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EVALUATION OF THERMAL STRESS INDUCED BY HELICOPTER AIRCREW CHEMICAL, BIOLOGICAL, RADIOLOGICAL (CBR) PROTECTIVE ENSEMBLE

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INTRODUCTION. The A/P22P-9(V) Chemical, Biological, Radiological (CBR) Protective Assembly for helicopter aircrews has been evaluated for the additional thermal stress it imparts to users in a hot environment. The standard aircrew life support system for helicopters, based on the CWU-27/P flight coverall, was employed as the experimental control. METHODS. Two environmental conditions were studied: 1) a simulated hot aircraft interior (hot), with chamber temperatures maintained at dry bulb temperatures (T_{db}) = 32.8 ± 0.1°C and a wet bulb temperature (T_{wb}) = 25.0 ± 0.5°C, and 2) a control environment (cool), with chamber temperatures maintained at T_{db} = 20.9 ± 0.1°C and T_{wb} = 15.0 ± 0.5°C. Three males, aged 24-35 years, were exposed twice to each garment/environment condition combination, for a total of eight exposures each, except for one subject who was studied in cool conditions only once in each of the configurations, for a total of six runs. Test durations were designed for 480 minutes. RESULTS. Comparison by ensemble show significant differences ($p<0.05$) observed for exposure durations, while rectal temperatures were significantly different ($p<0.05$) between ensembles only in hot conditions. Ambient conditions significantly impacted on nearly all measured parameters. CONCLUSIONS. The results indicate that the CBR ensemble represents a limiting factor in performance in a hot environment.

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INTRODUCTION

The use of chemical weapons in modern warfare has alerted the Navy to the need to provide adequate chemical protection for its aircrews throughout all stages of a mission. This has proven to be a daunting task, however, because of the thermal burden such systems have placed on users in the past. Designs for garments intended for in-flight use have proven to be cumbersome, reduce dexterity, and evoke thermal stress after a short time in use (6,14).

The development of the A/P22P-9(V) Chemical, Biological, Radiological Protective Assembly (CBR) was believed to have ameliorated a number of these problems. This system combines an impermeable ventilated mask (modified United Kingdom MoD AR-5 respirator) with a semipermeable charcoal-impregnated undergarment (USAF MK-1). With the decrease in bulk compared with earlier ensembles along with ventilation of the head and neck and a semipermeable undergarment, the CBR ensemble is intended to permit use for extended periods.

The purpose of this study was to evaluate the thermal load imposed on users of this system under hot and humid conditions and, if possible, quantify decrements in mission-related cognitive and psychomotor performance. This study attempted to simulate conditions which might be experienced within a helicopter during military operations (11,19). Trial durations of up to eight hours were used to simulate the sustained operations anticipated in a wartime situation.

MATERIALS AND METHODS

Three males (Table 1) volunteered to participate in the testing of two equipment configurations, both tested under hot and cool conditions for a total of four test conditions, after being fully informed of the details of the experimental protocol and associated risks.

SUBJECTS: Weight was recorded prior to each test run. Body surface area (BSA) was calculated (5) from the mean weight and height of each subject. Percent body fat was determined from estimates of body density (4), which were computed from skinfold measurements obtained with Lange Skinfold Calipers (Cambridge Scientific Inc., Cambridge, MD) and the equation of Lohman (17).

MATERIALS: Two ensembles were employed in this study: 1) the Aviation Life Support System (ALSS); and 2) the A/P22P-9(V) Chemical, Biological, Radiological (CBR) Protective Assembly. A list of the individual clothing items which comprise each ensemble is given in Table 2. While cotton undergarments are not standard items in the ALSS configuration, they were included in this study in order to minimize the number of variables.

Cotton undergarments and glove liners are intended to reduce skin irritation and to minimize the contamination of the chemical liner by perspiration. The chemical liner is a liquid-repelent garment coated on the inner surface with activated charcoal. Polyethelyne socks and butyl gloves are intended to provide chemical agent-impermeable barriers at the extremities. The MCK-3/P mask, CQK-2/P ventilator, and A/P37S-1 intercom, comprising the above-the-neck portion of the A/P22P-9(V) assembly, provide head, eye, and respiratory protection for users. A bromo-butyl hood encloses these items and covers the head and neck regions, extending past the neck to provide a seal against agent penetration. This hood is intended to be worn below the helmet.

Two items were not worn by subjects in this study: disposable footware covers and aircrewman's cape. These items are intended for use by aircrews enroute from a shelter to the aircraft and are to be discarded prior to entering the aircraft. Since they will contribute very little to the heat stress experienced by aircrews, the items were not included in the ensembles studied.

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 randomized. It was intended that each subject use each test garment in both hot and cool conditions. These exposures were to be repeated, resulting in each subject having a total of eight exposures. Two subjects successfully completed all eight runs. Due to lower back pain, one of the subjects was studied in cool conditions only once in each of the configurations, for a total of six runs.

Acclimatization, i.e., the physiological adaptation to environmental stress, provides a greater capacity for individuals to tolerate heat stress. Since it was not possible to fully acclimatize subjects prior to the start of testing and it would be difficult to compare the results from subjects with varying degrees of acclimatization, minimizing acclimatization appeared to assure the best data. In addition, the results would represent a worst case situation, somewhat akin to a unit being moved from a cool environment to the tropics. Testing was performed in November and December, with a minimum time interval between any tests for a given subject of two days, so that acclimatization effects could be minimized.

Test Procedures: 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, a blood sample was obtained from the antecubital vein for the determination of hemoglobin content (Ames Seralyzer, Elkhart, Ind., model 5110A) and hematocrit, 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 distal upper arm; (D) dorsum of left hand; (E) right anterior thigh; (F) left posterior thigh; (G) right shin; (H) right foot; (J) right proximal 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 the heat flux/thermistor transducers were amplified (Bioinstrumentation Assoc., San Diego, CA, model HF-12/Temp-14) and stored in the laboratory's computer (MDB MSLI-Micro 1123, Orange, CA) for later analysis. A rectal thermocouple (Sensortek, Clifton, NJ, model RET-1) was inserted 8-10 cm anterior to the anal sphincter and ECG electrodes were placed on subjects at this time.

