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G. R. Banta
D. E. Braun

Report No. 90-30

NAVAL HEALTH RESEARCH CENTER
P.O. BOX 85122
SAN DIEGO, CALIFORNIA 92186-5122

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
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Guy R. Banta, Ph.D.
Daniel E. Braun, B.A.

Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

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SUMMARY

Twelve Navy H-3 helicopter aircrew were monitored (heart rate, skin/rectal temperatures) in both microclimate cooling (ice) vest and nonvest conditions during at-sea operations in the high heat environment of the Persian Gulf. During all flights and flight phases, ambient dry bulb temperatures ranged from 31.0°C (in-flight) to 48.6°C (hover). Heart rate was greatest during hover and on-deck (range: 89.9 to 145.0 beats per minute) without an ice vest, yet, was significantly reduced with ice (range: 79.7 to 86.0 beats per minute) ($P < 0.05$). Rectal temperature was not found to be different between vest/nonvest conditions; however, change across flight phases in both conditions was significant ($P < 0.05$). Analysis of variance demonstrated significant differences between vest/nonvest conditions in mean weighted skin temperatures ($P < 0.05$). When wearing the ice vest, mean weighted skin temperature was lower, and peripheral skin sites of the extremities demonstrated an upward trend.

Aircrews performing at-sea helicopter operations in the high ambient heat of the Persian Gulf are subject to heat loads that may produce heat stress conditions that can result in marked cardiac and thermal strain. Wearing a protective cooling vest appears to reduce this effect.

INTRODUCTION

In the summer of 1988, during naval operations in the Persian Gulf, episodes of serious, symptomatic heat strain (nausea, disorientation, stomach cramps, collapse) among helicopter aircrews during flight were reported. These symptoms were reported as being attributed to high heat loads from engine exhaust and high ambient temperatures within the helicopter fuselage, especially during a hover flight phase. In response to a request by U.S. Navy Helicopter Detachment TWO (HC-2), Manama, Bahrain, a preliminary study was conducted by Naval Health Research Center (NHRC) investigators who, at that time (September-November, 1983), were in the Persian Gulf conducting heat stress research aboard U.S. Navy ships. The objectives of this preliminary study were: a) to identify fuselage ambient temperature ranges during flight and hover of a Navy H-3 helicopter during at-sea operations in a high heat environment; and b) to identify presence or absence of any cardiac strain, as determined by heart rate in response to this heat stress and when wearing a protective microclimate cooling (ice) vest. Based on the findings of this assessment, a Naval Air System Command tasking directed NHRC to acquire additional in-flight environmental and physiological data during their next deployment to the Persian Gulf (June-August, 1989). The tasking further directed a continued evaluation of the effectiveness of wearing a passive (ice) microclimate cooling vest during flight. The following report describes the results of both studies.

