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THE EFFECTS OF A PALM COOLING DEVICE AND A COOLING VEST DURING SIMULATED PILOT HEAT STRESS

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14. ABSTRACT
A cooling vest (CV) and a Rapid Thermal Exchange (RTX®) hand cooling device were tested in a thermal chamber simulating aircrew pre-flight walk-around at 95ºF. Physiologic cooling protection, cognitive performance and mood changes were studied. Twelve male subjects were tested. Rectal and skin temperatures as well as cognitive performance and mood changes were assessed. The chamber was heated to 35º C with a relative humidity of 85% and the subjects walked on a treadmill for 20 min. A period of slow cooling down over 75 minutes followed. The subjects' weight was recorded before and after each experiment. Three different conditions were tested: a control without any cooling device, a Rapid Thermal Exchange hand cooling device (RTX®) and a RFD® Beaufort Liquid conditioning Vest (CV). The CV provided significant cooling benefit as seen by core temperature, weight loss, heart rate, subjective heat and mood scores, compared to a control condition without any cooling devices. While RTX® appeared to have some slight benefits compared to control (i.e. mean values tended to fall in between control and cooling vest), there was little statistical evidence (other than weight loss) to support this tendency. The heat stress induced in this study (i.e. simulating aircrew pre-flight walk around) was moderate and not severe as some other operational environments could be (e.g. for flight-line maintenance crew). Therefore, cognition was not impaired by the heat stress generated in this study, and, thus, no observed improvement could be seen from the two cooling conditions.

15. SUBJECT TERMS
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SUMMARY

Purpose: A cooling vest (CV) and a Rapid Thermal Exchange (RTX®) hand cooling device were tested in a thermal chamber simulating aircrew pre-flight walk-around at 95º F with extra heat from heat lamps and a relative humidity of 85%. Physiologic cooling protection, cognitive performance and mood changes were studied.

Methods: Twelve male subjects were instrumented with skin and rectal probes for skin and rectal temperatures, and ECG electrodes for heart rate. Cognitive performance was tested with the Automated Neuropsychological Assessment Metric after training. Mood was assessed with the Profile of Mood States and the subjective heat score was recorded during the experiment in a thermal chamber. The chamber was heated to 35º C (95º F) with a relative humidity of 85% and the subjects were exposed to sixteen heat lamps suspended above their head to simulate the radiant heat of a hot summer day, while walking on a treadmill for 20 min. A period of slow cooling down over 75 minutes followed. Each subject's weight was recorded before and after each experiment. Three different conditions were tested on separate days: a control without any cooling device, a Rapid Thermal Exchange hand cooling device (RTX®) and a RFD® Beaufort Liquid conditioning Vest (CV).

Results and Conclusions: The CV provided significant cooling benefit, as seen by core temperature, weight loss, heart rate, subjective heat and mood scores, compared to a control condition without any cooling devices. While RTX® appeared to have some slight benefits compared to control (i.e., mean values tended to fall between control and cooling vest), there was little statistical evidence (other than weight loss) to support this tendency. The heat stress induced in this study (i.e., simulating aircrew pre-flight walk-around) was moderate and not as extreme as some other operational environments could be (e.g., for flight-line maintenance crew). Therefore, cognition was not impaired by the heat stress generated in this study, and, thus, no improvement was observed from the two cooling conditions.

INTRODUCTION

OBJECTIVE.

The objective of this study was to test the thermal protection of a cooling vest (CV) and a Rapid Thermal Exchange (RTX®) hand cooling device in a thermal chamber simulating aircrew pre-flight walk-around at 95º F with extra heat from heat lamps and in 85% relative humidity followed by a slow cooling down period. Physiologic cooling protection, as revealed by rectal and skin temperature measurments, heart rate, sweat loss, as well as subjective heat scores, cognitive performance and mood changes were also studied.

BACKGROUND.

The aviation environment can create significant thermal burdens for the operators of modern military aircraft (Nunneley, Strible 1979, Nunneley 1996). Operations in hot humid environments, in-flight heat from avionics, radiant heating through the canopy, and aerodynamic heating can combine with layers of aircrew life support equipment to overcome the body's normal mechanisms for heat dissipation. Such heat stress may impair the physical as well as cognitive performance of a pilot (Balldin et al. 2002, Balldin et al. 2003, Balldin, Siegborn 1992, Nunneley et al. 1979, Pilcher et al. 2002, Ramsey 1983, Ramsey, Morrisey 1978). The effectiveness of redistribution of blood flow from the core to the skin for transfer to the external environment as well as evaporative heat loss through sweating can be lessened because of impermeable materials such as the pneumatic bladder of anti-G suits and chest counter-pressure garments. Previous studies have examined the use of air-cooled and liquid-cooled vests. For the Joint Strike Fighter, consideration is being given to the use of a liquid cooled vest. Recently, a Rapid Thermal Exchange hand cooling device (RTX®, AVAcore Technologies) has been developed (see Figure 1). The RTX® device has been shown to reduce the rate of increase in core body temperature in exercising individuals (Whitish et al. 2003). The use of the RTX® device has also shown increased strength, endurance, and exercise performance (Grand and Elliot et al. 2003, Heller 2003). The RTX® device is non-invasive and takes advantage of the arterio-venous anastomoses and venus plexi in the hands. This study examined whether the RTX® device can also reduce the rate of increase in core temperature in a realistic simulation of flight operations in a hot humid environment. Results from the RTX® were compared to those obtained from a more traditional approach to aircrew cooling -- a liquid conditioned vest (see Figure 2).

