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Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

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FOR THE COMMANDER

CLYDE R. REPLOGLE, Ph.D.
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Five subjects completed four 80 minute heat exposures [46°C (115°F), 40% relative humidity]; twice wearing the water-cooled helmet liner and twice without for a total of 20 heat exposures. During the thermal exposure, the subjects accomplished psychomotor performance tests taken from the Neptune Battery developed at the School of Aerospace Medicine, Brooks AFB, Texas. Physiological measurements included mean skin, rectal, and body temperatures; mean heart rate, body heat storage; sweat loss; and

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Physiologic Index of Strain. The performance measurements included tracking, mental arithmetic, visual-motor response time, and auditory differentiation tasks. Head cooling significantly reduced the magnitude of all the physiological responses except for elevation of rectal temperature, which is the same for both the noncooled and heat-cooled conditions. The effect of head cooling on psychomotor performance was less impressive. The overall results indicate a lack of performance decrement as a result of the heat loads used here and no differential effect of head cooling on a subject's performance.

PREFACE

This research was conducted in the Aerospace Medical Research Laboratory by personnel of the Environmental Physiology Branch, Environmental Medicine Division, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Abbott T. Kissen, Willi J. Buehring, Major Robert O'Donnell, and Walter C. Summers were the project officers for the Aerospace Medical Research Laboratory. David C. Smedley was the project engineer for the Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton, Ohio.

The tests were conducted in the All Weather Room, a facility of the Environmental Physiology Branch. The authors are indebted to Capt Max Jerrell, Capt William Copeland, and Major Grant D. Callin of the Aerospace Medical Research Laboratory; Capt Gerald Shumaker of the Air Force Flight Dynamics Laboratory; Capt Harvey Dorney of the Aeronautical Systems Division, Air Force Systems Command; and MSgt Vernon F. Brannon of the Air Force Institute of Technology, who served as subjects for these experiments.

The authors are also indebted to Duane Starbuck of the Aerospace Medical Research Laboratory who monitored the Neptune device and assisted in acquiring the performance data and to Janet Regulinski who assisted in the statistical analyses.

The experimental program represents one phase of biothermal protection research. The work was done during the period of March to June 1974.

INTRODUCTION

Recent studies (3,4,6-10) concerning the efficiency of head cooling in attenuating the physiologic strain associated with hyperthermic exposure have stimulated Air Force interest. Hyperthermic stress has long been a problem in virtually all Air Force operational situations, and considerable effort has been expended in the research and development of air-ventilated undergarments for aircrew members.

During the past 10 years, the concept of water cooling has received increased attention with the development and testing of a wide assortment of water-cooled undergarments. An interesting offshoot of this line of investigation has been the identification of the head and neck area as the most efficient body region for heat removal. A recent NASA study (10) was initiated to evaluate a liquid-cooled helmet liner. In view of the heightened Air Force interest in water cooling as a protective measure in hyperthermic exposure, the NASA study was repeated in our Laboratory with the addition of a battery of psychomotor tasks in an attempt to uncover any performance advantage in using a liquid-cooled helmet liner.

MATERIALS

The Water-Cooled Helmet Liner

Eight liquid-cooled neoprene "patches" designed in form-fitting modules by the Acurex Corporation, Mountain View, California, were fastened to the inner surface of a thin, nylon head covering resembling a toque in configuration. Each patch incorporates a series of parallel, thin-walled, closely-spaced flow channels that are supplied and drained by two manifolds. The patches are connected in a parallel flow network that begins with the inlet at the neck and bilaterally distributes the flow up to the crown of the head and back to the outlet at the neck. The flow channels are about 2 mm wide while the space between channels is about 4 mm. The total surface area of the patches is about 900 cm^2; therefore, the surface area of that portion of the patches carrying water coolant is about half or 450 cm^2. The body areas in contact with the modules included the back and crown of the head (extending anteriorly to just below the hair line and laterally over the temples but excluding the ears), the jaw angles, and upper part of the neck. The liner was worn under a standard Air Force helmet. Coolant was delivered to the system through insulated tubing from a constant temperature water bath located outside the heat chamber. Inlet and outlet water temperatures were continuously recorded, the former being maintained at 18°C (65°F) ± 1°C. The coolant flow rate was held constant at 1 L/min.

Physiological Measurements

Skin temperatures were obtained from 17 disc thermistors in contact with the body surface. The rectal temperature was obtained from a thermistor probe inserted 10 cm into the rectum. These 18 thermistors and their cables constitute a "harness" which is associated with a one piece suit of cotton underwear having long sleeves and long legs. Inputs from these thermistors were delivered as analog signals to a "Temperature Computer" which scanned and digitized the signals at the rate of one per second and printed all the inputs plus the computed mean weighted skin temperature and the weighted body temperature (0.33 mean skin + 0.67 rectal). ECG electrodes were attached to the sternal area. ECG signals were delivered, in series, to a Sanborn 500 Viso Cardiette (for wave form study), a Waters C-225M Cardiotachometer, and finally a Honeywell Electronik 19 for continuous beat-to-beat heart rate recording.