METHODS

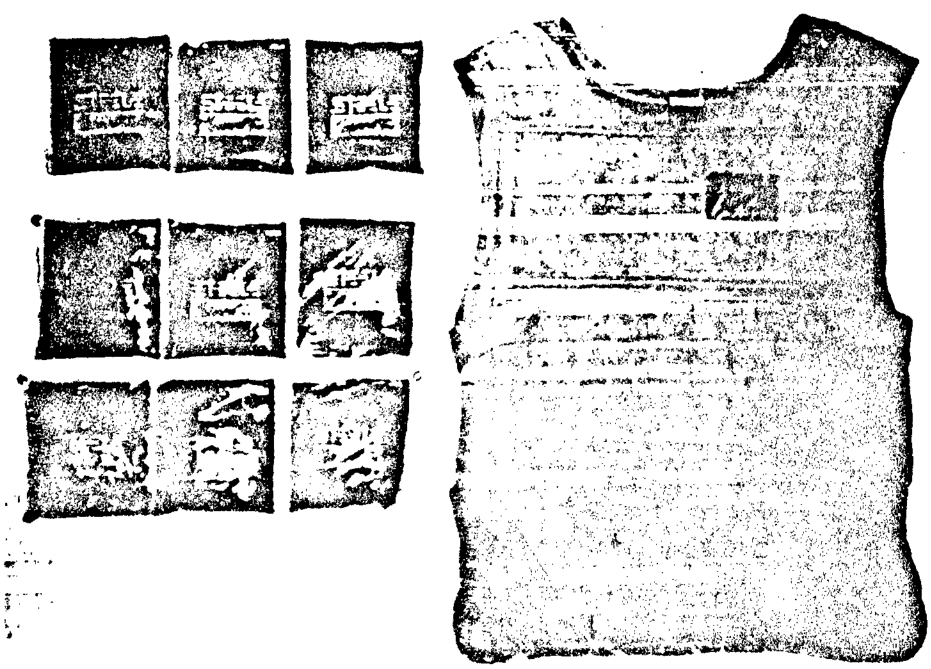
Subjects

Four aircrew (nonpilot) volunteers (mean age 33.5 years), following the signing of informed consent forms, participated in the preliminary single-flight study. Eight aircrew members, three pilots and five aircrewmen (mean age 29.9 years), volunteered for the second study, conducted during six separate flights. Additional physical profile means of the second study group are as follows: height 180.7 centimeters (cm); weight 79.3 kilograms (kg); body fat 16.6 percent (%).

Microclimate Cooling System

Microclimate cooling was provided for both studies by a cotton canvas, poncho-style, positive buoyant, passive (ice) cooling vest, referred to as the

"STEELE" ice vest (manufactured by STEELE, Inc. of Kingston, Washington) (Figure 1). The vest was worn under standard flight equipment and separated from the subjects' skin by a T-shirt and Nomex flight suit. The vest contained six frozen gel thermostrips--three placed horizontally in parallel position across the front of the vest in separate pockets externally insulated with Thinsulate, and three corresponding strips placed acro· the back. Thermostrips were frozen at -23°C the night before use and transferred to an Igloo insulated cooler just prior to flight departure. After placement in the vests, the thermostrips were not changed until flight completion.



Ambient Conditions

Fuselage temperature [dry, wet, globe, and Wet-Bulb Globe Temperature (WBGT) index] was determined by using a WBGT Meter RSS-220 manufactured by Reuter-Stokes Canada, Ltd. Fuselage carbon monoxide levels were measured during the second study using colorimetric detector tubes.

Physiological Indices

Physiological responses included: heart rate (HR) [modified V-5 electrocardiograph (ECG) placement], rectal temperature (Tre) (YSI Rectal Probe placed 10 cm past the anal sphincter), and five skin site temperatures [chest (left upper anterior), upper left arm (mid lateral), left forearm (mid volar), left thigh (mid anterior), and lower left leg (mid lateral). A solid-state physiological recorder (Vitalog) was used for continuous collection of HR and three skin site temperatures. A YSI Telemonitor was used for manual readings, approximately every ten minutes, of the remaining skin and rectal temperatures by an onboard investigator during each flight phase. Following attachment of electrodes and thermistors, the recorders were placed in a flight suit pocket prior to each flight and removed immediately following each flight.

Statistical Analysis

Skin temperatures represent mean weighted data using the regression equation of (Ramanathan 1964), and all physiological response data were computed as a mean ± standard error of the mean (S.E.M.) of each flight phase across all flights. Due to the small number of subjects and flights, HR response data for the preliminary study is descriptive only. All other analyses as described were used only for the second study. Analysis of variance (ANOVA) was used to assess significance of response for vest condition across all subjects and flight phases. Paired Student T-Test (two tailed) was used to assess differences within subjects during each flight phase between vest and nonvest conditions.

Test Design

The preliminary in-flight study evaluated cardiac strain (HR response only) during a 3.4-hour (midday), at-sea ship replenishment flight. Two subjects wore the passive (ice) cooling vest with their flight gear, and two wore only their normal complement of flight clothing/gear. During hover, two aircrewmen conducted mailbag hoists to and from a ship which was underway at 15 knots (kts). One crewman wore the vest and one did not; the other two crewmen remained seated in matched condition--one with a vest and one without. This design allowed assessment of combined workload and resting HR response with and without the vest across all flight phases. The second study was conducted during six 1.8-hour flights (midday) across a three-day period, with two flights in the same day. In addition to HR, physiological monitoring included rectal and skin temperatures. Each crewman flew one flight with the ice vest on and one without, again, while wearing standard flight equipment. Order of flight with or without the ice vest was randomized. One pilot flew two flight days and two aircrews flew three flight days in each condition. The remaining pilots and aircrew flew one flight day only. Fluid (water) intake during flight was ad libitum. In order to eliminate the influence of physical workload, all subjects in the second study avoided such workload conditions, with the exception of normal flight control during each flight phase. No mail hoists or other similar activities were conducted during hover. Time periods necessitating the aircrewmen to leave the aircraft during on-deck periods were eliminated from the analyses.

