DTIC FILE COPY

(2)

REPORT NO. NADC-88070-60

EVALUATION OF THERMAL STRESS INDUCED BY NASA CREW ALTITUDE PROTECTIVE SYSTEM

AD-A214 379

Jonathan Kaufman and Katherine Dejneka
Air Vehicle and Crew Systems Technology Department (Code 6023)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

1 DECEMBER 1987

FINAL REPORT
Period Covering 10 September 1987 to 21 September 1987
Task No. WX30403
Work Unit No. CW570
Program Element No. NIF

Approved for Public Release; Distribution is Unlimited

Prepared for
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION (Code SP)
Johnson Space Center
Houston, TX 77058

NOTICES

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Officer or the Functional Department responsible for the report. For example: Report No. NADC 88020-60 indicates the twentieth Center report for the year 1988 and prepared by the Air Vehicle and Crew Systems Technology Department. The numerical codes are as follows:

CODE	OFFICE OR DEPARTMENT
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
05	Computer Department
10	AntiSubmarine Warfare Systems Department
20	Tactical Air Systems Department
30	Warfare Systems Analysis Department
40	Communication Navigation Technology Department
50	Mission Avionics Technology Department
60	Air Vehicle & Crew Systems Technology Department
70	Systems & Software Technology Department
80	Engineering Support Group
90	Test & Evaluation Group

PRODUCT ENDORSEMENT - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

APPROVED BY: V. F. Moroney DATE: 24 July '89

V. F. MORONEY
CAPT U S N

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704 0188

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION AVAILABILITY OF REPORT Approved for Public Release: Distribution is Unlimited
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-88070-60	5 MONITORING ORGANIZATION REPORT NUMBER(S) 387929
6a NAME OF PERFORMING ORGANIZATION Air Vehicle and Crew Systems Technology Department 6b OFFICE SYMBOL (If applicable) 6023	7a NAME OF MONITORING ORGANIZATION National Aeronautics and Space Administration
6c ADDRESS (City, State, and ZIP Code) Naval Air Development Center Warminster, PA 18974-5000	7b ADDRESS (City, State, and ZIP Code) NASA-Johnson Space Center Houston, TX 77058
8a NAME OF FUNDING SPONSORING ORGANIZATION National Aeronautics and Space Administration 8b OFFICE SYMBOL (If applicable) SP	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Johnson Space Center Houston, TX 77058	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: NIF PROJECT NO: TASK NO: WX30403 WORK UNIT ACCESSION NO: CW570

11 TITLE (Include Security Classification)

(u) Evaluation of Thermal Stress Induced by NASA Crew Altitude Protective System

12 PERSONAL AUTHOR(S)

Jonathan Kaufman and Katherine Dejneka

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year Month Day)	15 PAGE COUNT
Final	FROM 9/10/87 TO 9/21/87	1987 December 1	37

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
06	10		Hyperthermia Anti-exposure Protection Space Shuttle
23	04		

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The Crew Altitude Protection System (CAPS) and the Navy CWU-62/P anti-exposure garment have been evaluated for their impact on aircrew performance in a simulated Space Shuttle cabin environment. Conditions were designed to simulate an extreme pre-launch situation, with chamber temperatures maintained at dry bulb temperature = 26.7 ± 0.1°C and wet bulb temperature = 21.5 ± 0.3°C. Four males, ages 23-38, were studied in each of the garments, with two subjects having two exposures in each ensemble. Test durations were designed for 480 minutes, which all subjects had no difficulty in achieving. No significant differences related to configuration were noted in rectal and mean skin temperatures, local surface heat fluxes, or sweat rates. Statistically significant differences observed for heart rate and $VO_{2\,max}$ were not thought to be physiologically significant. Cognitive performance was also found to be independent of garment or test conditions. The results indicate that these garments pose no danger of inducing unacceptable heat stress under the conditions expected within the Shuttle cabin during normal launch or re-entry.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Jonathan Kaufman	22b TELEPHONE (Include Area Code) (215) 441-2565 22c OFFICE SYMBOL 6023

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 UNCLASSIFIED

TABLE OF CONTENTS

FIGURES

FIGURES (Continued)

TABLES

INTRODUCTION

Within the last year, NASA has recognized the need to provide expanded Shuttle crew protection. In an attempt to address two potential hazards with one system, a Crew Altitude Protective System (CAPS) has been developed which incorporates a counter pressure system, i.e., internal bladders to protect against rapid cabin decompression, with dry-type anti-exposure protection. Based on an expanded polytetrafluoroethylene (PTFE) membrane, the anti-exposure protection inherent in the CAPS is intended to provide thermal protection in 4.4°C (40°F) water for up to six hours.

The CAPS is to be worn during launch and re-entry. Accordingly, it is conceivable that a person would be required to wear the CAPS for up to six hours due to a delayed launch. This would then be followed by two hours of flight time until a stable orbit is reached, at which time the CAPS could be removed. During these eight hours, heat stress, due to a combination of ambient conditions and clothing, could conceivably be experienced by crew members and adversely impact mission performance.

The present study was intended to evaluate the stress induced by the CAPS when used under conditions of temperature and time considered extreme for the Space Shuttle. The Navy's CWU-62/P dry-type anti-exposure garment, which is also based on a PTFE membrane, was used for comparison. The CWU-62/P is designed to provide 2 hours of physiological protection for downed aircrews in 7°C (45°F) water. Previous testing of the CWU-62/P under more severe heat stress conditions showed that both physical and psychomotor performance were unimpaired for up to two hours (8). Inclusion of this garment served to provide a means of determining the thermal cost of including altitude protection to an anti-exposure protective garment.

MATERIALS AND METHODS

Four healthy males (Table 1) volunteered to participate as subjects after being fully informed of the details of the experimental protocol and associated risks.

SUBJECTS:

Weight was recorded prior to each test run and the mean calculated. Body surface area (BSA) was calculated (6) from the mean weight and height of each subject. Percent body fat was determined from estimates of body density (5), which were computed from skinfold measurements obtained with Lange Skinfold Calipers (Cambridge Scientific Inc., Cambridge, MD) and the equation of Lohman (13).

METHODS AND PROCEDURES:

All tests were begun in the morning, and were intended to last up to eight hours. Each test simultaneously exposed two subjects to the experimental conditions, with subject pairings remaining constant throughout the study. Due to problems unrelated to the study, two of the subjects were studied twice in each of the configurations, while the other two subjects were studied only once. The minimum time interval between tests for a given subject was two days, so that acclimatization effects could be minimized.

Subjects reported to the laboratory on the morning of a test and were given physical examinations by the attending flight surgeon. After voiding, a urinalysis was performed, and each subject's baseline weight was obtained on a scale accurate to ± 10g (Scale-Tronix, Wheaton, IL, model 6006SP). Heat flux/temperature transducers were attached to the following body sites: (A) forehead; (B) left upper chest; (C) left lower upper arm; (D) left hand, dorsal; (E) right anterior thigh; (F) left posterior thigh; (G) right shin; (H) right foot; (J) right upper upper arm; and (K) left lower back. These transducers consisted of a thermopile heat flux transducer with a thermistor located in the center (Hamburg Associates, Jupiter, FL). Analog signals from these transducers were amplified (Bioinstrumentation Assoc., San Diego, CA, model HF-12/Temp-14) and stored on the laboratory's data collection system (MDB Systems, Orange, CA, model MLSI-1123C-R-X computer, Data Translation, Marlboro, MA, DT2782 A/D boards). A rectal thermocouple (Sensortek, Clifton, NJ, model RET-1) was inserted at least 8-10 cm anterior to the anal sphincter. Dew point sensors (2) were attached to the following body sites, adjacent to the heat flux/thermistor sensors, on subjects in the CAFS garment only: left upper chest, right anterior thigh, right shin, and right upper upper arm. ECG electrodes were placed on subjects at this time and capillary blood samples were obtained from the finger tip of the subjects, for the determination of hemaglobin content (Ames Seralyzer, Elkhart, Ind., model 5110A) and hematocrit.

Subjects were then dressed in the appropriate clothing configuration, i.e., the CWU-62/P or CAPS, for that run (Table 2). The CAPS includes a portable ventilation system which in normal operations would have a 10 CFM output. Since this type of ventilation system was unavailable for inclusion in these tests, a ventilation system with a 6 CFM output was substituted. On the external suit surface of both garments, type T thermocouples were placed on the following sites: (A) helmet-forehead; (B) left upper chest; (E) right anterior thigh; (G) right shin; and (J) right upper upper arm. Thermocouple outputs, including the rectal probes, were measured with isolated signal conditioners (Opto, Huntington Beach, CA, model TC.4). Upon completion of dressing, subjects were weighed, followed by a rest period of 20 minutes which enabled subjects' temperature and heart rate to return to a resting condition before commencing that day's trial. The laboratory temperature was maintained at approximately 20°C (68°F) to minimize thermal stress during dressing.

Following the conclusion of the rest period, subjects entered the chamber and were placed in a supine position upon Space Shuttle passenger seats (P/N 3172-13). Testing was performed in chamber conditions of dry bulb temperature (Tdb) = 26.7 ± 0.1°C and wet bulb temperature (Twb) = 21.5 ± 0.3°C. Initially, subjects were to remain supine until 6 hours had elapsed, at which time they could move to a seated position. This requirement was altered to permit sitting at the point a subject felt the discomfort was intolerable. Subjects were permitted to read, listen to music, or sleep during testing; no gross movements were allowed save for the effort to sit up. Eating and drinking were ad libitum throughout the trial (Table 3). Individuals were requested to remain in the chamber for eight hours, unless their run was terminated early due to a rectal temperature (Tre) exceeding 39°C, a rate of Tre increase of 0.6°C/5 minute period, heart rates exceeding the maximum predicted for age, or the subject, flight surgeon, or principal investigator requested termination.

Measurements of respiratory function and metabolism were obtained for 30 minutes every hour during the first week of testing, which was reduced to 20 minutes per hour during the second week due to complaints of subject discomfort caused by the sampling mask. This change did not appear to affect the data. Respiratory function was measured with a pneumotachometer (Hans Rudolph, Kansas City, Mo., model 3813) and expiratory gases were analyzed for determination of metabolic rate using a 5 liter mixing box and gas analyzers (Ametek, Pittsburgh, PA, models S-3A oxygen analyzer & CD-3A carbon dioxide analyzer).

Subjective sensations were evaluated by means of scales for fatigue, skin wetness, temperature, and comfort. Subjects were instructed to place a mark along a 112mm line indicating their subjective feeling for each of the scales. Extremes were indicated on each line by such terms as "extremely energetic", i.e., the most pleasant, on the left, versus "extremely exhausted", i.e., the least pleasant, on the right. These results are evaluated as the distance from the left.

Changes in cognitive performance were evaluated with tests of vertical addition and the Baddeley reasoning test (1,4). Vertical addition required subjects to sum as many columns of three 2-digit numbers as possible in 90 seconds. The Baddeley reasoning test was a true/false test, with questions in the form of; "True or False A follows B B:A" (1). This test was constructed of 31 questions/page, and subjects were permitted 90 seconds in which to answer as many as possible.

Results from the vertical addition and Baddeley reasoning tests are reported by both the total number attempted and those answered correctly. In some cases the subject answered all of the possible questions in less than 90 seconds. In these instances, the actual time taken to complete the questions was recorded and the results reported are extrapolations to ninety seconds. Later tests provided additional questions to eliminate this problem. Both the subjective sensation evaluations and the cognitive function tasks were administered prior to dressing, every 30 minutes during testing, and after the subjects had completed the post-test physical examination.

Mean weighted skin temperature (Tsk) was calculated using the equation:

$$\begin{aligned} Tsk = {} & 0.1(A) + 0.125(B+K) + 0.07(J+C) + 0.06(D) \\ & + 0.125(E) + 0.15(G) + 0.125(E+F)/2 + 0.05(H) \end{aligned}$$

where the variables A - K are the measured skin temperatures (12). Mean weighted skin surface heat flux (HF) was calculated from the equation:

$$\begin{aligned} HF = {} & 0.1(A) + 0.125(B+K) + 0.07(J+C) + 0.06(D) \\ & + 0.125(E) + 0.15(G) + 0.125(E+F)/2 + 0.05(H) \end{aligned}$$

where the variables A - K are the measured heat fluxes at each local site (10,12). The rate of heat storage was determined from:

$$S = (\Delta Tre/\Delta t)(60 \times 0.97 \times Mb)/BSA \qquad (W/m^2)$$

where ΔTre is the change in Tre over the test period (°C), Δt is the duration of the test period (minutes), 60 is a conversion factor from hours to minutes, 0.97 represents the specific heat of body tissue (W x hr/kg x °C), Mb is the lean body mass, and BSA is the body surface area (9).