Subjects were then dressed in the appropriate equipment configuration, i.e., the standard aircrew life support system assembly for helicopters (ALSS) or CBR, for that run (Table 2). On the external suit surface of both garments, type T thermocouples were placed on sites corresponding to the location of the heat flux/thermistor transducers. Thermocouple voltages were converted to a ± 5 V analog signal (TC.4 isolated signal conditioners, Bendec, Santa Ana, CA) and stored in the laboratory's computer. Upon completion of dressing, subjects were weighed, followed by a rest period of 20 minutes which enabled temperature and heart rate (HR) 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. Hot conditions for these tests were $T_{air} = 33°C$ with a relative humidity (RH) of 70%, while cool conditions were $T_{air} = 21°C$ and RH = 40%. Runs consisted of an initial 60 minute rest period upon entry into the chamber followed by a repeated cycle of: a) 7 minutes of subjective assessment of physiological condition, cognitive testing, i.e., Baddeley reasoning and vertical addition of 3 two digit numbers, and rest; b) 7 minutes of psychomotor testing, i.e., play three rounds on a video game (Atari Jet-Fighter); c) 7 minutes of physical exercise, i.e., 30 W of work on a bicycle ergometer (Bosch GmbH, Berlin, Germany, model ERG 551). This 21 minute cycle was repeated until termination of a given run. 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, HR exceeding 90% of the maximum predicted for age, or the subject, flight surgeon, or principal investigator requesting termination.

During the first 120 minutes in the chamber subjects had access to 2 liters of water in their canteen. After this time the canteen was removed from the chamber and no further drinking was permitted. This regimen was established to correspond to the concern of possible contamination by chemical agents due to drinking straw insertion into the mask, therefore individuals would probably have only potable drinking water for the period prior to the actual start of a mission (e.g., time in the ready room, etc.).

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. Given values were the marked distance from the left origin in millimeters and the rate of change of the distance determined from the final and initial values. The rates were obtained from:

$$\text{(1)} \qquad \text{Rate} = (V_f - V_p)/t \qquad \text{(mm/min.)}$$

where V_f = the final reported value for a given category, V_p = the value obtained prior to dressing, and t = the time elapsed when the final value was obtained.

Cognitive and Psychomotor Tests: Changes in cognitive performance were evaluated with tests of vertical addition and the Baddeley reasoning test (2,3). 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" (2).

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 were recorded by both the total number attempted and those answered correctly. If subjects completed all 31 questions in less than 90 seconds, the time required for completion was recorded, with analysis based on extrapolation to 90 seconds for both the number of correct and completed questions. 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.

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

(2)
$$Tsk = 0.1(T_A) + 0.125(T_B+T_K) + 0.07(T_J+T_C) + 0.06(T_D) + 0.125(T_E) + 0.15(T_G) + 0.125(T_E+T_F)/2 + 0.05(T_H) \quad (^\circ C)$$

where T_i are the measured skin temperatures at locations i = A - K (13). Mean weighted skin surface heat flux (HF), i.e., the amount of energy crossing the skin surface, was calculated from the equation:

(3)
$$HF = 0.1(HF_A) + 0.125(HF_B+HF_K) + 0.07(HF_J+HF_C) + 0.06(HF_D) + 0.125(HF_E) + 0.15(HF_G) + 0.125(HF_E+HF_F)/2 + 0.05(HF_H) \quad (W/m^2)$$

where HF_i are the measured heat fluxes at locations i = A - K (13). The rate of heat storage, i.e., the quantity of heat retained in the body, was determined from:

(4)
$$S = (\Delta Tre/\Delta t)(60 \times 0.97 \times Mb)/BSA \quad (W/m^2)$$

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 (m_{sw}) was determined by the difference between the post-test nude weight, corrected for fluid and food intake, and the pre-test weight from:

(5)
$$m_{sw} = (NW2 - NW1)/\Delta t/BSA$$

where NW is nude weight and 1 & 2 signify pre- and post-test values respectively. In one instance, a subject had the need to urinate during a run. The urine was collected and weighed, with the post-test weight corrected for the urine weight. The change in garment weight (ΔGW) due to the uptake of sweat was determined by:

$$(6) \qquad \Delta GW = (CW2 - NW2) - (CW1 - NW1)$$

where CW is clothed weight. The percentage of sweat evaporated (%E) was calculated from:

$$(7) \qquad \%E = (m_{sw} - \Delta GW)/m_{sw} \qquad (\%).$$

Statistical Analysis: Data for the individual dependent variables was analyzed using repeated measures analysis of variance (ANOVA). Analyses of significant changes within runs were also performed with paired-sample t-tests. Differences were considered significant at the level of $p<0.05$.

RESULTS

The results of this study indicate that the CBR configuration produced increased heat stress when worn in a hot versus cool environment or when compared with the ALSS configuration in either environment. Environment and subject variations were other variables which proved significant in the physiological differences observed between runs. Repeated exposure to the conditions appeared to affect cool trial results, though results of the hot trials were unaffected by repetition. The mean data for the dependent variables of voluntary duration time, T_{re}, T_{sk}, and S are given in Table 3 with T_{re} and T_{sk} plotted in Figures 5 and 6. Mean data for initial urine specific gravity, total water consumption, total weight loss, %E, m_{sw}, and % body weight lost are reported in Table 4.

Voluntary Duration Time: Because of the great variance in the length of time subjects would stay in the various conditions, the exposure duration time data was transformed using natural logarithms. Results of the ANOVA show pronounced differences in exposure duration times between the hot and cool conditions ($p < 0.01$), between equipment ensembles ($p < 0.01$), subjects ($p < 0.01$), and to some extent, between replications ($p < 0.05$).

The temperature of the environment, i.e., hot or cool, was found to be a significant main factor ($p < 0.01$), with subjects having a significantly lower tolerance time in the hot conditions regardless of equipment ensemble. The effect of equipment ensemble was highly significant ($p < 0.01$), with use of the ALSS configuration resulting in longer durations for subjects in all conditions (Table 3). There was a significant triple order interaction between clothing type, replication, and temperature, which is apparent in Figure 2.

Rectal Temperature: Pooled data was plotted in Figures 3 and 4 and shows that: 1) Final T_{re} is much higher in the hot conditions than in the cool conditions; 2) Increases in T_{re} over the time of the study are greater in the hot environment than in the cool environment; and 3) Use of the CBR suit resulted in higher T_{re}'s in all conditions when compared with the ALSS at the same time (Figure 5). In addition, T_{re}'s resulting from use of the CBR ensemble in the hot condition were significantly greater than the ALSS throughout the course of trials ($p < 0.05$) (Figure 5). Differences between T_{re}'s observed for CBR trials in the hot and cool conditions were found to be significant from minute 121 through the end of the trials ($p < 0.05$). The ANOVA revealed that across equipment ensembles, T_{re} was significantly higher in the hot environment than in the cool ($p < 0.01$), and there was a significantly greater change in (Final T_{re} - Initial T_{re}) in the hot environments ($p < 0.01$) There was a significant interaction between the replication and hot environments ($p < 0.04$). These interactions are shown in Figure 3.