RESULTS

Ambient Conditions

During the preliminary study, overall ambient temperatures averaged 38.8°C ± 0.42 dry bulb [range: 31.1°C (in-flight) to 46°C (hover)] and 32.3°C ± 0.28 WBGT [range: 27.6°C (in-flight) to 36.1°C (hover)] (Table 1). During the second study, average temperatures across all flights and flight phases were 39°C ± 0.35 dry bulb [range: 30.5°C (in-flight) to 48.7°C (hover)] and 33.4°C ± 0.26 WBGT [range: 26.4°C (in-flight) to 40.2°C (hover)]. Time spent in each flight phase of the second study is presented in Table 2. Carbon monoxide levels during nonhover and non-on-deck flight phases reached 50 parts per million (ppm). During selected hover and on-deck flight phases, carbon monoxide levels reached 100 ppm and 75 ppm, respectively.

TABLE 1. MEAN FLIGHT AMBIENT TEMPERATURES (°C)

	Overall	On-Deck	Take-Off	In-Flight	Hover	Landing
	* / **	* / **	* / **	* / **	* / **	* / **
Dry	38.8/38.8	39.6/39.3	39.5/38.4	33.8/36.7	42.2/41.5	39.1/37.5
Wet	¤ /31.0	¤ /32.5	¤ /31.6	¤ /27.9	¤ /32.7	¤ /31.6
Globe	¤ /39.3	¤ /40.2	¤ /39.3	¤ /37.5	¤ /41.8	¤ /37.1
WBGT	32.3/33.4	32.9/34.7	32.1/33.8	28.8/30.7	35.0/35.4	31.7/33.3

* = Preliminary Single Flight Study (September-November 1988)
** = Second Study (June-August 1989)
¤ = Values not recorded

TABLE 2. TIME SPENT ON SECOND STUDY FLIGHT PHASES

	Nonvest			Vest		
Flight Phase	Total Time (mins)	Number of Events	Average Time (mins)	Total Time (mins)	Number of Events	Average Time (mins)
On-Deck	80	6	13.3	22	3	7.3
Take-Off	18	6	3.0	11	4	2.8
In-Flight	230	7	32.8	145	8	18.1
Hover	28	3	9.3	40	3	13.3
Land	23	6	3.8	17*	3*	5.7*

* = All data for one landing phase missing.

Physiological Responses

During the preliminary study, mean HR for the combined workload/rest conditions was greatest during hover and on-deck [145.0 ± 2.3 and 133.2 ± 2.5 beats per minute (bpm), respectively] for aircrew not wearing the protective cooling vest. Corresponding HRs for aircrew wearing the vest were 95.3 ± 2.9 and 79.7 ± 1.5 bpm, even though workload was the same. In fact, HR was markedly reduced during each flight phase (Figure 2). For the second study's six flights, ANOVA revealed that the reduction of HR for subjects wearing the vest was significant during flight [$(F1, 82) = 4.02$, $P < 0.05$]. As demonstrated during the preliminary study, paired t-test analysis revealed mean HR (nonworkload conditions) was greatest during hover and on-deck (93.0 ± 2.6 and 90.2 ± 2.1 bpm, respectively) for aircrew not wearing the protective cooling vest. Corresponding HRs with vest (86.0 ± 1.5 and 85.6 ± 2.4 bpm) were significantly reduced, $P < 0.05$ (Figure 3). Heart rate response during the landing phase was extremely varied among subjects (vest: S.D. of 10.7 bpm; no vest: 7.4) and combined with the short duration prevented any statistical significance. However, a consistent trend of lower HR with vest was present (mean difference of 9.2 bpm).