Total sweat rate (SRT) was determined by the difference between the post-test nude weight, corrected for fluid and food intake, and the pre-test weight. The change in garment weight (ΔGW) due to the uptake of sweat was determined by:

$$\Delta GW = (CW2-NW2) - (CW1-NW1)$$

where CW is clothed weight, NW is nude weight, and 1 & 2 signify pre- and post-test values respectively. The percentage of sweat evaporated (%E) was calculated from:

$$\%E = (SRT - \Delta GW)/SRT \qquad (\%).$$

Percent changes in plasma volume (%ΔPV) were determined from the hemaglobin content and hematocrit of blood samples as follows:

$$\%\Delta PV = \{[(Hb1 \times (1-Hct2))/(Hb2 \times (1-Hct1))]-1\} \times 100 \ (\%)$$

where Hb1 and Hb2 are initial and final hemaglobin, respectively, and Hct1 and Hct2 are initial and final hematocrit (7). Percent change in red cell volume was similarly calculated by (7) :

$$\%\Delta RCV = \{[(Hb1 \times Hct2)/(Hb2 \times Hct1)]-1\} \times 100 \quad (\%).$$

The two garments to be evaluated, i.e., CAPS and CWU-62/P, were designed with tight fitting neck seals. On the first day of trials, the suits were used as designed. Subsequently, modifications were made to permit greater ventillation at the neck. These changes included the use of two short lengths of 14mm ID heat shrink tubing placed in the neck seal of the CAPS in order to vent the neck area, which were employed from day 4. On the CWU-62/P, a neck ring was used on day 5 and for 4 hours on day 8 for rolling the neck seal off the neck.

STATISTICAL ANALYSIS:

Due to minimal variation in the raw data, analyses were performed on 30 minute means. Each subject was used as his own control. Paired-t tests were used to compare variations over time, and for comparing pooled data when applicable. In order to discern differences between garments, paired-t tests were used to compare trials of the same and different garments for each subject. Wilcoxon ranked sign tests were used to examine error rates, due to the non-normal distribution of this data. Differences were considered significant at the level of $p<0.05$. Correlation coefficients were determined for sweat rate and water intake.

RESULTS

The results of this study indicate that no physiological strain was imposed by either the CAPS or CWU-62/P garments under the experimental conditions. Final values, i.e., those obtained at the end of each trial, of rectal temperature, mean skin temperature, heart rate, and metabolic rate (Table 4) exhibit no indication of stress. In addition, none of the trials were terminated early due to the stresses imposed by the garment.

Mean skin and rectal temperatures were found to be independent of garment type or time. No significant change was observed between initial and final Tsk, both by garment type and when pooled (Table 4). Similar results were obtained for Tre, though initial temperatures were found to be significantly different ($p<0.05$) between the CAPS and CWU-62/P (Table 4). The raw data for Tre for each subject are shown in Figures 1-6, while 30 minute mean values are displayed in Figures 7-10, and the effects of garment on Tre are shown in Figures 11 and 12. The raw data for Tsk are shown in Figures 13-18, 30 minute means in Figures 19-22, and garment effects in Figures 23 and 24.

Mean heart rate varied significantly between garments, initial and final values, and days of testing ($p<0.05$). Despite these differences, no final 30 minute mean heat rate was >85 beats/minute, and thus the observed changes were physiologically insignificant (Table 4). Figures 25-30 display the raw heart rates throughout the trials by subject, while in Figures 31 and 32 the data is grouped by garment, with 30 minute means being used.

Sweat rate was not observed to be significantly different between garments. Mean sweat losses for the CAPS and CWU-62/P are 1.0 and 1.4 kg respectively over the eight hour test period (Table 5). Sweat loss was also independent of water intake, which had a range of 0 - 690 ml of water over eight hours (Table 5). A significant difference was observed in the amount of water consumed by subjects wearing the two different test ensembles. Mean amounts of water consumed over eight hours were 138 ml and 441 ml for the CWU-62/P and CAPS, respectively. Changes in plasma volume and red cell volume were found to be independent of garment type (Table 5).

A statistical analysis of evaporative losses could not be made due to missing data. However, a comparison of the available data indicated that neck ventilation improved the percentage of evaporation (Table 5). Differences between configurations could not be assessed from the limited amount of data available.

Metabolic rates were found to reflect the low level of activity occuring in these tests (Table 4). Differences in metabolic rates between the CWU-62/P and CAPS were statistically significant for most of the intra-subject comparisons. However, these differences are of questionable physiological importance, as these rates were, in general, indicative of very light activity (14). No significant differences were observed between the final metabolic rates measured for each ensemble. Significant changes were observed between initial and final rates with the CAPS ($p<0.05$), but not with the CWU-62/P (Figures 33 and 34).

Surface heat flux data was found in general to be below the level of accuracy of the instrumentation, i.e., 1 Watt/m^2. No statistical analysis was feasible with this data. Similarly, heat storage means over eight hours were found to be smaller than their standard errors, thus no analysis was performed on this data set.

The cognitive performance tasks and subjective evaluations were analyzed on the basis of intra-subject variation, since inter-individual variations were large. Some significant differences were noted in the number of attempts for both the Baddeley reasoning and vertical addition tasks, and were primarily related to the first trial for a given subject. In contrast, no significant differences were observed in the error rates for either task between any of the subject/garment matchings. Thus, while the number of attempts for a given task rose as a result of experience, accuracy did not change.

Subjective evaluations of comfort indicated significant differences based on the date of testing. While no pattern of significant differences between garment types was observed, significant differences were observed between tests performed in successive weeks. Qualitative assessments of fatigue, skin wetness, and temperature produced greater ambiguity in the results, with no distinct pattern emerging from the analysis of responses. Significant differences were detected among garments as well as between dates of runs for certain trials, but neither of these types of differences were consistently observed.

Comparisons of supine versus sitting data indicate that no quantitative difference resulted from subject positioning. In addition, despite initial verbal responses that the seated position was more comfortable, analysis of the subjective data indicates no difference between positions. These results are also true of the cognitive tasks measurements.

DISCUSSION

It is clear from the results that the CAPS and CWU-62/P garments do not induce heat stress under the test conditions. While the two clothing ensembles certainly increase the amount of clothing insulation, the inactivity of subjects, coupled with relatively mild ambient conditions, permitted adequate physiological adjustments to prevent thermal strain.

This lack of physiological stress is demonstrated by the fairly constant rectal and skin temperatures, as well as low heart and metabolic rates. Circadian fluctuations and changes in alertness during trials probably account for any observed increases over time in these parameters. Though the sweat rates indicated exposure to elevated temperatures, evaporation was sufficient to dissipate heat without accumulation within body tissues. The fact that both heat flux and body heat storage are negligible indicates that the thermal stress was relatively minor.

Much of this physiological adjustment can be attributed to the near basal state of activity in the study. This is reflected in the heart rates and metabolic rates exhibited by the subjects. With the only exertion being the act of sitting up, the low metabolic response is not suprising. Likewise, the low heart rates observed in this study would be expected for the minimal exertion required of subjects (subjects often slept a considerable percentage of their time in the chamber). It appears from the widespread significant differences observed for heart rate that the variations detected are related more to the individual's condition on any given day than to the test conditions.

While the two garments differ in the method of construction, this difference did not impact appreciably on the results. This is to be expected, since it has been shown that the vapor resistance of PTFE-based garments is quite close to impermeable garments when subjects are at rest at temperatures of 21°C (11) and 26°C (3). Thus any differences in physiological responses would be expected to be subtle. Since significant differences between permeable and impermeable garments have been observed at higher temperatures, i.e., 30°C (11), it would appear that a threshold exists, below which the existence of vapor permeability is irrelevant.

The evaporation data highlight the negative impact of seals on ventilation. A considerably higher percentage of sweat was evaporated from open versus closed neck seals. If this greater evaporation was significant, then one would expect much greater heat losses. Though greater heat losses were not detected in this study, a more comprehensive study could examine the actual impact of the open neck. Inclusion of a cotton or polyester control garment in future studies would permit a broader and more precise examination of these factors. Caution should be exercised so as not to compromise the effectiveness of the neck seal, since if the opening is patent during immersion in cold water, the thermal protection of the suit becomes minimal.

It appears that practice results in an increase in the number of attempts made in cognitive testing. This was not unexpected, since familiarity with the tests would increase proficiency. That this occurred is borne out by the stability of the error rates. This seems to indicate that cognition will be unimpaired by the use of the CAPS garment in the ambient conditions employed in these tests.

It is interesting that water intake was lower with the CWU-62/P than the CAPS. Since SRT was not significantly different between garments, the observed difference may be solely a function of our small sample size, or may reflect the general discomfort experienced in the CAPS garment due to improper fit.

This study indicates that the conditions encountered in the Space Shuttle cabin during pre-launch should not act to produce heat stress nor impair astronaut performance when personnel wear the CAPS. It appears that proper fitting would reduce discomfort, but even this was tolerable by the test subjects. The discomfort would probably increase under G-forces imposed by launch, but should be ameliorated by proper sizing.

CONCLUSIONS

1. Ambient temperatures of 81°F were insufficient to produce heat stress in individuals wearing the CAPS ensemble.

2. Use of the CAPS ensemble in 81°F temperatures does not appear to impair Shuttle crew cognitive performance.

3. Ventilation through the neck seal is desirable from a comfort standpoint, though this increases the hazards should cold water immersion occur. Any system adopted for ventilation must not compromise the water-tight integrity of the garment.

4. No discernable differences were observed between the CAPS and CWU-62/P ensembles under these conditions.

REFERENCES

1. Baddeley AD, Cuccaro WJ, Egstrom GH, Weltman G, and Willis MA. Cognitive efficiency of divers working in cold water. Human Factors 1975; 17:446-454.

2. Berglund LG, Cunningham DJ, and Stolwijk JAJ. The resistance type dew point sensor for moisture measurements on sweating humans. In: Sixth Conference on Biometeorology and Aerobiology. Boston: Amer. Meteorological Society, 1984; 6-9.

3. Berglund L, Cunningham D, Hoppe P, Gwosdow A, and Fobelets A. Humidity measured near the skin under clothing and its relationship to thermal comfort. Seventh Conference on Biometeorology and Aerobiology, Scottsdale, AZ, May, 1985.

4. Bittner AC, Carter RC, Kennedy RS, Harbeson MM, and Krause M. Performance evaluation tests for environmental research (PETER): Evaluation of 114 measures. Perceptual and Motor Skills 1986; 63:683-708.

5. Brozek J, Grande F, Anderson JT, and Keys A. Densiometric analyses of body composition: revision of some quantitative assumptions. Ann. NY Acad. Sci. 1963; 110:113-140.

6. DuBois EF and DuBois D. Measurement of surface area of man. Arch. Int. Med. 1915; 15:868.

7. Harrison MH. Effects of thermal stress and exercise on blood volume in humans. Physiological Reviews 1985; 65:149-209.

8. Kaufman JW. Heat stress evaluation of anti-exposure flight gear. Naval Air Development Center. NADC-85061-60, May, 1985.

9. Kolka MA, Levine L, Cadarette BS, Rock PB, Sawka MN, and Pandolf KB. Effects of heat acclimation on atropine-impaired thermoregulation. Aviat. Space Environ. Med. 1984; 55:1107-1110.

10. Kuehn LA. Assessment of convective heat loss from humans in cold water. J. Biomech. Eng. 1978; 100:1-7.

11. Light IM, Gibson MG, and Avery AI. Sweat evaporation and thermal comfort wearing helicopter passenger immersion suits. Ergonomics 1987; 30:793-803.

12. Olesen BW. How many sites are necessary to estimate a mean skin temperature? In: Hales JRS (ed.). Thermal Physiology. New York: Raven Press, 1984; 33-38.

13. Sinning WE, Dolny DG, Little KD, Cunningham LN, Racanielli A, Siconolfi SF, and Sholes JL. Validity of "generalized" equations for body composition analysis in male athletes. Med. Sci. Sports Exerc. 1985; 17:124-130.

14. Webb P. Work, heat, and oxygen cost. In: Parker JF and West VR (eds.) Bioastronautics Data Book. National Aeron. and Space Admin., 1972; NASA SP-3006.

TABLE 1: Physical Characteristics of Subjects.

Subject	Age (yrs)	Height (m)	Weight (kg)	%Body Fat	Surface Area (m^2)
A	35	1.82	75.4	14.3	1.96
B	38	1.75	82.5	17.7	1.98
D	31	1.83	86.8	10.0	2.09
E	23	1.73	83.5	13.4	1.97

TABLE 2. Clothing Configurations Worn During Tests.

Configuration	Protective Garment and Ancillary Equipment
1	Crew Altitude Protective System (CAPS) a. Parachute harness b. Life vest c. Parachute pack d. Life raft pack e. CAPS helmet f. CAPS gloves g. Ventilation system
2	CWU-62/P a. Launch/Entry Helmet b. Navy flight gloves

Additional items worn or used during tests with both configurations: Capilene underwear, expedition weight; urine collection device; cotton socks; boots; lumbar pad (when requested).

TABLE 3. Food and Water Intake During Testing.

Subject	Day of Test	Garment	Water Intake (ml)	Food Intake
A	1	CAPS	496	N/A *
B	1	CWU-62/P	80	N/A **
A	3	CWU-62/P	160	N/A ***
B	3	CAPS	520	N/A ****
A	5	CAPS	550	0.4 kg (cookies)
B	5	CWU-62/P	160	0.2 kg (cookies)
D	6	CWU-62/P	230	0.35 kg (fruit)
E	6	CAPS	200	none
D	7	CAPS	690	0.3 kg (fruit)
E	7	CWU-62/P	0	none
A	8	CWU-62/P	200	0.1 kg (cookies)
B	8	CAPS	190	none

* - 1/2 lrg cookie

** - 1 lrg cookie

*** - 4 1/2 cookies

**** - 7 cookies, 1 plum

TABLE 4. Initial (i) and Final (f) Values of Physiological Parameters, Based on 30 Minute Means, Obtained From Subjects Following Exposure to Test Conditions.