Performance Measurements

The performance tests used were all taken from the Neptune Battery developed at the School of Aerospace Medicine, Brooks Air Force Base, Texas (5). Four subtasks of this battery were presented to the subject, either alone or in combination. This sequence occupied 16 minutes of testing time, and the experimental exposures were divided into 20 minute blocks so that there was a 4 minute rest for each block. Since the total period of exposure was 80 minutes, the sequence was reproduced four times during a given exposure.

The sequence of task presentations is shown in Table I, along with relevant parameters. The first subtask of the Neptune Battery presented to the subject was the tracking ("Satellite Tracking") task. In this,

TABLE I

SEQUENCE OF NEPTUNE TASKS

TIME	TASK	PARAMETERS
0:00 to 3:30	Rest	
3:31 to 4:41	Tracking Plus Auditory Codes	1 Min; 30 Codes
4:41 to 6:12	Mental Arithmetic Plus Monitoring	6 Problems
6:12 to 7:24	Tracking Plus Auditory Codes	1 Min; 30 Codes
7:24 to 8:26	Mental Arithmetic	10 Problems
8:26 to 9:39	Tracking Plus Auditory Codes	1 Min; 30 Codes
9:39 to 11:11	Mental Arithmetic Plus Monitoring	6 Problems
11:11 to 12:22	Tracking Plus Auditory Codes	1 Min; 30 Codes
12:22 to 13:26	Mental Arithmetic	6 Problems
13:26 to 14:37	Tracking Plus Auditory Codes	1 Min; 30 Codes
14:37 to 15:13	Mental Arithmetic Plus Monitoring	6 Problems
16:13 to 17:48	Tracking Plus Auditory Codes	1 Min; 30 Codes
17:48 to 18:51	Mental Arithmetic	6 Problems
18:51 to 20:00	Tracking Plus Auditory Codes	1 Min; 30 Codes
20:00 to 40:00	Repeat Above Sequence	
40:00 to 60:00	Repeat Above Sequence	
60:00 to 80:00	Repeat Above Sequence	

the subject was required to keep a needle dial centered at zero by manipulating a control knob. The needle was offset by an 0.1 Hz sine wave forcing function having a mechanical lag in the system which made it fairly difficult to achieve perfect tracking. A trial on this task lasts 1 minute; and in the present series, 7 trials were given in each testing cycle. Error is calculated by computing the number of seconds the subject is not within $\pm$ 5.5 mm from the zero point on the needle dial.

Another Neptune subtask used was the mental arithmetic ("Solar Radiation") test. The subject's task consisted of processing four digits presented on Nixie tubes and involves a complex series of mathematical and memory functions including several additions, multiplications, and decisions concerning whether results were odd or even. In the present case, a chain of either six or ten problems was presented, and the mean time to solution was determined for the ten trial block.

A third subtask from the Neptune Battery consisted of monitoring three needle dials for the occurrence of a deflection ("Meteorite Monitoring"). The dials were programmed to deflect in a random manner with an interdeflection time averaging 6 seconds (range of 1 to 10 seconds). When the subject noticed a deflection of one of the needle dials, he had to press a correct button which was keyed to both the dial deflected and the direction of deflection. Scoring of this task was in terms of the number of seconds between initiation of the deflection and the subject's correction. The percentage of deflections which were noted and corrected by the subject was also tabulated. In the present case, 48 deflections were given per trial.

The final Neptune subtask used was the "Auditory Code" task. In this, Morse Code letters (N, M, or A) were delivered at a rate of about one letter per 2 seconds, and the subject was simply to report which code was given. This task was used only to load the subject's reserve capacity and was not independently scored.

Subjects were given 1.3 hours of training on these tasks in order to assure plateau performance prior to the test runs. After training, a full 20 minute sequence was obtained from each subject in the chamber under ambient conditions. This constituted the "baseline" data used in later analyses.

PROCEDURES

A panel of five subjects, whose physical characteristics are given in Table II, was selected. Each of the subjects completed four 80 minute heat exposures [46°C (115°F), 40% relative humidity]; twice wearing the water-cooled helmet liner and twice without for a total of 20 heat exposures.

Pre-exposure procedures for each subject included obtaining a nude weight; application of ECG electrodes to the sternal area; and donning the thermistor underwear, a Nomex flight coverall, socks and boots, and helmet (with water-cooled liner when appropriate). The subject was then conducted into the thermal chamber and seated in a padded office-type chair before the Neptune device. Connections were established between the thermistor and ECG cables and he remote monitoring instruments. If the test called for head cooling, the insulated inlet and outlet water-conducting tubes were connected to the helmet liner, but coolant flow was not initiated immediately. The helmet headset was connected to the Neptune board for monitoring audio signals. Preparation of the subject within the chamber was always completed well before 3.5 minutes of elapsed time which was when the first psychomotor test series was begun. For those experiments which called for head cooling, the coolant flow was initiated after 20 minutes of hyperthermic exposure (at the conclusion of the first series of psychomotor tasks).

Heart rate data was obtained continuously with 10 minute data points selected for graphing purposes. The skin and rectal temperature parameters were scanned at 5 minute intervals with 10 minute data points selected for graphing purposes.

Body heat storage (Q_S) is derived from the formula

$$Q_S = (WC/A) \cdot \Delta T_b$$

where W = nude body weight (kg); C = specific heat of body mass (0.83 Kcal/kg-°C); ΔT_b = change in mean body temperature for a given unit of time; and A = body surface area (m^2).

