fat layer serves as an insulator and provides a proportionally larger peripheral heat sink for heat dissipation. Additionally, the increase in metabolism induced by the heat is proportional to the body mass, so the thermally induced increase in metabolism is less in women than in men (Paolone et. al., 1978).

The smaller muscle mass of women has a proportionally larger amount of fat to support when the body is in motion. The blood volume is proportional to the lean body weight rather than the total body mass leaving women with a smaller blood volume (Burse; 1979). Fortney and Senay (1979) observed through experimental testing in two thermal environments that women have an increased blood volume following acclimation to the hot environment. The women still exhibited cardiovascular strain when performing hard work, but the strain was reduced when compared to the performance of the women subjects prior to acclimatization.

The increased amount of perpheral tissue in women allows a greater fraction of total blood volume to be shunted to the peripheral heat sink for heat dissipation. At the periphery, plasma water is withdrawn from the plasma and is excreted as sweat. This process further reduces the already restricted blood volume of women (Burse, 1979).

Men and women differ in their responses to heat stress. Women maintain the same or slightly higher core temperature than men in moderate dry or wet heat situations (Bittel and Henane, 1975) and in brief exposures to severe dry heat (Shoenfeld et. al., 1978). Shapiro et. al. (1980) found that women had a lower rectal (core) temperature in a mild-wet and hot-wet climates while the core temperature of men was lower in hot-dry environments.

The skin temperature of women was found to be higher than men's by Bittel and Henane (1975) for a hot environment while Shapiro et. al. (1980) found women had a lower skin temperature in mild-wet and hot-wet environments. In a hot-dry climate, women had a higher skin temperature. The generally higher skin temperatures of women diminish the core-to-skin temperature gradient available for heat transfer and eventual dissipation. The diminished gradient results in lower heat conductance which averages only 65-88% that of men (Bittel and Henane, 1975; Shoenfeld et. al., 1978). Heat storage for women followed the same pattern found by Shapiro for skin temperature. In a hot-wet or mild-wet environment, heat storage was lower for women than men while equal or slightly higher than men for the hot-dry climate. These findings are in direct opposition to the results of Bittel and Henane (1975). The sample sizes are similar for men and women, but in the Bittel and Henane study, no work was performed while the subjects were exposed to the different thermal environments.

Under comparable heat stress levels, men were found to have higher sweat rates than women (Bittel and Henane, 1975; Paolone et. al., 1978; Shoenfeld et. al., 1978; Fortney and Senay, 1979; and Shapiro et. al., 1980). Shapiro et. al. (1980) found that men and women had equal sweat rates under hot-dry environmental conditions though Shoenfeld et. al. (1978) found that men had significantly higher sweat rates than women under extreme hot-dry conditions (Shapiro-49^{O}C, 20% rh and 54^{O}C, 10% rh as opposed to Shoenfeld-80-90^{O}C, 3-4% rh).

Paolone et. al. (1978) examined the ratio of evaporative weight loss to increase in core temperature as measured by the rectal temperature. The authors found that under neutral conditions, men lost slightly more body water than women (ratio values, men-0.27 and women-0.25). When the subjects were placed in a warm environment (32^{O}C, 50% rh), the ratios increased to 0.33 and 0.27 for the men and women, respectively. Both increases were due to the disproportionate loss of body fluids relative to the increase in core temperature. When the temperature was increased to 40^{O}C, the ratios dropped to 0.29 for the men and 0.26 for the women. The drop probably indicated the failing of the thermoregulatory mechanism. It was interesting to note that the ratio fell more for the men than for the women. The authors suggested that the sweat rate of women was more "adjustable" in response to the required heat loss (Paolone et. al., 1978).

Shapiro et. al. (1980) concluded that women were able to tolerate wet heat, whether mild or hot, better than men. The women displaced lower deep body and skin temperatures and stored less heat. The sweat rate of women was lower causing less dehydration than was found for the men. Under hot-dry conditions, men were found to have an advantage over women due to their lower deep body temperature and lowered skin temperature. The men also had a lower heat storage value as well as a lowered heart rate.

Bell (1978) designed an experiment to test the effects of heat and noise stress on the performance of a pursuit rotor task and secondary numerical task. Subjects were seventy-two male and 72 female undergraduates. No performance decrements were found due to heat or noise stress on the primary task. Significant main effects of heat and noise stress were found on the secondary (numerical) task. No interaction effect between the two stressors was found. The sex of the subject was not found to be a significant factor in performance under either heat or noise stress.

3.4.3 Menstrual Cycle Effects

The effects of the menstrual cycle on heat stress responses has been studied intensively by many investigators over the last twenty years (Wells and Horvath, 1973, 1974; Bittel and Henane, 1975; Shapiro et. al., 1980). For a comprehensive review, see Burse (1979). The effects of the menstrual cycle on the ability to tolerate heat in either a wet or dry environment have been minimal. The experiments performed by the authors listed above were designed to test the female subjects for heat tolerance at different phases of the cycle. Bittel and Henane had the women in a motionless situation while Shapiro et. al. (1980) and Wells and Horvath (1973, 1974) had the women exercising on a treadmill or an ergometer. In either case, no significant menstrual cycle effects were found. The use of oral contraceptives also failed to affect thermoregulatory processes (Shapiro et. al., 1980).

3.4.4 Evaluation

Men and women react to a neutral environment in the same physiological manner. When the heat is increased, men rely more on sweating as a cooling mechanism while women seem to have a greater reliance on the cardiovascualr system (Paolone et. al , 1978). Women tolerate hot-wet and mild-wet climates better than men while men tolerate the hot-dry climate more effectively. There are two possible explanations for these observations. One is that the higher surface area-to-mass ratio in women may provide a morphological advantage by allowing greater heat dissipation through the peripheral heat sink. Women also seem to have a more effective peripheral feedback from skin wettedness, which suppresses excessive sweating in humid conditions. While the literature indicates reliable sex differences in thermoregulatory processes, there is evidence that females can successfully overcome cardiovascular strain due to exercise in a hot-dry environment through adaptation, (Fortney and Senay, 1979).

Aside from the small sample study performed by LeBlanc et. al. (1978), no literature was found which focused on gender differences in cold tolerance. This is surprising considering the potential for morphological effects noted by Burse (1979).

Of note is the fact that the bulk of the literature reviewed here focused on heat/cold tolerance as measured by sweat rate, core temperatures, skin temperature, etc. Aside from the single study by Bell (1978), a body of literature which defines performance differences resulting from thermoregulatory processes is lacking. The "real world" significance of findings of reliable differences in thermoregulatory mechanisms between the sexes depends on the way these differences are manifested in task performance.

The absence of literature concerning male/female performance under different conditions of vibration and motion was noted earlier. The pervasiveness of these factors aboard ship clearly suggests that more study is needed in this area.

3.5 HUMAN ENGINEERING

Literature reviewed in this section concerns applications oriented human engineering research in clothing/tool design, manual materials handling and workplace/job design. The focus is on the impact of anthropometric, biomechanical and physiological gender differences discussed earlier on design parameters and job performance.

3.5.1 Clothing/Tools

A review of past anthropometric surveys of military women was undertaken by the Anthropology Research Project for the Navy Clothing and Textile Research Facility in Natick, Massachusetts to establish sizing programs for U.S. Navy women's clothing (McConville, Tebbetts, and Churchill, 1979). The key dimensions of bust circumference, bustpoint-to-bustpoint breadth, and neck-to-bustpoint length (for garments above the waist) and waist circumference combined with crotch length (for garmets worn on the lower torso) were selected to run a sizing analysis. The resulting analysis indicated that the sizing program did not satisfactorly cover the subjects measured in the study and would be similarly deficient for the Navy women population. The authors suggested selecting different key dimensions and sizing intervals based on the actual distribution of body size variability found in the previous anthropometric surveys. A limited-objective survey of U.S. Navy women was also proposed.

Female sizes have been traditionally derived by viewing the female body as a scaled-down version of the male body, with the 50th and 95th percentile values of female anthropometric measurements corresponding to the 5th and 50th percentile values for males. This oversimplified view of female anthropometrics was not supported by the proportional differences found between the sexes in the 1977 Army survey (Robinette et. al., 1979a). Additionally, use of the 5th to 95th percentile values of any particular anthropometric measurement leaves 5% of the population (2.5% on either tail or end of the distribution) unaccounted for in clothing sizes. Robinette and Churchill (1979) have suggested using regression methods to provide dimensional data which reliably characterize the sizes found at the extremes of the distribution. Unlike the percentile values, the regression values are additive and can produce a model in which all parts of the body are proportional.

The psychomotor performance of women in cold weather clothing designed for women versus clothing designed for men was evaluated in an experiment by Bensel, Bryan, and Millian (1977). The tasks of body flexibility, rate of movement, psychomotor coordination, and manual dexterity formed the test battery which was performed under ten clothing conditions (5 men's Arctic clothing; 5 women's Arctic clothing). The results indicated that certain features of women's Arctic clothing contributed to higher performance levels for females than those attained in men's clothing. The men's clothing ensemble restricted certain aspects of psychomotor performance, particularly flexibility of the body. The women's clothing ensemble was rated more favorably than the men's ensemble by the female subjects with specific reference to the relative bulk of the clothes, waist flexibility, and the weight of the clothes.

Richard Bruno (1979) evaluated male field clothing ensembles worn by fifteen female soldiers of the U.S. Army. Also evaluated was the chemical-biological protective clothing designed for men but worn by women. After completing a human factors evaluation of the fit and compatibility of male clothing for female Army personnel, it was recommended that female uniforms be designed with the same type of material as male's clothing. The women's clothing would have to take into account the body proportion differences of men and women. The waist/hip area of the chemical-biological protective jacket needed to be redesigned and enlarged to improve donning and doffing. The heel flaps of the protective footwear needed to be redesigned so the cover did not move while the subject walked. Glum (1976) found similar equipment and clothing deficiencies for Army women. The Personnel Armor System Ground Troop (PASGT) helmet, like the PASGT vest, required a smaller size to accommodate smaller women. Bruno cited the same requirement for the helmet.

Tebbetts and Mcconville (1979) presented a series of height/weight sizing programs for use by designers of protective clothing. The sizing values were based on the data collected in the 1968 anthropometric survey of Air Force women (Clauser et. al., 1972), but the resulting sizing programs should be applicable to Navy women.

Rock (1977) reviewed life support equipment and protective clothing to determine problem areas that might present safety hazards for the female flight personnel. Training procedures were also investigated to determine if there was the potential for female injury due to smaller anthropometric measures. The flight boot, oxygen masks and the harness of the BA-22 parachute assembly did not adequately fit the Air Force women. Women were issued combat boots to replace the flight boot, the oxygen masks were custom-made for perfect fit, and the harness assembly was altered by four inches in the back to accommodate the women fliers. The escape system of the T-38/F-5 ejection seat simulators was designed to accommodate individuals over 140 pounds. Extra ballast was therefore added to the seat so the simulators could accommodate personnel weighing 104-140 pounds. Another problem that might interfere with the escape and seat ejection for women was the force and squeeze strength required to initiate ejection using a right hand trigger. The T-37 ejection seat trainer required at least 60 pounds while the T-38 training aircraft ejection seat required approximately 20 pounds to raise the handles of the ejection seat and 10-19 pounds of squeeze force to initiate ejection. No corresponding strength values for women were given to estimate the women's performance. In a test situation, if the woman trainee failed to initiate ejection, a zero was averaged into the total score. The same procedure was utilized for male trainees.

Morrisey, Bittner, and Halcomb (1976) applied the Computerized Accommodated Percentage Evaluation (CAPE) model to clothing related variables. The model takes the intercorrelation matrix for the key anthropometric dimensions, the desired percentile cutoff ranges, and by Monte Carlo simulation yields the proportion of the population accommodated. A comparison of CAPE simulation results with actual values of 4063 USAF males taken in 1950 revealed that CAPE could be an efficient and accurate predictor of accommodated percentages in clothing design.

Armstrong (1978) reviewed the literature pertaining to manual performance in industry. Misuse of gloves or failure to protect the hands of the worker resulted in approximately 10% of all compensable injuries involving cuts or abrasions of the hand. The author concluded that guidelines for selection of gloves for particular tasks needed to be developed in future research. The accommodation of the hands of female workers by commercially available gloves is also in need of evaluation. Additionally, this report stated a need for an evaluation of the dexterity requirements of manually-operated equipment to assess equipment operability and safety for male and female workers.

Bolalek and Grumblatt (1975) initiated a study to assess the adequacy of tools and equipment used by women working in Air Force craft skills. The results of their study indicated women working in these crafts had problems with several tools (wire strippers, soldering iron, and crimpting tool) and two pieces of equipment/clothing (goggles and work shoes). The tools were designed to fit the hand of male personnel, so the women found it difficult to handle the tools with one hand due to inadequate hand breadth and grip strength. Sizing problems were the reasons submitted for fit inadequacies of the work uniforms, work shoes and goggles. The author concluded that a survey of male workers in the craft skills might reveal problems similar to the ones the women encountered. If this werethe case, smaller male workers in the craft skills would benefit from the ergonomic redesign of the tools and equipment/clothing mentioned.

Observation, interview and questionnaire methodologies were employed by Pepper and Phillips (1980) to assess the human engineering adequacy of clothing, tools and fittings used by women aboard Navy ships. The results of this investigation revealed that several items of ship equipment, clothing, and fittings were deficient for use by females. Protective gear such as the oxygen breathing apparatus (OBA), safety harness, life preserver, and foul weather gear did not adequately fit many of the women on board. Hand tools and fire fighting equipment were found to be difficult for many of the women to operate. Ship fittings such as escape scuttles and water tight doors were also reported as problematical in this study. The lesser grip and upper torso strength of females compared to males were identified as factors which contributed to female difficulties with equipment and fitting use.

3.5.2 Manual Materials Handling

Manual materials handling involves lifting and carrying boxes of different shapes and weights over varying distances. Laboratory investigations of manual materials handling typically involve dividing lifting and carrying ranges into discrete intervals. The weights handled and the distances the objects are moved are then varied in a systematic manner to delimit the maximum acceptable weight of lift and the distance the object is carried. The maximum frequency of lift for a given weight is also commonly a variable in the testing procedure.

Snook and Ciriello (1974) investigated six manual materials handling tasks; lifting, lowering, pushing, pulling, carrying, and walking. These six tasks were varied according to height of lift (three ranges), distance carried, and rate of work for a total of 54 separate tasks. The subjects included sixteen housewives, and fifteen female industrial workers. An earlier study utilized the same methods and employed twenty-eight male industrial workers as subjects (Snook et. al., 1970). For all tasks, the housewives handled significantly less weight and work load than the males and the female industrial workers. The weight handled by industrial women was significantly less than the weight handled by the male industrial workers except for the 7 foot sustained push, the 7 foot sustained pull, and the 25 foot sustained push. The maximum work load acceptable to industrial women was significantly less than the work load for male industrial workers except for the 7 foot sustained push, the 7 foot sustained, pull, walking, and all high carrying tasks. The maximum force acceptable to the average female industrial worker for pushing and pulling tasks was 85% of that for industrial men. For lifting and carrying tasks, the maximum acceptable force was only 65% of that for male industrial workers.

Mital, et. al. (1978) investigated, through the use of psychophysical methodology, the lifting capacity of male and female industrial workers. Six lifting height ranges were used in this study; floor to knuckle, floor to shoulder, floor to reach, knuckle to shoulder, knuckle to reach, shoulder to reach. Frequencies of lift included 2, 4, 6 and 8 lifts per minute. Box sizes used in the study were 12, 18, and 24 inches in length. The results of the study indicated that the lifting capacity of men and women differed significantly. Frequency of lift and box size affected the maximum acceptable weight of lift.

A psychophysical rating scale was used along with torque measures by Konz and Coetzee (1978) to investigate the difficulty men and women encountered in lifting and lowering boxes. Six men and six women lifted and lowered boxes of varying weights (150, 225, and 300 mm cubes) using bend and squat techniques. For the same weight, women rated tasks more difficult than men. Additionally, for each added kilogram of weight, the female difficulty rating increased 0.44 versus 0.14 for men. The volume effect was significant for women but not for men. Women, on the average, were unwilling to lift more than 12-14 kilograms while men, on the average, were willing to lift 35-41 kilograms. The task of lowering was significantly easier for both men and women than the task of lifting. The distance an object was moved also proved to be significant in the analysis. Isometric back muscle strength proved to be a good predictor of successful lifting performance for men and women. There was a sex difference for this criterion as well, indicating women will lift less than men.