Garment	Subject	T_{re} (°C)		T_{sk} (°C)		HR (bpm)		Metabolism, VO_2 (ml/kg/min)	
		i	f	i	f	i	f	i	f
CAPS	A	37.5	37.9	32.9	33.9	71	77	32.1	54.3
	A	36.9	37.3	32.1	31.7	61	74	35.9	58.7
	B	N/A	N/A	32.9	34.0	75	84	N/A	N/A
	B	36.8	37.3	33.2	34.0	51	77	31.1	46.8
	D	36.9	37.1	32.6	34.9	76	85	31.9	38.8
	E	36.8	36.8	33.9	33.0	52	47	30.1	30.8
CWU-62/P	A	36.5	37.2	33.6	34.0	61	77	35.7	42.7
	A	36.5	37.3	33.1	34.2	49	66	30.5	47.5
	B	36.7	36.9	N/A	34.7	62	62	43.8	33.0
	B	36.7	37.2	34.0	33.8	58	63	26.9	33.7
	D	36.9	37.0	33.5	33.7	70	84	31.9	36.1
	E	36.8	36.5	33.8	33.6	52	48	34.0	37.9

TABLE 5. Calculated Values of Physiological Properties Determined Over the Duration of Trials.

Garment	Subject	Water Intake (ml)	SRT (kg)	%E	%ΔPV	%ΔRCV
CAPS	A	496	1.00	N/A	-13.6	- 2.5
	A	550	1.00	N/A	- 5.8	+ 6.5
	B	520	1.87	N/A	- 1.2	+11.6
	B	190	0.79	87.3	+11.4	+11.4
	D	200	1.10	63.4	- 0.4	+ 8.0
	E	690	1.08	N/A	N/A	N/A
CWU-62/P	A	160	1.05	N/A	-12.6	+ 7.1
	A	200	0.75	66.7	-12.7	-12.7
	B	80	0.83	N/A	- 3.0	-17.6
	B	160	0.96	94.8	-12.8	- 1.5
	D	0	1.10	22.7	-19.7	+10.9
	E*	230	1.48	39.1	+ 2.0	+20.0

* - Subject drank diluted Gatorade instead of water.

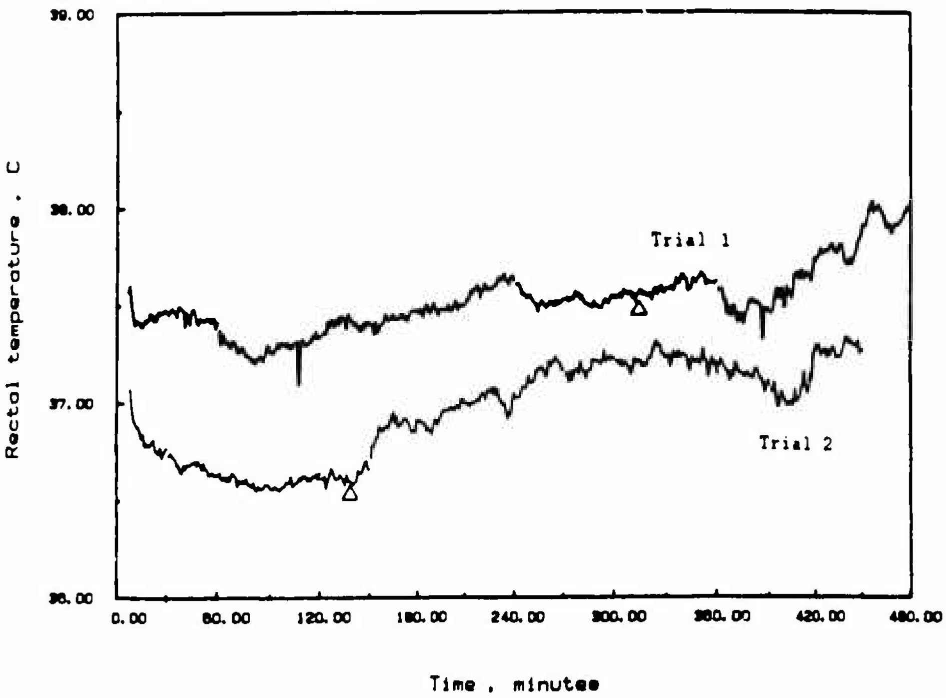

Figure 1. Tre versus time for subject A in the CAPS. Upward arrows indicate time at which subject sat upright.

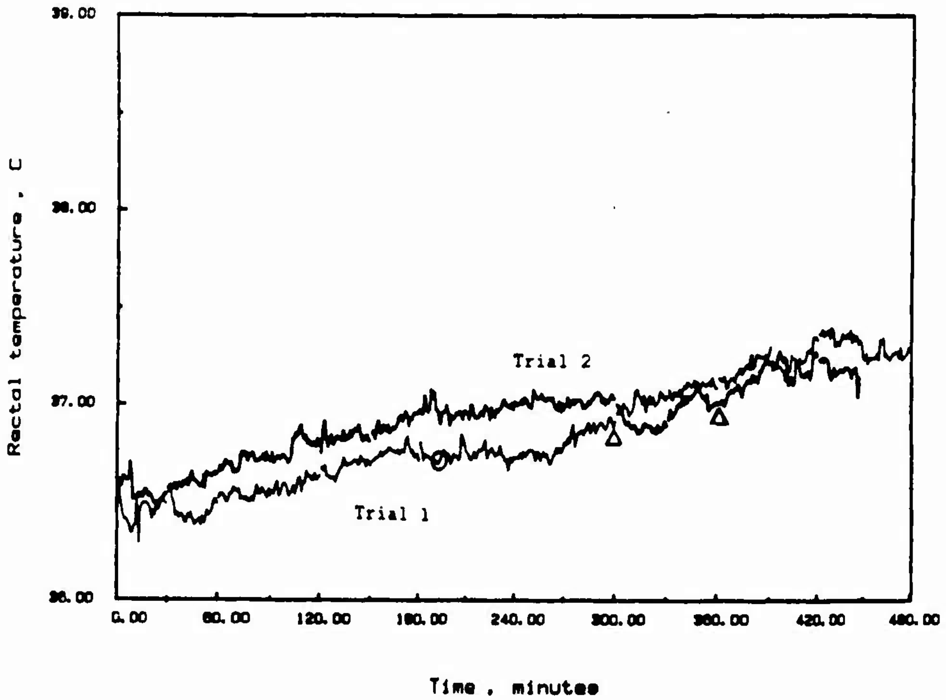

Figure 2. Tre versus time for subject A in the CWU-62/P. Upward arrows indicate time at which subject sat upright. Circle indicates time at which neck ring was first used.

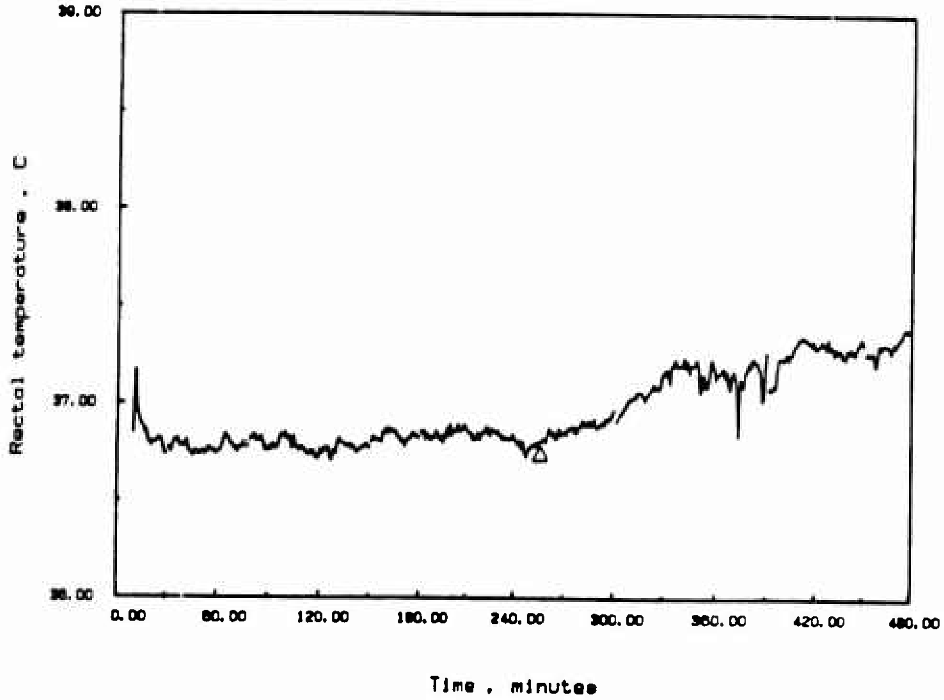

Figure 3. Tre versus time for subject B in the CAPS. Upward arrows indicate time at which subject sat upright.

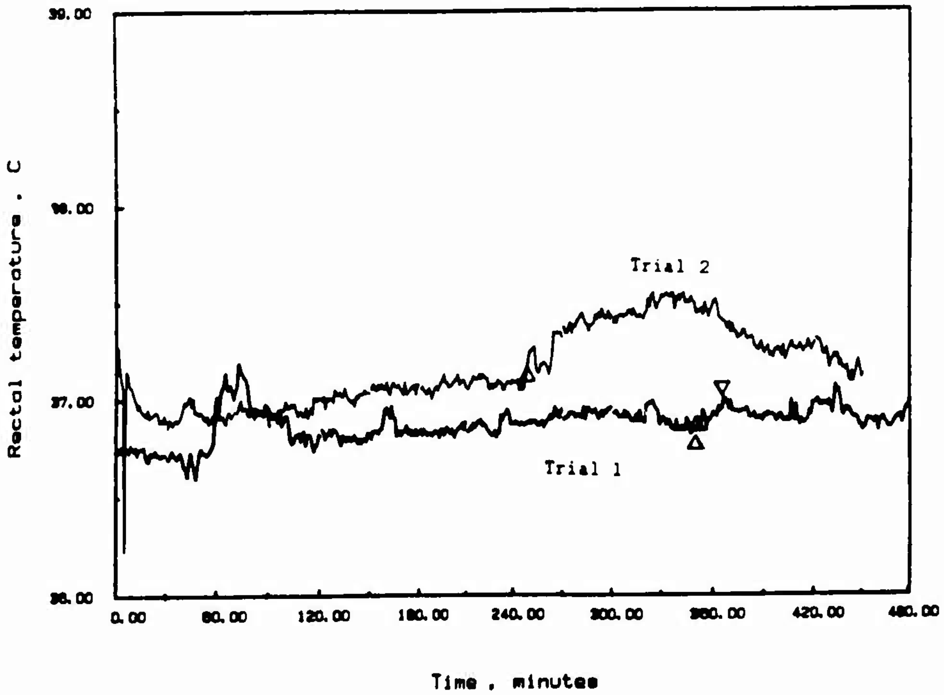

Figure 4. Tre versus time for subject B in the CWU-62/P. Upward arrows indicate time at which subject sat upright. Downward arrow indicates time when subject lay down.

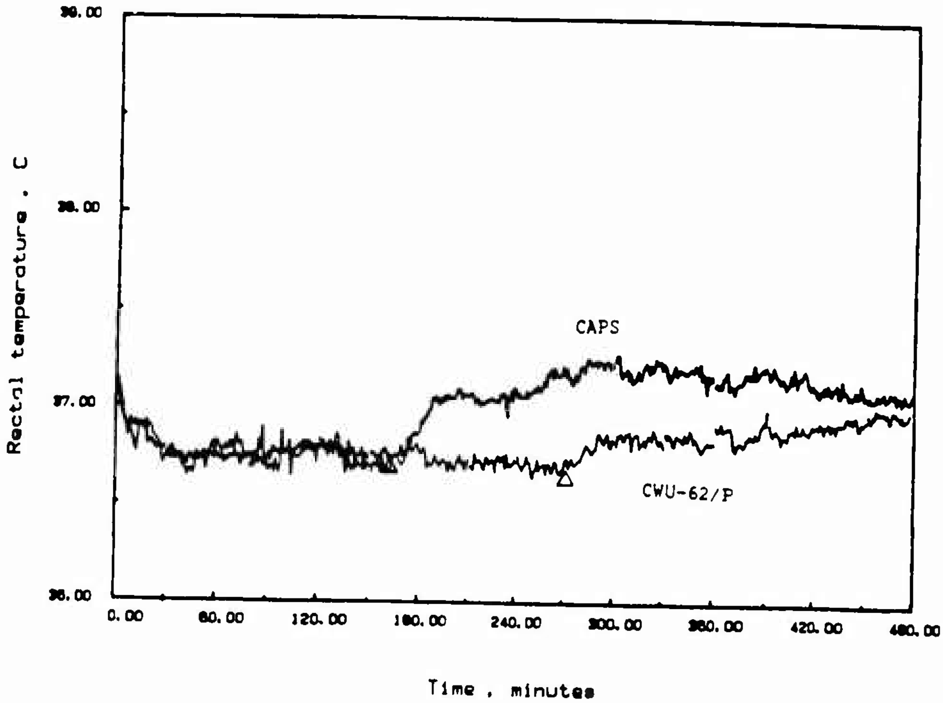

Figure 5. Tre versus time for subject D in both garments. Upward arrows indicate time at which subject sat upright.