Griffiths and Boyce (1971) specifically studied the relationship between performance, thermal sensation and comfort and found that correlations between performance and subjective assessments were lower than between performance and temperature. This suggests that even though the feelings of thermal discomfort and sensation of warmth

Figure 1. The Rapid Rapid Thermal Exchange (RTX®) hand cooling device built by AVAcore Technologies.

may be high this is not a critical factor for flight or other performance. Core temperature is the primary variable by which effectiveness of the cooling system was measured (Standard Test Method for Measuring the Performance of Personal Cooling System using Physiological Testing 2004).

Figure 2. The Liquid Cooling Vest with connecting liquid hoses on the subject's left side.

This study explored a recently developed novel approach to personal cooling as a countermeasure to heat stress for Air Force pilots. This technology was supported by the Defense Advanced Research Projects Agency (DARPA). DARPA is supporting evaluation of the RTX® cooling device for many different military applications. The US Navy is studying this technology for military-relevant tasks for their SEAL community, specifically the ability of the system to sustain human endurance, immune and cognitive function. This study will impact DARPA's evaluation of the RTX® and this technology for Air Force applications.

METHODS.

Equipment and facilities: Experiments were conducted in the Air Force Research Laoboratory's, Biosciences and Protection Divisions (AFRL/HEP) thermal chamber. The chamber was equipped with a treadmill to simulate aircrew workload, an ejection seat mock-up, and instrumentation for physiologic measurements. The AFRL/HEP Cockpit and Equipment Integration Laboratory was used for subject test preparation. Twelve volunteer subjects were recruited. All volunteers were members of the HEP centrifuge or altitude subject panels at Brooks-City-Base, TX. Their average age was 31 years (range 20-40), the average weight was 184 lbs. (range 126-227) and the average height was 70 inches (range 67-73).

Only male subjects were used. Since tests were conducted on three occasions with a minimum of 44 hours between tests, the effects of physiological heat production variability associated with the menstrual cycle of female subjects had to be controlled (ATSM Standard F2300-04a). Additionally, there appears to be a nonnoradrenergic mechanism of reflex cutaneous vasoconstriction in females that is associated with their reproductive hormone status (Stephens et al, 2002). To avoid this uncontrolled influence on the results only male subjects were used.

Subject's activity, food and fluid intake the day prior to each test were *ad libitum* with the exception of alcohol, which was prohibited. Subjects were asked to participate in 1-3 training sessions lasting about one hour each. Each subject was required to complete three experimental conditions (one was a control) conducted on separate days with at least 44 hours between tests.

Test Conditions: Subjects were dressed in one of the three sets of aircrew clothing that represents the three experimental conditions. The clothing sets consisted of COMBAT EDGE equipment (HGU-55/P Helmet, MBU-20/P Oxygen Mask, CWU-27/P Aircrew Coverall (flight suit), CSU-13B/P Anti-G Suit, CSU-17P Counter-pressure Vest, PCU-15A/P or PCU-16 A/P Parachute Harness with LPU-9/P Life Preserver, SRU-21/P Survival Vest, CRU-94/P Connector Block, Flight Boots) without any cooling device [Control condition], with a liquid cooling vest [condition CV] and with the RTX device (Condition RTX). The cooling vest was the RFD® Beaufort Liquid Conditioning Vest (RFD Beaufort Limited, Birkenhead, Merseyside, UK, Part Number LG6892) proposed for the Joint Strike Fighter (JSF) and was supplied with a known flow rate of constant temperature water (68º F or 20º C). Subjects were exposed in a balanced order to the three equipment conditions so as to avoid any effects of order. The tests were carried out at the same time of the day on different days. Total time of exposure to each test condition was about 1.5 h.

Test Procedures: The E Chamber at Brooks City-Base was used for the experiments. It has an internal volume of 5000 cubic feet. The chamber can be controlled either manually or automatically. In addition to its altitude capabilities, the chamber's temperature and humidity can be controlled via computer to meet the specific needs of the study/protocol conducted. At ground level, the temperature within the chamber may be reduced from ambient temperature to –67 degrees Fahrenheit (-55 C) or raised to 150+ degrees Fahrenheit (65.6 C). Aircrew preflight activity was simulated in the chamber using a treadmill and an ejection seat mock-up. The specific thermal conditions chosen simulate summer weather at USAF bases in the southern U.S.