Craig (1) introduced a relatively simple though empirical strain index which he utilized in studies of working subjects. Heart rate,

TABLE II

PHYSICAL CHARACTERISTICS OF SUBJECTS

SUBJECT NUMBER	MEAN HT (cm)	MEAN WT (kg)	AGE (Yrs)	MEAN SURFACE AREA (m^2) *
1	171.8	78.08	33	1.91
2	184.0	88.66	37	2.12
3	172.0	79.59	34	1.94
4	177.0	65.03	29	1.80
5	168.4	77.51	32	1.88
MEAN	174.6	77.77	33	1.93

*Mean surface area derived from nomogram in Documenta Geigy, copyrighted by J. R. Geigy, S.A., Basle, Switzerland, 1970.

changes in rectal temperature, and sweat rate are combined to give a single value: the Index of Physiological Strain. A slight modification of the Craig Index is routinely used in this Laboratory and has been shown to have great utility in describing the level of physiological stress induced by hyperthermic environments (2). The equation for calculating Physiological Index of Strain (I_s) is as follows:

$$I_s = \frac{HR}{100} + \Delta T_r + \Delta W_n$$

HR = the terminal heart rate

ΔT_r = the rise in rectal temperature (C/hr)

ΔW_n = the sweat production (nude weight loss, kg/hr)

At the end of each run, the subject was asked for a subjective evaluation of the thermal stress.

Statistical Treatment of Data

The NASA study (10) included three different exposure combinations, each lasting 80 minutes. Two of the conditions consisted of the control (no cooling) and head cooling for the full 80 minutes of exposure. In the remaining condition, head cooling was initiated after the completion of the first 20 minutes of exposure. This initial 20 minute "control" period was employed to study the effects of cooling a subject already exposed to a hot environment. Of the two head-cooling conditions, the latter places the greatest demand on the potential of the cooling system and for that reason was the condition repeated in the present study.

The data were, therefore, considered with respect to only the last seven time epochs, each of 10 minute duration. Data obtained after 20 minutes of heat exposure (just prior to the initiation of cooling) were treated as the "control" readings. This posed a problem in describing the effect of head cooling, per se, on sweat production since continuous, in-chamber weight loss readings were not obtained. Sweat production (body weight loss) was plotted as a linear unction, beginning at t = +5 minutes (when active sweating began) and terminating at t = +80 minutes (the conclusion of the thermal exposure) and at a value representing the difference between the pre- and post-experiment nude weights. The intersection of this line with the t = +20 minute time mark determined sweat loss in grams prior to the collection of experiment data and the difference between this value and the sweat loss shown at t = +80 minutes represents weight loss during the experimental period (Figure 6). The "baseline" nude weight, used in the calculation of body heat storage, was established by subtracting the weight loss value of the linear function at t = +20 minutes from the pre-experiment nude weight. Sweat loss calculated to occur prior to t +20 was assumed to be the same for both the cooled and uncooled runs.

A complete factorial, three-factor, two-replicate Analysis of Variance was performed on the readings. Factors in the Analysis of Variance were Subjects (5 levels), Cooling (2 levels), and Time (7 levels). A two-factor, two-replicate (time was not a factor) Analysis of Variance was performed on the sweat-produced data as well. For these analyses, attention was focused on the possible effect of cooling on each of the monitored variables.

In addition, calculation was made for each monitored variable and change of that variable (averaged over subjects and replicates) with respect to a start time of t = +20 minutes.

Data from the psychomotor performance tests were treated as follows. The scores for each trial within a given block of data for each subtask of the Neptune were averaged to yield a single score per subject per block. For example, the ten mental arithmetic scores obtained during each presentation of this subtask were combined for the three presentations given during a 16 minute testing cycle. From these data, eight sets of specific data points were analyzed. These consisted of: (1) tracking mean during simultaneous presentation of the auditory codes, (2) tracking standard deviation during auditory codes, (3) mental arithmetic mean when this task was presented alone or (4) when it was presented with the monitoring task, (5) mental arithmetic standard deviation alone or (6) with monitoring, (7) monitoring time to correction during mental arithmetic, and (8) percent cetected correctly.

At this point, two procedures were used to statistically analyze the data. One procedure was to (a) drop all data for the first 20 minute time segment and analyze data from the three remaining periods with a four-factor, single-replicate, full factorial Analysis of Variance. Here the main effects were Subjects (5 levels), Cooling (2 levels), Time Epochs (3 levels), and Run Number (2 levels); (b) submit data from all four time epochs (but for the noncooled condition only) to an Analysis of Variance; and (c) submit data from all time epochs (but for the cooled condition only) to the same Analysis of Variance as in (b) above which called for a three-factor, single-replicate design.

In view of the considerable variability in subject performance scores, a second analysis procedure was initiated in an attempt to improve resolution of the psychomotor responses.