Heart Rate: Comparisons of final HR's indicate that significant differences existed between $ALSS_{cool}$ and the hot ALSS and CBR runs. No other final HR differences were significant. Only initial HR differences between the cool and hot ALSS runs were found to be different, though even this difference was of questionable physiological importance. Mean values for HR are given in Table 3.

Mean Skin Temperature: Behavior of T_{sk} is given in Table 3 and plotted in Figure 6. This data shows a response pattern similar to that of T_{re}, i.e., a higher T_{sk} found at the end of all conditions and with higher T_{sk}'s in the hot condition than in the cool condition. The only significant difference that was revealed by the ANOVA was that final T_{sk} in the hot trials was significantly higher than final T_{sk} in the cold trials ($p < 0.01$). There were no significant differences in T_{sk} due to equipment ensemble or between the two replications. This finding argues against any physiological acclimatization having occurred between the two replications or across the experiment. Comparison of T_{sk}'s between hot and cool conditions over trial duration show significant differences from approximately the beginning through the end of trials. Significant differences in T_{sk} between ensembles appeared toward the end of trials ($p < 0.05$) in both environments.

Thermal Gradients: The thermal gradient examined in this study, T_{re} - T_{sk}, was studied along the time course of runs. No significant differences were discerned between ensembles in the same environmental conditions, i.e., hot or cool. However, comparing ensembles in different environments demonstrated significant differences resulting across environmental conditions ($p < 0.05$), with larger gradients observed in the cool environment.

Heat Storage: Environment, i.e., hot versus cool, appears to be responsible for the differences observed in this study ($p < 0.01$). No significant differences were observed between garments within an environmental condition. Mean S values are given in Table 3.

Sweat Rate: The m_{sw}'s calculated for the $ALSS_{hot}$ trials compared with the $ALSS_{cool}$ and CBR_{cool} trials indicated significant differences ($p < 0.05$), as did comparing CBR_{hot} to $ALSS_{cool}$ ($p < 0.05$). Pre-test urine specific gravity showed no statistical differences between configurations, indicating equivalent hydration levels upon entry into the laboratory. Water consumption was observed to be significantly different between $ALSS_{hot}$ and the two cool conditions ($p < 0.05$), though not between CBR_{hot} and the cool conditions. No statistically significant difference between CBR_{hot} and $ALSS_{hot}$ mean water consumption was observed. A statistical analysis of evaporative losses could not be made due to missing data. The mean total weight losses, percentage of total body weight lost as sweat, percentage of weight lost as evaporation, and total water consumption for each configuration are given in Table 4.

Cognitive and Psychomotor Data: No effects on either cognitive or psychomotor testing were discerned as a result of exposure to the experimental conditions. Neither differences in environmental conditions nor clothing configurations resulted in any observed changes in Atari scores or the number of attempts and correct responses to the vertical addition and Baddeley reasoning tasks (Table 5).

Subjective Responses: Comparing equipment ensembles on the basis of subjective criteria shows that the rate of onset of unpleasant sensations with $ALSS_{hot}$ to be significantly greater than either the $ALSS_{cool}$ or CBR_{cool} ($p < 0.04$) (Table 6). This was true for all four subjective criteria used in this study, i.e., fatigue, wetness, temperature, and comfort. No significant difference was observed between CBR_{hot} and the other ensembles for any of the subjective criteria.

DISCUSSION

The purpose of this study was to determine the impact of wearing the CBR ensemble on thermal homeostasis. It is clear from the analysis of exposure duration, T_{re}, and T_{sk} that the CBR ensemble induces heat stress under the test conditions. This stress is particularly pronounced under conditions of high heat and humidity. Thornton, et al (18) found similar results, though the stress experienced by their subjects appears to be considerably less than that observed in this study.

While final temperatures did not vary significantly between configurations during hot runs, the differences in onset rates and exposure durations indicate that the CBR ensemble produced significantly greater thermal stress on personnel. The elevated starting T_{re} observed in the CBR runs was probably a result of heat storage during dressing with the CBR ensemble, heat which was not dissipated during the cool down period prior to chamber entry. These results are not surprising considering the bulk and resulting insulation of the CBR ensemble compared with the ALSS configuration. While the MK-1 undergarment is permeable to water vapor, the CBR ensemble was found to permit less whole body ventilation, based on mean %E, than the ALSS ensemble and would be expected to result in reduced exposure durations and increased T_{re}'s and T_{sk}'s (10, 14, 18).

The state of hydration must be considered when interpreting the physiological changes (16). Initial hydration state appears to be equivalent among subjects, based on the initial specific gravities of urine samples, therefore hydration does not appear be a factor in the observed differences. As neither water consumption, M_{sw}, nor the percentage of body weight lost through sweating were significantly different between ensembles in the hot environment, evaporation at the garment surface clearly must be playing a major role in controlling T_{re}. It appears that the CBR ensemble is inhibiting the transfer of moisture to the outer garment surface, thus reducing effective heat transfer.

The significant triple order interaction between clothing type, replication, and environmental temperature, is believed to be an artifact from experimental procedures. The artifact is thought to have occurred because subjects quickly became uncomfortable in the hot conditions, and subjects in the first replication chose to voluntarily stop trials before their physiological measures indicated a significant heat load. By the second replication, subjects were more tolerant of the hot conditions and so their exposure durations were longer and more closely related to the physiological measures of heat stress. A second factor influencing the interaction effect is the experimental time limit, since with the ALSS garment in the cool condition some subjects were removed at 480 minutes, even though both subjective and physiological indices suggested that they could have endured longer exposures. It is believed that if either of these two factors were eliminated, the interaction effects would be non-significant. Similarly, the significant interaction between the replication and hot environments for T_{re} is also due to this "early out" phenomenon.