Twelve volunteers from the laboratory's subject panel were used as subjects. All subjects were required to pass an appropriate physical examination and were selected to represent the male USAF rated aircrew population. The written informed consent was obtained from each volunteer. Subjects were instructed to avoid moderate to high-level exercise prior to their tests. All individuals were normally hydrated prior to testing. Upon arriving at the Cockpit Equipment Integration Laboratory, hydration level was determined by measuring urinary specific gravity. If a level of 1.025 g/mL or lower was not obtained, the subject was required to drink water until this level was reached.

Before each test, the subject's nude weight was recorded. Whole body sweat rate was used to assess the performance of the personal cooling system and the level of dehydration caused by the thermal stress of the test conditions. Water consumption was allowed during the testing. Sweat rate was determined by subtracting the measured post-dry nude body mass from pre-dry nude body mass. Corrections were made if the subject urinated or consumed water during the test.

Standard EKG electrodes were attached. The subject was then instrumented with thermistors to measure skin temperature at the neck, chest, forearm, and calf (YSI-400 Yellow Springs Instrument, USA, accuracy ±0.158º C). Mean skin temperature was calculated using the formula of Ramanathan (Ramanathan, 1964). Rectal temperature is recommended when whole body work is being performed and was used in this study (YSI-700, Yellow Springs Instrument, USA, accuracy ±0.158º C). The rectal thermister was inserted into the rectum no less than 10 cm and no greater than 15 cm in depth past the edge of the anal sphincter. Since slight temperature differences can occur depending upon the depth of the themister, the probe was secured to maintain a constant position throughout the measurement period. Heart-rate was recorded by a Propac Physiological Monitoring Device model 242 (Protocol Systems Inc., Beavertown, Oregon, USA).

After placement of the rectal thermister, the subjects were dressed in one of the three sets of aircrew clothing that represents the three experimental conditions.

The RTX® consisted of a sleeve that created an airtight seal around the wrist with the individual's palms lying on top of the heat exchange manifold (see Figure 1). Negative pressure (15 mmHg) was applied within the sleeve, which may enhance the blood flow through the hand, which in turn is supposed to augment the heat transfer potential. Cool water (20° C) was pumped through the manifold with the intent to extract heat from the blood flowing through the palms of the underlying vascular tissue of the hand.

In each of the three conditions, the subject entered the pre-heated thermal chamber set to a dry bulb temperature (Tdb) of 35 °C (±0.1) and a relative humidity of 85 % (±2). This temperature and humidity condition simulated a hot day at a typical Air Combat Command Air Force Base location in the Southeastern U.S.. The subject stood for 5 min while instrumentation was connected. After the instrumentation period, sixteen 375 W infrared heat lamps in the ceiling (distance to the subject's head varying from about 1 to 2 m) were turned on creating a mat black globe temperature of 50 °C (± 0.1). The subject then started walking on a level treadmill at 4 km/hr for 20 min without helmet or oxygen mask to simulate walking to the aircraft followed by preflight inspection.

After this 20 minute exposure, the heat lamps were switched off and while still in the climatic chamber, the subject was strapped into an ejection seat mock-up located next to the treadmill, donned his helmet and mask allowing breathing air through the oxygen hose administrating ambient chamber air. Over the next 20 min, chamber Tdb was lowered linearly to 21 °C (± 0.1) with low humidity (about 40 % (±2) relative humidity in room air) to produce conditions expected in flight. The cooling vest or RTX® device was used throughout the complete CV and RTX® conditions respectively.

Total time in the climatic chamber was about 95 minutes. Every 10^{th} min the subject indicated his subjective heat stress level on a scale from 0 to 11 (maximum). Cognitive performance tests were performed at scheduled intervals to quantify any decrement in the subject's ability over the course of the test. The thermal exposure (as well as the experiment) could be discontinued for any one of the following indications: (a) subject request, (b) medical monitor or investigator request, (c) physiological measurements exceeding any one of the following: heart rate > 85% of estimated maximum (220-age); core temperature ≥ 39.0 °C; skin temperature (any site) > 43 °C. However, this never happened.

Subjects were trained on the cognitive tasks described below prior to their exposure to the first experimental condition. Cognitive assessment metrics were selected that are both critical to piloting skills and sensitive to ambient heat stress and changes in internal body temperature (Boff and Lincoln, 1986). Cognitive performance was examined throughout the experimental session according to the schedule shown below. Prior to the start of data collection, a three-hour orientation and training session was conducted. During the training sessions participants practiced each task to near asymptotic performance. The subjects moved the mouse for the computer testing with their left hand, since the right hand was used for the RTX® device (see Figure 3).