Shannon (1980b) investigated lifting injuries of 456 naval civilian government workers (79 women and 377 men) performing manual materials handling tasks. Four hundred and eight-four injury incidents were found through searching computer records kept on file at the Naval Safety Center in Norfolk, Virginia. The results indicated that the cause of injuries differed between the sexes. The prevention of male injuries could best be implemented by observing safe weight lifting standards, more managerial supervision and adherence to safety guidelines. The lifting techniques of men followed the recommended technique of the National Safety Council. Female injuries were hypothesised to be a result of lower body weight, poorer lifting techniques, lowered physical fitness and less physical strength when compared to men. Women supplemented their diminished strength capacities with the use of leg muscles and back motion which resulted in injuries to the shoulder/neck/arms. A training program to effectively teac' women how to utilize the biomechanical principles of lifting was suggested by the author as one method of reducing the incidence of female back injuries. The data reported in this study are limited since 1) they are derived from subjective accident reports and, 2) males and females were only matched on age group (rather than job-training or skill level), however the results compare well with prior studies using similar techniques (Shannon and Waag, 1974, Shannon, 1978).

Murphy and Nemmers (1978) presented a physical conditioning program which was used to condition 13 women soldiers to load and fire 105 mm (M101A1) and 155 (M114A1) howitzers. The training program was designed by analyzing the specific body movements utilized in loading and firing the howitzers. Jogging and eight training exercises on a universal weight machine were used to increase the subjects cardiovascular fitness, strength, and endurance. Pre- and post-testing estimated each individual's physical condition prior to the training program and to assess the effect of the program on the subject. Results of this phase of the program demonstrated a significant increase in the amount of weight lifted and improved physical fitness. The second phase of the test procedure had the women subjects participate in an actual ammunition loading and firing sequence to determine if trained female subjects could maintain the strength and endurance necessary for the firing sequence. Results showed that the women kept up the pace and in some cases exceeded criterion.

Capps (1977) reviewed two heavy craft skills in the Air Force; Fire Protection specialty and Aircraft Maintenance specialty. The purpose of the review was to identify problem areas encountered by women working in these heavy craft skills. Capps concluded that 90% of the women would not be able to install the battery in a T-39 aircraft on a repetitive basis or close the T-39 door. Women would also encounter problems operating the Hurst Jaws of Life. This piece of equipment was used by the Fire Protection specialty to enlarge escape routes for trapped personnel. This report indicated tha a significant percentage of the incoming Air Force women would be excluded from the heavy craft skills due to strength inadequacies. Much of the author's conclusions were based on the results of the "X" Factor lifting test. Since no relationship between job performance and this lifting test have been established, these results must be viewed as speculative.

3.5.3 Workplace/Job Design

The anthropometric differences of the sexes can impact the percentage of the male and female populations that is accommodated by a given workplace design. Depending on the anthropometric dimensions demanded by a particular configuration (e.g., overhead reach for controls or sitting eye-height for visual access), a significant proportion of female users may not be accommodated by a design based on the 5th through 95th percentile male dimensions. For example, the 5th percentile male height (US Army, 1977 = 64.16 inches) approximates the 50th percentile female height (US Army, 1977 = 64.07 inches).

The more anthropometric dimensions demanded for use by a design based on a male percentile values, the fewer females will be accommodated. Many modifications of the Computerized Accommodated Percentage Evaluation (CAPE) model have been proposed to assess the percentage of the female population that would be excluded in workplaces designed for males (Bittner, 1974, 1975, 1976a, 1976b;

Ketcham-Weidl and Bittner, 1976, 1977). To assess the percentage of individuals excluded, the anthropometric dimensions critical to the workplace design are used in the model. Tradeoff analyses to maximize the number of individuals accommodated are also a use of the CAPE model.

Ketcham-Weidl and Bittner (1976) utilized the CAPE model to evaluate the adequacy of an aircraft cockpit design. Eight anthropometric dimensions were used in a model that compared the military male and female body size distributions with several critical cockpit dimensions. This procedure found that 22% of the males and 90% of the females would be functionally excluded from one or more design parameters considered "cockpit critical." The findings of this study must be interpreted with caution since no measures of performance were taken by the authors. The magnitude of difference in accommodated percentages that was found, however, clearly indicates the potential for differential performance impairment due to workplace design.

A survey of Coast Guard women (Sinclair 1977) revealed that most women felt that they could perform in all roles of work required by the Coast Guard. Females generally reported that work assignments and advancement opportunities were fair. Over one-half the women cited the need to improve the design of living facilities. Clothing re-design was also noted as a need by many women.

The berthing and messing areas of ships in the Navy have been examined for accommodation of women aboard ship. Hassid et. al. (1973) and Martin et. al. (1973) found the redesign of the berthing areas aboard ship necessary before women could be assigned to shipboard duties. Privacy for crewmembers aboard ship was a consideration in the proposed redesign of berthing areas. Pepper and Phillips (1980) also found human engineering related difficulties for the female complement due to habitability and work place design. Reach difficulties were noted as an important contributory factor to gender based human engineering problems.

3.5.4 Evaluation

The literature reviewed in 3.5.1 indicates that the policy of fitting females into small male clothing sizes is an invalid approach. Comfort and satisfaction complaints as well as actual performance decrements have resulted from ill fitting garments. These problems are especially critical with respect to special clothing and gear design. These size inadequecies also seem to be paralleled in the design of many hand tool grips. Future investigations in this area should continue to clarify specific problem areas and their causitive basis, however, a shift in emphasis towards examining alternate modes of problem solutions is clearly warranted.

Performance differences have been demonstrated for men and women in the field of manual materials handling. The populations evaluated in the studies reviewed in 3.5.2 came from industry. The objects manipulated in these studies were of a general nature and could bear some resemblance to objects manipulated aboard ship. There have been no studies reviewing the correlation between the industrial population and the Naval population in terms of strength capacities, but the experiments reviewed here could serve as a baseline from which to predict the performance capabilities of Navy women.

Several studies (Snook and Ciriello, 1974; Murphy and Nemmers, 1978) suggested that physically trained females could handle greater loads than untrained females. Compensatory physical training programs and supportive research and documentation may therefore be a fertile ground for future work. Most useful would be research which developed generalizable methodologies capable of identifying physically demanding task variables, and translating these demands to successful compensatory training activities. Also needed are correlational studies between selected static strength measures and manual materials handling performance. More work in this area may enable the development of reliable, generalizable, predictive models.

Variables affecting workplace accommodation were discussed in 3.5.3. The magnitude of gender based anthropometric accommodation difficulties is a function of the quantity and criticality of demanding workplace dimensions, and the physical degrees of freedom allowed the operator. Fighter aircraft cockpit design therefore poses quite a different set of accommodation problems than do most shipboard work stations.

Gender related accommodation problems in ship work areas seem to be primarily affected by overhead reach difficulties. Also noted in several papers was the inadequacy of current shipboard habitability sub-system design for female use (Hassid et. al. 1973; Martin et. al., 1973; Sinclair, 1977; Pepper and Phillips, 1980).

The obvious potential problems imposed by ship motion in the work area have not been adequately researched. The pervasiveness of motion on board and the lack of performance oriented ship motion research suggests the need for future work in this area.

4.0 CONCLUSION

The studies reviewed in this report, combined with the work reported in Ayoub et. al. (1978), form an extensive data base on gender related differences in performance. Several general and specific needs exist, however, which must be addressed in order to increase the utility of this data base for system design applications.

There is a lack of standardization of methodologies in some areas. This is particularly apparent in biomechanical investigations, but is also true in other areas (e.g. manual materials handling, environmental influences, sensory/motor). This lack of standardization can lead to spuriously conflicting results. At very least, it renders strong conclusions tenuous, and design guidelines difficult to construct.

A gap between baseline performance established in laboratory investigations and actual job performance is also apparent. Predictive models are needed which reliably translate experimental data to real world performance. To be successful, these models will need to account for worker self paced performance and motivational factors as well as the more measurable and quantifiable parameters of performance.

In addition to these global needs, more baseline data needs to be accumulated in specific areas. Some areas identified in this review in need of further work include gender differences in: psychomotor skills, vigilance, cold tolerance and dynamic anthropometry/biomechanics.

Where female performance has been shown to be below criterion, the effectiveness of compensatory training programs needs to be explored. Several studies reviewed here suggest that compensatory training may be a practical and effective alternative to discimina-tory exclusion in some tasks (Hanson & Nedde, 1974; Murphy and Nemmers, 1978; Fortney and Senay, 1979).

The positive aspects of gender based performance differences need to be further examined and exploited in equipment design and task and function allocations. For example, gender differences in visual responses may imply selection, training or equipment design guidelines for monitoring and detection tasks in which female response traits are an advantage over male perceptual biases. There are, no doubt, other areas in which the gender differences reviewed here can be utilized to augment system performance. Applications orient-ed research focused on explicating these areas would be a most use-ful addition to the current data base.

APPENDIX I
CLASSIFICATION MATRIX

	BASIC SCOPE				ANTHROPOMETRICS	BIOMECHANICS	SENSORY/MOTOR	ENVIRONMENTAL INFLUENCES	HUMAN ENGINEERING		
	MALE	FEMALE	RESEARCH	REVIEW					CLOTHING/TOOLS	MANUAL MATERIALS HANDLING	WORKPLACE DESIGN
Armstrong, T.J. (1978)	X	X		X			X		X		X
Bell, P.A. (1978)	X	X	X				X	X			
Bernauer, E.M. & Bonnano, S. (1975)	X	X	X		X	X					
Bittel J. & Henane, R. (1975)	X	X	X					X			
Bittner, A.C. (1974)	X	X	X		X						X
Bittner, A.C. (1975)	X	X	X		X						X
Braybn, L.B. & McGuinness, D. (1979)	X	X	X				X				
Brown, J.W. (1979)	X	X	X	X	X	X		X	X		X
Bruno, R.S. (1979)		X	X						X		
Burse, R.L. (1979)	X	X		X				X			
Capps, T.E. (1977)		X	X			X			X	X	
Churchill, E. & Churchill, T. (1977)	X	X		X	X						
Churchill, et. al. (1977)		X	X		X	X					
Ducharme, R.E. (1977)		X		X					X		
Fortney, S.M. & Senay, L.C. (1979)		X	X					X			
Glumm, M.M. (1976)		X	X						X		
Haakonson, N.H. & McKee, V.A. (1978)	X	X		X	X	X		X			
Hanson, J.S. & Nedde, W. (1974)		X	X			X					
Hassid, S.Y. et. al. (1973)	X	X	X								X
Kennedy, K.W. (1973)	X	X		X	X						
Kennedy, K.W. (1978)	X	X	X		X						
Ketcham-Weidl, M.A. & Bittner, A.C. (1976)	X	X	X		X						X
Kipnis, D.M. & Kidder, L.H. (1977)	X	X	X				X				
Konz, S.A. & Koetzee, J. (1978)	X	X	X			X					

	BASIC SCOPE								HUMAN ENGINEERING		
	MALE	FEMALE	RESEARCH	REVIEW	ANTHROPOMETRICS	BIOMECHANICS	SENSORY/MOTOR	ENVIRONMENTAL INFLUENCES	CLOTHING/TOOLS	MANUAL MATERIALS HANDLING	WORKPLACE DESIGN
Kroemer, E.K.H. (1969)	X		X			X					
Laubach, L.L. (1976)	X	X	X	X		X					
Laubach, L.L. et. al. (1977)		X	X		X	X					
LeBlanc, J. et. al. (1978)	X	X	X					X			
Macnab, R.B.J. et. al. (1969)	X	X	X			X					
Marty, H.F. Jr. (1980)	X		X		X						
McConville, J.T. et. al. (1977)	X		X		X	X					
McConville, J.T. et. al. (1979)		X	X		X						
McGuinness, D. (1974)	X	X	X				X				
McGuinness, D. (1976)	X	X	X				X				
McGuinness, D. & Lewis, I. (1976)	X	X	X				X				
Mital, A. et. al. (1978)	X	X	X			X					
Morrissey, S.J. et. al. (1976)	X		X		X				X		
Murphy, M.A. & Nemmers, T.M. (1978)		X	X			X				X	
Paolone, A.M. et. al. (1978)	X	X	X					X			
Pepper, R.L. & Phillips M.D. (1981)	X	X	X						X		X
Polit, D. (1979)		X		X		X	X				
Printy, T.M. (1979)	X	X		X	X	X				X	
Reynolds, H.M. & Allgood, M.A. (1975)		X	X		X	X					
Robinette, K. et. al. (1979)	X	X	X		X						
Robinette, K. & Churchill, T. (1979)	X	X	X		X				X		X
Rock, L.C. (1977)		X	X						X		X
Shannon, R.H. (1980a)	X	X	X			X					
Shannon, R.H. (1980b)	X	X	X			X				X	
Shapiro, Y. et. al. (1980)	X	X	X					X			
Shoenfeld, Y. et. al. (1978)	X	X	X					X			

	BASIC SCOPE								HUMAN ENGINEERING		
	MALE	FEMALE	RESEARCH	REVIEW	ANTHROPOMET-RICS	BIOMECHANICS	SENSORY/MOTOR	ENVIRONMENTAL INFLUENCES	CLOTHING/TOOLS	MANUAL MATERIALS HANDLING	WORKPLACE DESIGN
Sinclair, T.W. (1977)	X	X	X						X		X
Snow, C.C. & Reynolds, H.M. (1975)		X	X		X						
Stoudt, H.W. (1978)	X	X		X	X						
Tebbets, I. & McConville, J.T. (1979)		X	X		X				X		
Thackray, R.I. et. al. (1978)	X	X	X				X				
Waag, W.L. et. al. (1973)	X	X	X				X				
Wardle, M.G. & Glass, D.S. (1977)		X	X			X					
Wells, C.L. & Horvath, S.M. (1973)		X	X					X			
Wells, C.L. & Horvath, S.M. (1974)		X	X					X			
White, R.M. & DeSantis, G. (1978)	X	X		X	X	X			X		X
White, R.M. (1979)	X	X		X	X						
Wilmore, J.H. (1974)	X	X	X			X					

APPENDIX II
LITERATURE ABSTRACTS

Study: Armstrong, Thomas Jeffrey
Manual Performance and Industrial Safety, Task Order No. 78-10433, DHEW, National Institute for Occupational Safety and Health, 1978.

Keywords: Hand, gloves, strength, handtools

Methods: This report reviews the available literature concerning the hazards and performance encountered in manual tasks found in industry. Factors considered in this review were hand size, strength, sensory function and dexterity. A taxonomy of the hazards and performance measures was developed to better organize the literature and appears at the end of the report. A hazard is defined as any object or situation that has the potential for injury to the worker. An injury is defined as a sudden event that produces a response that is considered not to be good for health. Physical attributes of the workers which contribute to hazards and injuries such as hand size are also considered. Workplace environments are considered from the standpoint of potential factors for manual injuries.

Summary & Application: Accidents in which the hand slides from a surface onto another surface, results in a fall or causes another object to be launched are common in the industrial workplace. This reports suggests that a hand model be developed that would describe the interaction of the hand and the workplace and the ability to hang on. Manual performance as well as tactile sensitivities are important in manual performance and can be reduced when gloves are used for safety reasons. The space requirements are also increased when gloves are introduced, so the report recommends that studies be undertaken to study the effects of the gloves currently in use and how they affect manual performance. The report focuses on male manual performance, but there is mention of the grip strength of Navy women as well as the dexterity of female industrial workers.

Cited References: 192 references

Study: Bell, Paul A.
Effects of Noise and Heat Stress on Primary and Subsidiary Task Performance. Human Factors, 1978, 20(6), 749-752.

Keywords: Heat stress, noise, task performance, sex differences

Methods: 72 male and 72 female undergraduate students were selected for the experiment. 12 males and 12 females were randomly assigned to 6 cells of a 2 X 3 factorial design with noise and temperature as the two variables. The room measured 2.7m X 3.7m with the humidity controlled. The low noise consisted of 55 dB(A) of "normal" background noise. The high noise condition consisted of 95 dBa white noise bursts and were of random duration and occurrence. Temperature was controlled by means of a KloDHF Koldwave unit. The subjects were put in the rooms individually and given a few minutes to get accustomed to the noise while the subjects performed filler tasks. After this time was up, the subjects began concurrent task performance. The primary task was a pursuit rotor task. At the same time, the subjects listened to a tape of two-digit numbers and with their non-dominant hand pressed a telegraph key once if a number was numerically lower than the preceding number and twice if it was higher.

Results: For the primary pursuit rotor task, time was treated as a dependent measure. A 2X3X2 analysis of variance was performed on the data (noise, temperature, and sex of subject as the factors) and revealed no significant main effects or interactions for noise, temperature or sex of subject. On the secondary task, the number of errors was treated as the dependent measure. A 2X3X2 analysis of variance revealed significant main effects for temperature and noise. Neither the main effect for sex or interactions proved significant.