The averaged score for each subject during each 16 minute testing period was subtracted from that subject's baseline in order to reduce the variability due to individual differences in skill. The subtraction from baselines was carried out in such a way that positive values indicated better performance. These difference values for the tasks performed during cooling were then subtracted from the scores obtained during the "no cooling" conditions, and the sign of the result was adjusted so that positive values always indicated better performance under no cooling. The original differences from baseline, as well as these compound difference values, were then entered into two separate Analyses of Variance (one-way, repeated measures) in order to determine whether there were performance differences over time under either condition and also as differentially affected by head cooling or no cooling. From a theoretical point of view, this analysis has the advantage of compensating for day-to-day fluctuations within a subject, differences in baseline performance between subjects, and also for the fact that all subjects received a "no cooling" condition for the first 20 minutes of all exposures.

RESULTS

The subjects completed all exposures and unanimously reported that the tests involving head cooling were less stressful.

Table III presents the terminal mean values for physiological temperatures (skin, rectal, and body), body heat storage, heart rate, and

TABLE III

TERMINAL AND Δ MEAN VALUES FOR PHYSIOLOGIC TEMPERATURES,
BODY HEAT STORAGE, HEART RATE, SWEAT LOSS,
AND INDEX OF STRAIN (WITH AND WITHOUT HEAD COOLING)

		NONCOOLING	COOLING	P-VALUE
Rectal Temperatures	Terminal	37.94	37.62	
(C)	Δ Mean	0.79	0.50	N.S.
Skin Temperatures	Terminal	37.87	37.41	
(C)	Δ Mean	0.46	0.10	<.01
Body Temperatures	Terminal	37.90	37.49	
(C)	Δ Mean	0.68	0.35	<.05
Heart Rate	Terminal	118	100	
b/min	Δ Mean	28	16	<.05
Heat Storage ($Kcal/m^2$ hr)		23	12	<.01
Sweat Loss (g/m^2)		273	234	<.05
Index of Strain		2.13	1.58	<.01

sweat produced for the cooling and noncooling conditions. This table also presents as the Δ mean, the extent to which the terminal values of some of the parameters differed from their respective control values established at t = +20 minutes.

Mean skin temperatures were not significantly different at the end of the control period (t +20). As an experiment progressed, the uncooled subjects experienced an elevation of mean skin temperature to a terminal value of 37.9°C, approximately 0.4°C above the mean skin temperature of the cooled subjects (Figure 1). The difference is significant ($p < .01$).

Rectal temperatures of the uncooled and cooled subjects rose to values of 37.9°C and 37.6°C, respectively (Figure 2). The difference was not significant.

Mean body temperature and body heat storage values (Figures 3 and 4) are derived by calculation and are functions of the mean skin and rectal temperatures. The Δ mean body temperature of 0.7°C for the uncooled condition is nearly twice that for the cooled condition (0.4°C). The difference is significant ($p < .05$).

At t = +20 minutes (the beginning of the experimental period), subjects were storing heat at the rate of 57 Kcal/m^2. For those subjects who remained uncooled for the rest of the exposure period, the heat storage rate increased an additional 23 Kcal/m^2. Under the condition of head cooling, the heat storage rate was reduced to 12 Kcal/m^2. The difference is significant at the $p < .01$ level.

In the absence of head cooling, the mean terminal heart rate (Figure 5) was 118 beats/min or 28 beats/min above control values. With cooling, heart rates rose to 100 beats/min or only 16 beats/min above control values. The reduction of heart rate with head cooling is significant ($p < .05$).

Figure 6 illustrates the effect of head cooling on total sweat production and the Physiologic Index of Strain. Total sweat production, with (or without) head cooling, amounted to 234 grams/m^2 (or 273 grams/m^2), respectively. Using sweat production in the uncooled condition as reference, the data indicate a significant ($p < .05$)