The lack of a significant clothing effect on final T_{re} was of particular interest. This non-significant effect indicates that subjects were reaching similar final T_{re}'s. However, use of the ALSS ensemble, versus the CBR, led to subjects staying for significantly longer periods of time before trials were stopped either by the subject or T_{re} = 39.0°C. The lack of difference in T_{re} can thus be viewed as indicating that the trials were terminated at similar physiological states, though the time to reach such a state differed. This may also serve as an explanation for the lack of observed final T_{sk} differences between garments. In addition, the differences in rates of change of subjective responses observed between clothing configurations may be more a function of exposure duration than any other factor. It may be that the additional time spent in the $ALSS_{hot}$ compared with the CBR_{hot} is responsible for any perceived differences between these and the $ALSS_{cool}$ and CBR_{cool}, respectively.

The relatively small mean exposure duration for the CBR ensemble in hot runs, i.e., 155 minutes, suggests that use of this ensemble may present a serious impediment to sustained operations due to inability to tolerate the induced stresses. Exposure durations were limited by both high T_{re}'s and subjective tolerance. Extreme fatigue and discomfort were the causes for trials to be terminated for subjective reasons. This shows that the onset of high thermal stress, as indicated by final T_{re}, is brought on at a significantly faster rate by the CBR ensemble versus the ALSS during heat exposures. Hydration, and thus the blood volume available to muscles (7, 16), probably accounted for some of the differences observed in exposure durations, since blood is preferentialy supplied to muscle tissue during exercise in heat (15). Reduced hydration, and consequently a reduced blood volume, would reduce the muscle blood volume and would ultimately lead to fatigue and exhaustion (7).

It can be argued that the hot conditions used in this study are themselves limiting, as indicated by the mean duration observed for ALSS runs, i.e., 219 minutes. The range of durations for these runs (177-285 minutes), however, overlap the observed durations in cool runs for both the ALSS (236-480 minutes) and CBR (173-414 minutes). This contrasts with the range observed for CBR_{hot} runs (142-175 minutes). This suggests that while the ALSS in the heat can be expected to allow performance comparable to cool conditions, the CBR will restrict operations to a much shorter time, i.e., less than 3 hours. Though other factors, such as physical conditioning and heat acclimation, would likely increase the durations observed for either of the hot runs, it would appear that the CBR ensemble represents a significant impediment to sustained military operations.

This is further supported by the observation that while there is evidence of habituation with the ALSS under both conditions and the CBR under cool conditions (Figure 2), no such conditioning is witnessed for the CBR ensemble under heat conditions. This suggests that the maximum performance has been elicited for the CBR ensemble under the hot conditions of this test.

The energy expenditure and cyclic nature of the work load were chosen to model helicopter crew missions. Measurements of in-flight work loads (11,19) of helicopter pilots indicate that the energy requirements of piloting are low, i.e., approximately 1.5 times or less than at rest. Work loads of 30W are within this range (20). The cyclic nature of tasks used in this study were an attempt to model the periodic nature of tasks, e.g., level flight followed by hovering, experienced while flying. Cycling of tasks might suggest that physiological measurements obtained will reflect the duration of each cycle, thus the physiological responses being idiosyncratic to a given situation. Mairiaux, et al. (12) have shown that cycle time is not reflected in changes in T_{re} but does impact on T_{sk} and m_{sw}. Simililar results were found in this study (Figures 5 and 6), though it appears that the CBR ensemble tended to damp out the response. This suggests that the state of hydration will, over time, be affected and subsequently lead to an increase in T_{re}. In addition, modification of T_{sk} will have an impact on cognitive and psychomotor performance.

The lack of significant changes in the cognitive and psychomotor performance tasks may be the result of either a lack of test sensitivity (3) or insufficient physiological changes (1) to induce cognitive and psychomotor deficits. The Atari task has been previously studied and shown to be a sensitive test for performance changes (3), but an earlier heat stress study (8) also resulted in inconclusive changes with regard to Atari performance. Similarly, the cognitive function tests used have previously been sensitive indicators of cognitive changes (2). Therefore, the results from this study suggest that the lack of significant differences are the consequence of inadequate physiological change to elicit a performance change.

In addition to the physiological and psychological indices observed in this study, the functioning of equipment was also monitored. A number of potentially serious equipment faults were witnessed during this study. The entire water supply system presented problems in that subjects complained it was difficult to obtain an adequate water flow during drinking. One indication of the difficulty experienced by subjects attempting to drink from the CBR canteen system was the fact that mean water consumption was approximately 8 times greater in the hot versus cool ALSS runs, while nearly equal for the CBR runs. It was found necessary to either use both hands to squeeze the canteen or to place the canteen on the top of the helmet if one was to obtain a satisfactory flow of water. Either of these methods would probably be untenable in a combat situation since drinking would thus require total concentration, forcing the user to stop performing other tasks, if drinking could be accomplished at all in the cramped environment of a cockpit.

The breathing filters may also present users with difficulties in a humid environment. On two separate occasions, new filter cartridges exposed to a 35°C, 70% RH environment for three hours greatly restricted airflow, though the cartridges were not found to be dirty upon visual inspection and the ventilator operated properly. In both cases, filters were changed to permit the subjects to breath unimpaired. It was determined that the cartridges increased in weight by >35 g, which was believed to be absorbed water. The air passing through the effected cartridges was described as "warm and moist".

Other problems which were experienced in this study included the fit of the mask and the 9V battery in the communication device. Subjects with certain facial shapes (2 of 8 volunteers) were found to have difficulty in getting a good mask fit despite numerous fitting attempts by trained personnel, resulting in considerable leakage occurring around the facial seal. The communication device was found to impose a sufficient electrical load on the battery to require fresh batteries before each trial. This was after only very infrequent use of the communication device over an eight hour period. Battery changes while the system is in use appear impractical due to the design of the intercom, therefore some means of reducing the power drain needs to be examined, particularly since more frequent communications would decrease battery life.

The results of this study indicate that the CBR ensemble imposes a considerable thermal stress on the user, and apparently limits the duration of its use to under three hours on a continuous basis under conditions similar to this study. This could present serious problems in a wartime scenario, when numerous sorties per day would be expected from individuals, requiring the CBR ensemble to be continuously worn for many hours. One possible way of reducing the thermal stress might be imposing lengthy rest periods, much greater than 7 minutes, between activity cycles (12), a situation which was not examined in this study. This would reduce the number of personnel available for missions, but might reduce the number of heat casualties. It is also important to address the equipment weaknesses observed in this study, since these design flaws could create potentially fatal situations in a chemically contaminated environment for individuals using the CBR protective system.