Summary & Application: The results of this experiment indicate that exposure to high temperature and/or high levels of noise has a detrimental effect on the secondary task performance, but not on the primary task performance. The observed performance difference may be due to the overloading of the subjects' capacities to process information. The combined

Bell, Paul A. (continued)

Summary & Application: (continued) effects of noise and heat were found to be additive rather than interactive with respect to the decrements in the secondary task performance. Attention may then be shared between the two tasks and be allocated separately. The way attention is shared may be a function of the degree of difficulty of the two tests and the extent to which one is subsidiary to the other.

Cited References: 10 references

Study: Bernauer, E.M. & J. Bonanno
Development of Physical Profiles for Specific Jobs. Journal of Occupational Medicine, 17 (1), 27-33. 1975.

Keywords: Dynamic strength, static strength, sex differences, physical fitness, profile analysis, anthropometric measurements

Method: Forty test items including anthropometric measurements such as height, weight and skinfolds, as well as several measures of strength were selected as representative of physical performance factors needed for certain jobs in industry that require high levels of physical activity. The data were analyzed by factor analysis with the resultant six factors becoming the FBT (field battery test). This FBT was then given to an additional 300 subjects for validation studies. The subjects came from Pacific Telephone in the State of California and were enrolled in pole climbing school. The group consisted of 15 men and 15 women. An additional test battery was composed and administered to a sample of students who were judged to be either fit or unfit physically. Ten males and 10 females were the sample tested. A further study was conducted on two groups of young adults with known fitness levels to better characterize the strength factors involved in pole climbing performance.

Results: The completion of pole climbing school is judged to be the acceptable physical performance criterion against which the various test items were validated. Mean difference with a significance level of 0.05 is interpreted as having the power to discriminate between successful and unsuccessful completion of pole climbing school. Grip strength did not differentiate between fit and unfit individuals while sit-ups did discriminate. Dynamic arm strength was also shown to be a good discriminator.

Summary & Application: A field test battery (FTB) of simple, objective job-related test items were identified and validated for predictive purposes for job requirements. This process can be used as a screening program for future employees to identify areas where this person might develop problems.

Cited References: 16 references

Study: Bittel, J. & R. Henane
Comparison of Thermal Exchanges in Men and Women Under Neutral and Hot Conditions. Journal of Physiology, 250:450-489. 1975

Keywords: Thermoregulation, sex differences, sweating, pre- and post-ovulation effects

Methods: Nine men and five women all considered unacclimatized to heat were subjected to sweating tests involving three phases: pre-heating (neutral), heating stage and steady state phase. Ninety minutes were spent in the neutral phase. The temperature in the room was then rapidly raised until thermal balance was reached, approximately 90-120 minutes. The temperature was then rapidly reduced until it reached the level of the neutral phase. The experiment ended when the body temperature returned to its initial level. Skin and deep body temperature (rectal and tympanic) were continuously monitored with thermocouples. Sweat rate was measured by means of a mesh hammock connected to a beam balance which was in turn connected to an electric differential balance outside the room. The metabolism rate was monitored by the Douglas bag technique where expired gases were analyzed for O_2 and CO_2.

Results: The table listed below displays the results of the experiment.

TABLE 2. Metabolism ($W.m^{-2}$), rectal, tympanic and mean skin temperatures (°C) body conductance k_b ($W.m^{-2}.°C^{-1}$), increment of body temperature ΔT_b (°C), rectal temperature, threshold for sweat onset (T_{re} thr.), during neutral stage and heating period.

	Neutral stage $T_a = 30°$ C					Heating stage $T_a = 45°$ C					
	M	T_{re}	T_{ty}	T_{sk}	k_b	T_{re}	T_{ty}	T_{sk}	ΔT_b	T_{re} thr.	k_b
(1) Women Pre.	43·2 ± 5·5	36·9 ± 0·1	36·5 ± 0·3	34·3 ± 0·1	12·7 ± 3·2	37·8 ± 0·1	37·5 ± 0·2	35·6 ± 0·6	1·0 ± 0·07	37·0 ± 0·02	19·5 ± 7·8
(2) Women Post.	44·7 ± 5·0	37·4 ± 0·2	36·7 ± 0·4	33·6 ± 0·5	11·7 ± 2·9	37·9 ± 0·2	37·9 ± 0·1	36·0 ± 0·3	1·6 ± 0·2	37·4 ± 0·1	23·3 ± 3·1
(3) Men	51·8 ± 6·9	36·9 ± 0·3	36·3 ± 0·3	34·3 ± 0·4	10·9 ± 1·9	37·4 ± 0·1	37·2 ± 0·2	35·3 ± 0·5	1·1 ± 0·09	37·1 ± 0·1	24·7 ± 6·8
P (1) − (2)	N.S.	< 0·01	N.S.	< 0·01	N.S.	N.S.	< 0·01	N.S.	< 0·01	< 0·01	N.S.
P (1) − (3)	< 0·05	N.S.	N.S.	N.S.	< 0·01	< 0·001	< 0·01	N.S.	N.S.	N.S.	N.S.
P (2) − (3)	N.S.	N.S.	< 0·02	< 0·02	< 0·01	< 0·001	< 0·001	< 0·02	< 0·01	< 0·01	N.S.

(1) Women: pre-ovulation period. (2) Women post-ovulation period. (3) Men (means ± S.D.; N.S. = non-significant).

Summary & Application: Women have a lower heat dissipation which is associated with a reduced rate of sweating as compared to men under the same climatic conditions. This was also reflected in a lower total weight loss in the

Bittel (continued)

Summary & Application: (continued) steady state phase as compared to men. Females had a delayed onset of sweating when compared to men. During the post-ovulation phase, women had a further delay in the onset of sweating.

Cited References: 24 references

Study: Bittner, A.C.
Reduction in Potential User Population as the Result of Imposed Anthropometric Limits: Monte Carlo Estimation. TP-74-6. Naval Missile Center, Point Mugu, California. 1974.

Keywords: Anthropometric accommodation, accommodated percentages, anthropometric limits, multivariate analysis

Methods: Workspaces such as cockpits and desktop consoles have been designed to accommodate individuals with anthropometric measurements within a specified range of distribution. The actual percentage of individuals accommodated may be smaller due to the correlation between variables (Moroney and Smith, 1972). When further restrictions are imposed such as a percentile range of 5th to 95th percentiles, the user population is further reduced. Accommodated percentage is the percentage of the user population that can comfortably use the designed workspace. This percentage has to be taken into account when setting limits of the anthropometric variables for the design of the workspace. This report compares the empirically derived accommodated percentages to those percentages derived by a Monte Carlo model. This model is a multivariate computer analysis which simulates random sampling from a 13-variate normal population. The model utilizes the intercorrelation matrix of the 13 anthropometric features specified by Moroney and Smith (1972).

Results: The Monte Carlo results are highly correlated with the results of Moroney and Smith's study of the percent excluded when percentile limits were imposed. It is also of interest that the computer program took less than ten minutes on a time-sharing terminal and was of minimal cost

Summary & Application: The Monte Carlo model correlated highly with the percentage of Naval pilots excluded as 13 anthropometric variables were successively screened. This model can be applied to summary data i.e. where the population is not well defined and takes very little time, money or storage to utilize the model.

Cited References: 16 references

Study: Bittner, A.C.
Computerized Accommodated Percentage Evaluation (CAPE) Model for Cockpit Analysis and Other Exclusion Studies. TP-75-49. Pacific Missile Test Center. 1975.

Keywords: Anthropometry, accommodated percentages, bioengineering, cockpit design, computer model, human factors engineering, workspace design

Summary & Application: This report describes and illustrates the application of a baseline CAPE (Computerized Accommodated Percentage Evaluation) model to cockpit accommodation analysis. In section 1, the model is discussed as an alternative to conventional design approaches as illustrated in MIL-STD-1333 (1969)*. The CAPE model also functions as a tool to guide design improvement. Section 4 compares the percentage of individuals excluded by various cockpit designs and gives an example of CAPE application to progressively optimizing a cockpit design. Recommendations for future work and a comparison of current and proposed advanced model features are included in Section 5. The results presented in this report deal primarily with cockpit design, but the approach is applicable to the design of any workplace.

Cited References: 42 references

* Department of Defense. Aircrew Station Geometry for Military Aircraft. MIL-STD-1333. Washington, D.C., DoD, 2 June 1969.

Study: Braybn, Lesley B. and McGuinness, Diane. Gender Differences in Response to Spatial Frequency and Stimulus Orientation. Perception and Psychophysics, 26(4), 319-324, 1979.

Keywords: Sex differences, visual threshold, spatial frequency, stimulus orientation.

Method: Twenty male and 19 female undergraduate students possessing or corrected to 20/20 acuity or better participated in two contrast threshold experiments. In the first experiment, S(s) were seated 160 cm from a raster scan VDT. S(s) made contrast threshold judgments on each of 13 spatial frequency gratings presented either horizontally, vertically, 45^{0} (right oblique) or 135^{0} (left oblique). The stimulus was increased in luminance from imperceptible until the S perceived it as visible. Trials were run under mesopic conditions with the experimental room being illuminated only by equipment piolet lights and a small light source near E. The second experiment followed the same procedure, with the added feature of stimulus motion. Here, the gratings were set to drift across the screen at a constant velocity of 10 deg/sec.

Results: In experiment one, the anisotropy effect found in prior research was confirmed. Males and females had better resolution in vertical and horizontal orientations than they did for oblique orientations. A significant interaction of Sex x Spatial Frequency was found. Females had superior resolution for the three lowest frequency gratings (.4, .6, .8 cycles/deg) while males' resolution was best for the highest frequency gratings (8.0, 9.0, 10.0 cycles/deg). Mid range frequencies showed no sex differences in resolution. This effect was more pronounced for vertical and oblique orientations than it was for horizontal orientations. These effects were paralleled in the results of experiment two, indicating that they are robust to the addition of stimulus motion.

Summary & Application: The results indicate that fundamental mechanisms responsible for visual processing may operate with a different bias between the sexes. The authors apply these findings to potential implications for pattern recognition. It is suggested that females, with primary sensitivity to low frequency information, may take an "integrative" approach to pattern analysis while males may take a "segragative" approach, attending primarily to high frequency information and isolating objects of interest from the field. Further investigation is needed to explain the finding that the sex difference exhibited in the frequency domain is considerably weaker for horizontal gratings.

Cited References: 29 references

Study: Brown, Jeri W.
Considerations Associated with the Introduction of Female Crewmembers in Spacecraft and Space Stations IAF-79-A-22. XXX Congress International Astronautical Federation, Munich, F.R.G., September 17-22, 1979.

Keywords: Female, human engineering, human factors, anthropometrics spaceflight, weightlessness

Summary & Application: The inclusion of females in the Space Shuttle program raises certain considerations in terms of man/systems integration and spacecraft habitability. This report addresses these considerations from two main areas. The first is the anthropometric and physiological differences between men and women as related to spaceflight. The second deals with hardware and the modifications needed to accommodate female crewmembers. Two examples of the considerations mentioned are the design of the Shuttle spacesuit which needs to fit both sexes. The second example is the design of the cockpit seating area where the pilot must be able to see out of the window for landing the Shuttle. Other tests were performed to assess the impact of the menstrual cycle on strength and endurance. The results indicated that isometric strength did not vary throughout the cycle while the magnitude of heart rate and blood pressure responses to the isometric exercises were unaffected by the menstrual cycle. This report indicates that no major problems have arisen during testing that would limit women in spaceflight.

Cited References: 15 references

Study: Bruno, Richard S.
Human Factors Evaluation of Male Field Clothing Ensembles Worn By Female Soldiers (Hot-Dry, Hot-Wet, Cold-Wet Environment). U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland. 1979.

Keywords: Equipment, protective clothing, female soldiers, human factors assessment

Methods: Women are now being assigned to combat support roles in the U.S. Army. The protective clothing designed for use by females was not constructed for rigorous field situations, so the U.S. Army Natick Research and Development Command is exploring the possibility of issuing male field clothing to women. The objective of this report was to assess the fit and degree of discomfiture experienced by female soldiers in male field clothing. Fifteen women soldiers were the subjects in the test cycle. Uniform and equipment combinations were worn by the women in the prescribed layered clothing principle. This allows for adjustment of clothing to fit the environment. Areas focused upon were ease of donning, doffing and how the clothing combinations integrated with field equipment and body restrictions. Fitting problems were noted and recorded by the subjects. An exercise routine followed the fitting sessions to further assess the fit of the field clothing in a dynamic situation.

Summary & Application: The trousers and jacket of the chemical biological protective garmet needs to have the waist/hip area redesigned to accommodate women's hips while the wrist opening of the protective needs to be enlarged for easier donning and doffing. The heel flaps of the protective footwear should be fish-tailed to assure a more positive alignment while walking. The chin strap of the PASGT helmet needs to be lengthened for easier donning and doffing. The insulating cap that fits under the PASGT helmet has to be redesigned so that it is compatible with the helmet. The material of the female field clothing should be changed to that of the men's and the design of the women's clothing should also parallel that of the men's. The men's leather boots fit the women except for the heel and a slight tightness in the instep. The women preferred the men's boot because it was more appropiate for the field conditions. When the changes

Bruno (continued)

Summary & Application: (continued) recommended above for the women's field clothing are implemented, the women will be comparably outfitted for the field situation.

Cited References: 4 references

Study: Burse, Richard L.
Sex Differences in Human Thermoregulatory Response to Heat and Cold Stress. Human Factors 21(6):687-699, 1979.

Keywords: Sex differences, thermoregulation, rectal temperature, heart rate, sweat rate, mean skin temperature, maximal oxygen uptake, skin surface area, body fat percentage, surface area-to-mass ratio, heat stress, cold stress, human factors

Summary & Application: This report is a comprehensive literature review of the sex differences found in thermoregulation in cold as well as hot environments. Anthropometrically, women average 20% smaller body mass, 14% more body fat, 33% less lean body mass, but only 18% less surface area than men. Women have greater body insulation when vasoconstricted (except hands and feet) and a larger peripheral heat sink, but at the cost of greater fat burden, less muscle mass and strength and smaller circulating blood volumes which require greater physiological strain to balance heat production and loss. When women are under heat stress, they generally exhibit relatively more peripheral blood pooling, more frequent circulatory embarassment, greater heart rate, lower maximal sweat rate, higher skin temperatures with greater body heat storage, and poorer maintenance of circulating blood volume with more impact from dehydration. Based on the literature reviewed, the author concludes that proportionally fewer women than men can be successfully acclimated to the heat. In the cold, women usually have less capability for maximum heat production by either exercise or shivering. They have a more extensively vasoconstricted periphery and lower foot, hand and mean skin temperatures than men. Women have greater surface heat loss especially in the area of the extremities (not the core) resulting in relatively greater risk of cold injury.

The morphological and physiological differences between men and women and the resulting differences in thermoregulation are covered exceptionally well in this current article. The descriptions of the different physiological measures are clear and easily understood by the non-physiologist.

Cited References: 66 references

Study: Capps, Thomas E. (Major, USAF)
Physical Capacity of Females to Perform Heavy Craft Skills in the United States Air Force. Report # 0390-77. Air Command and Staff College. Air University, Maxwell Air Force Base, Alabama. 1977.

Keywords: Females, strength, lifting

Methods: Two heavy craft skill specialties were examined by the author with the goal to identify the percentages of women who would be excluded from the jobs involved because of strength deficiencies. The craft skills observed were the Fire Protection Specialty and the Aircraft Maintenance Specialty. In the first specialty, the author observed women performing fire-fighting duties in a bunker, the required protective clothing coupled with an oxygen breathing apparatus named Air Pac. Women were also observed operating th Hurst Jaws of Life, a portable, hydraulically-operated device used to enlarge narrow openings for rescue purposes. In the Maintenance Specialty, the author observed women changing aircraft tires, the replacement of batteries in aircraft, closing an aircraft entrance door, connecting and disconnecting oxygen trailer to tow truck and manually moving the power trucks. No measurements were actually taken though the specifications on the equipment such as height and weight were noted. To approximate the strength requirements of the various jobs, the author assumed that a job was equivalent to a standardized strength measure and from there determined the percentage of women that would be excluded. Estimation of the strength abilities of each woman was accomplished through the "X" Factor test. Four levels are defined by the amount of weight an individual can lift to a specified height. Level 1 requires the individual to lift 70 pounds to a height of 6 feet. Level 2 requires the individual to lift 40 pounds to elbow height. Level 3 requires the subject to lift 20 pounds to elbow height. Category 4 is the level that a subject is assigned to if the subject is unable to qualify for any of the other three levels. Aircraft Maintenance Specialty requires a level 2 "X" factor rating while the Fire Protection Personnel Specialty requires a level 1.

Summary & Application: Jobs should accommodate 90% of the work force in terms of the strength requirements. Based on this report, a significant percentage of the female work

Capps (continued)

Summary &
Application: (continued) force would be excluded from the jobs in the craft skills.