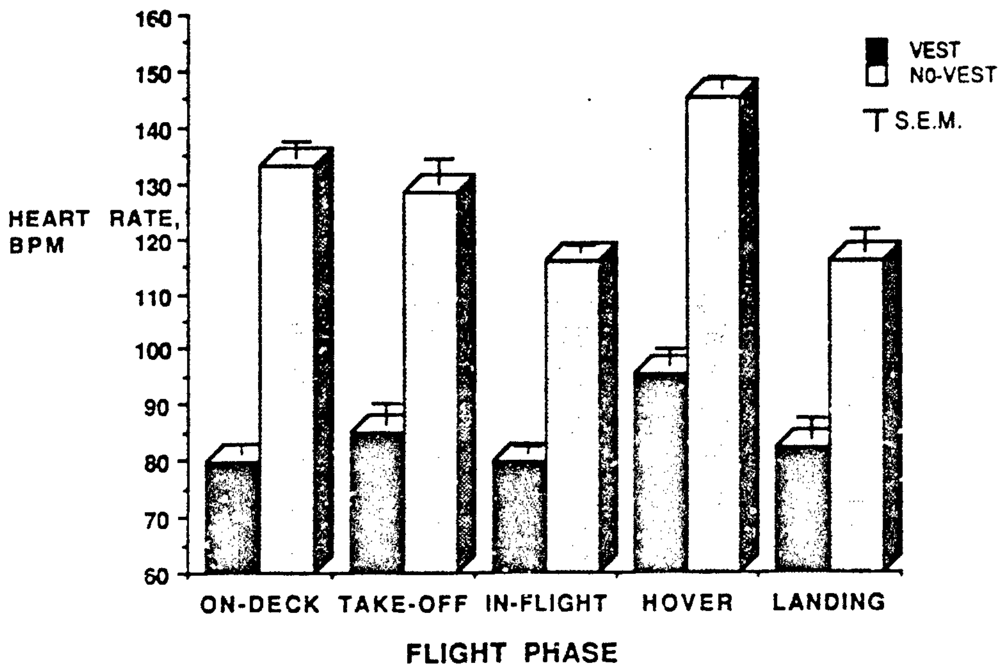


FIGURE 2. MEAN HEARTRATE BY FLIGHT PHASE / COOLING VEST CONDITION (WORKLOAD / REST), H-3 HELICOPTER - PERSIAN GULF, SEP - NOV 1988