CONCLUSIONS

1) The A/P22P-9(V) ensemble imposes significant heat stress on personnel wearing this ensemble in the hot test conditions. This suggests that operations in hot environments should be limited to relatively short durations, i.e., less than 3 hours, when this ensemble is in use.

2) In a cool environment, the A/P 22P-9(V) ensemble imposes no greater thermal stress than a standard flight suit ensemble.

3) Design changes should be made to correct the problems with the water supply, breathing filters, and intercom which represent potential hazards to users of the A/P22P-9(V) ensemble.

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TABLE 1: Physical characteristics of subjects.

Subject	Age (yrs)	Height (m)	Weight (kg)	%Body Fat	Surface Area (m^2)
A	25	1.65	65.3	15	1.72
B	24	1.68	63.3	14	1.72
D	35	1.76	92.3	20	2.09

TABLE 2. Equipment configurations worn during tests.

Configuration	Protective Garment & ancillary equipment
Standard Flight Ensemble (ALSS)	a. CWU-27/P flight coverall b. cotton long underwear c. flyer's boots d. flyer's gloves, GS/FRP-2 e. CWU-23/P survival vest f. LPU-21C/P flotation device g. HGU-60/P helmet
A/P 22P-9(V) Ensemble	a. All items in standard flight ensemble b. MCK-3/P CBR protective mask c. MK-1 chemical liner d. CQK-2/P CBR protective ventilator e. cotton gloves f. butyl rubber gloves g. polyethylene socks h. canteen, MIL C 43603 i. A/P37S-1 CBR protective intercom

TABLE 3. Mean values of exposure duration, rectal temperature (T_{re}), mean weighted skin temperaure (T_{sk}), and heat storage (S), by configuration, resulting from exposure to experimental conditions. The configurations denoted below are: CBR - A/P 22P-9(V) ensemble; ALSS - standard flight suit ensemble. Values reported are means and standard errors of the mean (SEM).

Configuration		Exposure Duration (minutes)	Tre (°C)		Tsk (°C)		Heart Rate (beats/min)		S (W/m^2)
			i	f	i	f	i	f	
CBR_{hot}	mean	155	37.7	38.7	33.5	36.9	84	131	12.2
	SEM	5.3	0.2	0.2	0.1	0.3	4	7	1.5
$ALSS_{hot}$	mean	219	37.2	38.6	33.0	36.9	80	139	12.5
	SEM	17.9	0.2	0.2	0.3	0.2	2	8	1.2
CBR_{cool}	mean	305	37.2	37.5	32.3	33.8	91	102	2.8
	SEM	41.2	0.2	0.2	0.5	0.2	2	7	1.1
$ALSS_{cool}$	mean	382	37.2	37.4	32.7	33.6	82	99	1.3
	SEM	40.3	0.3	0.3	0.3	0.3	5	10	0.4

TABLE 4. Mean values of initial urine specific gravity, water consumption, total sweat rate (M_{sw}), percentage of sweat evaporated (%E), body weight change, and % of total body weight change, by configuration, obtained during study. The configurations denoted below are: CBR - A/P 22P-9(V) ensemble; ALSS - standard flight suit ensemble. Values reported are means and standard errors of the mean (SEM).

Configuration		Initial Specific Gravity	Water Intake (kg)	M_{sw} ($g/min/kg_{body}$)	%E	Weight Loss (kg)	%Body Wt. Loss
CBR_{hot}	mean	1.024	0.37	3.50	31.2	1.04	1.3
	SEM	0.0008	0.10	0.62	15.3	0.23	0.1
$ALSS_{hot}$	mean	1.024	0.79	3.87	41.0	1.57	2.1
	SEM	0.0011	0.27	0.67	12.5	0.29	0.3
CBR_{cool}	mean	1.026	0.35	1.75	50.7	1.02	1.3
	SEM	0.0015	0.29	0.23	11.4	0.23	0.1
$ALSS_{cool}$	mean	1.027	0.10	1.26	79.0	0.84	1.1
	SEM	0.0011	0.05	0.10	7.9	0.10	0.1

TABLE 5. Mean values of number of correct responses and attempts for the Baddeley reasoning test and vertical addition task, by configuration. The configurations denoted below are: CBR - A/P 22P-9(V) ensemble; ALSS - standard flight suit ensemble. Values reported are means and standard errors of the mean (SEM).

Configuration		Baddeley Reasoning		Vertical Addition	
		correct	attempts	correct	attempts
CBR_{hot}	mean	18	20	14	15
	SEM	1.1	1.0	0.8	0.8
$ALSS_{hot}$	mean	19	20	13	14
	SEM	0.7	1.2	0.5	0.4
CBR_{cool}	mean	21	22	14	15
	SEM	1.1	1.1	0.9	0.7
$ALSS_{cool}$	mean	21	21	14	14
	SEM	0.7	0.8	0.7	0.8

TABLE 6. Mean rates at which subjective criteria changed during exposures. Subjective sensations were evaluated on the basis of 4 categories; fatigue, skin wetness, temperature, and comfort. The rates were obtained from: Rate = $(V_f - V_p)/t$, where V_f = the final reported value for a given category, V_p = the value obtained prior to dressing, and t = the time elapsed when the final value was obtained. The values are measured in millimeters from the left limit of the scale (see text). The configurations denoted below are: CBR - A/P 22P-9(V) ensemble; ALSS - standard flight suit ensemble. Values reported are means and standard errors of the mean (SEM).

Configuration		Rate (mm/minute)			
		Fatigue	Skin Wetness	Temperature	Comfort
CBR_{hot}	mean	0.27	0.39	0.25	0.30
	SEM	0.10	0.09	0.05	0.10
$ALSS_{hot}$	mean	0.37	0.46	0.36	0.37
	SEM	0.09	0.08	0.08	0.10
CBR_{cool}	mean	0.19	0.20	0.13	0.21
	SEM	0.07	0.07	0.04	0.06
$ALSS_{cool}$	mean	0.16	0.23	0.14	0.20
	SEM	0.07	0.03	0.05	0.06

Figure 1. The A/P 22P-9(V) Chemical, Biological, Radiological (CBR) protective ensemble as worn in this study.

