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Effects of a New Cooling Technology on Physical Performance in U.S. Air Force Military Personnel

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14. ABSTRACT
Heat-related illness is a critical factor for military personnel. Operating in high-heat environments can alter judgment and physical performance and even result in death. Therefore, the primary purpose of this study was to determine the effects of a cooling shirt provided by Arctic Ease® on core body temperature during high-intensity physical activity. Twelve trained (≥ 80^{th} percentile for aerobic fitness according to the American College of Sports Medicine, ≥ 90% on the U.S. Air Force fitness test), male Air Force participants (mean age 25 ± 2.8; height 178 cm ± 7.9; bodyweight 78 kg ± 9.6; VO_{2max} 57 mL/kg/min ± 1.9; and % body fat 10 ± .03) completed this study. Subjects performed a 70-minute weighted treadmill walking test and 10-minute, 50-pound sandbag shuttle test under two conditions: (1) "loaded," shirt with cooling inserts and (2) "unloaded," shirt with no cooling inserts. Order of conditions was counterbalanced by subject with a 72-hour recovery period between visits. Core body temperature, exercise heart rate, capillary blood lactate, and ratings of perceived exertion were recorded. Use of a "loaded" cooling shirt on core body temperature was statistically significant (p=0.001) during the 70-minute treadmill walking test. Peak core temperature during the 70-minute walking test was also statistically significant (p=0.038). No other statistically significant differences were observed for ratings of perceived exertion or blood lactate in either the treadmill or 10-minute sandbag shuttle tests. Heat-related illness is a critical factor for military personnel operating in high-heat environments. Traditional cooling technologies are limited by the need for a power supply, the added weight of the product, and the cooling duration. This lightweight (471 grams), passive cooling technology offers multiple hours of sustained cooling and reduced core and peak body temperature during a 70-minute weighted vest walking test.

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1.0 SUMMARY

Current cooling devices either must be frozen or contain a form of cooling crystals or gel packs that are enclosed within a fabric and are activated by soaking in water or by pressing a sensor attached to the cooling vest. The cooling effects provided are minimal and are not sustained, especially when ground troop soldiers are exposed to hot, humid conditions for long periods. The aim of this study was to determine the effects of a new cooling technology on various physiological parameters approximating the demographics of U.S. Air Force Special Operations Forces (Battlefield Airmen).

This group of researchers developed a cooling garment that can provide sustained cooling effects for longer than 2 hours. Initial research was conducted under dry heat conditions at 35°C/ 50% relative humidity as the first step to evaluate the technology. Effective cooling was determined to be 30 watts for the system. Calculations were based on the manikin zones covered by the shirt. Once thermal manikin data revealed a significant cooling effect, a human subject study was approved by the Air Force Research Laboratory Institutional Review Board. This study examined the effects of a cooling garment on core body temperature during physical activity with a 50-pound weighted vest, military issue boots, and fatigue pants. Participants completed two rigorous physical tests with and without cooling inserts to include a 70-minute treadmill weighted vest walking test where only core body temperature was measured and a physical work capacity test that required participants to carry a 50-pound sandbag until reaching volitional fatigue, which measured the work completed within a specific time period.

This cooling garment was a custom-designed shirt containing 44% pima cotton micro model, 8% polyester, and 4% spandex. Pockets of the same material were created to fully encapsulate the lightweight cryotherapy pad. The cooling medium is flame resistant to 815°C, adding to the garment's capabilities of meeting Air Force requirements for flame resistance. The shirt weighs 203 grams for a total of 471 grams with the cooling insert.

Physiological parameters measured included the following: (1) exercise heart rate, (2) capillary blood lactate, (3) core body temperature, and (4) subjective ratings of perceived exertion. There were two statistically significant findings. There was a significant difference in core body temperature during the 70-minute weighted vest walking test with the cooling shirt "loaded" (p=0.001) and peak core temperature (p=0.038).

2.0 INTRODUCTION

Heat-related illness is a critical factor for military personnel operating in high-heat environments and can alter judgment and physical performance. Therefore, the primary purpose of this study was to determine the effects of a novel cooling shirt on core body temperature during high-intensity physical activity.

Battlefield Airmen suffering from heat illness may experience reductions in physical performance that decrease their work capacity. Reductions in work capacity could severely limit the ability of Airmen to adequately sustain and satisfactorily complete specified duties required during intense ground operations. Physiological stressors caused by heat stress are expressed in individuals as reductions in cardiac output and reduced blood flow to splanchnic, skeletal muscle, brain, and skin tissues. Prolonged work (e.g., 8 hours) in hot, humid environments may also cause dehydration resulting from excessive sweat and associated sodium chloride losses in working skeletal muscle tissue, which collectively result in physical and mental exhaustion [1-4].

Basic physical training techniques exist that may aid in the prevention of heat stress, including heat acclimatization and ingestion of fluids before and during vigorous physical activity. Physical training techniques that aid in reducing resting core body temperature and conserving blood plasma volume are normally included in a military training program [5]. For example, acclimatization to the heat involves the subject engaging in intense exercise for a minimum of 6 days. Very fit subjects may require less time (e.g., 4 days) to become acclimated to the heat [1,5]. Once subjects become acclimated to the heat, 3-27% increases in blood plasma volume help maintain stroke volume and sweating capacity [1,5].