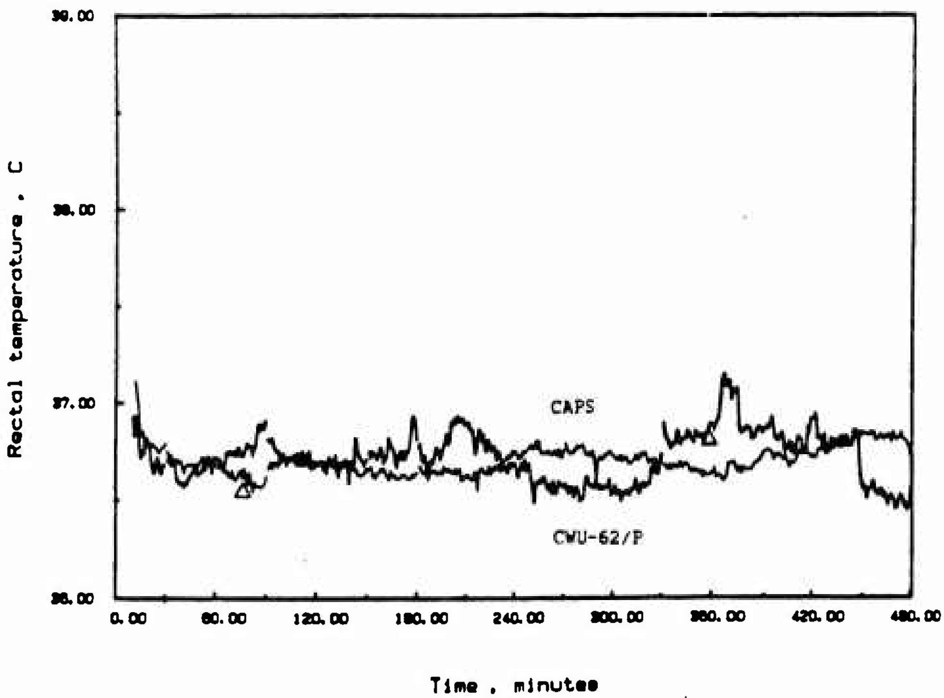

Figure 6. Tre versus time for subject E in both garments. Upward arrows indicate time at which subject sat upright.

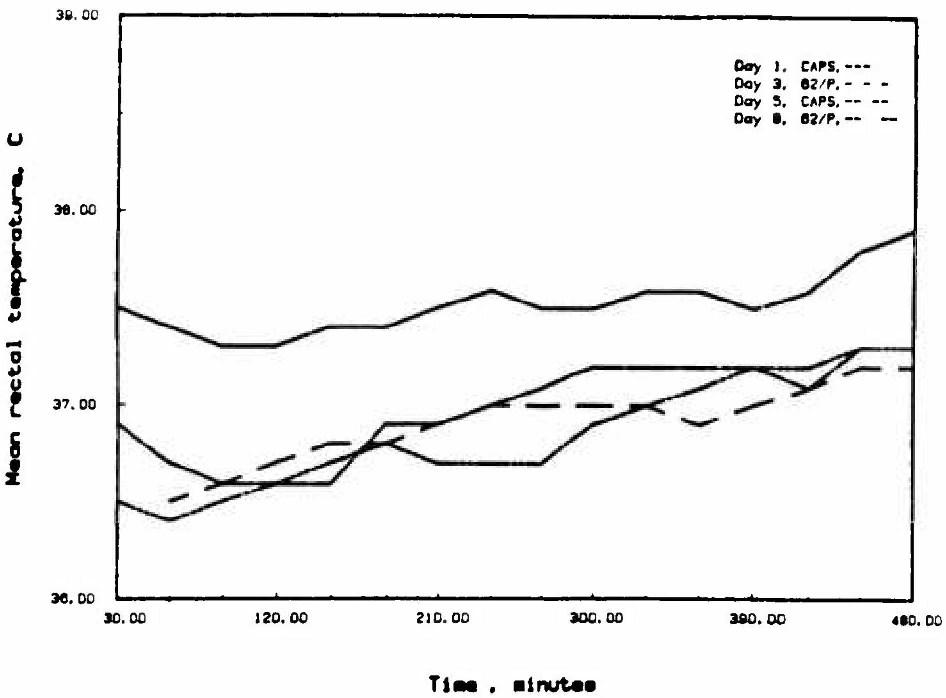

Figure 7. Mean Tre over 30 minutes versus time for both garments, subject A.

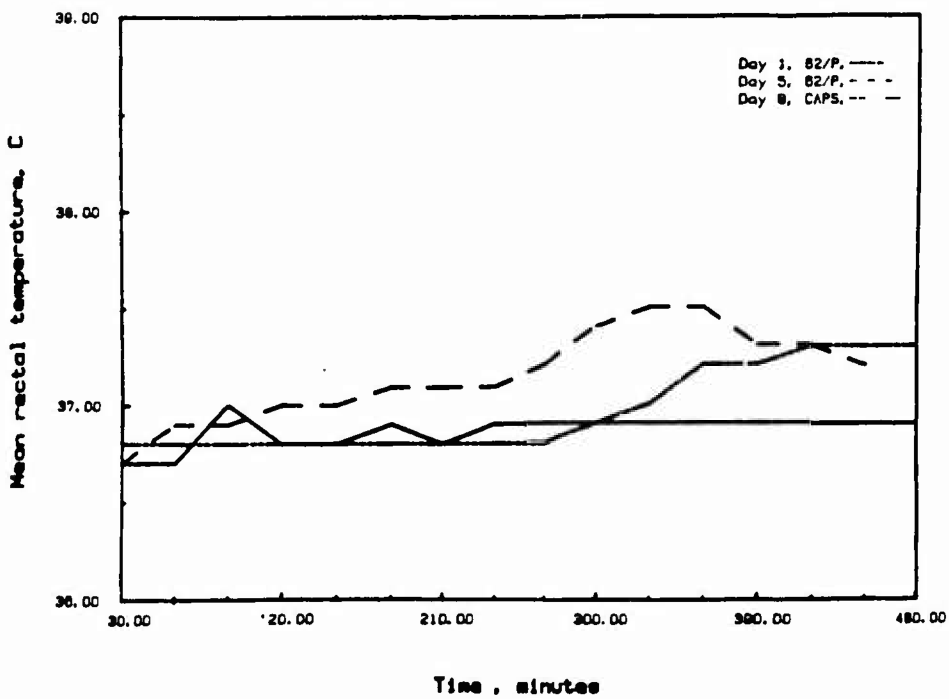

Figure 8. Mean Tre over 30 minutes versus time for both garments, subject B.

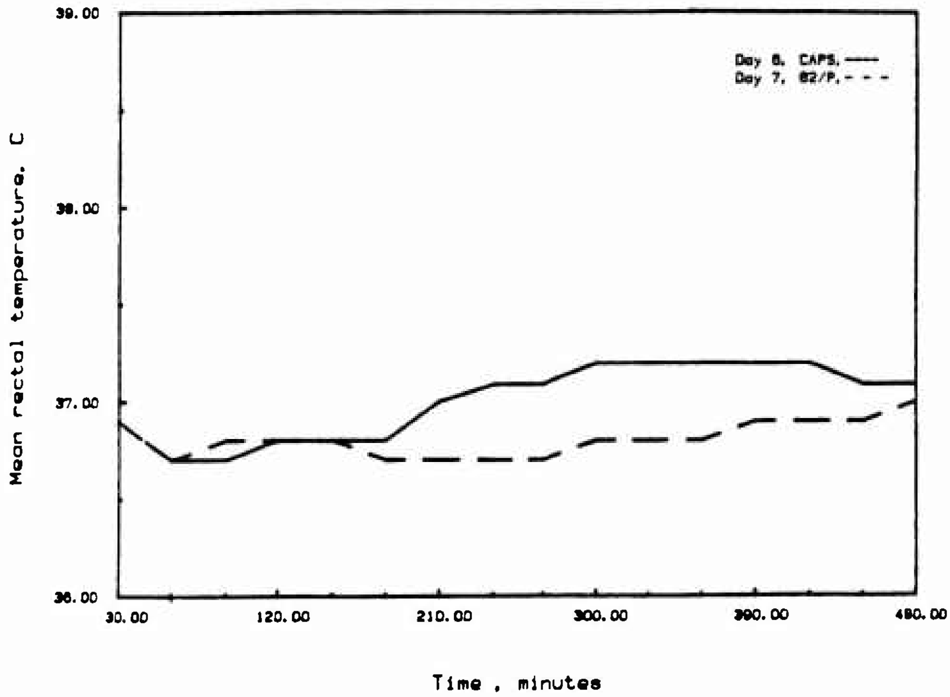

Figure 9. Mean Tre over 30 minutes versus time for both garments, subject D.

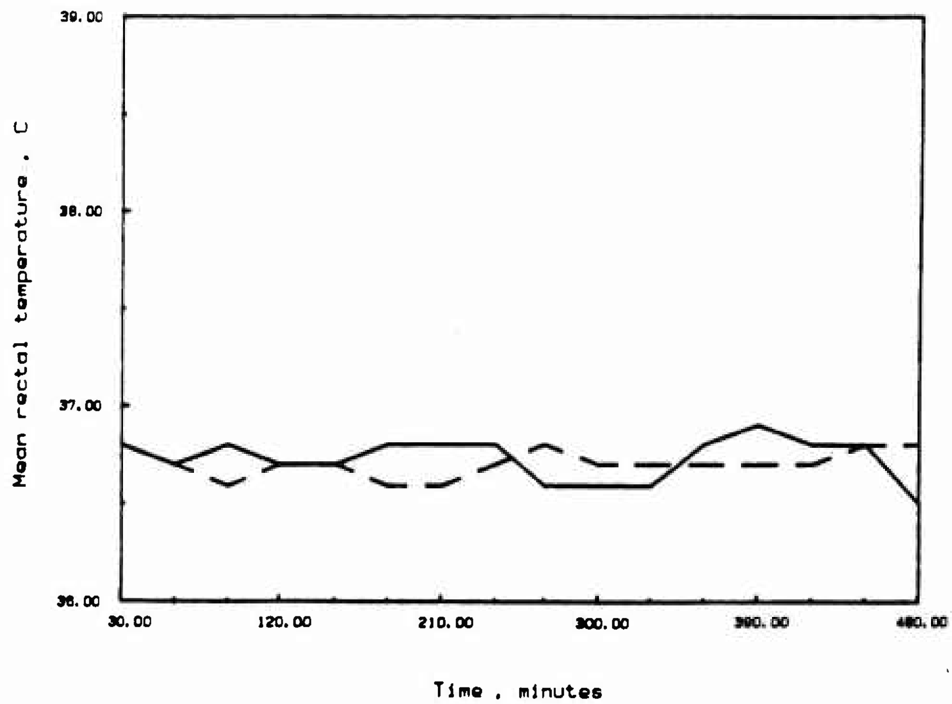

Figure 10. Mean Tre over 30 minutes versus time for both garments, subject E.

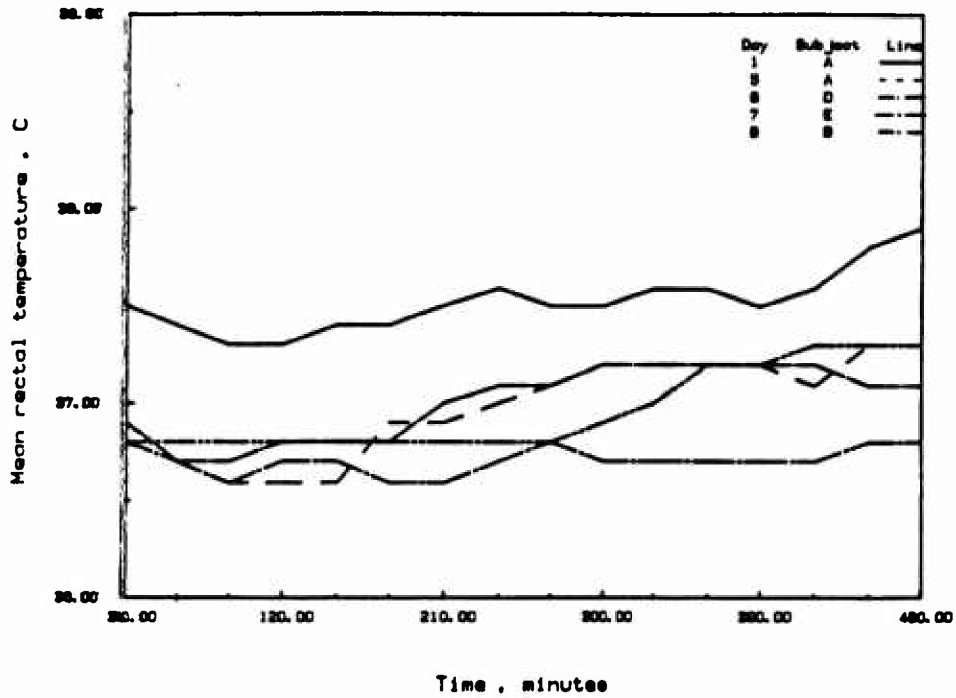

Figure 11. Mean Tre over 30 minutes versus time, CAPS.