Cited
References: 15 references

Study: Churchill, Edmund and Thomas Churchill
The AMRL Anthropometric Data Bank Library: Volumes I-V. Technical Report AMRL-TR-77-1. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1977.

Keywords: Anthropometry, body size, anthropometric measurements, computer, data bank, women.

Summary & Application: This report summarizes and compares the results from four USAF anthropometric surveys: 1950 and 1967 surveys of flying personnel, the 1968 survey of USAF women, and the 1965 survey of male personnel. Volume V contains the 1946 survey of Army separatees, the Health Examination survey of 1960-1962 and the law enforcement survey of 1974. The correlation coefficients of the four USAF surveys listed above are also included in Volume V. The raw data and the correlation coefficients are stored on magnetic tape to be used on a variety of computers. The format of the tapes, the abbreviations of the measurement names and a discussion of the XVAL computer program used to analyze the data are included in the report.

Cited References: 12 references

Study: Churchill, Edmund, Thomas Churchill, John T. McConville, Robert M. White

Anthropometry of Women of the U.S. Army-1977. Report No. 2. The Basic Univariate Statistics. Natick-TR-77-024. U.S. Army Natick Research and Development Command. 1977.

Keywords: Anthropometry, body size, anthropometric measurements, military personnel, women, human factors engineering, static strength

Summary & Application: This report is a second in the series dealing with the women of the U.S. Army. The basic summary statistics are reviewed in this report. Data for 69 body size measurements were obtained on a sample of 1,331 women with wide ranges of age, rank, and military assignment represented. Additional data were obtained on a subsample of women totaling 200-300 individuals. Other traditional body measurements were taken as well as anthropometric measures pertaining to workspace design. Nine static strength measurements were also taken on these women. The summary statistics included the mean, standard deviation, standard error, range, and percentile values for each measurement. Frequency distributions were also included for each anthropometric and strength measurement.

Cited References: 7 references

Study: Ducharme, Richard E.
Women Workers Rate "Male" Tools Inadequate.
Human Factors Society Bulletin, 20(4):1-2.
1977.

Keywords: Anthropometry, women, tools, grip strength, human factors engineering

Summary & Application: This article reviews in brief the U.S. Air Force study of the tools and equipment used by women in the craft skills (Bolalek, P.J. & A.G. Grumblatt, 1975)*. The women were asked to provide anthropometric data such as height, age, and weight on a self-administered questionnaire. The women were also asked to evaluate the tools they used in their specialty as superior, adequate or inadequate. Reasons for their evaluation were also to be provided on the questionnaire. Each craft skill had at least one tool or equipment item that was considered to be inadequate. Three common inadequate tools were the wire stripper, the crimping tool, and the soldering iron. All these tools had very similar reasons for their inadequacy, mainly that they were too large for the women to operate effectively. Air Force women have an average hand length of 17.3 cm. When this hand length is compared to the hand length of Air Force men (19.7 cm.), the problems with these tools is obvious, the tools were designed for men.

Cited References: 0 references

* Bolalek, P.J. & A.G. Grumblatt, Jr. A Study to Determine the Adequacy of the Tools Used by Air Force Women in the Craft Skills. Report No. SLSR-14-75A, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio. 1975.

Study: Fortney, Suzanne M. and L.C. Senay Jr.
Effect of Training and Heat Acclimation on Exercise Responses of Sedentary Females. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 47(5): 978-984, 1979.

Keywords: Women, sweat rates, mean skin temperature, body fluids, heat stress

Methods: The authors designed an experiment to study why women experience greater strain than men during exercise in a heat stress environment. Nine women performed moderate exercise (40% maximum oxygen uptake) on a cycle ergometer in a cool (16-20°C) and in a hot environment (45°C, 30% relative humidity). Venous blood was sampled before, during and after the exercise periods. Test runs were then performed during a four-week training program (phase 2) and heat acclimation (phase 3).

Results: There were no changes observed in the constituents of the subject's plasma except for a shift in the potassium concentration. The volume of plasma change during exercise. After exercising in a cool environment, a 3.9% decrease was found in plasma volume. When the women exercised in the hot environment, there was a 11.9% decrease in plasma volume. Plasma osmolality and protein concentration in plasma increased after exercising due to the loss of plasma water. The resting plasma volume increased 9.7% after training while the total protein content increased 11.6% after training. During heat acclimation, the sweat rates of women increased and the mean skin temperature significantly decreased.

Summary & Application: The factor primarily responsible for improved cardiovascular fitness in the women subjects during acclimation may be the maintenance of a larger central blood volume. These women still exhibited strain when exercising in a hot environment. One reason may be the distribution of the increased blood volume and the lower sweat rate observed in women when compared to men.

Cited References: 34 references

Study: Glumm, Monica M.
The Female in Military Equipment Design. Technical Memorandum 13-76. U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland. 1976.

Keywords: Anthropometry, women, human factors engineering, equipment design

Summary & Application: Equipment designed for a male user population and now being used by both males and females is highlighted here. Load-bearing systems such as the ALICE (Army Lightweight Individual Carrying Equipment) and the ALICE rucksack present the problem of a woman often carrying burdens approaching one-half her own body weight. The straps on this system criss-cross the shoulder and breast area causing comfort and injury problems. The PASGT (Personnel Armor System Ground Troop Helmet and vest are not sized to accommodate women. Gas masks also are not sized to accommodate the narrower and smaller facial structure of women.
This report was based on the anthropometric data available from the USAF women survey so adequate data may be available for design purposes from the 1977 U.S. Army survey of Army women.

Cited References: 6 references

Study: Haakonson, N.H. and V.A. McKee
Medical Considerations for Employment of Women in the Canadian Military. DPM Report No. 1/78. National Defence Headquarters, Ottawa, Ontario, Canada, 1978.

Keywords: Anthropometry, cardiovascular system, heat tolerance, menstrual cycle, motion sickness, psychological factors

Summary & Application: This report is a literature review of the basic differences in male and female anthropometry and body composition, physiology, and psychology. These differences were then related to the performance of men and women. Thirty-six Canadian trades (rates) which had been closed to women (most still are) were reviewed with the specific requirements of each rate listed (physical demands, stresses, special factors). The report had several annexes that were informative and well organized. Annexes F-N listed the statistically significant pre- and post-test variates that distinguished men from women. Included here were various anthropometric measures and measures of strength. Annexes O and P presented a summary of the anthropometric varaiables that were relevant to physical performance for both men and women.

Cited References: 69 references

Study: Hanson, John S. and William Nedde
Long-term Physical Training Effect in Sedentary Females. J. Appl. Physiol. 37(1): 112-116, 1974.

Keywords: Women, exercise, psychological testing, physical working capacity, oxygen transport system, self-concept

Method: Eight sedentary women between the ages of 20-44 years of age, participated in an 8-month, 5 sessions a week physical training program. Evaluation of physical working capacity and other physiologic variables was made with a bicycle ergometer and treadmill walking prior to training and following 4 and 8 months activity. Psychological testing in the form of a self-concept scale was also employed at these time intervals.

Results: The results indicated significant increases in work capacity with marked declines in expired minute volume, oxygen utilization, carbon dioxide production, respiratory exchange ratio, and exercise heart rates for a given work load. Indices of self-concept were also altered significantly in a positive manner. Two subjects were identical twins, and differences in their training responses emphasize factors related to results of physical training.

Summary & Application: The trainability of nonathletic women and their oxygen transport system does not differ from that of their male counterparts, and that identical benefits can and should be gained from regular activity by both sexes.

Cited References: 28 references

Study: Hassid, Sami Y., Craig J. McArt, Hugo G. Blasdel
Methods for the Development of Shipboard Habitability Design Criteria. Progress Report No. 3
The Regents of the University of California, Berkeley, California. 1973.

Keywords: Shipboard habitability, human factors engineering, furniture design, color preference, women aboard ship

Summary & Application: One hundred and sixty-two men were selected as subjects from the seven ships in San Diego and Treasure Island. A second sample of men and women (N=23) were selected from the crew of the first Naval ship to have women crewmembers. The group of Navy men rated the messing areas aboard ship using slides of the areas. Also collected were the assessments of the same areas by visitors and women who had served aboard ship. (The USS Sanctuary was not mentioned by name, but this was the first Navy ship to have women serving aboard.) Berthing areas and availability of privacy were also considerations of shipboard habitability. The data was gathered by questionnaire and analyzed using multidimensional scaling.

Cited References: 32 references

Study:	Kennedy, Kenneth W. Anthropometry and Kinematics in Crew Station Design. AD-A011 581. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1973.
Keywords:	Anthropometry, body size, kinematics, military populations
Summary & Application:	Kinematics is defined as a branch of dynamics that deals with aspects of motion apart from considerations of mass and force. Attention to kinematic and anthropometric characteristics of the aircrew member is essential to the best design of the cockpit of an aircraft. Many of these characteristics are crucial to the safety of the pilot and to the success of the mission. The amount of variability of body size and proportion among the various military populations is a big problem for the designer. This report reviews the anthropometric and kinematic data available at the time the report was written (1973). The necessity of functional anthropometric and kinematic measures of the user population is also reviewed with regards to the use of computers in cockpit design.
Cited References:	73 references

Study: Kennedy, Kenneth W.
Reach Capability of Men and Women: A Three-Dimensional Analysis. AMRL-TR-77-50. Aerospace Medical Research Laboratory. Wright-Patterson Air Force Base, Ohio. 1978.

Keywords: Reach capability, anthropometry, cockpit layout and design human kinematics, sex differences, women, men

Method: Thirty men and thirty women comprised the sample used in the study. The individuals were college students and research personnel from the Aerospace Research Laboratory. The Aerospace Medical Research Laboratory Reach and Strength Measuring Device was used to derive information on the reach capability of the sample described above. The device employed a rotatable seat mounted on a platform beneath an arch. The seat was so situated that the reference point of the seat lay in the plane of the arch. One side of the arch held measuring rods radiating at 15° intervals and pointing to the center of the arch. Each rod was calibrated to indicate the distance from the center of the arch to the midpoint of the knob at the inside ends of the rods. The center of the arch was at the level of the subject's shoulders and remained fixed in that position as the seat rotated. Each subject was allowed a brief time to orient themselves before the test began. Each measuring phase lasted approximately one hour. Reach throughout the forward half of the mid-sagittal (0°) plane was always measured first. The seat was then rotated to the left and reach measurements were taken at 15° right. This procedure continued until reach along 15° left were measured. Twelve anthropometric dimensions were measured on each subject. Two reach values were obtained for each reach angle, a smaller one representing the minimum reach distance and a larger one representing the maximum reach distance. All raw data were recorded in inches.

Results: The results are presented in tabular form and graphic displays of the reach envelope. The reader is referred to the original report for the actual results since they are too numerous to reproduce in this summary.

Summary & Application: The most important anatomical factors affecting the size and shape of the reach envelope are the length of the arm and the characteristic movements associated with the shoulder, the elbow and the waist. Movement of the shoulder is the result of synchronus participation of three joints (glenohumeral, acromisclavicular and sternoclavicular). Reduction in mobility for any one of these three joints results in a decrease in mobility and reduced reach capacity. Other factors that affect the reach envelope are body dimensions such as the distance between the joint-center of the gleno-

Kennedy (continued)

Summary & Application: (continued) humeral joint and the sitting surface. Torso size also affects reach capability. Individuals who are heavily muscled or have many fat layers will find the size of their torso obstructing their reach. The reach capability of women is reduced by the increased fat layers which reduces the women's mobility. The length of the lower limbs also influences the reach of an individual. When the legs are long, the knees protrude into the reach envelope and obstruct the mobility of the individual.

Women are found to have a greater angular reach to the rear which is associated with the greater mobility in the shoulder area of women. This report demonstrates that there is some variation between the sexes concerning reach envelopes, but just as importantly, the report illustrates the range of variability found within each sex regarding reach capabilities.

Cited References: 44 references

Study: Ketcham-Weidl, M.A. and A.C. Bittner
Anthropometric Accommodation of a Female Population in a Workplace Designed to Male Standards. TP-76-3. Pacific Missile Test Center, Point Mugu, California. 1976.

Keywords: Anthropometry, sex differences, anthropometric measurements, workplace design, accommodated percentages, CAPE, computerized accommodated

Method: This report deals with the percentage of potential female user population that would be excluded from the cockpit of an aircraft due to the design of the cockpit. To accomplish this task, the CAPE exclusion analysis was used which employs a Monte Carlo routine. This routine will generate the representative user anthropometric measurements and from these, the percent of the population excluded can be determined. Because of the reduced data available on female anthropometrics, the authors investigated the possibility of using the male correlation matrices when the information is not available for females.

Results: The substitution of the male correlation matrix was acceptable in the analysis, but should only be employed when the appropiate female correlation matrix is unavailable. Since this report was published before the 1977 U.S. Army anthropometric survey of Army women, the appropiate data may now be available.
The report demonstrates that the use of male anthropometric limits on a female population will reduce the number of individuals accommodated. While only 22% of the men were excluded, almost 90% of the women were excluded.

Summary & Application: Workplaces such as cockpits of aircraft have been traditionally designed for men. With more women entering non-traditional occupations in the armed services, these workplaces are either going to have to be redesigned for both male and female anthropometric measurements or women are going to be excluded from these workplaces.

Cited References: 11 references

Study: Kipnis, Dorothy McBride and Louise H. Kidder
Practice, Performance, and Sex: Sex-Role Appropiateness, Success, and Failure as Determinants of Men's and Women's Task Learning Capability. Technical Report #1. University City Science Center, Philadelphia, Pensylvania. May, 1977.

Keywords: Sex differences, sex roles, motor skills, motor learning, race differences

Methods: Men's and women's performance in two motor learning tasks (pursuit roto and a labyrinth) was examined in an experimental learning situation in which unfamiliar tasks were defined as either tasks that men did well or tasks that females did well. The subjects were 43 male and 42 female psychology students at Temple University. The two tasks were designed so that the learner could keep track of his/her progress on performance improvement. Feedback through the instructor was also given describing the success or failure of the subject for the two tasks. The subject's performance was compared to that of other individual's performance. Observations were made on the learner's goal-setting, duration of voluntary practice, actual performance, and attributions of performance effectiveness by learners to ability, luck, task difficulty, effort, and sex.

Results: Both men and women demonstrated best task learning when they believed that most other members of their sex did well on the tasks they were learning and no evaluative comments were made on the subject's progress in learning. Both men and women learned least well when they believed that even though most other members of their sex could do well at the task they were working on, their own learning progress was poor. However, men reacted to feedback describing their own progress as poor by discounting the importance of the task as a measure of ability, and by emphasizing the importance of effort. Women accepted and believed in the negative evaluation of their performance capability.

Men performed better on a test trial than they had during their practice just before the test. Women did more poorly on the test trial than they had been doing during their practice.

Women enjoyed the task more when they were described as activities which men did well as opposed to tasks that were described as ones women did well. When tasks were described as needing masculaine skills, both men and women saw them as demanding more effort for effective performance than when the tasks were described as dependent on female skills. When tasks were described as tasks women could do well, both men and women saw the tasks as dependent on luck.

Kipnis and Kidder (continued)

Results: (continued) Black men and women subjects described themselves as more masculine on the Bem Sex-Role Inventory than did white men and women.

Conclusions: College men and women performed best when their performance was not subject to feedback from instructors no matter if the evaluation was positive or negative. The subjects also performed best when they were told that members of their own sex performed well. Men's self-appraisals of their progress in learning at the end of the tasks did not show long range conscious acceptance of information criticizing their learning progress. Men decreased the extent to which they believed performance reflected ability if their own rate of learning had been criticized. Women did not show this belief. Men performed better when they believed they were being tested while women performed more poorly.

Cited References: 32 references

Study: Konz, Stephan A. & Jacobus [illegible] Prediction of Ratings [illegible] Lifting [illegible] Difficulty from Individual and Task [illegible] Factors, 20(4): 481-487. 1978.

Keywords: Manual materials handling, lifting, [illegible] strength, analysis of covariance, sex di[illegible]rences [illegible]scle strength

Methods: The relationship between manual materials handling and injuries in industry were investigated. The area of interest was the momentary overload of the skeleto-muscular system rather than the cardiovascular system. The variables influencing lifting were divided into task, technique and individual categories. Techniques included body posture, foot and hand positions. Under individual were sex, strength, cardiovascular fitness and various anthropometric measurements. Under task were distance between load and spine, object weight and height, vertical direction of movement and angle of movement. Lifting difficulty was assessed by two criteria: forces and torques from a six-axis force platform and the subject's rating of difficulty.

Table 1 lists the 8 tasks. Tasks 1-4 required lifting an object from the floor to a shelf at head height. Tasks 5-8 required lowering an object from a shelf at head height to the floor. Distance refers to the distance from the object center of gravity to the subject's spine. Tasks 1, 2, 5 and 6 were straight-ahead tasks while tasks 3 and 7 started with the torso twisted and then moved vertically. Tasks 4 and 8 required a turn while moving the object. For each task, the subject moved 3 different weights: 5, 10, and 15 kg for males and 5, 7.5, and 10 kg for females. The subjects did not know which weight was in the box.