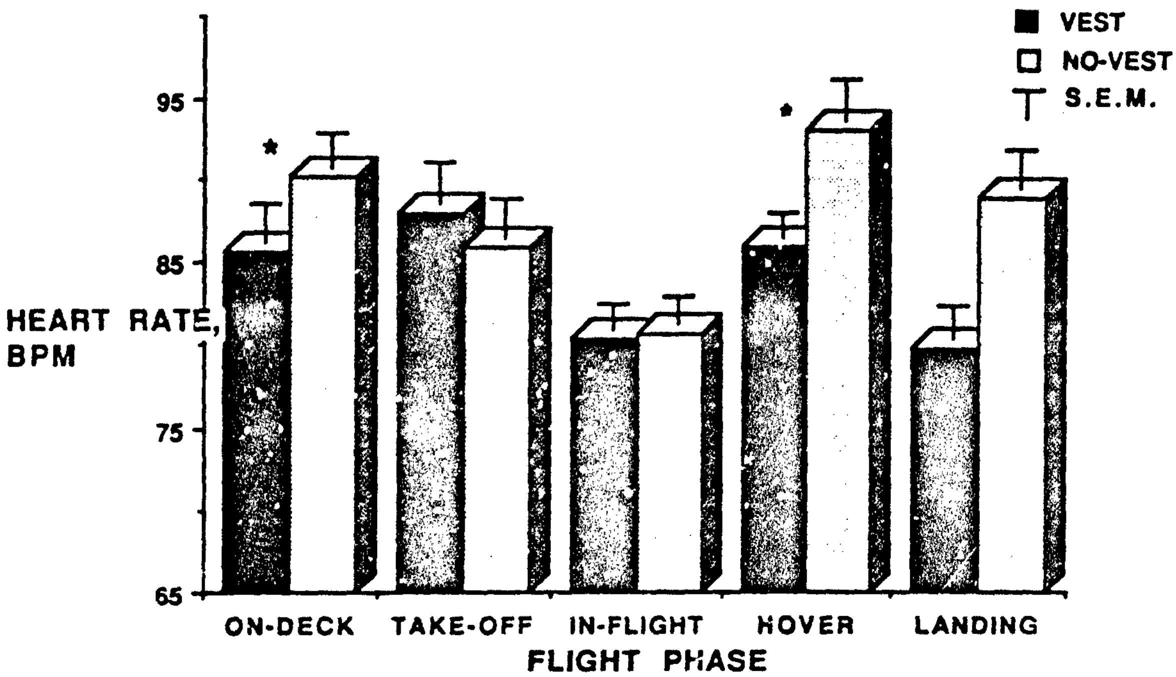


FIGURE 3. MEAN HEARTRATE BY FLIGHT PHASE / COOLING VEST CONDITION (AT REST)
H-3 HELICOPTER - PERSIAN GULF, JUNE-AUG 1989

* SIGNIFICANT $P < 0.05$

ANOVA of skin temperature response demonstrated a marked reduction of mean weighted skin temperature with the vest during flight [(F1, 82) = 19.24, $P < 0.001$] (Figure 4). The greatest difference in mean weighted skin temperature, as assessed by t-test analysis of each flight phase, was on-deck [35.6 ± 0.2°C without the vest and 33.9 ± 0.7°C with the vest ($T = 2.88$, $P < 0.02$)] and during hover [35.4 ± 0.35 without the vest and 33.4 ± 0.57 with the vest ($T = 3.20$, $P < 0.01$)].

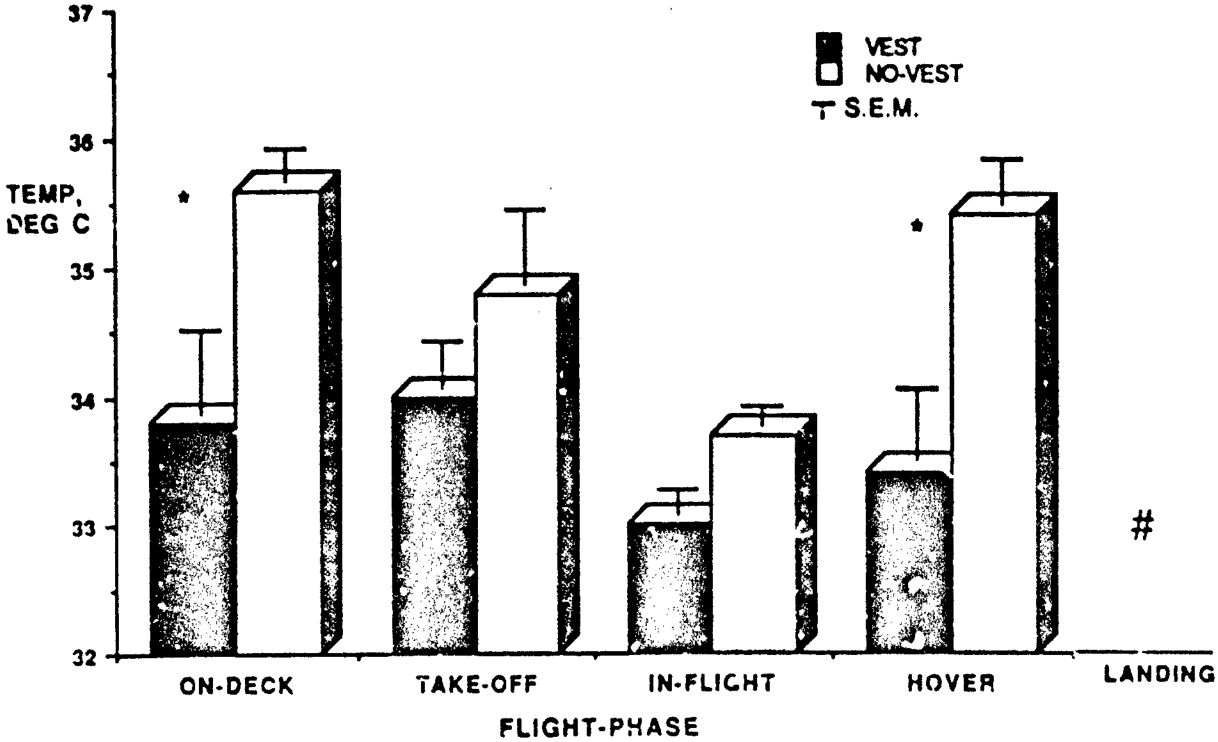


FIGURE 4. MEAN WEIGHTED SKIN TEMPERATURE BY FLIGHT PHASE / COOLING VEST CONDITION , H-3 HELICOPTER - PERSIAN GULF, JUNE - AUG 1989