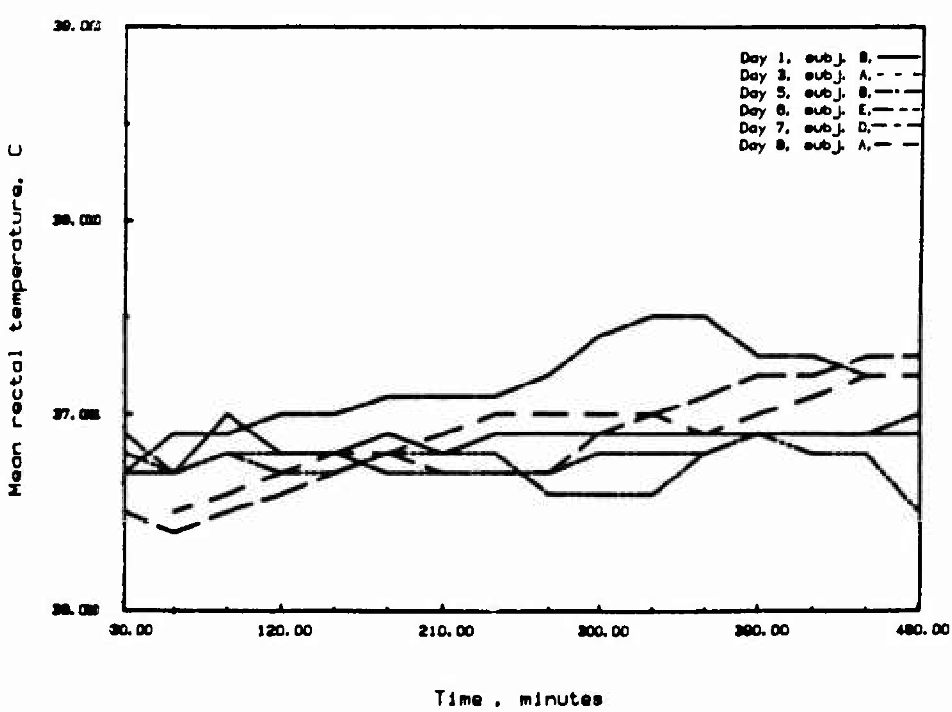

Figure 12. Mean Tre (over 30 minutes) versus time, CWU-62/P.
Upward arrows indicate time at which subject sat upright.

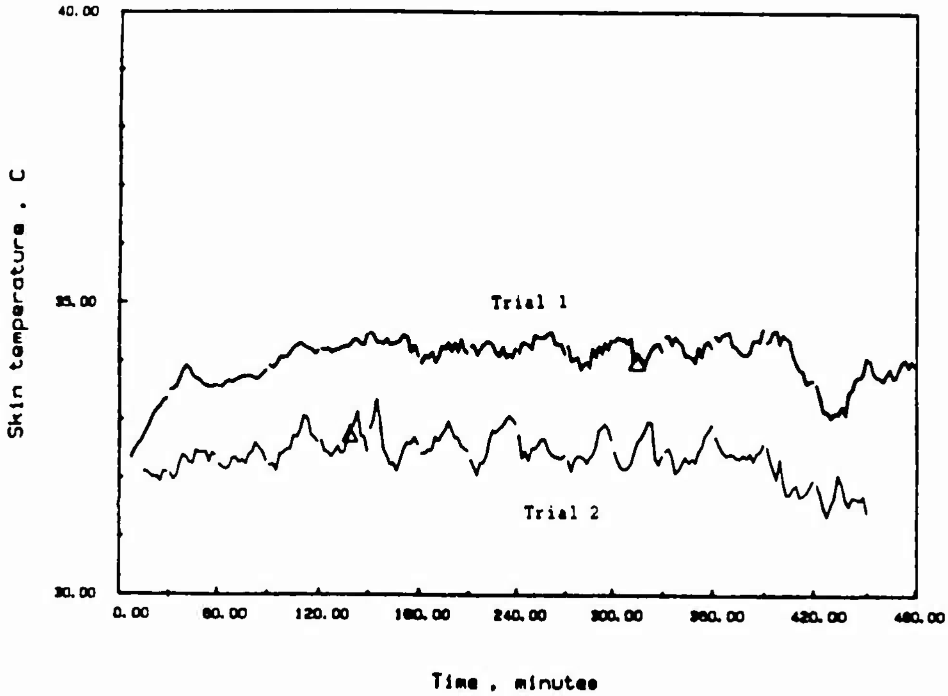

Figure 13. Tsk versus time for subject A in the CAPS. Upward arrows indicate time at which subject sat upright.

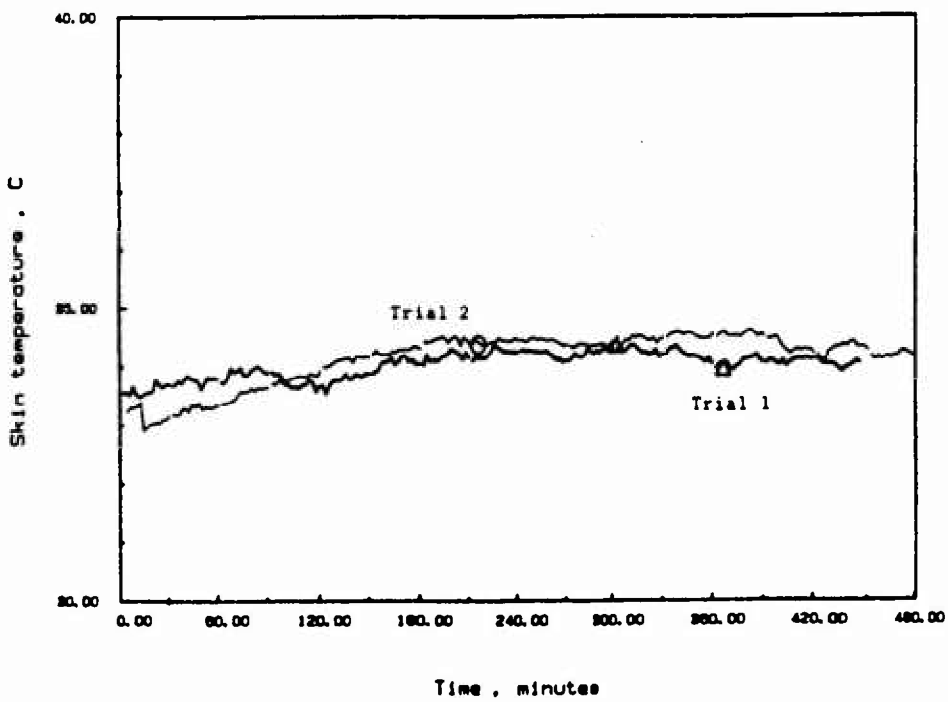

Figure 14. Tsk versus time for subject A in the CWU-62/P. Upward arrows indicate time at which subject sat upright. Circle indicates time at which neck ring was first used.

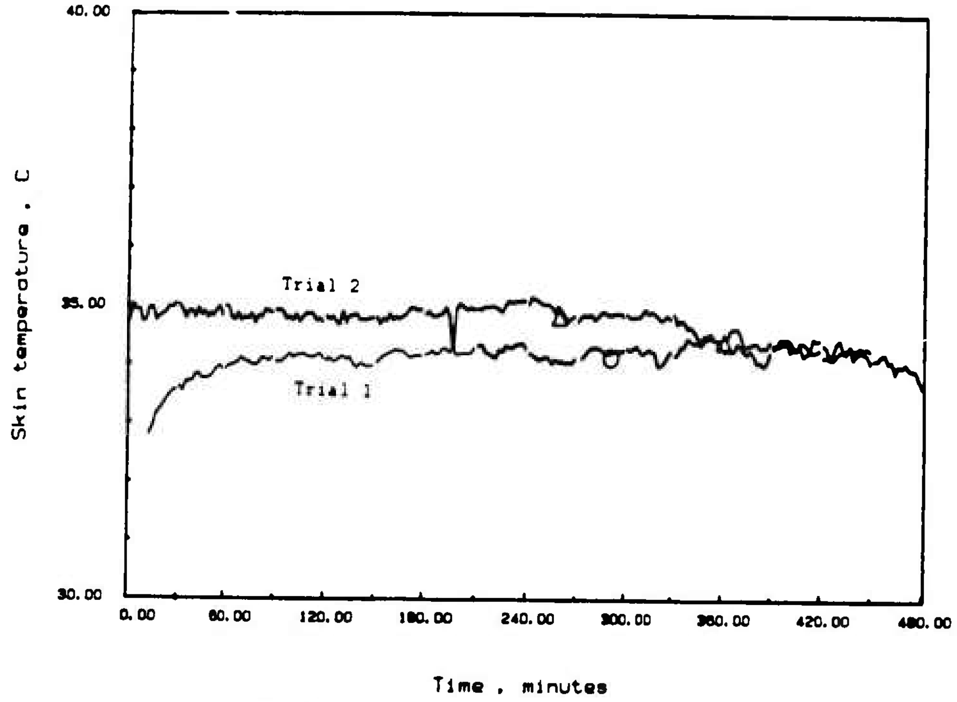

Figure 15. Tsk versus time for subject B in the CAPS. Upward arrows indicate time at which subject sat upright. Circle indicates time at which neck ventillation tubing was first used.

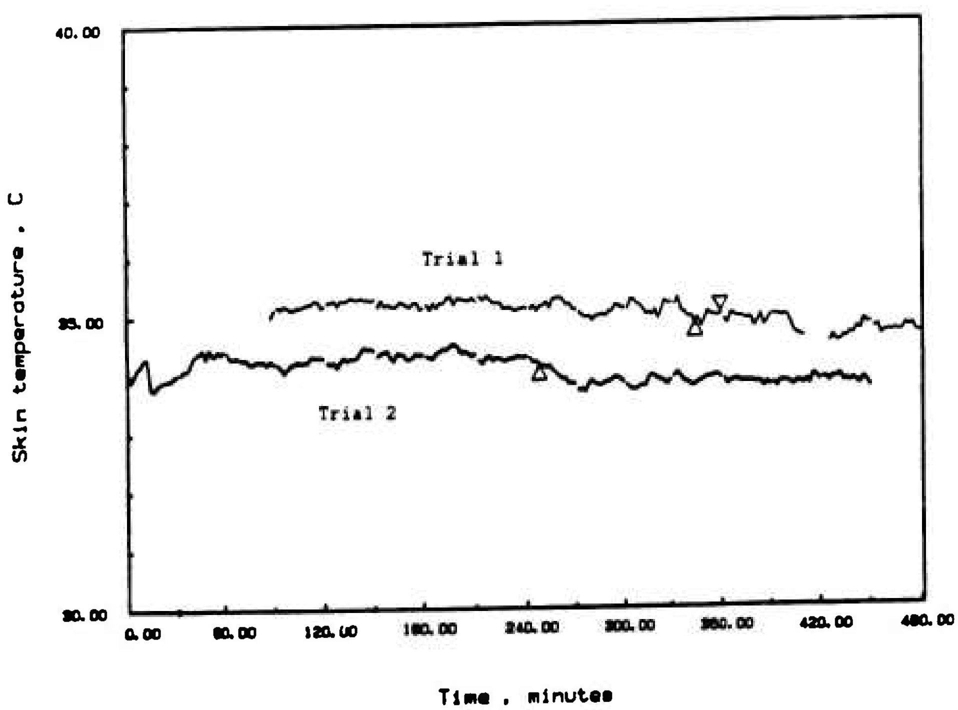

Figure 16. Tsk versus time for subject B in the CWU-62/P. Upward arrows indicate time at which subject sat upright. Downward arrow indicates time when subject lay down.

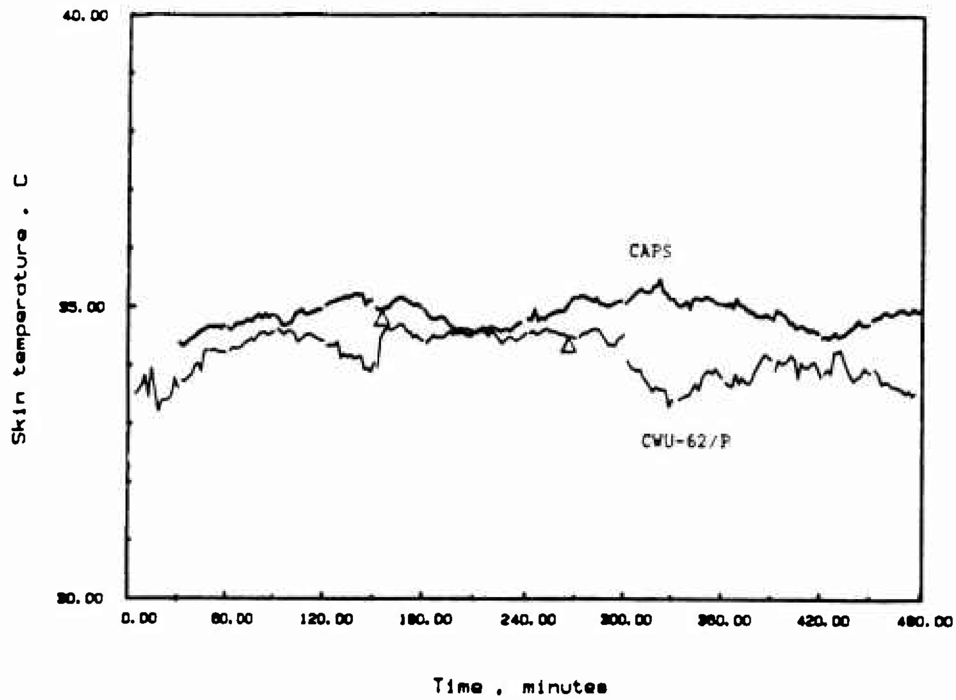

Figure 17. Tsk versus time for subject D in both garments. Upward arrows indicate time at which subject sat upright.