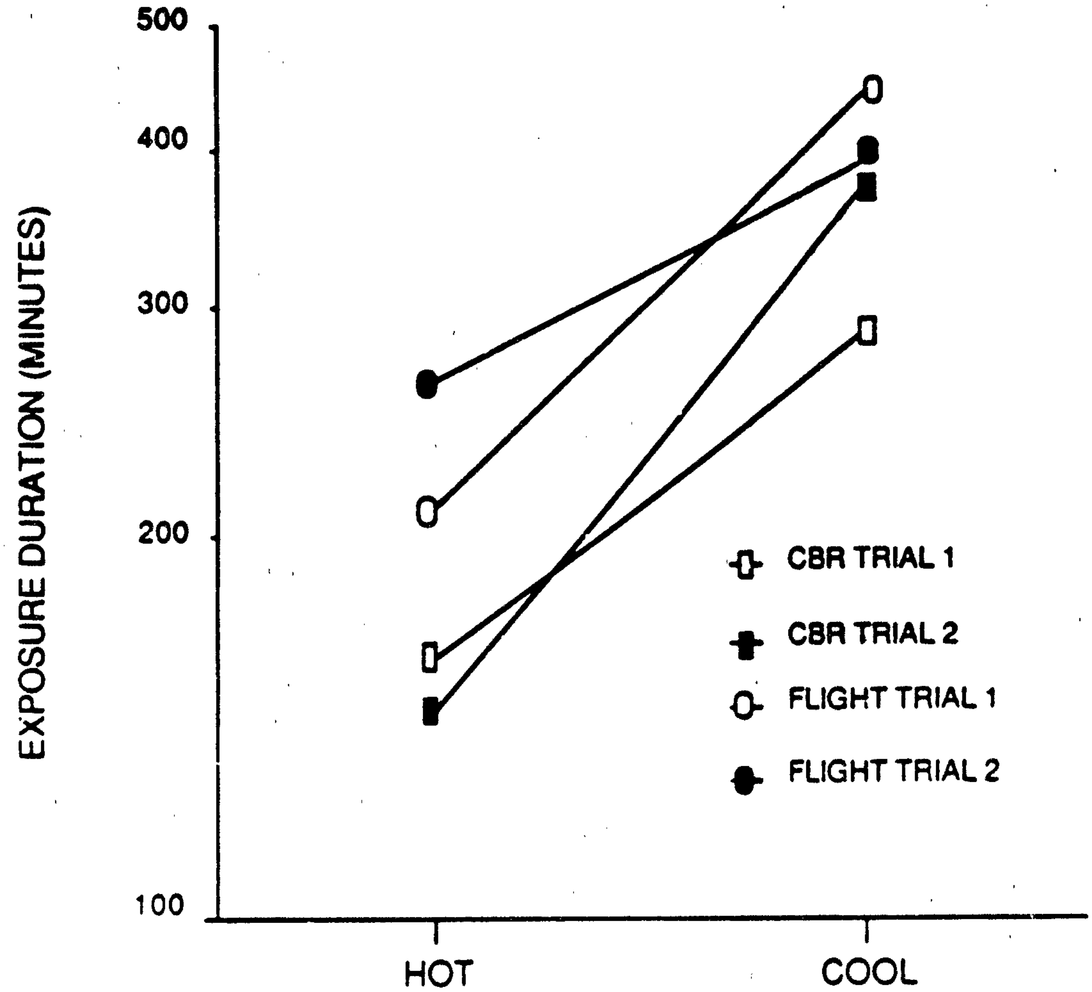

Figure 2. Environment, suit, and trial effects on voluntary exposure durations.

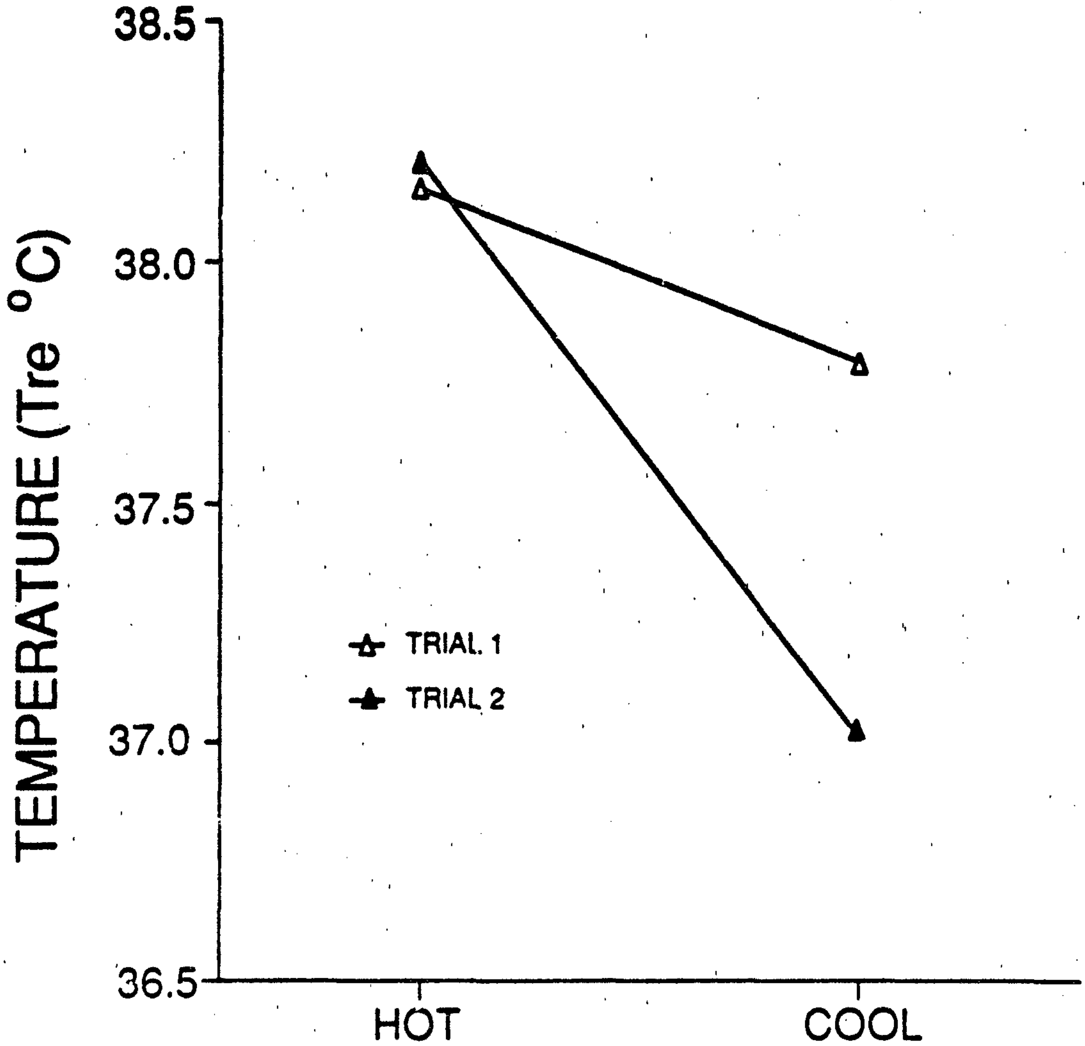

Figure 3. Environment and trial effects on mean rectal temperature (Tre °C).