LANDING PHASE NOT SHOWN DUE TO MISSING THIGH & CALF DATA

* SIGNIFICANT $P < 0.05$

Individual skin site temperature of the extremities, except for the forearm, showed a tendency to increase during cooling (Table 3). Most consistent were the upper arm and calf during take-off, in-flight, and hover flight phases. However, these were not statistically significant. When peripheral temperatures were combined as an arithmetic mean, vest effect was demonstrated [(F1, 86) = 6.94, P = 0.01]. Mean peripheral temperature in the nonvest condition was 35.0 $\pm$ 0.18 and in the vest condition was 35.5 $\pm$ 0.12.

TABLE 3. MEAN SKIN TEMPERATURES -- ALL FLIGHTS: SECOND STUDY (°C)

	On-Deck		Take-Off		In-Flight		Hover		Landing	
	No Vest	Vest	No Vest	Vest	No Vest	Vest	No Vest	Vest	No Vest	Vest
Chest	33.8	28.7	33.8	28.3	32.6	27.1	33.3	26.9	33.4	26.6
Upper Arm	35.0	35.2	34.8	35.5	33.3	34.7	35.0	35.2	34.7	35.6
Forearm	34.7	34.3	34.3	34.3	33.6	33.5	34.7	33.9	34.6	34.0
Thigh	37.0	36.9	35.5	37.1	35.1	36.1	37.2	36.6	*	37.4
Calf	36.5	36.3	34.5	36.4	34.8	35.7	36.6	36.6	*	37.1
Mean-Weighted	35.6	33.9	34.8	34.0	33.8	33.0	35.4	33.4	*	33.9

*Due to missing data, mean values are not presented

Rectal temperature was not found to be significantly different between vest and nonvest conditions during flight. Following an equal increase from on-deck to take-off, Tre in both conditions returned to near preflight levels during the remaining flight phases (Figure 5). The change across flight phases (specifically, on-deck to take-off, take-off to in-flight, and take-off to landing) was significant across both vest conditions ($P < .05$).