Cognitive and Mood Testing

Cognitive performance was assessed using two tests from the Automated Neurospychological Assessment Metrics (ANAM) (Reeves, Winter, Kane, Elsmore, & Bleiburg, 2001) test battery. The continuous performance task (CPT) and the grammatical reasoning task (GRT) were given 10, 25, 35, 45, 55, 65, 75 and 85 minutes after the start of the threadmill. CPT provides a measure of working memory by presenting a number which must be memorized for comparison to a follow-on number, which is in turn compared to another number. This sequential number presentation lasts for 2.5 min. GRT presents two statements which must be compared to a row of three symbols. The participant must confirm whether the statements actually describe the relational order of the three symbols. This test lasts for 2.5 min as well. The outcome measures were the same for both tests: accuracy, reaction time to correct responses (MRTC), standard deviation of reaction time (SDRTC), and throughput (TP - number of correct responses per minute).

Mood was assessed with the Profile of Mood States (POMS -- McNair, Lorr, Droppleman, 1994**).** POMS consist of 65 items to which the participant indicates their level of agreement on a four point scale. Results are broken into six scales: Anger, Confusion, Depression, Fatigue, Tension, and Vigor. POMS was given after the CPT and GRT tests at the 25, 45, 65 and 85 minutes interval after the start of the threadmill.

Figure 3. Subject with his right hand in the Rapid Rapid Thermal Exchange (RTX®) hand cooling device in the thermal chamber. The left hand is moving the mouse for the responses in the computer operated cognitive performance tests.

Data Analysis

<u>Physiologic and Thermal Rating Outcome Variables.</u> Prior to analysis of the variables, changes from baseline were calculated at each data collection point, for each participant, to adjust for possible differences in the participant's physical state from visit to visit. Using these "deltas," a repeated measures analysis of variance (ANOVA) was then performed on each variable to test for differences among the three experimental conditions (control, cooling vest, RTX®) across the data collection time points. If the assumption of sphericity of the ANOVA covariance matrix was invalid (using Mauchly's test), ANOVA degrees of freedom were adjusted before performing the tests. When significant (or borderline, i.e. $p<0.10$) condition by time effects were detected in the ANOVA, post-hoc analyses (Student's t-tests) were used to compare the three conditions at each specific time point.

<u>Cognitive Performance and Mood Variables</u>. True baseline data was not available for the cognitive and mood tests. Consequently, no adjustments were made to the raw data before statistical analysis. As above, a repeated measures ANOVA was performed on each outcome variable, followed by post-hoc tests, where appropriate, to identify specific differences among the three conditions.

<u>Power Analysis</u>. The power analysis was based on the post-hoc comparisons following the ANOVAs. The proposed sample of 12 participants provided an 80% chance (i.e., power = .80) of detecting relatively large effects (i.e., differences that are about 85% of the magnitude of the standard deviation of the difference), when testing at the two-tailed 0.05 alpha level. .

<u>RESULTS.</u>

Physiologic data and subjective and heat scores

The core temperature results were obtained from only 11 of the 12 studied subjects, due to a malfunction of one of the rectal probes. The core temperature was measured continuously, but data for analysis was recorded at the time immediately after entering the 95º F chamber, at the end of maximal chamber temperature (when the heat lamps were switched off), at the maximal core temperature level and at the end of the experiment (just before leaving the chamber) (Table I). The initial core temperature was for the control condition 98.7 ºF (±0.8), for RTX® 98.9 ºF (±0.7) and for vest condition 99.0 ºF (±0.5). The core temperature increased in all subjects for all conditions during the heat exposure in the chamber. The maximal core temperature was for the control condition 99.9 ºF (±0.7), for RTX® 100.0 ºF (±0.5) and for vest condition 99.9 ºF (±0.4). Since the initial core temperature was not the same for the different conditions, only the changes in core temperature from the initial value for each condition were analyzed. The temperature changes from starting time to maximal chamber heat exposure duration were not statistically different between any of the conditions. However, at maximal core temperature and at the end time, the core temperature increase was significantly higher with control compared to the vest condition (+0.4±0.1 ºF, p<0.05 in both cases) and with RTX® compared to the vest condition (+0.2±0.1 ºF, p<0.05, and +0.3±0.1 ºF, p<0.05, respectively) (Table I).

Table I
Core Temperature: Descriptive Statistics for Each Condition and Time, and ANOVA Test Results

Condition	Baseline	Change from baseline at:			ANOVA Results			
		Peak	Max	End		Condition	Time	Condition by Time
Control	98.7	.7	1.3	.4				
	.8	.4	.5	.4	MSE	.090	.207	.029
RTX®	98.9	.6	1.1	.3	df(n,d)	(2,20)	$(2,23)^h$	$(5,49)^h$
	.7	.4	.4	.6	F ratio	5.42	47.14	4.53
Vest	99.0	.6	.9	.0	p	.013	<.001	.002
	.5	.3	.5	.4				

Notes: 1. Numbers in each cell are the mean (top) and standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the degrees of freedom.