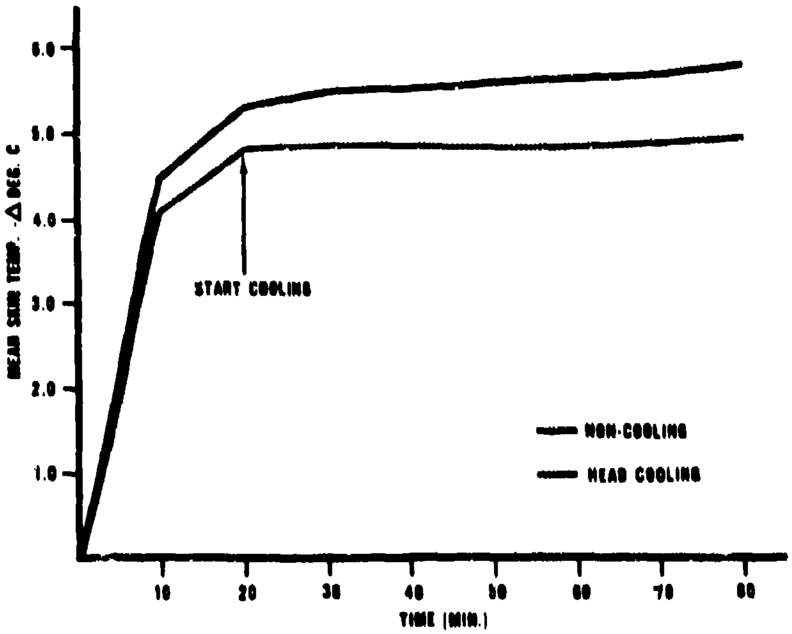

Figure 1. Changes in Mean Skin Temperature
With and Without Head Cooling

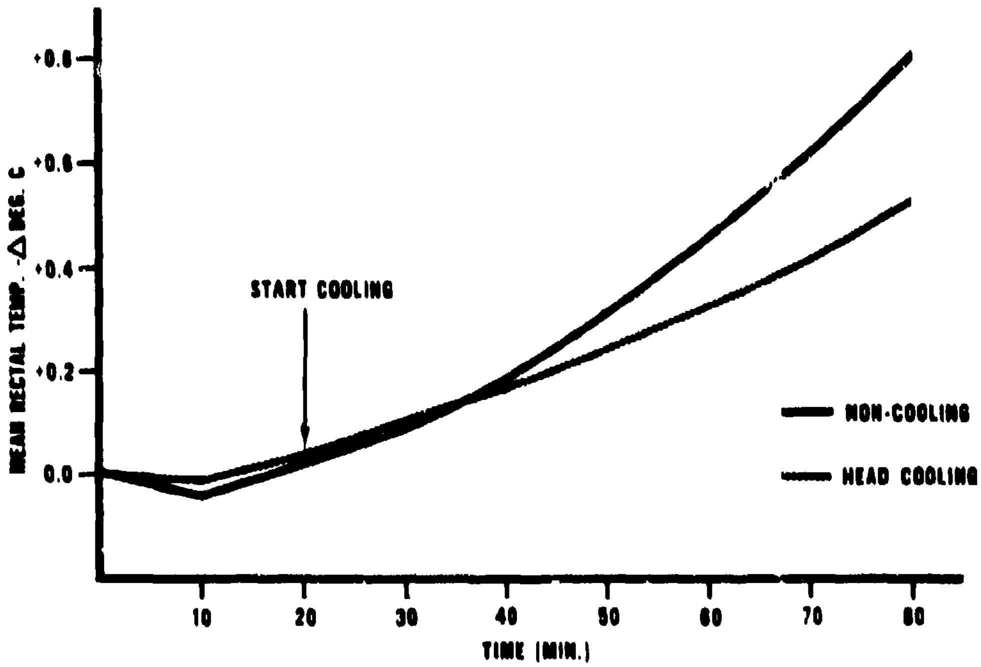

Figure 2. Changes in Mean Rectal Temperature
With and Without Head Cooling

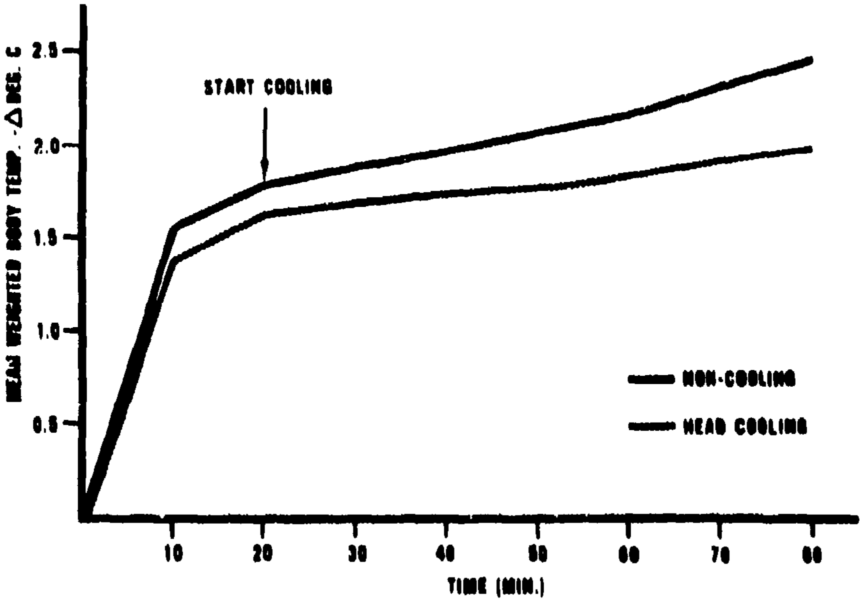

Figure 3. Changes in Mean Body Temperature With and Without Head Cooling

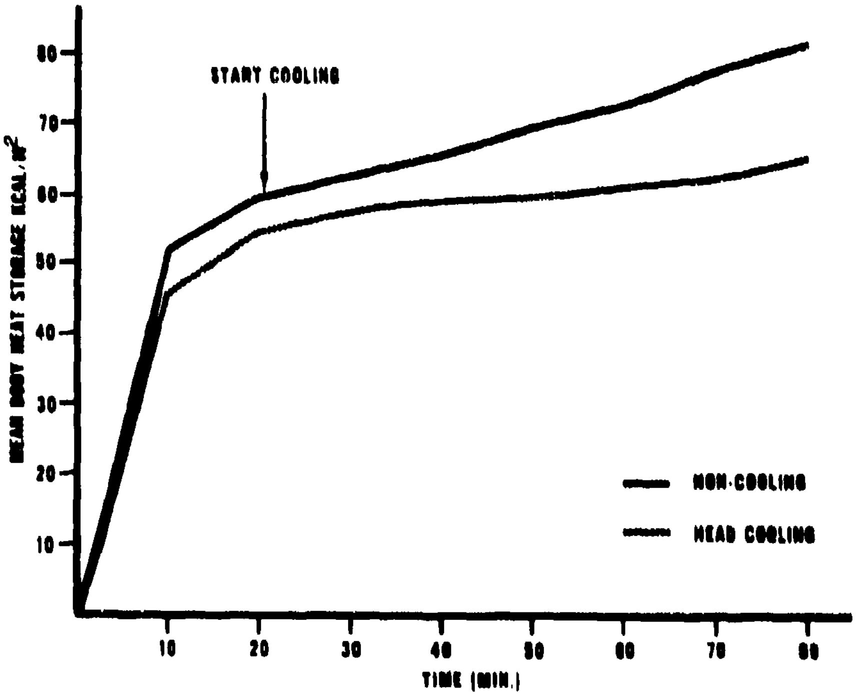

Figure 4. Mean Body Heat Storage With and Without Head Cooling