The subj[illegible]cts were six men and six women (students and housewives). Medical screening took place before the experiments. Also before beginning the procedures, the subjects viewed a tape of the process and had twenty minutes to practice before actually starting the testing. The procedure involved the subject lifting the object, replacing it, lifting the object again , then resting. During the rest, the subject orally rated the difficulty of the task using the scale in Table 3. Eight sessions of about an hour each were required to run the experiment for each of the twelve subjects. The sequence of conditions was randomized for each subject.

TABLE 1

Eight Tasks Used in the Experiment

Location 1			*Location 2*			*Task Number*	
Height	*Angle (deg)*	*Distance (cm)*	*Height*	*Angle (deg)*	*Distance (cm)*	*Lift*	*Lower*
Floor	0	30	Head	0	30	1	5
Floor	0	50	Head	0	50	2	6
Floor	45	30	Head	45	30	3	7
Floor	45	30	Head	0	50	4	8

Konz (continued)

Methods:
(continued)

TABLE 3

Rating Scale Used in the Experiment

Rating Value	Description	Prepared to do: Frequency	Number/8 hou
1	Very, very light	Continuously	--
2	Very light	1/min	480
3	Fairly light	1/10 min	48
4	Fairly hard	1/hr	8
5	Hard	1/2 hrs	4
6	Very hard	1/8 hrs	1
7	Very, very hard	Refuse to do	0

Results:

The output from the experiment was analyzed with the analysis of covariance (1727 degrees of freedom). A preliminary regression was run with the main effects and their two- and three-way interactions. Covariates (individual characteristics) which were not significant or were highly correlated with another variable were dropped from the analysis. After deleting the nonsignificant covariates, the final prediction model was formed with regression analysis. Table 2 presents the results.

TABLE 2

Subject Characteristics (Subjects 1–6 are Males and 7–12 are Females.)

Subject Number	Age (yr)	Weight (kg)	Height (cm)	Maximum O_2 ml/(kg-min)	Back Rotational Flexibility (deg)	Trunk Flexibility Ratio	Leg Strength (kg)	Back Strength (kg)	Mean Grip Strength (kg)	Mean Arm Push Strength (kg)	Body Fat (%)	Mean Rating
1	21	71.5	179	39	66	0.787	181	96	51	20	11.5	2.57
2	24	80.0	176	49	85	0.717	287	130	54.5	37	17	2.77
3	27	83.0	180	48	80	0.677	215	141	53	41	17	2.79
4	31	85.5	184	42	85	0.705	195	140	58.5	54	17	2.41
5	32	75.5	174	39.5	70	0.685	245	98	67.5	34	16	2.75
6	35	79.0	172	38	55	0.917	145	105	44	37	18.5	2.55
Male Mean	28	79.1	177	44	73	0.745	208	118	55	37	16.5	2.64
7	22	61.5	172	35.5	95	0.763	104	68	25	11.5	20	3.61
8	26	65.5	177	45.5	83	0.667	109	85	28	22	21	3.80
9	27	54.0	162	36.5	92	0.886	95	55	30	27	[illegible]	3.78
10	32	53.5	165	39.5	75	0.664	109	62	32.5	13	18.2	4.12
11	32	50.2	158	48	10	0.856	68	52	24.5	17	16.4	3.77
12	39	53.4	163	42	82	0.825	68	60	27.5	16.5	20	4.74
Female Mean	30	56.3	166	41	69	0.778	92	64	27.9	17.8	18.9	3.97
Grand Mean	29	67.7	172	44.7	71	0.761	150	90	41.3	27	17.7	3.30

Results: (continued) The significant covariates included sex, age and back rotational flexibility. The subjects ranged in age from 21 to 39 with a mean age of 29 years. A one year deviation from the mean changed the rating by .6%. A one degree deviation in back rotational flexibility changed the rating by .02%. Flexibility ranged from 10^{0} to 92^{0}. Subjects who were younger and had more flexibility had lower ratings. The sex effect indicated that females considered a specific weight more difficult than males. Task did have an effect on the rating. Lowering was significantly easier than lifting. Moving the more distant objects was also found to be more difficult. The object at 50 cm was 4.8% more difficult than the object at 30 cm. Movement of an object involving a twist was considered 4.2% more difficult than a move with no twist-involved. Squatting was found to be 2% more difficult than bending when the two types of techniques were compared. The volume of the box had no effect on the males, but was found to be significant for the females. The authors could not explain why the box volume was statistically significant for the women but not for the men.

Summary & Application: The effect of sex dominated the individual results. Overall, men are willing to lift more than women. As a group, women will not lift more than 12-14 kg while men will lift 35-41 kg. Isometric back strength was found to be a good criterion for selecting individuals for lifting. It must be remembered that the subjects were not professional material handlers, but students and housewives. The lack of conditioning may have an effect on the results of this experiment.

Cited References: 11 references

Study:	**Kroemer, K.H. Eberhard** Push Forces Exerted in Sixty-Five Common Working Positions. AMRL-TR-68-143. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1969.
Keywords:	Biomechanics, anthropometry, push forces, static muscle strength, isometrics
Methods:	A series of experiments were performed to determine the maximum isometric horizontal push forces exertable in sixty-five common working positions. The forty-five male college students either anchored their feet against a footrest or braced themselves against a vertical wall while pushing horizontally. The experimental equipment included a three-dimensional box (230 cm X 230 cm X 75 cm) with the front and bottom filled with plywood. Holes, 2 cm in diameter, were drilled into the bottom and top angle irons at specified intervals to provide an adjustable wall-wall or wall-footrest situation for the series of experiments. A push panel consisting of an oval-shaped, stainless steel ring mounted centrally between two aluminum plates (25 cm X 20 cm X 1 cm deep) was bolted onto the front side of the iron frame. The panel was adjustable in height to the subject's acromial height.
Results:	For each trial, the mean force was given in kiloponds (1 kilopond = 2.2 pounds) as well as the basic summary statistics such as mean, standard deviation and the 5th percentile value. The results of the experiments were displayed in tabular form. Male operators were able to exert horizontal static forces of at least 25 kp (55 lbs.) pushing with one hand, at least 50 kp (110 lbs.) pushing either with both hands or with the shoulder, and at least 75 kp (165 lbs.) pushing with the back (providing the subjects anchor their feet or brace themselves against a vertical wall.
Summary & Application:	Large horizontal push forces can be exerted if the subject can wedge his body between the vertical surfaces of the push panel and the wall. The highest push forces were exerted when pushing backwards. Wedging both shoulders between the wall and push panel produces rather high push forces, but the panel must be adjusted to an oblique angle which is uncomfortable. Pushing with one arm does not yield much push force while pushing with two hands is only slightly less than the pushing forward with the preferred shoulder.
Cited References:	69 references

Study: Laubach, Lloyd L.
Muscular Strength of Women and Men: A Comparitive Study. AMRL-TR-75-32. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1976.

Keywords: Muscle strength, sex strength differences, push forces, comparitive muscle strength, static strength, dynamic strength.

Methods: Experiments were conducted to measure the static strength on 31 women subjects and compare these results with similar data obtained on males by K. H. E. Kroemer (1969). Twelve measures of static strength, twenty-two body size measurements and measurements to determine the subject's somatotype were investigated. Six of the static strength measures involved cable tension strength. These measurements included flexion of the shoulder, hip, and trunk; and extension of the knee. Hand grip strength was measured with a Smedley adjustable hand dynamometer. The strength score was the maximum amount of force without jerking that the subject could exert against the calibrated cable tensiometer. The second group of six static strength tests measured the maximum isometric horizontal push forces exertable in 65 common work positions. The subjects either anchored their feet against a footrest or braced themselves against a vertical wall while pushing horizontally. A survey of the literature pertaining to static and dynamic strength is included.

Results: The results of the measures of the various flexions, the tests of static strength, and the results of the literature review are presented in a graphic and tabular form. The correlations between the anthropometric variables and the strength exertions were rather low. This is not an unexpected finding since it has been well documented that measures of size, composition and physique are not good predictors of muscle strength (Laubach and McConville, 1969).

Summary & Application: Comparitive muscular strength capabilities are presented in this report for men and women. The results should be of value to the design and industrial engineer as well as to researchers working in the fields of sports medicine and biomechanics.

Laubach (continued)

Cited References: 20 references

Kroemer, K.H. Eberhard 1969 Push Forces Exerted in Sixty-Five Common Working Positions. AMRL-TR-68-143.

Laubach, Lloyd L. and John T. McConville 1969 The Relationship of Strength to Body Size and Typology. Medicine and Science in Sports, Vol. 1 (4):189-194.

Study: Laubach, Lloyd L., John T. McConville, Edmund Churchill, Robert M. White

Anthropometry of Women of the U.S. Army-1977. Report No. 1. Methodology and Survey plan. Natick-TR-77-021. U.S. Army Natick Research and Development Command. 1977.

Keywords: Anthropometry, body size, anthropometric measurements, military personnel, women, human factors engineering, static strength

Summary & Application: An anthropometric survey of the women of the U.S. Army was conducted in 1976-1977. This was the first survey of Army women since the anthropometric survey completed in 1946. Because women have benn taking a more active role in the Army and the armed services, there was a real need to have current data concerning the range of body sizes in women and the strength capabilities of women. The main purpose of this survey was to accumulate statistical data on body size, workspace parameters, and static muscle strength of U.S. Army women. The measurements gathered included 128 conventional body size dimensions, 14 workspace dimensions, and 9 static strength measurements. Several measurements had not been previously reported for any large-scale survey of women, military or civilian. Other measurements were selected to supplement and complement data already available to provide up-to-date information for use in the design of protective equipment and clothing, workspace, regular clothing, and industrial equipment which Army women wear, use, operate, or within which they work. This report outlines the survey plan and discusses the methodology used in implementing the survey requirements. Each measurement is described with the defining landmarks illustrated on a female figure. Measurements and measuring techniques of previous surveys are reported here as well.

Cited References: 40 references

Study: LeBlanc, J., J. Cote. S. Dulac, and F. Dulong-Turcot
Effects of Age, Sex, and Physical Fitness on Responses to Local Cooling. J. Appl. Physiol.:Respirat. Environ. Exercise Physiol. 44(5):813-817, 1978.

Keywords: Sex differences, cold, skin temperature, heart rate, blood pressure, physical fitness, age

Summary & Application: The response to local cooling was estimated by the cold hand test (5° C for 2 minutes) and the cold face test (0° C with 66 km per hour wind for two minutes). Heart rate, blood pressure, and skin temperature were measured before and after as well as during the tests. The increase in blood pressure in the cold hand test and the fall of skin temperature in the cold face test was reduced in trained subjects. Older subjects (53-60 years of age) responded less to the cold hand test than younger subjects aged 20-40 years of age. The responses to the cold hand test and the cold face test were similar in males and females. During the two minutes after the test, blood pressure and heart rate fell below initial levels in the women subjects (8) but not for the male subjects (9) The men experienced a rise in heart rate during the test, but the rate returned to normal during the two minutes following the completion of the test. Women responded faster during the first minute of the test, but exhibited lower heart rates following the test.

Cited References: 11 references

Study: Macnab, Ross B.J., Patricia R. Conger, & Peter S. Taylor Differences in Maximal and Submaximal Work Capacity in Men and Women. Journal of Applied Physiology, 27(5): 644-648. 1969.

Keywords: Aerobic capacity, exercise, heart rate, sex differences, women, men

Methods: Twenty-four men and 24 women, all college students, were randomly selected from physical education majors at the University of Alberta. The subjects completed two trials of the following tests: Mitchell, Sproule, and Chapman maximal oxygen uptake test (motorized treadmill), a modified Sjostrand physical work capacity test on an ergometer, and a progressive step test. One trial was made of the Astrand bicycle ergometer test of maximal oxygen uptake. The order of the tests for each subject was one trial of the Mitchell, Sproule, and Chapman treadmill test. The seven remaining trials were assigned randomly in terms of sequence. Body density was determined by the hydrostatic method.

Results: The table below summarizes the results of the four different tests. Test reliabilities were tested with the test-retest method employing the Pearson product-moment correlation technique. The results were as follows: Mitchell, Sproule, and Chapman, 0.88 (men) and 0.83 (women); modified Sjostrand, 0.91 (men) and 0.75 (women); progressive step, 0.75 (men) and 0.86 (women). The correlation coefficients were quite adequate especially since the sample was homogeneous with regard to age and background.

TABLE 2. *Test results*

Test	Male	Female	F*
Mitchell, Sproule, and Chapman			
l/min	3.92±0.58	2.32±0.41	121.45
ml/kg per min	51.71±5.13	39.06±5.05	73.56
ml/kg fat-free wt per min	59.41±5.86	50.42±5.97	49.73
Åstrand			
l/min	3.52±0.61	2.12±0.41	87.23
ml/kg per min	46.47±6.25	35.67±5.39	39.28
ml/kg fat-free wt per min	53.31±6.55	46.87±7.20	25.80
Modified Sjöstrand			
kpm	1,345.08±209.40	769.42±198.23	81.51
kpm/kg	17.75±3.04	12.97±2.26	36.99
kpm/kg fat-free wt	20.40±3.51	16.90±2.59	25.71
Progressive step			
kgm	870.67±180.15	488.17±109.81	79.41
kgm/kg	11.47±1.88	8.23±1.57	40.09
kgm/kg fat-free wt	13.19±2.27	10.78±1.90	27.11

Values are means ± SD. * All F ratios significant at 0.01 level.

Macnab (continued)

Summary &
Application: In all tests, men performed at a significantly higher level than women whether the scores were in a raw form or expressed as a function of the fat-free weight.

Cited
References: 27 references

Study: Martz, H. F., Jr.
Anthropometric Data Reduction Using Factor Analysis and Stepwise Regression. TM-80-23. Pacific Missile Test Center. 1980.

Keywords: Anthropometry, anthropometric measurements, factor analysis, stepwise regression, human factors, engineering.

Method: In this study, 185 anthropometric measurements were selected from 204 measurements taken on 2,420 male U.S. Air Force personnel in 1967 (Clauser, Alexander, and Kennedy; 1967).* All measurements measuring the same body part were identified and collected into groups signifying that body part. The next step consisted of separate factor analysis by groups to identify intragroup relationships. If these relationships existed, the measurements could be reduced to a representative factor. The loadings of variables upon the factors are considered correlations between the variable and the factors. Therefore, if many variables load heavily on one factor, the variable with the highest correlation with the factor should be selected with the remaining variables discarded. Stepwise regression was performed on the discarded variables in terms of the selected subset. In this way, the variables not selected could be predicted based on the selected subset. Simple statistics such as mean and standard deviation were generated from the data. Principal components and product-moment correlation coefficients were also calculated. The final phase of the factor analysis was the construction of the factor pattern matrix where the numbers in a row represent the regression coefficients of factors to describe a given variable. The numbers also represent the correlation of the factors and the variables.

Results: Ten groups were identified (skinfold, height, length, breadth, circumference, scrotal, miscellaneous, foot, hand, and head). Thirty-two variables were selected as the most useful in explaining the variation of all variables in all groups. This represents a significant reduction in data.

Summary & Application: The objective of this report was to extract from the initial 185 variables a subset of measurements that could collectively account for most or all of the remaining variables. The reduction in the number

* Clauser, C.E., M. Alexander, K.W. Kennedy (1967). "USAF Anthropometry of Flying Personnel-1967", Aerospace Medical Research Lab. Wright-Patterson Air Force Base, Ohio.

Martz (continued)

Summary &
Application: (continued) of measurements employed in an anthropometric survey is cost and time effective without the loss of pertinent information. Since this analysis was performed on a male U.S. Air Force population, the results are restricted to a male U.S. military population.

Cited
References: 2 references

Study: McConville, John T., Edmund Churchill, Thomas Churchill, and Robert M. White
Anthopometry of Women of the U.S. Army--1977. Report No. 5. Comparitive Data for U.S. Army Men. Technical Report # TR-77-029.1977.

Keywords: Anthropometry, body size, anthropometric measurements, human factors engineering, static strength, males

Method: This report is fifth in a series dealing with the anthropometric survey of U.S. Army women done in 1977. This report contains comparitive anthropometric data from a sample of 287 U.S. Army males. Data obtained in the survey included 44 of the original 69 body measurements made on women, 13 of an additional 24 standard body size measurements measured on the women and three identical subseries of workspace, head and face, and static strength measurements. Summary statistics include mean standard deviation and percentile values for the 5th, 10th, 15th, 25th, 35th, 50th, 65th, 75th, 85th, 90th and 95th percentile levels. Frequency distributions were computed on the socio-military background variables rank, age, length of service, race, birthplace and handedness. Frequency tables are included for the face and head measurement subseries, the workspace and static strength measurements as well as for the basic measurements.