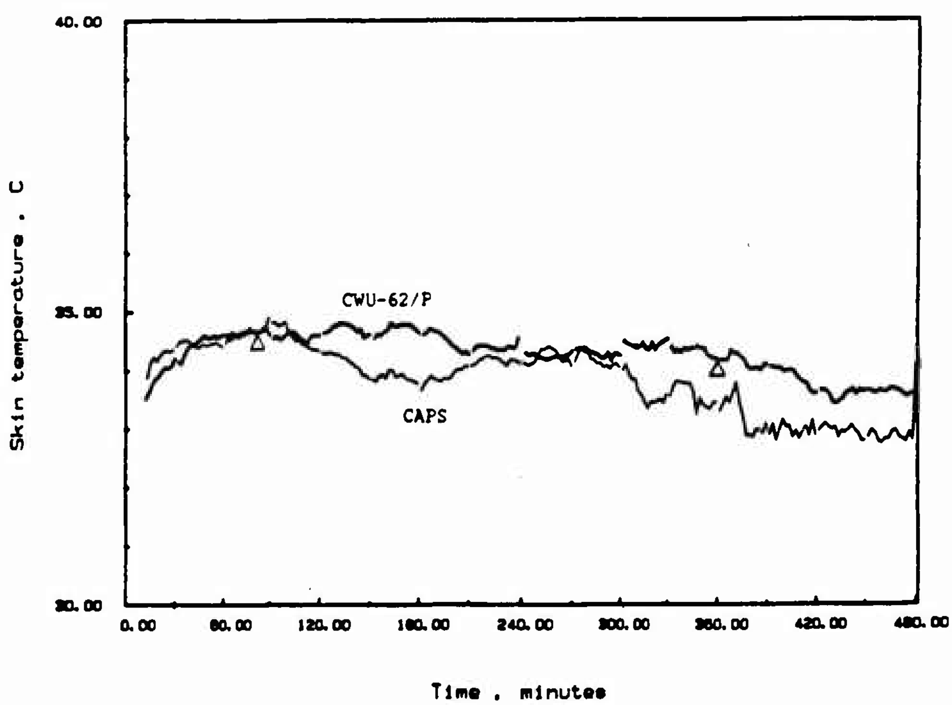

Figure 18. Tsk versus time for subject E in both garments. Upward arrows indicate time at which subject sat upright.

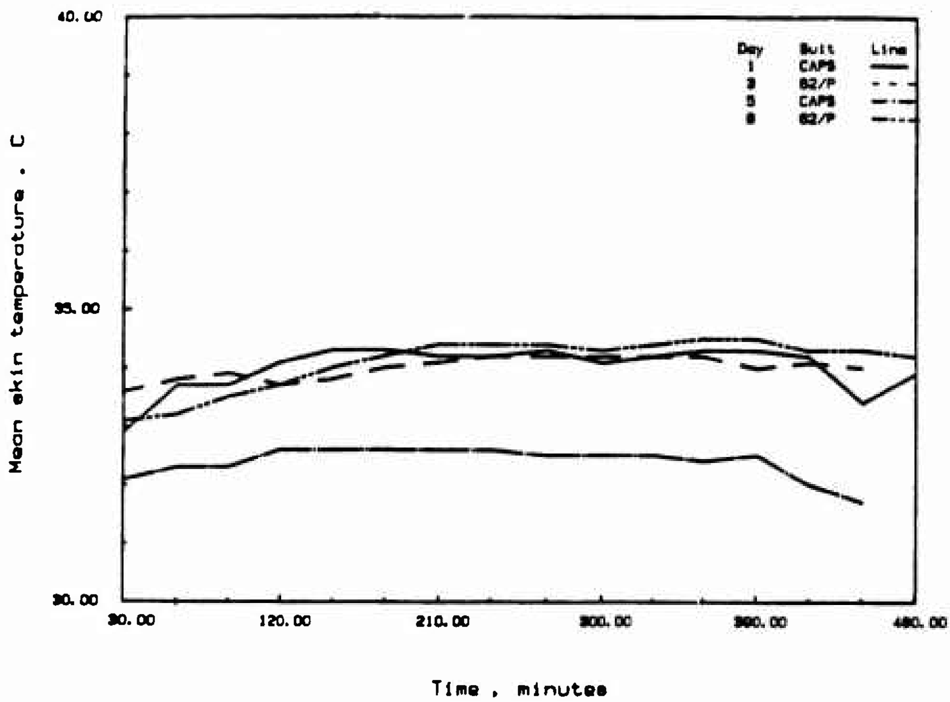

Figure 19. Mean Tsk over 30 minutes versus time for both garments, subject A.

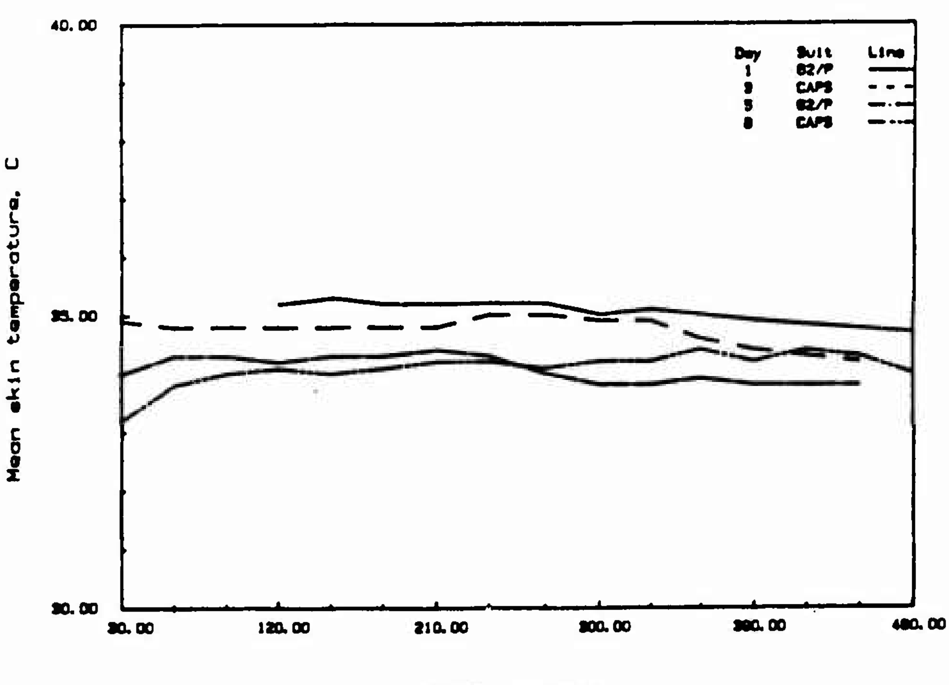

Figure 20. Mean Tsk over 30 minutes versus time for both garments, subject B.

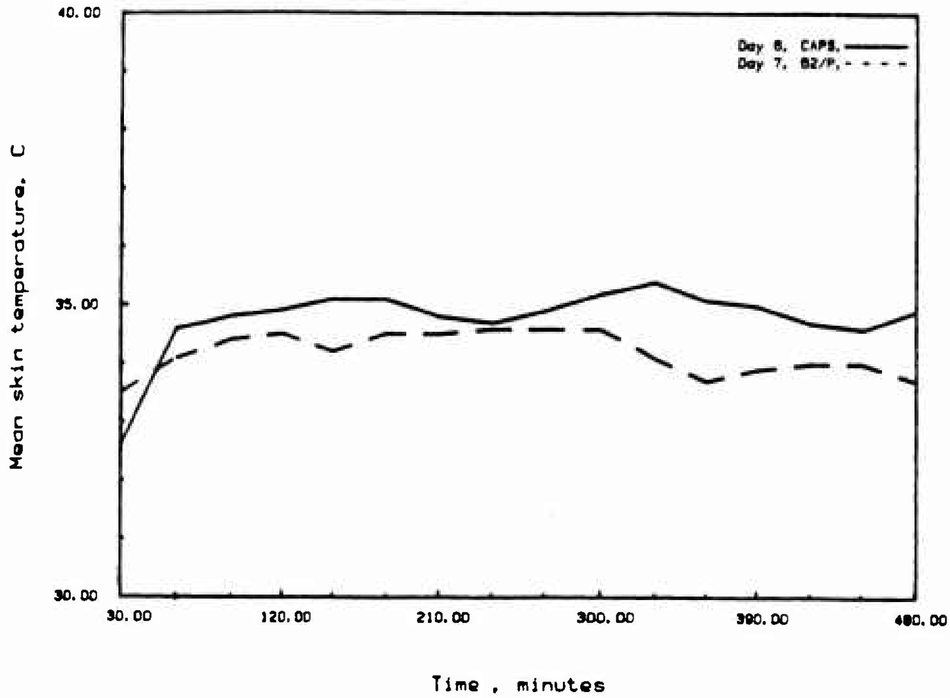

Figure 21. Mean Tsk over 30 minutes versus time for both garments, subject D.

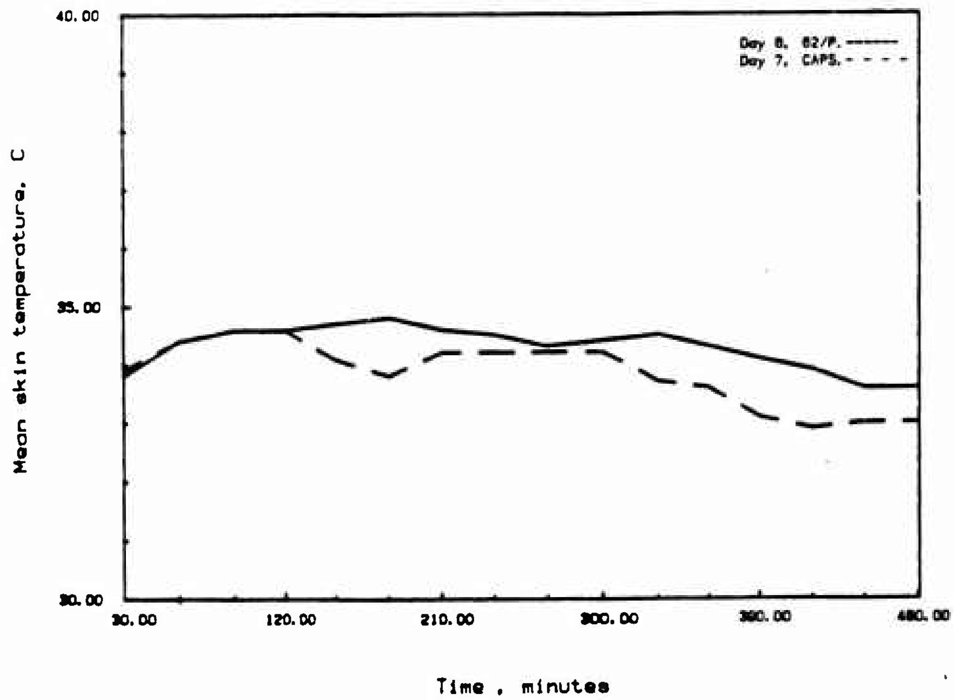

Figure 22. Mean Tsk over 30 minutes versus time for both garments, subject E.

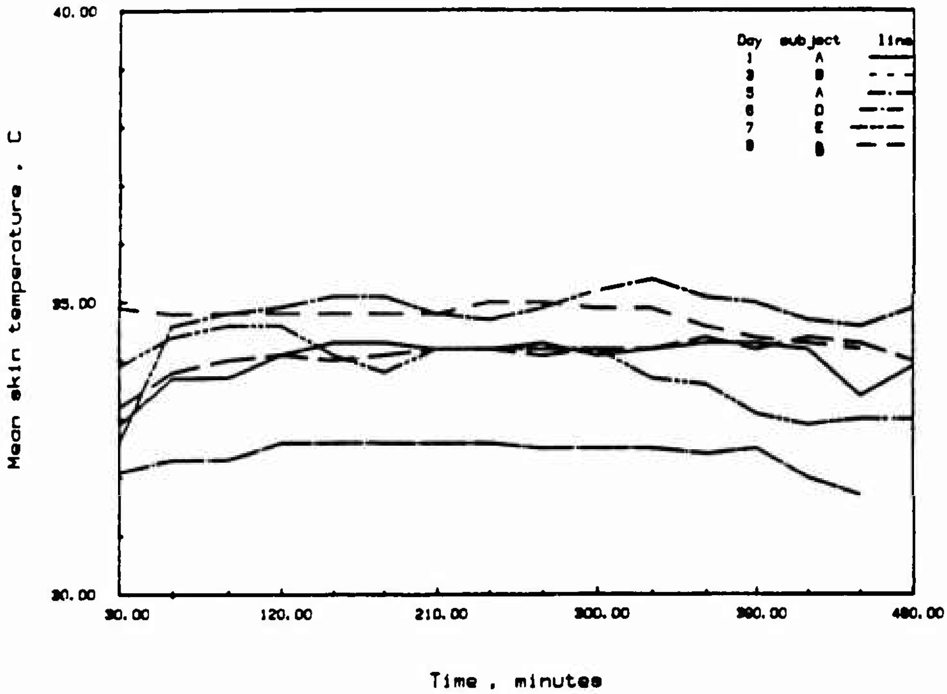

Figure 23. Mean Tsk over 30 minutes versus time, CAPS.