The different changes in skin temperatures for all 12 subjects are shown in Table II. At the separate skin sites, the only statistically significant differences between control, RTX and vest are for the scapula temperature. The vest condition showed a lower scapula temperature both at the peak temperature time and at the end time compared to control and RTX® (p<0.001 in each case). There were no significant differences in the temperatures recorded on the left hand, neck and shin between contr, RTX® and vest. The average skin temperature from these measurements showed accordingly (as a result of the scapula temperatures) a lower temperature at the peak temperature with vest compared to control and RTX® (p<0.001) and at the end time (p<0.001 for control and p<0.01 for RTX®).

Table II
Skin Temperature: Descriptive Statistics for Each Condition and Time, and ANOVA Test Results

Location	Condition	Baseline	Change from baseline at:		ANOVA Results			
			Peak	End		Condition	Time	Condition by Time
Scapula	Control	94.6 1.4	4.9 1.5	1.2 1.8	MSE df (n,d) F ratio p	1.64 (2,22) 175.31 <.001	2.32 (2,22) 108.27 <.001	1.76 (3,33)^{h} 68.67 <.001
	RTX®	94.0 2.1	5.4 1.8	1.6 2.4				
	Vest	95.0 1.3	-.1 1.5	-8.1 1.6				
Left Hand	Control	92.0 3.3	6.6 2.7	-1.0 2.3	MSE df (n,d) F ratio p	4.95 (2,22) 4.28 .027	7.30 (2,22) 103.27 <.001	3.64 (4,44) 2.23 .081
	RTX®	91.2 3.9	7.9 3.6	-1.3 4.0				
	Vest	92.5 2.9	5.8 2.8	-3.6 3.1				
Neck	Control	92.0 3.0	7.1 2.3	.2 2.9	MSE df (n,d) F ratio p	4.11 (2,20) 2.10 .148	11.12 (1,14)^{h} 69.03 <.001	8.18 (2,22)^{h} .75 .495
	RTX®	91.8 3.6	7.2 2.6	-.9 3.2				
	Vest	92.9 2.3	5.8 1.9	-1.5 3.6				
Shin	Control	93.5 .9	5.3 .7	-1.3 1.7	MSE df (n,d) F ratio p	1.79 (1,15)^{h} 2.18 .157	3.77 (1,13)^{h} 185.42 <.001	1.65 (2,21)^{h} 1.06 .362
	RTX®	93.2 .7	5.4 .8	-.9 2.3				
	Vest	93.5 .9	4.8 1.0	-1.9 1.9				
Skin Average	Control	93.1 1.1	5.9 1.1	-.2 1.4	MSE df (n,d) F ratio p	1.72 (2,22) 22.53 <.001	3.37 (1,15)^{h} 221.63 <.001	.72 (4,44) 16.52 <.001
	RTX®	92.6 1.6	6.4 1.4	-.8 2.9				
	Vest	93.5 .7	4.1 .7	-3.8 1.4				

Notes: 1. Numbers in each cell are the mean (top) and standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the degrees of freedom.

The average heart rate (n=12) was not statistically different during the initial measurements in the chamber (about 79±8 bpm for all conditions) but was significantly higher during control and RTX® compared to vest condition (p< 0.05, p<0.01) at the end of the walking, but not different when comparing control to RTX® (Table III). The maximum heart rate was higher during the control compared to the vest condition (p<0.01), but not compared to the RTX® condition during the rest period after walking.

At the end time the heart rate was higher for the RTX® condition compared to the vest condition (p<0.01).

Table III
Heart Rate: Descriptive Statistics for Each Condition and Time, and ANOVA Test Results

Condition	Baseline	Change from baseline at:			ANOVA Results			
		Max Walk	Max Rest	End		Condition	Time	Condition by Time
Control	78.7 8.4	40.6 9.3	23.6 14.7	-10.1 8.4	MSE df(n,d) F ratio p	140.30 (2,22) 3.10 .065	80.66 (3,33) 191.74 <.001	100.38 (3,29)[h] 2.38 .097
RTX®	75.9 8.9	37.3 10.2	18.4 15.1	-8.5 6.8				
Vest	75.2 10.1	32.6 8.1	10.7 10.4	-12.6 7.5				

Notes: 1. Numbers in each cell are the mean (top) and standard deviation (bottom).
2. [h] indicates that the Huynh-Feldt adjustment was made to the degrees of freedom.

The heat score registrations (n=12) at peak core temperature were higher for the control compared to vest (p=0.001), but not compared to RTX® (see Table IV). At the end of the experiments the heat scores did not differ between control, RTX® and vest conditions.