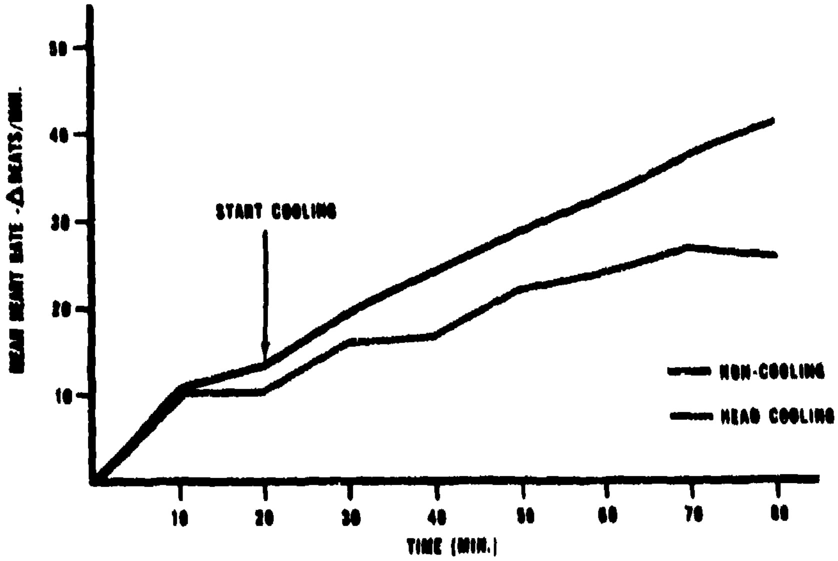

Figure 5. Changes in Mean Heart Rate With and Without Head Cooling

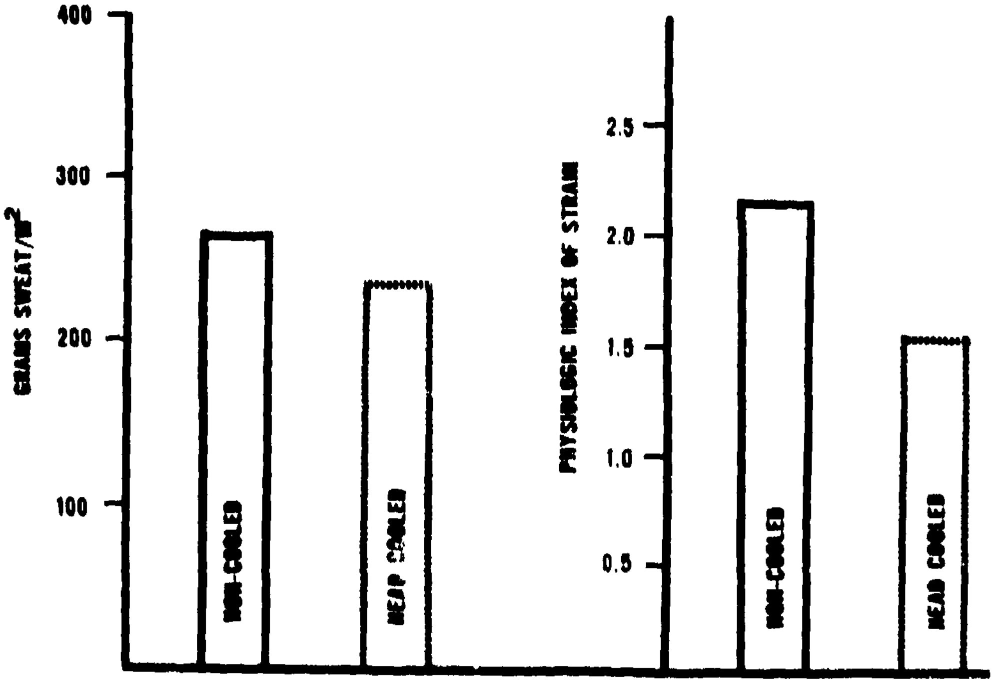

Figure 6. Mean Weight Loss and Physiologic Index of Strain With and Without Head Cooling

reduction in total sweat production. Similarly, head cooling significantly ($p < .01$) reduced the level of physiologic strain from a value of 2.13 to 1.58.