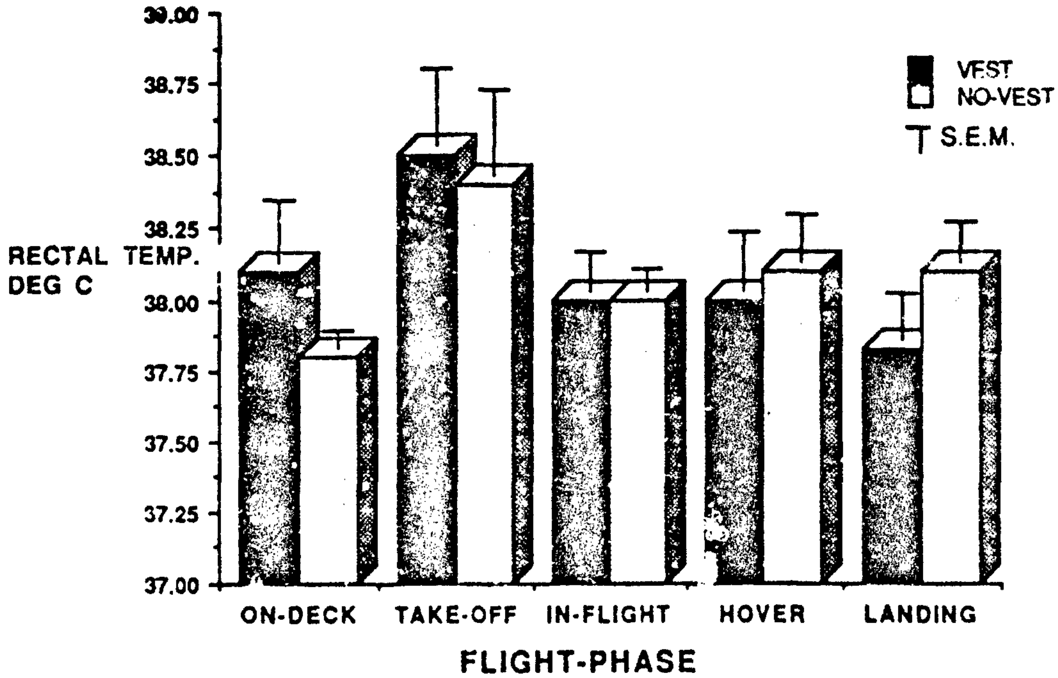


FIGURE 5. MEAN RECTAL TEMPURATURE BY FLIGHT PHASE / COOLING VEST CONDITION
H-3 HELICOPTER - PERSIAN GULF, JUNE - AUG , 1989

DISCUSSION

A review of the literature reveals previous reports of in-flight high heat ambient temperatures (heat stress); however, these conditions were generally associated with fixed-wing aircraft (Bollinger and Carvell 1975; Joy 1967). The nature of aircraft design differences between fixed-wing and rotary-wing would suggest that each would create a unique thermal environment. Research studies directed at quantification of in-flight or ground standby heat loads (heat strain) and monitoring of physiological response have also been principally directed at fixed-wing aircraft conditions (Constable et al. 1988; Gibson et al. 1969; Harrison and Higgenbottam 1977; Nunneley and Myhre 1976; Nunneley and James 1977; Nunneley et al. 1981; Stribley 1980). Published reports of thermal conditions in military helicopters during operational flight have been mainly from British sources describing flight conditions in the European theater (Allen

1984). Studies of the effectiveness of microclimate cooling systems during flight have been evaluations of either air- or water-cooled systems and are usually associated with the added stress of chemical defense or water immersion protective ensemble (Brooks et al. 1981; Cohen et al. 1989; Nunneley and Maldonado 1983; Richardson et al. 1987). Therefore, this study is the first to report in-flight heat stress and aircrew heat strain in U.S. Navy helicopters during at-sea operations in a high heat environment. This study is also the first to report the effectiveness of using a passive (ice) microclimate cooling system during flight.

Findings of the second study of this report were similar to those in the preliminary study, with the addition of rectal and skin temperature response. As described in the Methods section, physiological response data during periods in which aircrew were required to leave the aircraft during on-deck time periods were eliminated from the analysis. However, it is possible that the portion of on-deck time, as well as take-off, in which data was collected may still reflect heat storage that occurred during those out-of-aircraft periods; thus, higher Tre in both vest/nonvest conditions were noted during take-off. It is well known that Tre response time can be delayed as much as 20 to 30 minutes (Constable et al. 1988; Gibson et al. 1969). Even though nonvest time periods while on-deck and vest time period during hover were nearly twice the length of time than when in the opposite vest condition, Tre did not differ. In other studies (Pimental et al. 1988; Pimental et al. 1989), when using greater metabolic heat loads (treadmill walking), rectal temperature was less when wearing an ice vest. Therefore, in order to reflect differences in Tre temperatures with ice vest use, a greater heat load (ambient and/or metabolic) over time must be presented.

In a warm environment, for purposes of improving radiant heat loss, thermoregulatory response would be to widen the heat gradient at the skin and ambient air boundary to maintain a greater skin temperature than the environment. With an improved central blood volume return, because of torso cooling and resultant improved cardiac reserve, more blood flow could be shunted to the periphery (extremities) to improve the heat gradient. Combined with possible reduction in sweating due to skin wetness (Candas et al. 1983) or sweat gland fatigue (Wyndham et al. 1966), the increased blood flow would have a tendency to reflect a higher temperature. Current heat chamber studies at our laboratory with measured peripheral blood flow, however, indicate a trend towards a decreased extremity skin blood flow during ice vest conditions. The only similar findings previously reported was an unpublished report by Exotemp, Ltd. (a microclimate cooling system manufacturer) in which they too found peripheral skin site temperatures increasing as compared to the torso during cooling. A decreased skin blood flow would suggest that application of an ice vest to the torso could be causing peripheral vasoconstriction in the extremities as well as the chest. This, combined with the appearance of reduced sweating and, thereby, reduced means of evaporative cooling, would suggest that the higher skin temperature is due to radiant heat gain. Since rectal temperature was not different in this study between vest and nonvest conditions, it can't be determined what effect a hypothesized reduction in peripheral blood flow is having on core temperature. The appearance of reduced cardiac strain (decreased HR) suggests that total body heat dissipation is still occurring. Very likely, much of the heat dissipation during ice vest wearing is by tissue conductance at the torso skin/vest interface. We will continue to measure peripheral blood flow during vest conditions in future studies to better understand these blood flow dynamics.