Table IV
Heat Score: Descriptive Statistics for Each Condition and Time, and ANOVA Test Results

Condition	Baseline	Change from baseline at:		ANOVA Results			
		Max	End		Condition	Time	Condition by Time
Control	1.2 1.2	3.2 1.2	-1.0 1.1	MSE df (n,d) F ratio p	1.150 (2,22) 3.50 .048	2.301 (2,22) 44.79 <.001	.550 (4,44) 6.89 <.001
RTX®	1.0 1.2	2.4 2.1	-1.0 1.2				
Vest	1.3 1.4	1.2 1.3	-1.0 1.3				

Notes: 1. Numbers in each cell are the mean (top) and standard deviation (bottom).

The average weight loss (n=12) due to sweating (corrected for urine disposal or drinking water) was 1.6±0.6 lbs. for control condition, 1.3±0.6 lbs for RTX® and 1.0±0.3 lbs. for vest condition. The differences from control were significant (p<0.01 for RTX® and p<0.001 for vest condition). The RTX® condition also showed a significantly greater fluid loss compared to the vest conditon (p<0.05).

Cognitive Performance and Mood

Due to technical problems during data collection, only 10 participants were available for CPT analysis, and eleven were available for Grammatical Reasoning and POMS analysis. Descriptive statistics and ANOVA results are presented in Table V for the cognitive variables, and in Table VI for the POMS variables. Results of the post-hoc tests will be reported in the text, when appropriate.

Continuous Processing Task – No significant condition, time, or condition by time effects were seen for any of the outcome measures. Though not statistically significant, there was a general trend for performance to decline over the experimental session.

Grammatical Reasoning Task – No significant condition, or condition by time effects were seen for any of the outcome measures. Significant time effects were seen for MRTC, SDRTC, and TP. Large performance decrements were seen going from trial 2 to 3.

Profile of Mood States – A significant effect of condition was seen for the confusion, fatigue, and vigor scales. In all three cases, participants responded more positively under the vest condition. With regard to these three scales: Vest was statistically superior to Control for the confusion and fatigue scale; and results from the vigor scale showed Vest to be statistically superior to both conditions.

DISCUSSION.

The heat exposure chosen for this experiment induced a moderate body temperature increase. The heat exposure was supposed to represent the Air Force condition when a pilot walks to the aircraft, makes an external inspection in a hot and humid airbase in the summer in the southern USA and then enters the cockpit and uses the aircraft's air conditioning system. The rectal temperature increased modestly in all subjects for all conditions during the heat exposure in the chamber and, in contrast to the skin temperature, continued to increase during the first half hour after the heat lamps were turned off and the temperature of the chamber slowly was cooled down. Upon observation of max core temperature, mean control temperature was highest, followed by RTX® and then cooling vest. However, there was no statistical difference between control and RTX®, but both were significantly higher than cooling vest.

Table V Cognitive Performance: Descriptive Statistics for Each Condition and Time, and ANOVA Results