The analysis based on psychomotor data is summarized in Table IV where the average score for each subtask over the five subjects is presented for each 20 minute block of time during each exposure. These values represent the difference in the subject's performance during baseline trials as compared to trials during heat exposure. In all cases, negative values indicate poorer performance (or more variability) during the heat exposure as compared to baseline conditions. Analyses of Variance performed for each condition over time separately failed to reveal any significant changes in performance. Thus, there was no reliable decrement in performance under either the "no cooling" or "head cooling" conditions as a function of the 80 minute heat exposure.

A more meaningful comparison in terms of probing for effects of head cooling is obtained by directly comparing performance under cooling with performance for comparable periods under no cooling. To do this, the difference scores used to obtain the values above were subtracted from each other and the sign adjusted in such a way that positive values indicated better performance under the "head cooling" condition for a given amount of heat exposure. The results of this analysis are presented in Table V, along with the F ratios obtained from the Analyses of Variance on these data.

It can be seen from the table that the only subtask on the Neptune Battery which showed any statistically significant variation in performance as a function of head cooling over time was the tracking task and specifically, the time-off-target error score of the tracking task. Surprisingly, the significance of this result is in the direction of better performance without cooling as compared to performance with cooling. Inspection of the data from Table IV reveals that this significant result arises because performance in the "no cooling" condition began at a poor level and improved over time, while under cooling the opposite effect was seen. Inspection of individual records indicated that this trend appeared to some degree in four of the five subjects

TABLE IV

MEAN DIFFERENCES FROM BASELINE PERFORMANCE DURING HEAT EXPOSURE

WITH AND WITHOUT HEAD COOLING

NEGATIVE VALUES INDICATE POORER PERFORMANCE	TIME OF EXPOSURE 20 MIN NO COOLING	20 MIN NO COOLING	40 MIN NO COOLING	40 MIN HEAD COOLING	60 MIN NO COOLING	60 MIN HEAD COOLING	80 MIN NO COOLING	80 MIN HEAD COOLING
Tracking Mean Time Off Target	-7.97	-.59	-6.04	-2.54	-2.20	-10.43	-5.40	-9.98
Mental Arithmetic Mean (During Monitoring)	4.34	4.85	.88	5.57	7.29	6.64	6.57	6.87
Mental Arithmetic Mean (Alone)	4.28	3.74	1.92	1.93	5.31	2.68	9.14	7.05
Monitoring (Cum. Time to Detect, Sec.)	12.64	16.84	13.96	20.98	21.54	21.88	19.48	19.06
Monitoring (Percent Detected)	3.40	5.20	4.60	6.50	5.50	5.40	8.10	7.30
Mental Arithmetic S.D. (Alone)	1.36	.59	-1.04	.10	2.23	.52	4.16	3.64
Mental Arithmetic S.D. (During Monitoring)	3.92	3.19	1.44	2.43	4.55	5.74	6.91	5.69
Tracking S.D.	-1.76	.11	-1.42	.92	2.89	-1.09	1.29	-2.47

TABLE V

DIFFERENCES IN MEAN PERFORMANCE DURING HEAT EXPOSURE WITH AND WITHOUT HEAD COOLING

SIGN ADJUSTED TO MAKE POSITIVE VALUES INDICATE BETTER PERFORMANCE UNDER COOLING MEASURE	20 MIN	40 MIN	60 MIN	80 MIN	F
Tracking Mean	+7.39	+3.51	-8.23	-4.57	5.49*
Mental Arithmetic Mean (During Monitoring)	+ .50	+4.69	- .65	+ .30	.59
Mental Arithmetic Mean (Alone)	- .55	+ .01	-2.63	-2.09	.31
Monitoring (Time to Detect)	+4.20	+7.02	+ .34	- .40	.44
Monitoring (Percent Detected)	+1.80	+1.90	- .10	- .80	1.06
Mental Arithmetic S.D. (Alone)	- .77	+1.14	-1.71	- .51	.34
Mental Arithmetic S.D. (With Monitoring)	- .73	+ .99	+1.18	-1.22	.32
Tracking S.D.	+1.87	+1.90	-3.99	-3.75	1.25

*Sig. .05

but was especially strong in one subject who accounted for a great deal of the mean effects.

None of the other tasks used in this study showed any statistically significant changes in performance in either direction. The changes which did occur were rather erratic; and if any trend at all is apparent, it is a very weak tendency for performance in all tasks to be slightly better under the no cooling condition as time of exposure increases (e.g., in 7 of the 8 measures at the 80 minute point). However, this is an extremely tenuous observation and can be used to indicate nothing more than a lack of obvious decrements in performance as a result of the lack of head cooling.

DISCUSSION

The findings of this study sustain those reported by all other workers in the area of head cooling and, in particular, those reported by Williams (10). There are, however, some discrepancies between our study and that of Williams in the matter of magnitude of heat loss. This could very well be a function of differences in the physical characteristics of the thermal chamber, insulation value of the subject's clothing, or the amount of physical activity involved in the psychomotor task.

For this study, we chose to pattern our procedure after one of the two experimental conditions employed by Williams; namely, 20 minutes of heat loading prior to the initiation of head cooling. We can, therefore, compare results only on that basis, excluding reference to Williams's third experimental condition of continuous (80 minutes) of head cooling. The "control" was regarded as the set of data points collected after 20 minutes of heat exposure but just prior to the initiation of head cooling. The intent of this procedure was to enhance differences between the cooling and noncooling conditions.