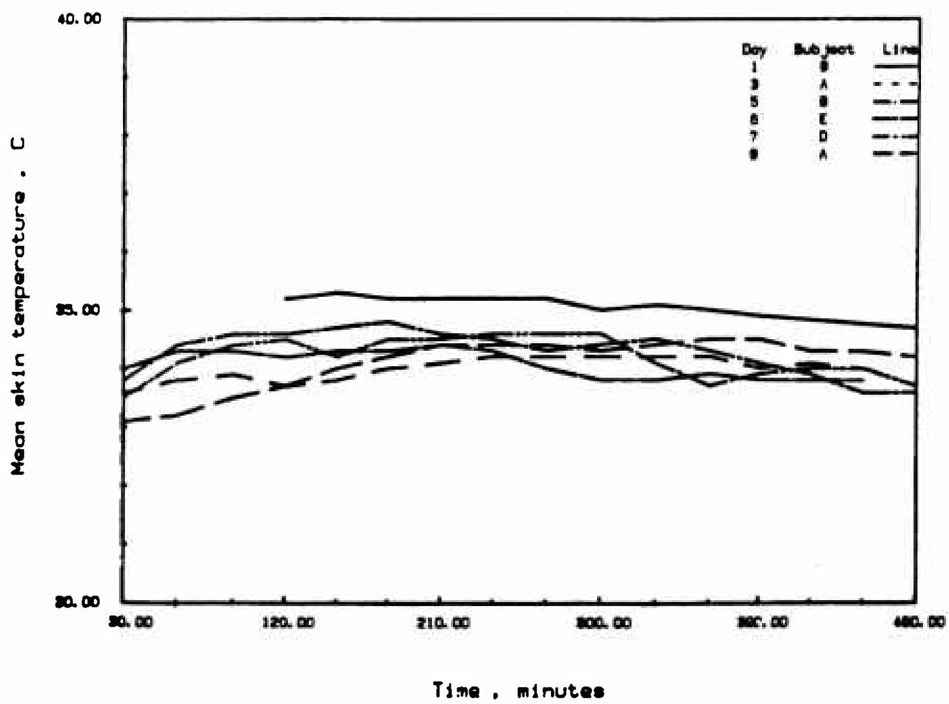

Figure 24. Mean Tsk over 30 minutes versus time, CWU-62/P.

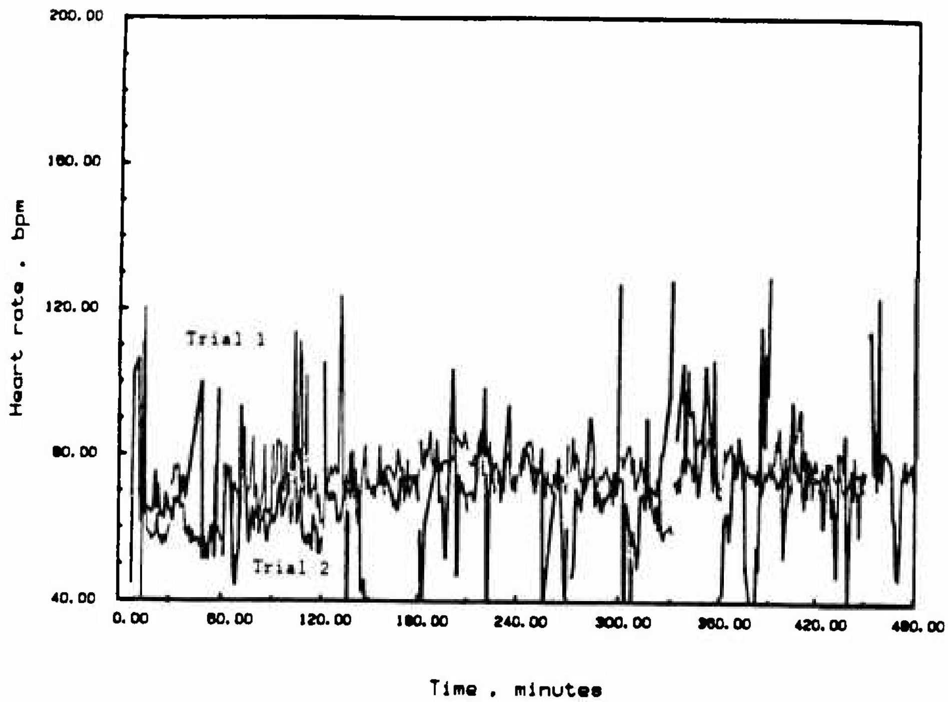

Figure 25. <u>Heart rates versus time for subject A in the CAPS.</u>

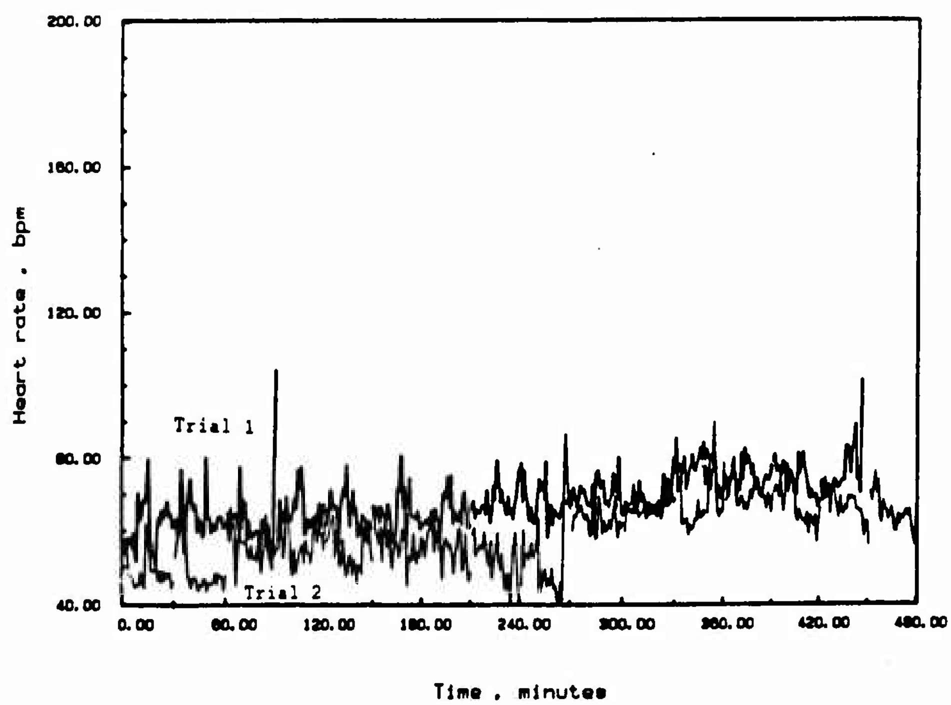

Figure 26. <u>Heart rates versus time for subject A in the CWU-62/P.</u>

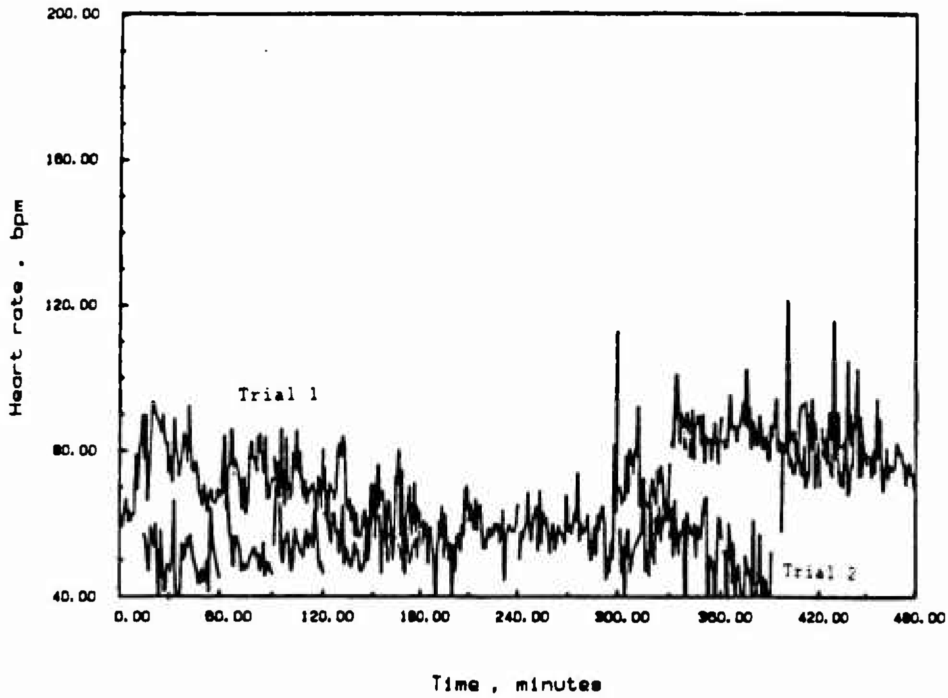

Figure 27. Heart rates versus time for subject B in the CAPS.

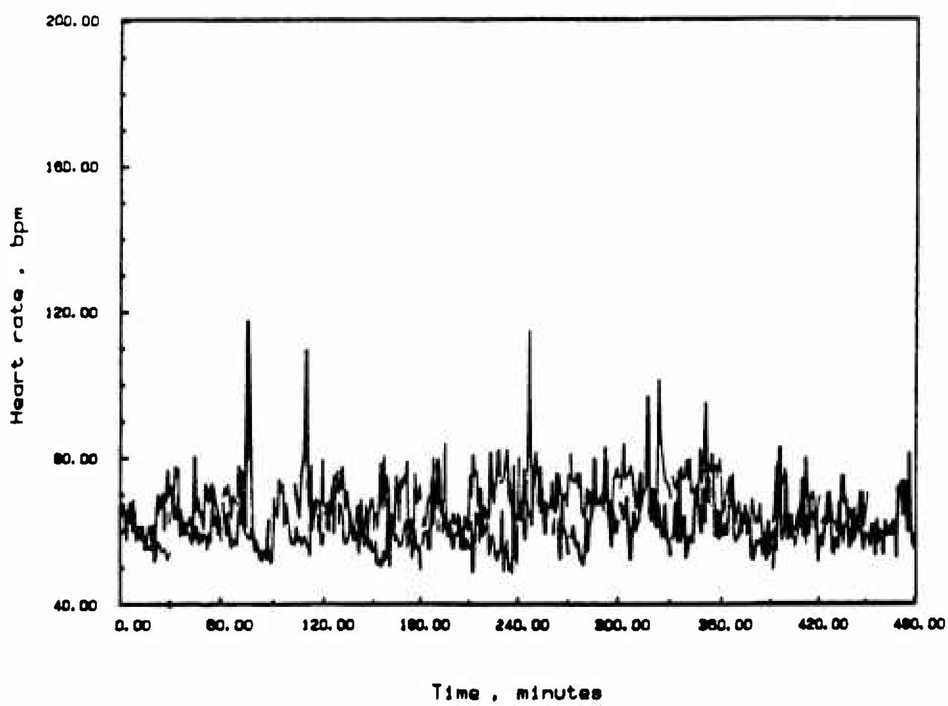

Figure 28. Heart rates versus time for subject B in the CWU-62/P.

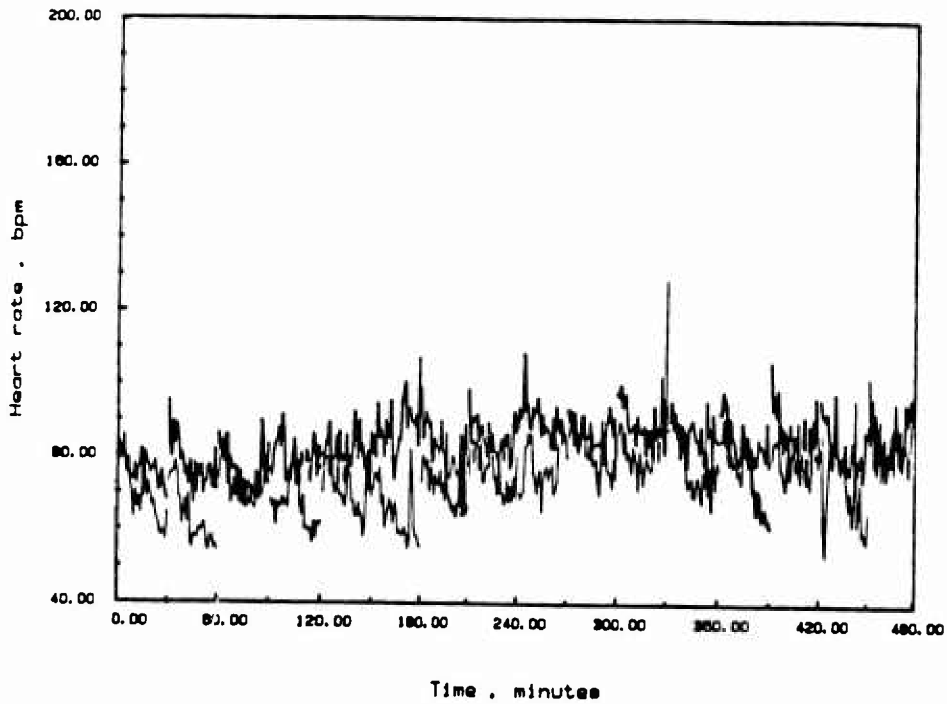

Figure 29. Heart rates versus time for subject D in both garments.