Results: Comparison of the results of the survey on U.S. Army males with the results of the survey on U.S. Army females will be published in a later report.

Summary & Application: This report provides comparitive data for U.S. Army men to be used in conjunction with the results of the 1977 anthropometric survey of U.S. Army women. These surveys will be useful in the design of equipment, workspace and clothing for military personnel.

Cited References: 3 references

Study: McConville, John T., Ilse Tebbetts, and Thomas Churchill
Analysis of Body Size Measurements for U.S. Navy Women's Clothing and Pattern Design. Technical Report # 138. Natick Clothing & Textile Research Facility, Massachusetts. 1979.

Keywords: Anthropometry, body size, anthropometric measurements, key dimensions, clothing design.

Method: The anthropometric surveys of the U.S. Air Force women and the U.S. Army women were reviewed to establish a sizing program for U.S. Navy women for clothing design. The two surveys indicated the populations were very similar in composition except the U.S. Army survey had more Blacks (23%) as opposed to the U.S. Air Force survey which had 5%. 49 dimensions were examined with the result of 5 measurements being selected as key dimensions for clothing design. These are Bust Circumference, Bustpoint-to-Bustpoint Breadth, and Neck-to-Bustpoint Length for garments worn above the waist. For garments worn on the lower torso, Waist Circumference combined with Crotch Length were used. Selection of measurements for design should include variables which correlate highly with many measurements but not with the measurements selected to base the clothing design upon.

Results: The authors found that several of the key dimensions were not included in either one or the other survey. The U.S. Army survey contained the majority of the measurements so it was used for the Navy women's clothing design. Any gaps in data could be filled through regression analysis. One other critical problem was several of the measurements were significantly different from one survey to the other. The Army women had larger waists with smaller bustlines when compared to the Air Force women. The authors feel that this difference was due to the difference in the women sampled and not an artifact of the measuring process.

Summary & Application: The key dimensions that were selected proved to be less than adequate to describe the sizing dimensions required to fit the sample population. The authors suggested that alternate key dimensions be selected. A revised sizing scheme would reflect the actual body size range and variability. A small sample of Navy women should also undergo anthropometric

McConville (continued)

Summary & Application: (continued) measuring to validate the regression analysis which was used to fill in any gaps in the U.S. Army survey for the key dimensions. The authors suggest the existing anthropometric surveys provide adequate data so that a large-scale Navy women survey does not need to be undertaken.

Cited References: 12 references

Study: McGuinness, Diane
Equating Individual Differences for Auditory Input. Psychophysiology, 11(2): 11--120. 1974.

Keywords: Sex differences, sensation level, uncomfortable loudness level

Method: Fifty undergraduate psychology students (half female/half male) participated in a study to test the hypoth esis that different individuals will perceive a specific stimulus as being equivalent. An audiometer was used in the experiment along with TDH-39 earphones. The experiment took place in a semi-soundproofed windowless room. The subject was presented with a series of continuous tones (2 ascending and 2 descending) to determine the thresholds. The loudness test involved the subject adjusting the sound to a level that was judged to be "too loud".

Results: For the loudness test, the sex difference was significant with men tolerating louder sound than women. Men had a negative correlation between threshold and loudness estimation while women had positive correlations.

Summary & Application: The hypothesis that different subjects would perceive the level of loudness intensity as equivalent was rejected when the subjects were separated by sex. Women were more sensitive to loud sounds than men and set the level of loudness lower than the male subjects. The author suggests that this observation is more the result of heredity than cultural or environmental conditions.

Cited References: 28 references

Study: McGuinness, Diane
Away from a Unisex Psychology: Individual Differences in Visual Sensory and Perceptual Processes. Perception, 5, 279-294, 1976.

Keywords: Sex differences, visual acuity, detection threshold, visual persistence.

Method: Twenty-five male and 25 female undergraduate students participated in four tests of visual perception. These were a test of acuity, threshold for four field positions, visual persistence and a measure of comfortable brightness. Subjects also completed five personality questionnaires. Acuity was measured using both Snelling and E charts. For the threshold test, dark adapted S(s) viewed a red fixation light 30 cm away through a binocular visor. An illuminated slot was presented at 20^{o} of visual angle away from the fixation point in either a 0^{o}, 90^{o}, 180^{o} or 270^{o} orientation. The illumination of the stimulus was varied from 10^{-5} to 10^{-1} millilamberts. S(s) were required to report the location of the stimulus upon perception. Visual persistance was measured through the use of a strobe light focused behind a rotating disk with a 10 cm radial slot. The strobe was varied from 600 to 2700 flashes/min, during which time S reported the number of lines perceived. This procedure was used first in ambient darkness, then in a light adapted state. Comfortable brightness was measured by requiring S(s) to adjust a headlamp to a level they felt would be indefinately tolerable.

Results: Males were found to have better acuity than females. Sex did not prove to be a significant factor in threshold detection although significant main effects for stimulus position and time in trial were found. Interaction effects of position x time and sex x position x time were also significant. When acuity was held constant, females showed lower detection thresholds than males. Females also had greater visual persistance in the dark, while no sex differences were found in visual persistance in lighted conditions. Additionally, males set their comfortable brightness levels significantly lower than females did. Correlations between this data and data gained from the same S(s) who participated in an earlier audition study showed a significant positive relationship between comfortable levels of illumination and sound volume.

Summary & Application: In most measures, differences were found to be related to sex rather than to personality factors. In fact, the analyses performed suggest that personality tests do not measure equivalent processes in men and women. Correlational analysis showed all visual functions to be independent of one another with the exception of photopic acuity and scotopic threshold, which were highly correlated. Two new findings on the visual system emerged which have not been reported elsewhere: (1) Four distinct dark adaptation curves were produced, and have been labeled as exponential, flat-exponential, linear, and plateau. All subjects fell into one of these categories and showed a consistent trend to exhibit these curves for all field positions. (2) Highly significant differences were found in sensitivity for the four visual fields, the upper field was superior, followed by the right, then left, with the lower visual field considerably poorer.

Cited References: 31 references

Study: McGuinness, Diane and Ian Lewis
Sex Differences in Visual Persistence : Experiments on the Ganzfeld and Afterimages. Perception, 5: 295-301. 1976.

Keywords: Sex differences, visuospatial ability, psychophysical

Method: Twenty males and twenty females participated in an experiment to assess the sex differences in visual persistence (the presence of afterimages). Two experiments were designed. The first used a slide projector to display red light to half the subjects and green light to the other half of the subjects. The subject was placed in the dark for 3 minutes then a colored light was swithched on and a tone was sounded at 15 second intervals. When the tone beeped, the subject was asked to report the color or colors that were seen at that exact moment. This procedure continued until a complete cessation of color lasting two minutes occurred or until a 20 minute time period has elapsed. Subjects were allowed to rest twenty minutes between experiments.
The second experiment used a 500w photoflood lamp at the back of a perspex screen where a black cross was mounted. The subject was seated 3.33 meters away from the screen. The flood lamp was turned on and the subject was asked to stare at the cross for five seconds, then turn to face the wall after that time period when the lamp was switched off. The subjects were asked to report all visual changes at the tone beep. The subjects had been briefed as to what they might expect in terms of colors, fragmentation and reversal of figure.

Results: For the first experiment, green produced a more rapid offset of sensation than red. For loss of color, the sex difference was significant with males reporting far less loss of sensation than females. Females held red longer than green while there was no difference for males. Men experienced significantly more blank outs for color loss. Experiment number two resulted in more men taking longer for the loss of the stimulus. Males experienced a smaller range of colors than females. When stimulated by the white light, women reported colors in the long-wave range (red, or pink) while males reported blue, green or yellow. The sex difference was found to be significant.

Summary & Application: In the Ganzfeld experiment three main effects were found. Males had a far greater persistence of color

McGuinness and Lewis (continued)

Summary & Application: (continued) and showed little difference in their responses to red and green. Women held red sensation longer than the sensation of green. Males had more variety in their visual experience (colors fading and reappearing, colors unrelated to the stimulus, and complementary colors). Males also experienced blank outs far more regularly than females. Women were found to be more responsive to colors from the long-wave region of the color spectrum. One explanation for the sensitivity to colors in the long-wave region of the spectrum is that this ability would allow women to find "a wandering infant in the dark".

Cited References: 19 references

Study: Mital, A., M.M. Ayoub, S.S. Asfour, and N.J. Bethea Relationship Between Lifting Capacity and Injury in Occupations Requiring Lifting. Proceedings of the Human Factors Society-22nd Annual Meeting-1978.

Keywords: Manual materials handling, lifting, factor analysis, sex differences, muscle strength, endurance

Methods: A balanced, incomplete block factorial design was used to develop a lifting capacity model for industrial workers in jobs that required lifting of materials. Factors affecting lifting capacity can be categorized into three groups. These include individual characteristics, task variables, and environmental conditions. Six height ranges were defined for testing purposes. The floor to reach range was divided into floor to knuckle, floor to shoulder, and floor to reach. The knuckle to reach measurements were divided into knuckle to shoulder and knuckle to reach. Shoulder to reach was the last height level. The rate of lift was divided into 2, 4, 6, and 8 lifts/minute. Box size was divided into three levels; 12, 18, and 24 inch box length. Seventy-three males and seventy-three females were recruited from local industries and divided into three age groups; 20-29, 30-39, and 40-49 years. The subjects were also divided into two weight groups; above median and below median where the median values of 135 and 170 pounds were established for women and men respectively. A psychophysical appoach was used in the experiment which allowed the subject to adjust the weight of lift to their own capacities. Before beginning the tests, several anthropometric measurements were made on the subjects as well as strength and endurance measures. During the testing, a metronome was used to pace the subjects.

Results: The maximum acceptable weight of lift at the rate of one lift per minute is defined as the capacity . Age did not have an effect on the lifting capacity.

Mital (continued)

Results: (continued) Based upon the results of the lifting experiments, a regression analysis was conducted to predict the lifting capacity of individuals. The dependant variable was the maximum acceptable weight of lift plus body weight. Eight independant variables explained 85% of the total variation. Sex, one of the independent variables, explained 50% of the variance. The other seven variables were weight, arm strength, age, shoulder height, back strength, abdominal depth, and dynamic endurance.

Data also were collected on 41 jobs involving 250 workers over a three year period. The total number of man-hours worked was 1.48 million. There were 271 lifting injuries per 1000 man-hours worked resulting in 1034 work days lost per 1000 man-hours worked. The number of strains and sprains were 93 per 1000 man-hours worked and caused a loss of 842 work days per 1000 man-hours worked.

Summary & Application: The sex of an individual was the single most important independent variable. Sex accounted for 50% of the total variation in the predictive model for lifting capacity. The back injury and work days lost models led to some interesting conclusions about weight and work rate. Both were important for predicting back injuries in industrial situations, but work rate was a more effective predictor of work injuries involving the back.

Cited References: 14 references

Study: Morrissey, S.J., A.C. Bittner, and C.G. Halcomb
Applicability of Computerized Accommodated Percentage Evaluation (CAPE) to Clothing Variables. TP-76-37. Pacific Missile Test Center, Point Mugu, California. 1976.

Keywords: Anthropometry, Clothing designs, Empirical studies, Computerized accommodated percentage evaluation model (CAPE)

Summary & Application: Comparison was made of empirical results for 10 anthropometric measurements taken on 4,063 USAF male personnel in 1950 and the results generated by the application of a Monte Carlo CAPE model based on the intercorrelation matrix of the same 10 anthropometric measures and the percentile range desired (35th to 65th). A comparison of the results (accommodated percentages) of the two studies demonstrate that the CAPE model is an accurate predictor of accommodated percentages. The model was initially designed for cockpit exclusion studies, but this report indicates that the CAPE model would also be appropiate for clothing design.

Cited References: 7 references

Study: Murphy, Marcia A. and Theresa M. Nemmers
Ammunition Loading and Firing Test-Pretest Physical Conditioning of Female Soldier Participants. Technical Note 11-78. U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD. 1978.

Keywords: Physical conditioning, women soldiers, exercises, ammunition loading study, howitzers, human factors engineering

Method: Thirteen women soldiers were the subjects in an experiment to test a training/physical conditioning regimen based on the requirements of ammunition handling/loading for howitzers. The conditioning program included endurance, strength and cardiovascular exercises. These exercises included ten minutes of stretching and warm-up calisthenics, 12-minute aerobic run, bench press, leg press, sit-ups, back extension, and cool-down walks. The women demonstrated increases in the distance covered in the 12-minute run and in the ability to lift an increased amount of weight. Both of these tests indicated that the physical endurance of the subjects was improved with no significant injuries incurred during the conditioning program. This training prepares the women for artillery loading tasks but makes no provisions for other task-related effects when the situation is real rather than the situation presented in this report.

Cited References: 3 references

Study: Paolone, Albert M., Christine L. Wells, and Girard T. Kelly
Sexual Variations in Thermoregulation During Heat Stress.
Aviat. Space Environ. Med. 49(5):715-719, 1978.

Keywords: Sex differences, thermoregulation, heat stress, maximal oxygen uptake, rectal temperature, skin temperature, heart rate, sweat rate

Summary & Application: Four males and three females all physically fit, but untrained, performed a treadmill walking task in neutral (25° C), warm 32° C), and hot (40° C) environments. The treadmill grade for each subject was based on 50% maximal oxygen uptake as determined in a neutral environment. Exposures in the different climates were two hours in length and divided into 40 minutes of rest, work, and recovery respectively. No distinct sexual differences in rectal and skin temperature responses were observed in the three environments. The male subjects had higher heart rates and greater sweat rates during exercise in all environments. The female subjects experienced less severe increases in heart rates and sweat rates during work in the warm and hot climates than the men. The greater percentage of increase in heart rates relative to changes in the metabolic cost of work in women suggested a greater cardiovascular component of thermal regulation in the female than in the male subjects. The results found in this experiment suggest that women are capable of working in the heat about as well as men relative to the individual's level of physical fitness and their maximal aerobic capacity.

Cited References: 12 references

Study: Pepper, Ross L. and Phillips, M.D. Naval Architectural Research for Women Aboard Ships. NOSC-TR-658 Naval Ocean Systems Center, San Diego, CA, March 1981.

Keywords: Anthropometrics, biomechanics, ergonomics, ship fittings, women.

Method: Qualitative techniques (questionnaires, interviews, observations) were used to identify human engineering problems related to the assignment of women aboard ships. Questionnaires were administered aboard a sample of Naval and Coast Guard ships. Additional data were extracted from questionnaires administered during the Occupational Physical Standards (OPS) project conducted by NPRDC personnel. An analysis of the human engineering and human performance relevant data was conducted on a subset of the OPS generated data. Personnel in the occupational fields of general seamanship, marine engineering, ship maintenance, and their related apprenticeships were included in this subset. Task observations were conducted aboard the USS Dixon (AS 37), the USS Gray (FF 1054), the USS O'Callahan (FF 1051) and at Fire Fighting School. All ships were in port for routine maintenance during observation times. Hull technicians (HT), boatswains mates (BM), machinist mates (MM), and mess management specialists (MMS) were observed performing a variety of tasks in their billet. At Fire Fighting School, S(s) were observed fighting Class A (solid substance), B (flammable liquid) and Class C (electrical) fires using the same equipment and protective gear employed aboard ship. Structured and informal interviews were conducted with selected personnel at the observation sites listed above. Subjects interviewed included seven Officers and 15 enlisted male and female personnel.

Results: Several items of ship equipment, clothing, and fittings emerged as being deficient for use by females. Protective gear such as the oxygen breathing apparatus (OBA), safety harness, life preserver, and foul weather gear did not adequately fit many of the women on board. Hand tools and fire fighting equipment were found to be difficult for many of the women to operate. Ship fittings such as escape scuttles and water tight doors were also reported as problematical.

Summary & Application: The results indicate that sexually based anthropometric differences do cause difficulties with the use of shipboard items by women and smaller male personnel. Factors that contribute to these difficulties included differences in grip strength, upper torso strength and reach envelope The high motivational level of women, the select on of larger males for more demanding tasks, a d womens' relative lack of experience at sea biased some of the data collected by the self report mea ures. Additional work is recommended to identify problematic equipment types and the common factors causing the difficulties as women are assigned in greater numbers and gain more experience using shipboard equipment.

Cited References: 9 references

Study: Polit, Denise, Ronald L. Nuttal, and Eleanor King
Utilization of Women in Industrial Career Fields. AFHRL/TR 78-48. Air Force Human Resources Laboratory, March 1979.