A comparison of average percent reductions in sweat production (body weight loss), rectal temperature rise, final heart rate, heart rate increase, body heat storage, and Physiological Index of Strain is given in Table VI.

TABLE VI

COMPARISON OF AVERAGE PERCENT REDUCTIONS IN VARIOUS PHYSIOLOGICAL PARAMETERS RESULTING FROM USE OF THE COOLING HOOD (KISSEN AND WILLIAMS STUDIES)

CONDITIONS COMPARED	WILLIAMS	KISSEN
Body Weight Loss (Sweat Production)	35	14
Rectal Temperature Rise	47	36
Final Heart Rate	20	15
Heart Rate Increase (Δ HR)	48	43
Body Heat Storage	53	48
Physiological Strain Index	34	25

We are in agreement with the Williams study (within 10%) with respect to the magnitude of reduction in heart rate activity, body heat storage, and Physiologic Index of Strain. We differ markedly with respect to the parameters of sweat production and rectal temperature rise.

There can be little doubt that water cooling the head and neck significantly reduces the impact of a hyperthermic environment, at least in terms of physiological responses. In these studies, the effect of head cooling was, to some extent, blunted by two factors. One was the delay of 20 minutes (under heat exposure conditions) before the cooling was initiated. By this time the subject has stored a considerable amount of heat and the role of head cooling becomes more of a therapeutic one rather than prophylactic. The other factor is the level of environmental stress. The temperature and humidity levels used in these studies are moderately stressful but still well below those which would drive men to tolerance for this exposure duration. The less severe the thermal stress, the less demonstrable is the strain-ameliorative potential of head cooling.

The effect of head cooling on the psychomotor tasks employed here are less impressive. The overall results indicate a lack of performance decrement as a result of the heat loads used here, and no differential effect of head cooling on subject's performance. Subjectively, this is in line with comments made by the subjects after exposure which indicated they did not believe that the heat loads used here severely affected performance. The one statistically significant result with respect to psychomotor performance indicated that tracking <u>without</u> head cooling was somewhat better than tracking during head cooling. It must be remembered that this result is fairly tenuous in view of the number of analyses performed, the initial differences seen in the first 20 minutes of exposure, and the fact that the trend was especially strong in only one subject. In spite of this, however, it does appear that, for these exposures at least, tracking was reliably worse during head cooling than with no cooling. This is further confirmed by the data on variability in tracking performance. The standard deviations of the tracking scores were larger during the later periods of exposure with cooling and generally paralleled the changes in mean time-off-target scores. It would thus appear that this form of psychomotor control was affected more adversely by the combined conditions of heat and head cooling than by heat alone. The reasons for such an effect are not immediately clear but may be related to the overall "activation level" of the subjects with cooling producing a somewhat reduced activation which did not lead to optimal performance. In any case, neither condition led to a reliable absolute decrement in tracking performance over time, and only in comparison to each other were the changes in tracking statistically significant.

REFERENCES

1. Craig, F. N., "Ventilation Requirements of an Impermeable Protection Suit," Medical Division Research Report No. 5, Chemical Corps, Army Chemical Center, April 1950.
2. Hall, J. F., Jr. and J. W. Polte, "Physiological Index of Strain and Body Heat Storage in Hyperthermia," J. Appl. Physiol. 15:1027, 1960.
3. Kissen, A. T., J. F. Hall, Jr., and F. K. Klemm, "Physiological Responses to Cooling the Heat and Neck Versus the Trunk and Leg Areas in Severe Hyperthermic Exposure," Aerospace Med. 42:882-888, 1971.
4. Konz, S. and J. Duncan, "Cooling with a Water-Cooled Hood," Proc. Symposium on Individual Cooling, Kansas State University, pp 138-169, 1969.
5. McKenzie, R. E., D. D. White, and B. O. Hartman, "Neptune, a Multi-element Task for Evaluating Human Performance," U.S. Air Force School of Aerospace Medicine, SAM-TR-69-25, 1969.
6. Nunneley, S. A., S. J. Troutman, Jr., and P. Webb, "Head Cooling in Work and Heat Stress," Aerospace Med. 42:64-68, 1971.
7. Shiratori, T. K. Sasaki, K. Sugawara, T. Iwamatsu, and S. Kuroda, "The Prophylactic Effect of Head-Cooling on Coal Miner's Cramp," J. of School of Medicine, Tohaku University, 66:258-271 and 289-293, 1963. (Original in Japanese)
8. Shvartz, E., "Effect of a Cooling Hood on Physiological Responses to Work in a Hot Environment," J. Appl. Physiol. 29:36-39, 1970.
9. Shvartz, E., M. Aldjem, J. Ben-Mordechai, and Y. Shapiro, "Objective Approach to a Design of a Whole-Body, Water-Cooled Suit," Aerospace Med. 45:711-715, 1974.
10. Williams, B. A. and A. Shitzer, "Modular, Liquid-Cooled Helmet Liner for Thermal Comfort," Aerospace Med. 45:1030-1036, 1974.

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