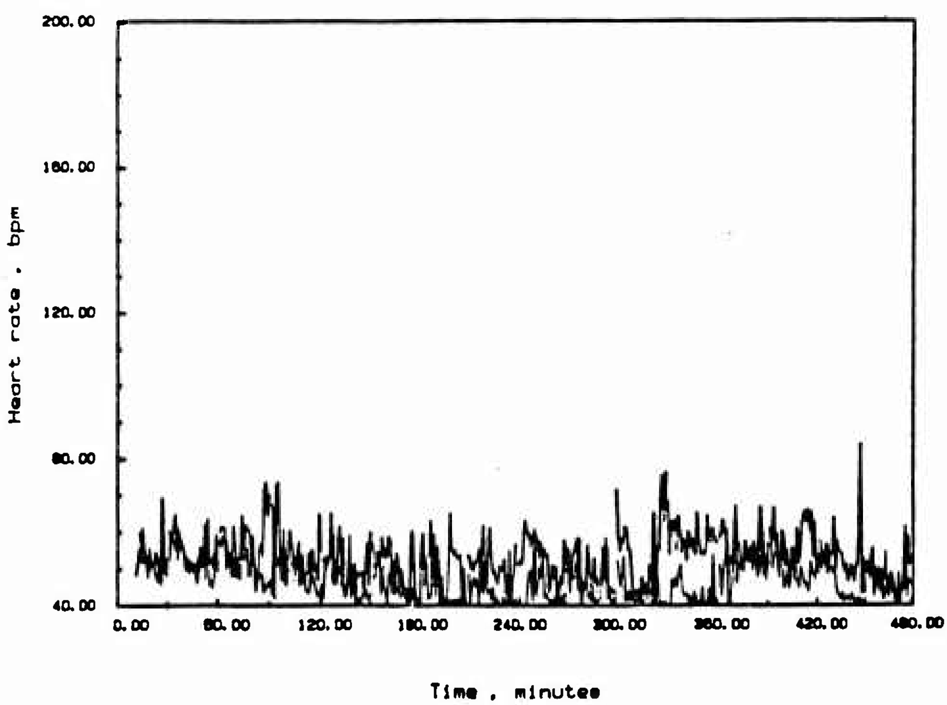

Figure 30. Heart rates versus time for subject E in both garments.

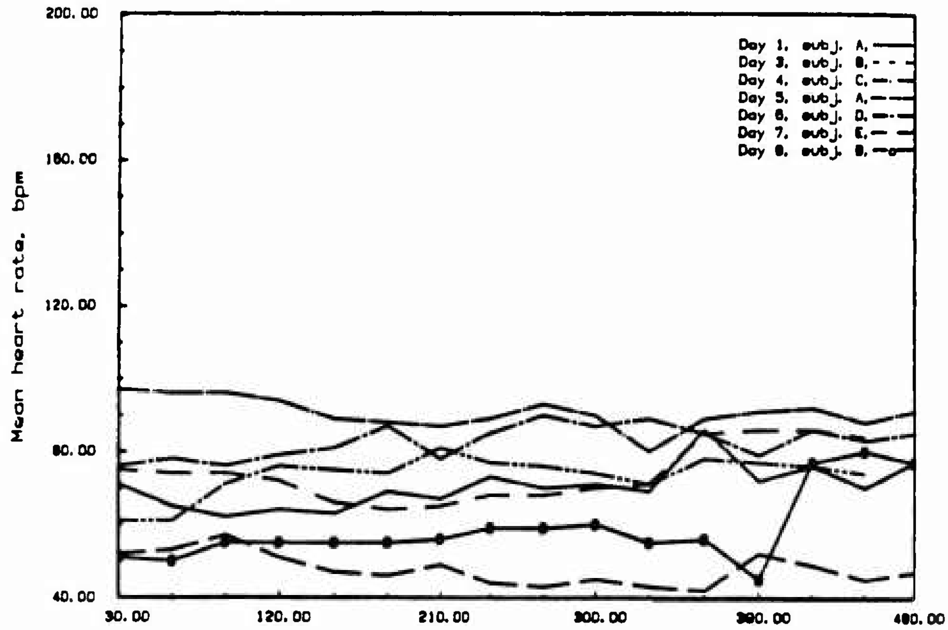

Figure 31. Mean heart rate over 30 minutes versus time, CAPS.

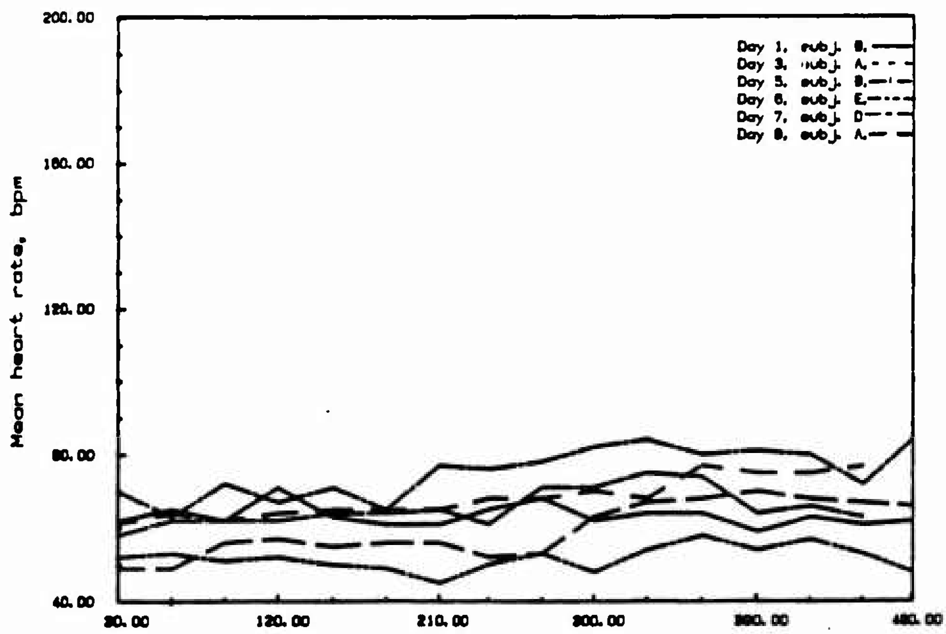

Figure 32. Mean heart rate over 30 minutes versus time, CWU-62/P.

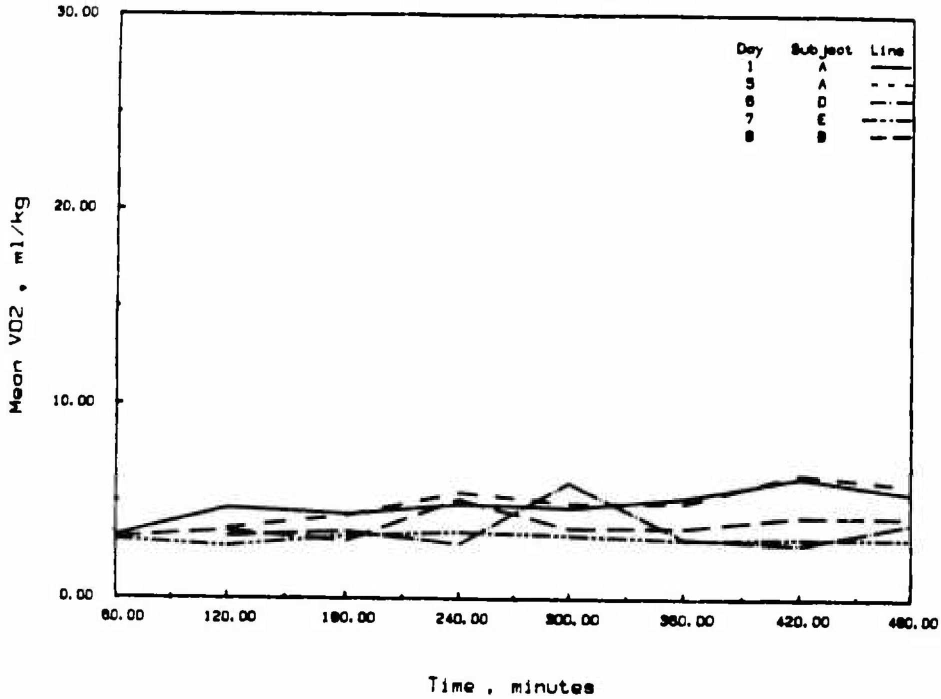

Figure 33. Mean maximum VO2 over 60 minutes versus time, CAPS.

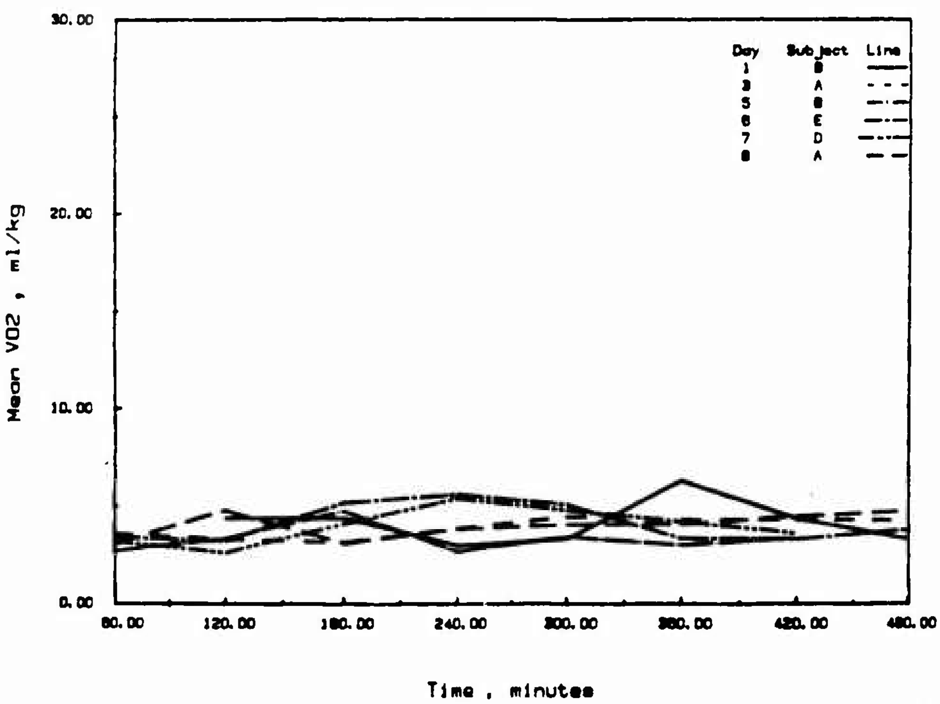

Figure 34. Mean maximum VO2 over 60 minutes versus time, CWU-62/P.

DISTRIBUTION LIST

Report No. NADC-88070-60

No. of Copies

Director 20
NASA-Johnson Space Center, Code SP, Houston, TX 77058
ATTN: J. H. Barnett, Jr.

Director 2
NASA-Johnson Space Center, Code CB, Houston, TX 77058
ATTN: Dr. J. P. Bagian

Defense Technical Information Center 2
Cameron Station, Bldg 5, Alexandria, VA 22217

Commander 7
Naval Air Systems Command Headquarters
Washington, DC 20361
Code: AIR 950-D (1 copies)
AIR 531 (2 copies)
AIR 5311 (2 copies)
AIR 340 (1 copies)
AIR 410 (1 copies)

Senior Naval Officer... 1
NASA-Ames Research Center
Moffett Field, CA 94035

Commanding Officer 1
Naval Medical Research and Development Center
Naval Medical Command, National Capital Region
Bethesda, MD 20814-5044

Commanding Officer 2
Naval Aerospace Medicine Research Laboratory
Naval Air Station, Pensacola, FL 32508

Commanding Officer 1
Naval Aerospace Medical Institute
Naval Air Station, Pensacola, FL 32508
Code: 13

Chief of Naval Education and Training 2
Naval Air Station, Pensacola, Fl 32508
Code: N431

Commanding Office 1
Naval Aerospace and Regional Medical Center
Pensacola, FL 32512

DISTRIBUTION LIST

Report No. NADC-88070-60

Commander 3
Naval Safety Center
Naval Air Station, Norfolk, VA 23511
Code: 122

Chief of Naval Air Training 2
Naval Air Station, Corpus Christi, TX 78419
Code 5113

Commander 2
Naval Air Test Center,
Patuxent River, MD 20670
Code: SY 7

Commanding Officer 1
Navy EDU
Panama City, FL 32407-5001
ATTN: Dr. J. Sterba

Commanding Officer 1
Naval Air Engineering Center, Naval Air Station
Lakehurst, NJ 08733

Commanding Officer 2
Naval Training and Equipment Center
Orlando, FL 32813
Code: N-337

Commander 2
Naval Air Force, US Pacific Fleet
Naval Air Station, North Island, San Diego, CA 92135
Code: 721

Commander 2
Naval Air Force, US Atlantic Fleet
Norfolk, VA 23511
Code: 522

Commanding Officer 2
Naval Weapons Center
China Lake, CA 93555
Code: 64
ATTN: Lt. S. Moll

Naval Clothing and Textile Research Facility 2
21 Strathmore Road
Natick, MA 01760
ATTN: Dr. B. Avellini