Keywords: Women, women in industry, women in non-traditional jobs, utilization of women, mechanical aptitude, sex differences, spatial and perceptual abilities, leadership ability,

Summary & Application: This report presents a comprehensive literature review, an annotated bibliography, data analysis from a pilot study of three corporations, and recommendations and conclusions for the above mentioned sources. The literature review covers the areas of women in non-traditional careers, sex differences in abilities and aptitudes (spatial/perceptual, problem-solving, mechanical, a little strength) and sex differences in job-related attributes (turnover/tenure, absenteeism, overtime/hours of work, job satisfaction, job motivation, job performance, leadership ability and behavior). Attitudes toward women in different work situations are also studied. A review of managerial attitudes is included and the impact of these attitudes is given.

Cited References: 313 references

Study: Printy, Theodore M.
A Consideration of Factors Contributing to Strength Differences in Men and Women. Master's Thesis, June 1979. Naval Postgraduate School, Monterey, California 1979.

Keywords: Strength, endurance, stamina, physiological sex differences, strength sex differences, comparitive muscle strength

Summary & Application

This thesis reviews past reports dealing with sex differences in the fields of physiology and anatomy. These differences then form the basis for analyzing physical strength differences. Other influences such as biomechanics, cultural differences, stature, weight and amount of training received are also considered in the thesis. Printy draws heavily upon the work of Lloyd Laubach (1976 and 1978) and reproduces Laubach's graphic representations of strength differences between men and women. Printy advocates task analysis as a very useful tool for defining job requirements and the strength needed to effectively perform the jobs. After strength testing is accomplished on men and women and the task analysis on jobs is completed, men and women can be assigned to the appropiate job based on the job requirements and the individual's abilities.

Cited References: 25 references

Laubach, Lloyd L. 1976 Muscular Strength of Women and Men: A Comparitive Study. AMRL-TR-75-32.

Laubach, Lloyd L. 1978 "Human Muscular Strength" in Anthropometric Source Book, Volume I: Anthropometry for Designers. Edmund Churchill et al., eds. National Aeronautics and Space Administration.

Study: Reynolds, Herbert M. and Mackie A. Allgood
Functional Strength of Commercial Airline Stewardesses. FAA-AM-75-13. Office of Aviation Medicine, Federal Aviation Administration, 1975.

Keywords: Static strength, isometrics, women, aviation medicine, anthropometry, human factors

Methods: Anthropometric measurements and measures of static strength were obtained from 152 on-line airline stewardesses from Braniff Airlines. The body measurements included height and weight as well as six measures of body breadth and height, three circumferences and two skinfolds. The static strength measurements included leg lift (25 cm from floor), back lift (50 cm from floor), arm lift (100 cm from floor) and a push (110 cm from floor). The different heights reflected common working heights for stewardesses aboard aircraft.

Results: Results of the anthropometry supported the findings of the work done by C.C. Snow et al. (1975) that the airline stewardess did not represent the average American female. The push forces exerted by the stewardesses were measured at 66.3% of their mean stature. The maximum force exerted was on the average 97.. pounds. The leg lift was found to be the most difficult task of the four strength tests. The mean maximum leg lift was 130.9 pounds. The average maximum back lift was 163.3 pounds while the average maximum arm lift was 90.8 pounds.

Summary & Application: The leg lift demonstrated that there is a behavioral tendency to lift loads with the back musculature as opposed to the traditional method of lifting with the leg musculature. The authors pointed out that the maximum force recorded for each test was the maximum voluntary force and not the maximum produced when the individual is under stress.

Cited References: 20 references

Snow, C.C., H. M. Reynolds, and M.A. Allgood 1975 Anthropometry of Airline Stewardesses. FAA Office of Aviation Medicine Report No. AM-75-2.

Study: Robinette, Kathleen, Thomas Churchill, John T. McConville
A Comparison of Male and Female Body Sizes and Proportions. AMRL-TR-79-69. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1979.

Keywords: Anthropometry, body size, anthropometric measurements, percentiles, design

Summary & Application: Certain assumptions have been made in regard to designing clothing, equipment and workplace areas for women. Two of these are that the women can be viewed as a scaled-down male and that the 50th percentile value of a measurement correlates to the 5th percentile value of a man while the 95th percentile value of a woman will correlate to the 50th percentile of a man. This is based on the variables height and weight which fulfill the correlation.
This report demonstrates that the proportions of body size vary in the dimensions associated with the primary sex characteristics. The correlation of the percentile values is also skewed because of these characteristics. For measurements such as height and weight and other measurements not associated with these characteristics, a scaling down from the male dimensions can be made. One other area of unreliability is the measurements of the head, feet and hands of males and females.

Cited References: 5 references

Study: Robinette, Kathleen, Thomas Churchill
Design Criteria for Characterizing Individuals in the Extreme Upper and Lower Body Size Ranges. AMRL-TR-79-33. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1979.

Keywords: Anthropometry, range of human body sizes, percentile values, regression method

Summary & Application: The common design solution to accommodating a wide range of body sizes to a given piece of equipment or workspace was to incorporate the body size data from the 5th, 50th and the 95th percentiles. This would exclude the individuals on either end of the distribution. To remedy this situation, the authors have suggested using multiple regression to predict the tails of the distribution based upon given values of height and weight. The results are comparable to percentile values but are more realistic. Another method for prediction is the subgroup method which draws upon the individuals below the 10th percentile and above the 90th percentile and uses the mean from each group as the representative percentile value. The smaller sample size is a drawback to be considered. The preferred method of the authors is the regression method because the regression values are additive and can be estimated for any other variable for any desired height and weight.

Cited References: 8 references

Study: Rock, Lee C.
Report of the Study Group on USAF Female Aircrew Requirements for Life Support Equipment and Protective Clothing. ASD-TR-77-32. Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. 1977.

Keywords: Anthropometry, life support equipment, protective clothing, safety

Method: This report is a review of the pilot training program for the USAF. It identifies areas that might present safety problems for the female flight personnel. Equipment and clothing worn or used during flight was analyzed for problems. Training situations were also investigated to determine if any of the situations had the potential for female injury due to smaller anthropometric measures.

Results: The flight boot posed the greatest fit problem for clothing. Women were issued combat boots which have a greater size range and could accommodate the smaller foot size. Additional adjustment pads were required to improve the fit of the helmet. Oxygen masks did not fit the narrower faces of the women. Masks can be custom-fitted for the women who can not be fitted out of stock.

The harness of the BA-22 parachute assembly could not be adjusted to adequately fit the women with smaller statures. It was necessary to remove 4 inches from the back adjustment straps to accommodate the women of smaller stature.
The escape system of the T-38/F-5 ejection seat simulators was designed to accommodate subjects who did not weigh less than 140 pounds. Extra ballast was added to forward and/or bottom of the spacer so that personnel of less than 140 pounds could be accommodated. The risk of spinal injuries during the testing was judged to be the same as for the subjects weighing over 140 pounds.
The longer hair of women was seen as a potential problem area due to the low flash point of hair in a fire and also to the unsanitary condition created when longer hair was kept under a helmet for hours at a time.

Summary & Application: Several problem areas were identified for women

Rock (continued)

Summary & Application: who would be participating in flight training school and eventually qualifying as pilots. Solutions for the clothing problem came from issuing substitute items until new sizing programs provided the proper fitting clothing. The harness of the parachute assembly was altered by 4 inches in the back to accommodate women. Training simulators were altered by adding additional ballast to the apparatus to accommodate lighter individuals. Training programs were not changed to accommodate women. If women were not able to perform a certain test, a zero was scored for that particular station with the score averaged into the total score. This is the same situation encountered for a male trainee. The report determined that if proper fitting clothing and equipment were issued to women, no problem should be encountered in terms of safety and escape.

Cited References: 7 references

Study: Shannon, Richard H.
Factor Analytic Approach to Biomechanical Modeling.
NATO Symposium on Biomechanics & Anthropometry, Cambridge, England, July 1980.

Keywords: Factor analysis, lifting, multiple analysis of variance,

Methods: Sixteen subjects, eight males and eight females, were selected to participate in this experiment. The subjects had no previous lifting training and were of similar age and body dimensions. The group of subjects was divided into two groups of equal proportions. One would receive training while the other remained untrained as a control for the experiment. The experiment encompassed four treatments. These include weight (10, 25, 40 pounds), time intervals between lifts (0-.25, .26-.50, .51-.75, .76-1.00, 1.01-1.25 seconds), time of measure (pre and post training), and lift regimens (floor-knuckle, knuckle-shoulder). The two groups were measured a second time after a period of two weeks. The experimental design included six independent variables (the variables listed above plus sex-2 and group-2, between subject variables) and 960 cases per lift and dependent variable. The dependent variables were the various reactive forces and torques on the joints and links of the body. Equipment used to collect data during the experiment included a force platform, a still camera, strobe lights (stroboscopic photography) and equipment used in electromyogram methodologies.

Results: Factor analysis was performed separately for each lift regimen on the 1[illegible] dependent variables involving acceleration patterns in the x and y axes, forces at the feet in three planes, and two electromyograms (medial deltoid and rectus femoris, quadriceps muscles). Validation of the predicted and observed results was accomplished with the Kolmogorov-Smirnov goodness-of-fit test. Results indicated that there was a close similarity in both lift regimens for the angular displacements and the resultant forces in the x and y axes for the hands and feet.

Summary & Application: The factor analysis was performed on a group of independent and dependent variables to sort out interdependence between variables and thereby reduced the size of subsequent analyses. Combining the factor analysis with an analysis of variance yields an experimental design which determines the significant main and simple main effects in the total system of lifting.

Cited References: 13 references

Study: Shannon, LCDR Richard H.
Manual Materials Handling Injuries of Naval Civilian Workers. Human Factors & Industrial Design in Consumer Products Symposium, Medford, Maine. May, 1980.

Keywords: Manual materials handling, injuries, sex differences, task variables

Methods: The introduction of this paper serves as a review for the contribution of human factors methodology to the consumer product industry. The files at the Naval Safety Center in Norfolk, Virginia were searched for injuries resulting from load handling. The search yielded 484 strain/sprain/overexertion injuries to naval civilian government workers between July 1, 1976 and June 30, 1977. Information concerning sex, age , type of injury, days absent, month of year, occupation, type of handling, weight handled, and human error causality were accumulated. The data presented in this report has limitations such as subjective opinion, lack of detail on injuries, and a lack of totality of incidents due to omitted reports of injury.

Results: Age within the sample ranged from 17 to 60 years with the median age of 37 years. Female median age was 34 while the median age for men was 38. An injury was found to be either minor or major. Both injury severity and sex functioned as dependent variables. A t-test of percentage differences was performed on the resulting data to determine if there were significantly higher numbers of major and minor injuries per variable category. Males had significantly more injuries to the back between April and June. The men functioned as craftsmen/operatives/laborers using heavy or very heavy weights. Males failed to observe safety precautions more often than the women. Women showed more injuries to the shoulders/neck/arms during the months of January through March. The women were employed as clerical/service/sales personnel using light to medium weights and exhibiting poor handling techniques when compared to the male sample.

Summary & Application: Lifting injuries resulting in back strain, sprain and/or overexertion occurred in 57% of the cases reviewed in the Safety files in Norfolk, Virginia. The injuries resulted in a loss of an average of five days per worker. Male injuries can best be prevented by observing the recommended lifting standards, more managerial supervision and safety observation. Techniques of lifting for males follow the recommended techniques set forth by the National Safety Council. Women have less effective lifting techniques resulting in injury by a lighter weight.

Shannon (continued)

Summary & Application: (continued) Women also have a lower level of physical fitness than men contributing to more injuries. A training program can teach women the biomechanical principles of lifting and the proper techniques of lifting to avoid injuries.

Cited References: 34 references

Study: Shapiro, Yair, Kent B. Pandolf, Barbara A. Avellini, Nancy A. Pimental, and Ralph F. Goldman
Physiological Responses of Men and Women to Humid and Dry Heat. J. Applied Physiol: Respirat. Environ. Exercise Physiol. 49(1): 1-8, 1980.

Keywords: Sex-related differences, thermoregulation, rectal temperature, heart rate, mean skin temperature, sweat rate, maximal O_2 uptake, skin surface area, body fat percentage, surface area-to-mass ratio

Method: Nine women and 10 male volunteer soldiers served as the subjects of this study done by the U.S. Army Research Institute of Environmental Medicine located at Natick, Massachusetts. Age, height, weight, body fat percentage, body surface area, and maximal oxygen uptake were computed for each subject. The subjects were acclimatized for six days to the testing situation by walking on a level, motor-driven treadmill for two 50-minute periods with preceding and intervening rest periods. After acclimatization, the subjects were exposed to six environmental conditions: control (comfortable), mild-wet, two hot-wet climates, and two hot-dry climates. Each exposure lasted for 120 minutes and included the exercise schedule described for the acclimatization period. Rectal temperature, skin temperature, heart rate, sweat rate and heat storage were measured during the experimental period. A one-way analysis of variance was used to evaluate the results of the experiments.

Results: The sex-related differences found in this experiment are listed in the table below.

TABLE 1. *Sex differences in various climatic conditions for males (M) and females (F)*

	Control		Mild-Wet		Hot-Wet				Hot-Dry			
	20°C, 40%		32°C, 80%		35°C, 90%		37°C, 80%		49°C, 20%		54°C, 10%	
	M	F	M	F	M	F	M	F	M	F	M	F
Final T_{re}, °C	37.53 ±0.07	37.60 ±0.08	37.82 ±0.08	37.67 ±0.04	38.52 ±0.11	38.18* ±0.07	38.73 ±0.09	38.49 ±0.07	37.94 ±0.08	38.19 ±0.07	38.12 ±0.09	38.44* ±0.10
Final HR, beats·min^{-1}	85.9 ±2.6	85.2 ±3.0	105.1 ±2.4	102.4 ±2.7	138.7 ±4.7	136.8 ±3.2	148.8 ±3.8	143.0 ±3.0	117.0 ±3.4	130.1* ±4.6	127.3 ±5.1	147.9* ±1.6
Final $\bar{T}_{sk}$, °C	31.02 ±0.33	30.49 ±0.40	34.13 ±0.15	33.43* ±0.13	36.17 ±0.09	35.77 ±0.10	36.51 ±0.08	36.30 ±0.11	35.80 ±0.20	36.23 ±0.29	36.29 ±0.17	37.30* ±0.14
Metabolism, ml·kg^{-1}·min^{-1}	14.34 ±0.46	13.93 ±0.29	14.66 ±0.40	13.85 ±0.37	15.25 ±0.53	14.74 ±0.28	14.74 ±0.62	14.38 ±0.33	14.42 ±0.39	14.35 ±0.31	14.64 ±0.38	14.39 ±0.34
ΔS (1st h), W·kg^{-1}	0.112 ±0.074	0.055 ±0.051	0.381 ±0.064	0.219 ±0.042	0.978 ±0.067	0.697† ±0.081	0.949 ±0.070	0.751 ±0.049	0.500 ±0.055	0.599 ±0.062	0.619 ±0.060	0.900† ±0.097
$\dot{m}_{sw}$, g·kg^{-1}·h^{-1}	2.34 ±0.26	2.33 ±0.24	7.52 ±0.32	6.70 ±0.31	14.27 ±1.03	12.65 ±0.63	14.46 ±0.66	11.32* ±0.64	12.98 ±0.58	13.08 ±0.50	15.11 ±0.54	16.49 ±0.77
$\dot{m}_{sw}$, g·m^{-2}·h^{-1}	92 ±12	84 ±10	293 ±16	238 ±14	554 ±41	448* ±22	560 ±26	401* ±30	502 ±19	462 ±15	566 ±23	582 ±24
Dehydration, % of LBM	0.225 ±0.079	0.222 ±0.094	0.550 ±0.160	0.632 ±0.218	1.412 ±0.207	0.990 ±0.229	1.136 ±0.202	0.607 ±0.242	1.303 ±0.148	1.197 ±0.200	1.178 ±0.256	1.152 ±0.236
H_2O consumption, % of LBM	0.35 ±0.11	0.45 ±0.07	1.29 ±0.25	1.29 ±0.25	2.06 ±0.21	2.63 ±0.28	2.38 ±0.21	2.62 ±0.17	1.85 ±0.15	2.53 ±0.25	2.50 ±0.22	3.21 ±0.24

Values are means ± SE for various T_a °C, rh %. * $P < 0.05$. † $P < 0.06$.

Shapiro et al. (continued)

Summary & Application:

There appear to be sex-related differences in thermoregulation but the physiological advantage seems to be related to whether the climate is wet or dry. The lower sweat rates observed in women in hot-wet climates may be related to skin wettedness which causes the suppression of sweating.

The authors suggest that the sex hormonal influence in women be discounted in the study of thermoregulation because the hormonal level should not react preferentially to hot-dry or hot-wet climates, but should show a response with increased environmental temperature. In the women included in this experiment, no effect of the menstrual phase appeared evident when the women were divided into two groups. One group was exposed to different climatic conditions before ovulation while another group was exposed to different climatic conditions after ovulation. Oral contraceptives were also found to have no effect on thermoregulation.