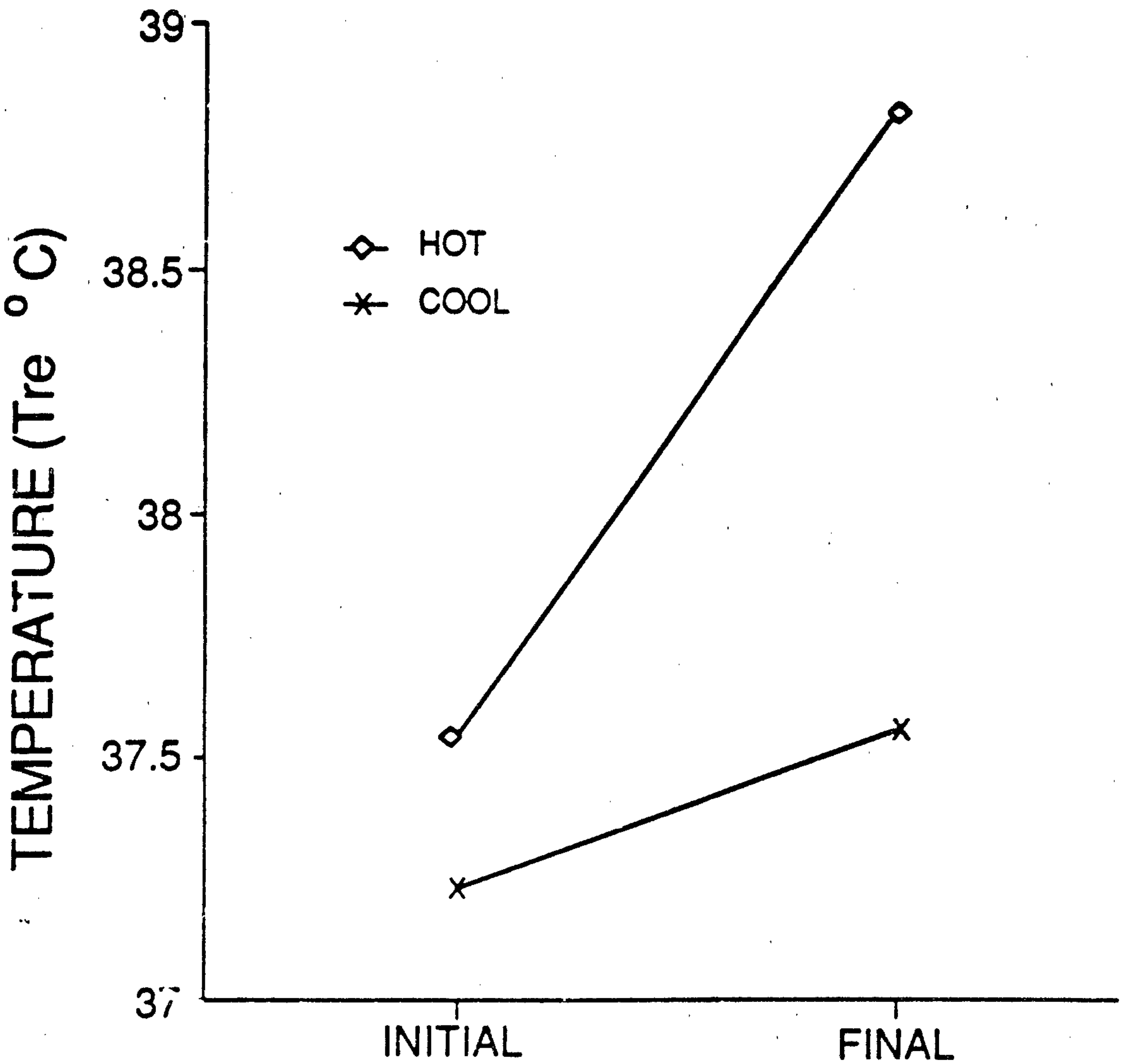

Figure 4. Environmentally induced changes in rectal temperature (Tre °C)