	Variable	Condition	Time 1	ANOVA Results 2	3	4	5	6	7	8		Condi- tion	Time	Condi- tion by time
Continuing Processing Task	Accuracy	Con- trol	95.1 3.8	96.2 2.8	95.4 4.1	93.4 5.6	94.6 3.6	93.3 4.4	94.1 3.9	96.4 1.9	MSE df(n,d) F-ratio P	20.22 (2,20) .07 .934	18.02 (4,41)^h 1.58 .196	12.24 (8,79)^h 1.61 .137
		RTX®	95.7 2.9	97.0 3.7	96.1 2.8	94.0 4.1	93.5 5.4	94.6 3.4	94.6 3.6	94.1 3.7				
		Vest	95.9 4.5	94.5 5.4	94.5 3.7	95.9 4.1	94.7 3.8	93.7 6.4	94.5 3.3	93.8 4.8				
	MRTC	Con- trol	463.9 45.9	454.5 55.9	460.2 54.1	476.5 78.6	477.1 52.6	497.4 93.4	487.5 60.8	481.8 55.0	MSE df(n,d) F-ratio p	1621.29 (2,20) .72 .501	3076.97 (3,27)^h 2.11 .127	1626.34 (6,61)^h 1.10 .373
		RTX®	474.3 45.6	463.2 48.1	489.5 68.6	491.5 62.8	490.4 70.7	485.9 56.7	481.2 66.0	475.6 67.2				
		Vest	473.2 57.6	470.9 59.3	469.9 68.7	482.1 67.8	475.9 61.3	485.3 87.4	484.1 63.7	462.6 65.9				
	SDRTC	Con- trol	84.6 12.4	89.8 23.9	92.6 24.4	105.8 46.3	105.7 27.2	122.6 66.1	114.0 41.0	110.3 30.5	MSE df(n,d) F-ratio p	1140.76 (2,20) .02 .981	2150.34 (2,23)^h 3.21 .053	1066.63 (5,55)^h 1.23 .305
		RTX®	97.6 26.2	89.7 19.1	104.8 31.8	109.9 31.1	116.1 37.9	100.3 24.6	107.0 29.0	108.1 31.2				
		Vest	92.3 23.6	98.1 29.3	99.82 30.2	103.0 32.3	102.4 32.9	117.4 55.0	112.1 41.7	102.9 42.7				
	Throughput	Con- trol	123.9 13.5	128.6 16.2	125.6 15.0	120.6 19.3	120.4 12.3	116.4 22.5	117.6 15.7	121.3 13.6	MSE df(n,d) F-ratio p	148.61 (2,20) .53 .597	214.17 (3,33)^h 2.29 .092	107.41 (7,68)^h 1.03 .417
		RTX®	121.8 12.1	126.8 13.7	119.9 16.4	116.6 17.3	116.2 18.2	118.7 15.2	119.6 16.5	120.9 18.9				
		Vest	122.9 17.1	122.0 16.7	122.9 18.0	121.3 16.0	121.5 17.2	119.6 22.8	118.8 17.7	124.1 18.2				
Grammatical Reasoning	Accu- racy	Con- trol	92.9 9.6	94.1 5.6	87.1 12.2	90.4 8.3	91.7 9.0	87.1 11.2	87.9 14.6	89.2 12.2	MS df(n,d) F-ratio p	111.32 (2,18) .09 .916	68.69 (7,63) .76 .622	95.57 (7,64)^h .68 .688
		RTX®	90.8 3.9	91.7 7.1	90.4 5.9	87.9 10.3	88.3 8.3	92.0 6.8	91.7 6.2	89.2 7.1				
		Vest	92.5 10.0	91.7 9.2	89.2 8.4	91.2 7.2	92.1 6.3	88.3 15.6	90.4 11.3	90.4 12.3				
	MRTC	Con- trol	4712.5 1026.8	4365.9 905.0	5463.5 1493.1	5176.9 1161.9	5331.3 1332.1	5339.8 1464.1	5315.4 1517.1	5147.6 1383.0	MSE df(n,d) F-ratio p	145727 7.16 (2,18) 1.29 .300	913947 .69 (4,36)^h 9.18 <.001	406487.01 (8,73)^h 1.04 .418
		RTX®	4714.5 1127.5	4246.5 939.2	5669.0 1613.1	5494.3 1572.2	5345.3 1363.8	5186.6 1123.6	5662.5 1304.5	5084.8 1508.6				
		Vest	4476.6 1443.7	4318.3 1345.0	4999.5 1637.2	5062.2 1333.1	5240.1 1489.7	5154.3 1278.6	5262.1 1476.0	4545.9 776.9				
	SDRTC	Con- trol	1357.7 366.0	1257.4 226.2	1687.8 543.9	1676.0 662.4	1869.6 723.7	1536.6 628.4	1921.2 704.6	1532.1 754.6	MSE df(n,d) F-ratio p	418310 .46 (2,18) 3.39 .056	237893 .61 (7,63) 5.00 <.001	129021.22 (13,121)^h .96 .495
		RTX®	1545.7 566.4	1336.1 549.2	1681.5 811.3	2009.4 744.3	1922.2 595.7	1667.5 677.0	2017.8 525.3	1737.5 719.3				
		Vest	1123.6 503.8	1446.9 630.3	1426.4 790.6	1444.5 516.5	1696.1 569.7	1441.8 524.2	1708.8 717.6	1499.9 627.7				
	Throughput	Con- trol	12.4 3.2	13.5 3.12	10.6 4.3	10.9 2.7	11.0 3.4	10.6 3.6	10.7 3.6	11.1 3.4	MSE df(n,d) F-ratio p	5.28 (2,18) 3.04 .073	4.10 (7,63) 8.56 <.001	2.60 (9,84)^h .506 .872
		RTX®	12.2 3.2	13.6 3.2	10.5 3.9	10.6 4.2	10.6 3.4	11.1 2.7	10.3 2.8	11.4 3.4				
		Vest	13.6 4.4	14.1 4.7	11.7 3.6	11.5 3.0	11.3 3.2	11.0 3.5	11.1 3.5	12.4 3.3				

Notes: 1. Numbers in each cell represent the mean (top) and standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the degrees of freedom.