High carbon monoxide levels identified during flight could have accentuated the observed cardiac strain during this study (Manual of Naval Preventive Medicine 1988). Ambient carbon monoxide levels of 100 ppm could result in a significant carboxyhemoglobin saturation, thereby stimulating a marked chemoreceptor cardiovascular response (Brobeck 1973). This effect would be more pronounced by reducing blood pressure and total vascular resistance. Heart rate could be slightly increased. The reduction of thermal strain when wearing an ice vest seems to retard the heat-load-related cardiac response, but it is unlikely that it would affect the carbon monoxide effect. Thermal regulation (peripheral blood flow and sweat rate) could also be compromised by these levels of carbon monoxide; however, this effect is not well documented in the literature. Depending on the rate of carbon monoxide removal by in-flight air circulation, the effect could be extremely variable. Whether the amounts of carbon monoxide identified during flight in this study had a major effect on thermal strain cannot be answered. Even though carbon monoxide was present, wearing of the ice vest still demonstrated a reduction in strain.

CONCLUSIONS

Aircrews performing at-sea, in-flight helicopter operations in an area of high ambient heat are subjected to heat loads that may produce marked cardiac strain and potential heat injury conditions. This strain is greatest during hover and on-deck flight phases when temperatures are the highest. Wearing a protective cooling vest appears to reduce this threat and substantiates findings of other studies using air/water/ice cooling vests (Janik et al. 1987; Pimental et al. 1988; Shapiro et al. 1982; Pimental and Avellini 1989).

Postflight questionnaires regarding the cooling vest document the fact that all aircrew members wearing the ice vest felt it was beneficial in reducing the thermal load they were subjected to. There are some flight equipment/ice vest compatibility issues, as well as difficulties in maintaining frozen thermostrips and changing those strips when necessary during extended flights (approximately 2 to 3 hours, depending on ambient temperature). However, the concept of microclimate cooling using ice, air, or water is certainly substantiated and encourages development of microclimate cooling for helicopter aircrews when operating in high heat/humid environments.

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High heat loads due to engine exhaust intake and high ambient temperatures within a helicopter fuselage during flight, specifically hover, have resulted in reported episodes of symptomatic heat strain among aircrew. An in-flight study was conducted to assess: a) fuselage ambient temperature during Navy H-3 helicopter at-sea operations in a high heat environment (Persian Gulf); b) presence or absence of any cardiac strain or excessive physiological heat load; and c) effectiveness of reducing these responses by wearing a protective cooling (ice) vest (IV). METHODS. Twelve helicopter aircrew were monitored [heart rate (HR) and skin (SK) and rectal (RT) temperature] in both IV and non-IV conditions during flight while wearing standard flight equipment. RESULTS. Across all flights and flight phases (FP), average ambient temperatures were 39°C dry bulb [range: 31°C (in-flight) to 48°C (hover)] and 33°C WBGT [range: 26°C (in-flight) to 40.0°C (hover)]. Heart rate was greatest during hover and on deck (mean 145 and 133 bpm, respectively, during workload/rest; 93 and 90 bpm during rest only) for non-IV conditions. Corresponding HR

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with IV (95 and 80 bpm during workload/rest; 85 bpm during rest only) was significantly reduced ($P < 0.05$). Rectal temperature was not found to be different between IV/non-IV conditions; however, change across FP was significant in both conditions ($P < 0.05$). Analysis of Variance (ANOVA) demonstrated interaction of individual skin sites and mean weighted skin temperature with IV/non-IV and FP ($P < 0.05$). CONCLUSIONS. Aircrew performing at-sea helicopter operations in an area of high ambient heat are subject to heat loads that may produce heat stress conditions that can result in marked cardiac and thermal regulatory strain. Wearing of a protective cooling vest appears to reduce this threat.