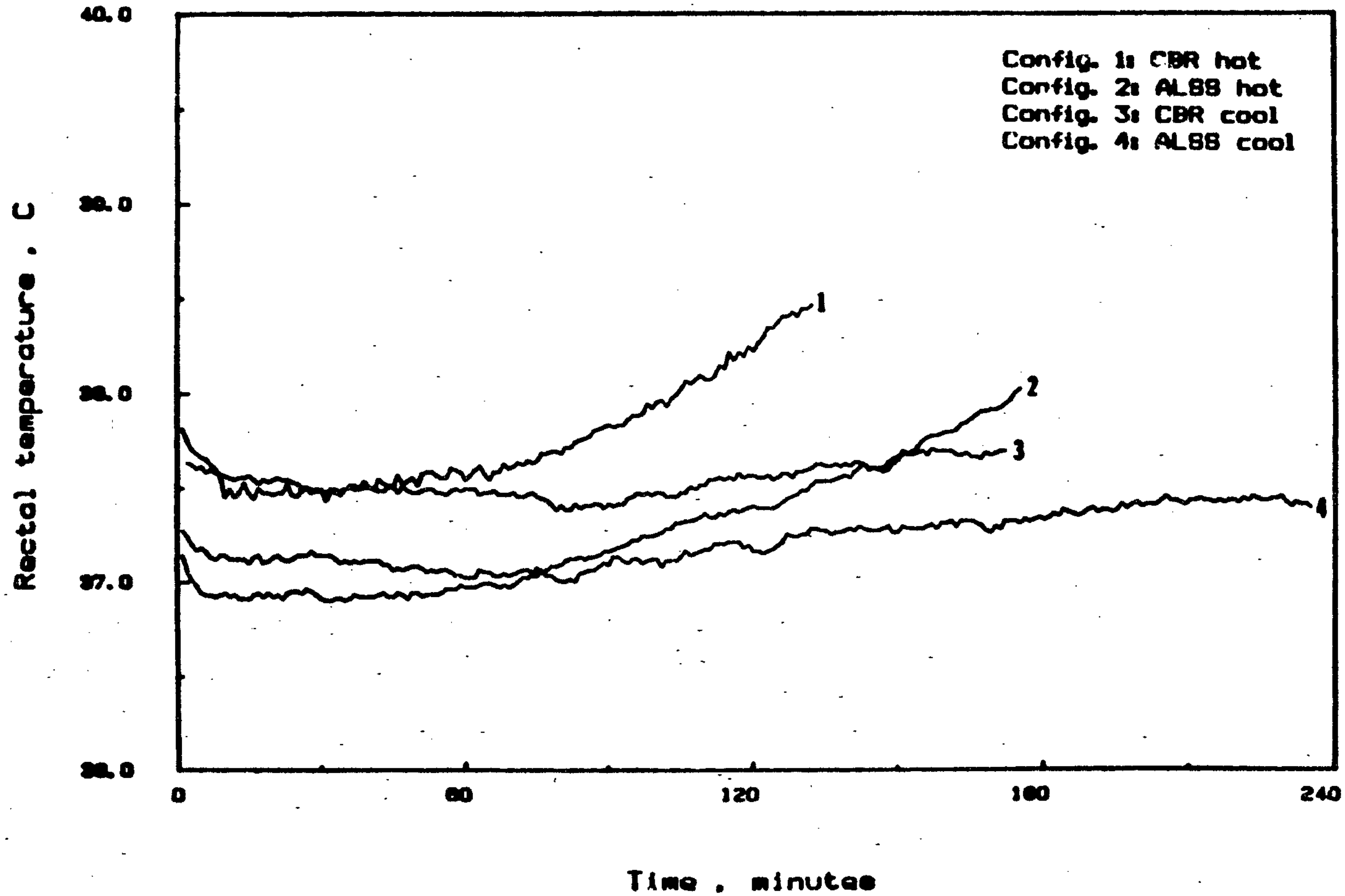

Figure 5. Mean values for rectal temperature versus time for each configuration. (Configuration 1 and 2, n=6, Configurations 3 and 4, n=5).

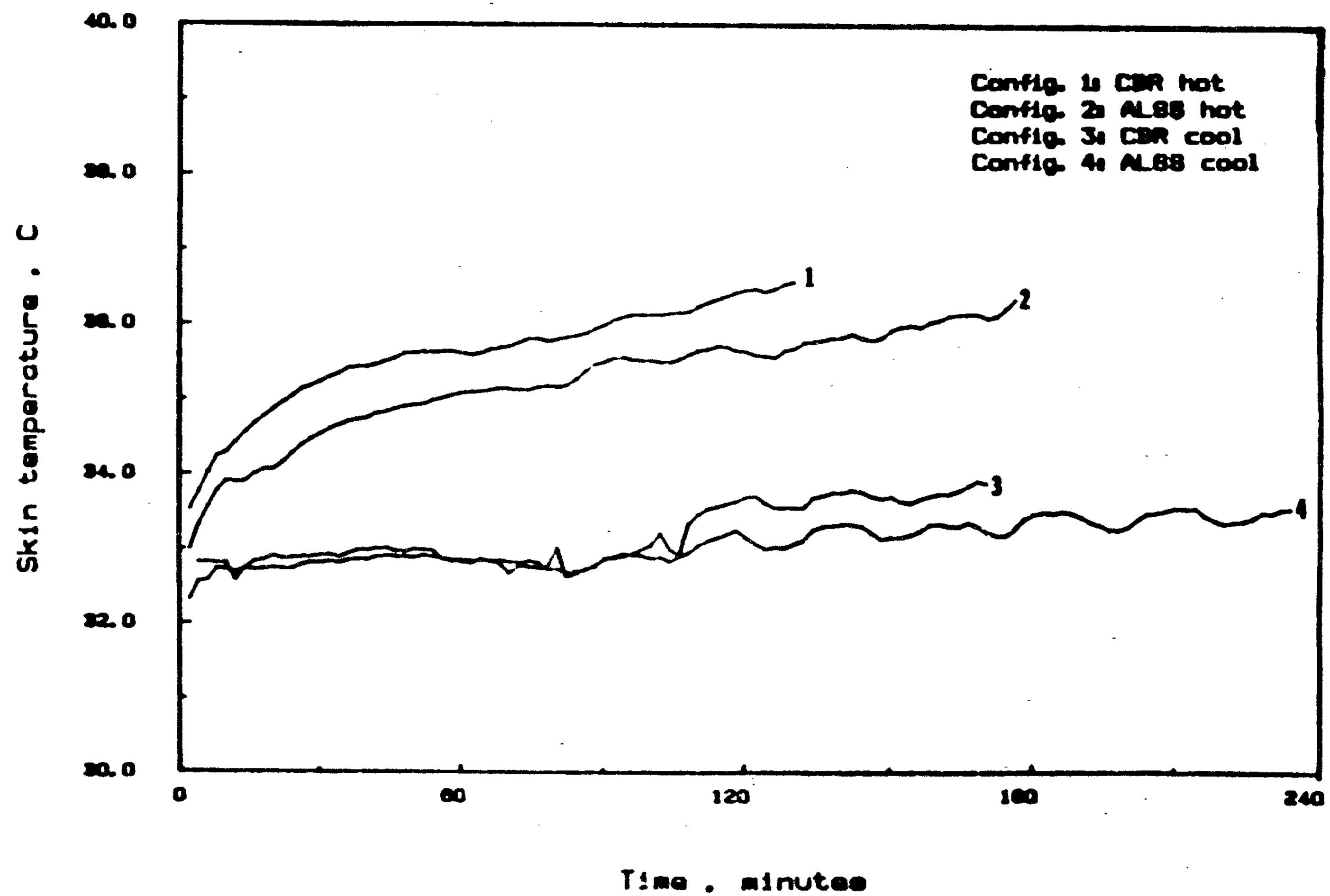

Figure 6. Mean values for mean weighted skin temperature versus time for each configuration. (Configuration 1 and 2, n=6, Configurations 3 and 4, n=5).

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