Women were found to have an advantage in hot-wet climates while men were found to have the advantage in the hot-dry climate. Three possible explanations of these findings are women have a higher surface area-to-mass ratio which may be an advantage in a hot-wet climate but a disadvantage in a hot-dry climate. Females seem to have a better peripheral feedback from skin wettedness which surpresses nonefficient sweating. Women also appear to have a higher central thermoregulatory set point than men which makes women more intolerant of hot-dry environments.

Cited References: 32 references

Study: Shoenfeld, Yehuda, Raphael Udassin, Yair Shapiro, Abraham Ohri, and Ezra Sohar
Age and Sex Difference in Response to Short Exposure to Extreme Dry Heat. J. Applied Physiol.: Respirat. Environ. Exercise Physiol. 44(1): 1-4, 1978.

Keywords: Sweat rate, heat stress, heat tolerance, women, men, sex differences

Method: Thirty-three males and twenty-seven females (18-63 years of age) were divided according to age and sex. They were exposed for 10 minutes to extreme dry heat: 80-90° C dry bulb temperature and 3-4% relative humidity. Their rectal temperature, skin temperature (8 locations), weight, and heart rate were recorded prior to and immediately following the exposure. Total sweat loss was determined through weight difference before and after the test.

Results: A mean rise of only 0.5° C in rectal temperature was recorded following exposure as compared to a mean rise of 5.2° C in mean weighted skin temperature. Female subjects showed a significantly higher rise in mean weighted skin temperature than male subjects. Similarly, a significantly higher rise in mean weighted skin temperature was found in elderly male subjects as compared to young male subjects. Men had significantly higher sweat rates than women.

Summary & Application: The differences in mean weighted skin temperature may have resulted from differences in mean skin blood flow causing differences in skin conductance. Large individual variations in heat response were recorded in rectal temperature as well as in weighted skin temperatures. The increase in skin temperature during the first 10 minutes of exposure to extreme dry heat may serve as an indicator for heat tolerance time, and may help predicting heatstroke susceptible individuals.

Cited References: 18 references

Study: Sinclair, Terry William
Perceptions of United States Coast Guard Women Concerning Their Integration Into Active Service. Master's Thesis, Naval Postgraduate School, Monerey, California, 1977.

Keywords: Women in the service, military women, coast guard, women at sea, career women, sexual distrations, women

Method: This thesis is a report on the current perceptions of women who are now being integrated into active service in the Coast Guard. The perceptions of men concerning the problems faced by women are also included in the thesis. A questionnaire was developed to survey all Coast Guard women for their opinions. Of the 575 questionnaires sent out, 191 were returned and used in this report. An equal sized sample was drawn from Coast Guard men. SPSS (Statistics Package for the Social Sciences) was used to analyze the results of the questionnaire.

Results: Enlisted responses came from E-2 through E-7 and officier responses came from Ensigns through Lieutenant. Most women felt they could perform in all roles of Coast Guard work. Women at air stations and training center had little problem with acceptance while women at other units felt the need for Headquarter involvement in overcoming resentment (33%). Much of the resentment was generated by women filling shore billets causing men to double rotate on sea duty. Most women felt advancement opportunities were no problem (79%). Two-thirds of the women felt they received fair work assignments and were treated as career-oriented individuals. Over half of the women cited the need to have changes and improvements made on their living facilities. Bar graphs, histograms, and quotes from the questionnaires illustrated the results of the survey.

Summary & Application: Four problems were found that required the attention of headquarters. These were 1) equal opportunities for both sexes; 2) a review of the current "work or resign" policy concerning maternity leave for expectant mothers; 3) redesign of the current uniform for Coast Guard women; 4) alteration of living facilities aboard ship.

Cited References: 26 references

Study: Snow, Clyde C. and Herbert M. Reynolds
Anthropometry of Airline Stewardesses.
FAA-AM-75-2. FAA Civil Aeromedical
Institute. 1975.

Keywords: Anthropometry, body size, anthropometric measurements, women, human factors engineering, civil aviation

Summary & Application: This report presents the body measurements of 423 stewardess trainees enrolled in the American Airlines Stewardess Training Academy in Fort Worth, Texas. The survey took place between February and June of 1971. Summary statistics include the means, standard deviations, coefficients of variation, percentiles, and related statistics of the 72 standard anthropometric and functional measurements. The survey was initiated to provide adequate criteria for improving the emergency equipment availability and workspace design for the stewardess.
The sample population may not represent a normal distribution statistically speaking. The ranges of selection criteria (height, weight, age, education, health and marital status) for stewardess trainees may be narrower when compared to the ranges of the criteria for military populations.

Cited References: 8 references

Study: Stoudt, Howard W.
Are People Still Getting Bigger-Who, Where, and How Much? Society of Automotive Engineers Technical Paper Series # 780280. 1978.

Keywords: Anthropometry, equipment design, accommodated percentages

Summary & Application: Human body size has been increasing over time with a summary estimate of one centimeter per decade. Improved environmental conditions as well as a more nutritious diet account for this increase. Where these conditions do not exist or where populations have been living at an optimal level for a long period of time, the size increase is not present.
Designers of workplace environment have to take into account the increase of body size to accommodate the population over a given period of time. This paper addresses the probability of the secular trend and if it will taper off as more populations achieve optimal living conditions. The author feels body size is increasing still, but at a slower rate with the end in sight.

Cited References: 24 references

Study: Tebbetts, Ilse and John T. McConville
Height/Weight Sizing Programs for Women's Protective Garments. AMRL-TR-79-35. Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. 1979.

Keywords: Anthropometry, sizing tables, dimensional data, women, protective clothing

Summary & Application: The goal of any sizing program is to achieve a good fit for the maximum number of people with the smallest number of sizes. This report developed the cost-effective 4- and 5-size systems along with a more accommodating sizing system of 8- and 12- size schemes. The protective garmets were sized on anthropometric data presented in the 1968 anthropometric survey of USAF women. For the purposes of design, the female body was not considered to be a scaled-down version of the male body, but to have unique proportions necessitated a different sizing scheme.
The development of an anthropometric sizing program is reviewed along with the selection of the appropiate program given a specific population. A review of statistical terms and their uses in a sizing program is also included.

Cited References: 4 references

Study: Thackray, Richard I., R. Mark Touchstone, and J. Powell Bailey
Comparison of the Vigilance Performance of Men and Women Using a Simulated Radar Task. Aviation, Space and Environmental Medicine, 49(10): 1215-1218. 1978.

Keywords: Sex differences, detection performance, monitoring task,

Method: Twenty-six men and twenty-six women were tested over a two hour period to determine if possible sex differences in the ability to sustain attention to a complex monitoring task. The task required only a detection response to critical stimulus changes. The visual display was designed to approximate an automated air traffic control radar display containing computer-generated alphanumeric symbols. Sixteen targets appeared on the screen at all times with ten signals randomly presented during each half hour of the test session.

Results: The results of the experiment showed a mean detection latency for critical stimuli correctly identified. Analysis of variance applied to the resulting data revealed that there were significant main effects for the four half hour periods for mean latencies, maximum latencies and minimum latencies (latency refers to the time from critical stimulus onset to the button press). The main effects for sex were not significant.

Summary & Application: All of the subjects whether men or women demonstrated increases over time for all latency measures. The author cites the results of Waag et al. (1973) on the performance of men and women on a simple vigilance task. The results would seem to be in conflict with the results of this report, but the authors explained that there are scanning factors and a basic alertness needed to complete the complex task. Further studies are needed to contrast the performance of the subjects on both a simple vigilance task and a complex monitor-task. The two tasks may require different skills and abilities.

Cited References: 17 references

Study: Waag, Wayne L., Charles G. Halcomb, and Dolores M. Tyler
Sex Differences in Monitoring Performance. *J. of Applied Psychology*, 58(2): 272-274. 1973.

Keywords: Sex differences, detection performance, monitoring

Method: Two hundred and twenty males and two hundred and twenty females who were first-year psychology students at Texas Tech University participated in an experiment to investigate the sex differences found in performance monitoring. The task of each individual was to monitor a visual display for one hour in order to detect aperiodic signals occurring against a background of discrete, regularing occurring signals. Signals, events and responses were recorded on a digital printout counter.

Results: The results indicated that females detected 10% fewer signals and committed more false alarms. The sex differences accounted for only 4% of the variance of detection performance and 1% of the variance of the false alarm measure.

Summary & Application: Females were found to be poorer monitors by not detecting more signals and tripping more false alarms. The effects of sex on performance were small as indicated in the Results section.

Cited References: 7 references

Study: Wardle, Miriam Gayle and David S. Gloss
Women and Strenuous Work. Human Factors, 19(5): 515-517. 1977.

Keywords: Physical work capacity (PWC), women

Methods: Eight females volunteered to participate in this experiment. The subjects ranged in age from 18 to 23 years. Each subject participated in eight different sessions of 45 minutes each, at two speeds, (4km/h and 6 km/h), two grades (0% and 10%), and carrying two loads (0kg and 10 kg). The periods of work were 1 of light work, 2 of moderate work, 3 of heavy work, and 2 of very heavy work. Heart rate was recorded at the last five seconds of each third minute as the subject worked on the treadmill.

Results: All of the eight subjects completed 100% of the light work, 95% of the moderate work, 97.5% of the heavy work and 92.1% of the very heavy work. Three of the subjects completed all the work. Mean heart rate for light work was 119.8 beats/min., for moderate work the mean heart rate was 130.0 beats/min. The mean heart rates for heavy and very heavy work were 139.9 beats/min. and 158.8 beats/min. respectively. Analysis of variance of the results indicated that the order of work was not significant, but that there was a significant difference between the work grades. Heart rate and work output were found to be linearly related by the correlation coefficient of +0.52 at 62 degrees of freedom.

Summary & Application: The main conclusion resulting from this experiment is that the women of average stature and weight can perform jobs requiring hard physical work. This conclusion is based on only one type of measure of physical work capacity, treadmill walking.

Cited References: 11 references

Study: Wells, Christine L. and Steven M. Horvath
Heat Stress Responses Related to the Menstrual Cycle.
J. Appl. Physiol. 35(1): 1-5, 1973.

Keywords: Thermoregulation, electrolyte loss, serum electrolytes, women

Summary & Application: Seven young adult females were exposed to an environment of 48° C, 11 mm water vapor pressure for two hours at three distinct menstrual phases. Cyclic changes in basal body temperature associated with ovulation were accompanied by significantly higher hemoglobin and hematocrit values during the ovulatory phase. Serum electrolyte (sodium, potassium, and chloride) concentrations showed little relation to menstrual phase. There was a tendency toward higher heart rates and lower ventilation volumes during the ovulatory phase heat exposures. No significant differences in core or peripheral temperatures, oxygen consumption, or total body sweating rates occurred during phases of the menstrual cycle. The few differences occurring with the menstrual cycle phase had minimal influence upon the ability of the women to regulate body temperature when exposed to environmental heat stress.

Cited References: 24 references

Study: Wells, Christine L. and Steven M. Horvath
Responses to Exercise in a Hot Environment as Related to the Menstrual Cycle. J. Appl. Physiol. 36(3): 299-302, 1974.

Keywords: Thermoregulation, menstrual cycle, heat stress, women

Summary & Application: The menstrual cycle has been shown to have minimal effect upon thermoregulation while the female subjects rested in a hot-dry environment. For the current study, exercise was added to the external heat load of the hot environment. Seven untrained and unacclimatized females rested for 40 minutes and worked 40 minutes at 50% of their maximum oxygen uptake, and then rested again for an additional 40 minutes. No menstrual phase differences were found for such parameters such as rectal temperature, skin temperature, sweat rate or body heat content. Water gain from the interstitial compartment was maintained at the same level as water loss from the skin, while electrolyte losses in sweat were proportionally higher than water losses.

Cited References: 13 references

Study: White, Robert M. and Gregory Desantis
The Impact of Female Anthropometry on the U.S. Army. Technical Report, U.S. Army Natick Research and Development Command, Natick Massachusetts. 1978.

Keywords: Anthropometry, body size, anthropometric measurements, static strength, women, human engineering

Summary & Application: This report is a summarization of the 1977 anthropometric survey of U.S. Army women and an assessment of their impact on the U.S. Army. Areas that this report is concerned with are field clothing such as fatigues, cold weather clothing and combat boots and different workspace situations such as consoles, tracked vehicles, aircraft and other equipment systems that were designed for male use. For body size comparisons, the 1966 survey of U.S. Army men is used in this report. The average age difference is one year with women being older. Men are 27 pounds heavier and four and one-half inches taller than women. Women are one-half inch larger in the hip circumference than men while in every other measure men are larger. Differences in body proportions are also apparent between men and women. The sizing of clothing that both men and women can wear is contingent on identifying these differences and designing clothing that will accommodate the different body shapes encountered.
Static strength comparisons were also made in the anthropometric surveys. The results of the comparison of the male and female strength tests reaffirms the importance of human factors consideration when designing equipment and in assigning people to performance tasks.
Comparison of surveys done in 1946 for both men and women to surveys done in 1966 and 1977 revealed that there had been little increase in body size over the given period of time.

Cited References: 12 references

Study:	White, Robert M. The Anthropometry of United States Army Men and Women: 1946-1977. Human Factors, 21(4): 473-482. 1979.
Keywords:	Anthropometry, workspace design, static strength, human engineering, anthropometric measurements
Methods:	U.S. Army males were the subjects of a 1966 anthropometric survey with 6,682 males participating. U.S. Army women were the subjects of an anthropometric survey with 1,331 women measured. The male subjects had 70 body measurements taken though it was not reported if any of these measurements represented static strength or workspace measures. The female sample had a core of 60 basic body measurements with an additional 31 head and face measurements as well as 9 measures of static strength. 14 workspace measurements were taken on a sample of 300 women. Mean, standard deviation and range were established for each measurement along with percentile values for the 1st, 5th, 25th, 50th, 75th, 95th and 99th percentiles.
Results:	Comparisons were made between the male and female U.S. Army populations. Males were larger in all measurements except the hip circumference. The degree of difference was greater at the 95th percentile as compared to the 5th percentile.
Summary & Application:	Differences in body size are found to exist with males being larger in all measurements except hip circumference. The proportions are also different with the women having smaller waists and larger hips. This underscores the necessity of having up-to-date anthropometric data for clothing and equipment design with more and more women being incorporated into the armed services.
Cited References:	11 references

Study: Wilmore, Jack H.
Alterations in Strength, Body Composition and Anthropometric Measurements Consequent to a 10-Week Weight Training Program. Medicine and Science in Sports, 6(2): 133-138, 1974.

Keywords: Strength training, body composition, anthropometry, training in females, sex differences

Methods: A sample of 47 women and 26 men was selected from volunteers. Age and physical characteristics such as weight, height and per cent fat were noted for each subject. Both sexes were enrolled in weight training classes at University of California, Davis. The classes met for 10 weeks with attendance averaging two, forty minute sessions a week. Each session would begin with warm up exercises followed by two sets of the following lifts: half squats or leg presses, toe raises, two arm underhand curls, standing press, bench press, bent arm pull-overs, bent rowing and side bends. Additional weight was added as the subject increased his or her strength.

Results: Significant increases were found for both men and women for each of the strength tests. Women exhibited the greatest relative increase in bench press and leg strength. The results are presented in the table below.

Summary & Application: The initial strength values were greater for men when compared to women for all the tests of strength. When strength was expressed relative to the subject's weight, leg strength for the women almost equaled the strength value for men's leg strength. When lean body weight was substituted for weight, the women surpassed the men for leg strength. For all other strength tests, men exceeded women regardless of how the values were expressed.

Cited References: 29 references

	Absolute		Absolute/Weight		Absolute/Lean Body Weight		Absolute/Girth*	
	Women	Men	Women	Men	Women	Men	Women	Men
Leg Strength							(Thigh Girth)	
Initial	658.9	897.4	11.37	12.30	15.12	14.25	12.20	16.27
Final	853.3	1130.4	14.74	15.44	19.12	17.62	15.85	20.61
Two Arm Curl							(Flexed biceps Girth)	
Initial	44.7	85.0	0.77	1.17	1.03	1.35	1.64	2.60
Final	49.5	101.1	0.85	1.38	1.11	1.58	1.77	3.02
Bench Press							(Deltoid Girth)	
Initial	54.1	146.3	0.93	2.01	1.24	2.32	1.73	4.04
Final	69.6	170.3	1.20	2.33	1.56	2.65	2.23	4.57
Grip Strength							(Forearm Girth)	
Initial	29.3	51.3	0.51	0.70	0.67	0.81	1.25	1.87
Final	33.1	53.9	0.57	0.74	0.74	0.84	1.40	1.93

* Girth of the area in closest proximity to the muscle group being used in the strength test

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