Table VI.
Profile of Moods: Descriptive Statistics for Each Condition and Time, and ANOVA Results

Variable	Condition	Time 1	Time 2	Time 3	Time 4	ANOVA Results	Condition	Time	Condition by time
Anger	Control	40.1	38.8	40.5	39.8				
		3.3	2.4	3.5	2.1	MSE	9.26	5.40	16.46
	RTX®	40.0	40.7	40.8	40.2	df(n,d)	(2,20)	(3,30)	(2,22)^h
		6.2	5.5	3.9	2.6	F-ratio	.78	.85	.393
	Vest	39.6	39.1	40.1	39.9	p	.474	.476	.697
		2.9	1.8	4.7	3.2				
Confusion	Control	38.4	38.6	40.2	40.0				
		5.3	5.1	6.0	6.9	MSE	22.78	35.03	16.06
	RTX®	37.3	39.4	39.3	37.6	df(n,d)	(2,20)	(2,15)^h	(3,34)^h
		5.6	6.1	5.3	3.9	F-ratio	5.82	1.43	.57
	Vest	34.6	36.4	37.2	35.6	p	.010	.264	.662
		2.1	3.9	4.4	4.1				
Depression	Control	39.0	37.55	38.6	37.8				
		3.1	1.036	2.3	1.0	MSE	7.04	1.65	4.07
	RTX®	38.6	39.0	38.7	38.4	df(n,d)	(2,20)	(3,30)	(2,22)^h
		3.6	3.4	2.6	2.2	F-ratio	1.29	1.04	1.52
	Vest	37.7	37.5	38.0	37.9	p	.297	.382	.242
		1.3	.7	1.6	1.1				
Fatigue	Control	43.6	45.0	47.7	47.2				
		7.6	8.4	10.4	10.7	MSE	87.52	79.43	36.15
	RTX®	42.1	43.4	43.3	43.6	df(n,d)	(2,20)	(1,14)^h	(3,29)^h
		9.8	10.9	10.0	10.0	F-ratio	4.43	1.07	.41
	Vest	38.7	40.3	40.1	40.7	p	.026	.343	.741
		4.5	7.3	7.3	7.5				
Tension	Control	37.7	36.3	39.6	38.8				
		3.3	2.8	7.6	5.9	MSE	49.49	23.30	22.38
	RTX®	38.6	38.6	40.7	40.2	df(n,d)	(1,13)^h	(2,17)^h	(3,27)^h
		8.6	10.5	8.3	8.2	F-ratio	1.45	3.25	.14
	Vest	36.7	36.6	38.6	38.2	p	.260	.070	.920
		3.0	2.6	7.2	6.4				
Vigor	Control	44.0	39.5	36.3	37.2				
		11.0	9.7	7.7	8.6	MSE	61.63	73.39	13.93
	RTX®	45.4	39.0	39.9	38.6	df(n,d)	(2,20)	(1,14)^h	(6,60)
		9.9	8.6	9.9	8.3	F-ratio	3.96	9.02	.88
	Vest	47.9	42.9	41.2	43.4	p	.036	.006	.515
		11.8	11.0	8.9	11.7				

Notes: 1. Numbers in each cell are the mean (top) and standard deviation (bottom).
2. ^{h} indicates that the Huynh-Feldt adjustment was made to the degrees of freedom.

The weight loss (sweating rate) followed a similar pattern with most sweating during the control condition followed by the RTX® and then the cooling vest. In this case, there were statistical differences between all three conditions. Thus, it appears that the best cooling effect based upon the sweating rate was found with the cooling vest with the RTX® equipment in between control and cooling vest conditions.

The subjective heat score contiued to increase after the cooling down period in the chamber had started, representing the delayed response in core temperature compared to the rapid response in the skin temperature. The subjective heat score also showed the highest rating during the control condition compared to the cooling vest, but there was no statistical difference between control and RTX® conditions. The same pattern was seen for some of the mood variables, and for the heart rate recordings.

The skin temperatures were about the same for control, RTX® and vest conditions, except for the scapula temperature, which was lower with the cooling vest than the other two conditions. This may be explained by the fact that the scapula temperature was measured directly under the cooling vest and, thus, was directly influenced by the cooling effect of the vest. That also explains why the mean skin temperature was increased more for the control and RTX® conditions than for the cooling vest condition.

Neither cognitive test evinced sensitivity to the thermal manipulations used in this study, as evidenced by the lack of change between trial 1 and trial 2. This result is not surprising considering that the amount of heating which occurred (core temperature increased to an average of 98.7-99.0ºF for the different conditions) was below what others have found to be necessary for cognitive performance changes (e.g., Ramsey, 1983). For all conditions, performance declined on a number of outcome measures over the experimental session. The principal change was between the walking and sitting portion of the session. Performance was actually best during the walking portion (during the heating period). It appears that participants found it difficult to maintain attention to the tasks as the session progressed. This is most likely due to the repetitive testing regimen.

CONCLUSIONS.

For the aircrew preflight walk-around scenario in a hot and humid environment modeled in this study, the CV device will provide significant physiological cooling protection, but is not needed for cognitive protection since heat stress exposure was insufficient to cause cognitive decrements in the similarly hot and humid control condition. While RTX ®appeared to have some slight benefits compared to control (i.e., mean values tended to fall between control and cooling vest), there was little statistical evidence (other than that seen for sweating rate) to support this finding.

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