Other physiological benefits may also occur, such as reduced blood flow to the skin and increased central blood volume [1]. Although the training techniques may work to improve physiological functions of participants exposed to hot, humid conditions, the effects can be short lived when a soldier performs sustained, high-intensity physical activity in the heat. For example, excessive exposure to heat with impeded heat removal through the cerebral circulation can lead to accumulation of heat in the brain [6,7]. When heat accumulation exceeds removal in the brain, temperatures may exceed 40°C, potentially impairing the ability of soldiers and athletes to sustain normal work intensity [8]. With ongoing exertion, there may be restricted availability of glucose in the brain, invoking central fatigue. Continued bouts of high-intensity activity impose strains on the cardiovascular and locomotive systems leading to increases in soldiers' perceptions of efforts [9,10].

Additionally, when skeletal muscle contractions are combined with heat stress, the cardiovascular system can be pushed to its limit to simultaneously support the competing thermoregulatory demands for skin blood flow and metabolic demands of contracting skeletal muscles. Therefore, environmental heat stress and skeletal muscle exercise can interact synergistically to degrade human performance and induce heat illness [11].

3.0 BACKGROUND

During war and training, Battlefield Airmen are routinely exposed to a variety of environmental conditions that can alter judgment and physical performance and even result in death. Reductions in work capacity could also severely limit the ability of Airmen to adequately sustain and satisfactorily complete specified duties required during intense ground operations. Physiological stressors caused by heat stress are expressed in individuals as reductions in cardiac output and reduced blood flow to the brain, skeletal muscle, kidneys, and skin tissues. Prolonged work (e.g., in excess of 8 hours) in hot, humid environments may also cause dehydration resulting from excessive sweat and associated sodium chloride losses in skeletal muscle, which collectively result in physical and mental exhaustion [12-14].

The principal cause of heat stroke is failure of the hypothalamus temperature regulatory system. The failure of the hypothalamus to regulate body temperature results in the body's inability to dissipate heat, which induces an immediate excessive rise in core body temperature [15,16]. A high core body temperature, defined as greater than 41°C, may result in mental confusion, dry skin, delirium, convulsions, and unconsciousness [17,18]. The estimated death rate for subjects suffering from heat stroke is 20% [15].

Failure to train troops correctly or use the appropriate cooling devices in hot, humid environments may result in mission mishaps. For example, when heat accumulates in the brain and cannot be removed, brain temperatures may exceed 40°C, potentially impairing the ability of soldiers to sustain normal work intensity [8]. With ongoing exertion, there may be restricted availability of glucose in the brain, invoking fatigue. Brain temperature is a critical factor affecting motor skill ability during exercise in hot, humid conditions. During exercise under high temperatures, there is impaired ability to remove heat from the blood, and there is estimated to be a $7 \pm 2\%$ greater heat production in the brain. Based on these results, the mean brain temperature is estimated to be at 0.2°C higher than core body temperature during sustained aerobic exercise in either normal or hot, humid conditions, ultimately impairing cognitive ability [10]. Additionally, when a troop member suffers from fatigue because of a physical or cognitive heat-related illness, an estimated four members of the squadron are needed to carry him/her any distance [17]. Therefore, the prevention of heat illness among military troop members seems prudent in ameliorating battlefield mishaps and improving field performance.

Although Battlefield Airmen are normally acclimated to extreme environmental conditions before battlefield exposure, acclimation is not complete unless physical training is performed at high exercise intensities in the heat. For example, optimal acclimatization requires subjects to elevate their core body temperature and produce an hourly sweat rate of 400-600 mL at temperatures in excess of 30°C for a minimum of 5 days [9,15]. Many Battlefield Airmen may not have the opportunity to experience such exposure durations before deployment to a battlefield zone. Therefore, they may be prone to developing heat-related illnesses, which may place limitations on their physical performance.

Cooling devices have been introduced to combat heat illness. They are often applied to the neck and head region, based on the concept that brain temperature can be controlled through regulation of cerebral blood flow, which can be regulated through active cooling of that region [6,10,18,19]. The degree of constriction within the carotid arteries is related to the temperature. Active cooling of the neck enhances the vasodilator response of the carotid arteries, effectively cooling the cerebral vessels [2,19].

Local cooling of the carotid arteries during high-intensity exercise has been found to attenuate increasing brain temperatures, reduce core temperatures, and improve perceptions of physical efforts [10]. Researchers suggest that cooling of the neck region (e.g., right and left carotid arteries) may attenuate heat-related illnesses during strenuous physical effort in hot environments and may improve physical performance (work capacity) [6,7,18,19].

Cooling devices, including neck-cooling collars, cooling bandanas, cooling vests, neck-cooling devices, and clothing containing cooling micro-gels, have been effectively used to reduce core temperature. This cooling may contribute to enhanced work capacity. However, these cooling vests, bandanas, and neck-cooling devices may be bulky and frequently require ice or gels, which are impractical for many troops who must carry all of their gear for long distances. Supplies become a burden for logisticians. Traditional cooling treatments (such as immediate hydration or placing overheated individuals in a cool room) remove the troops suffering from heat illnesses from their relevant wartime duties, which places greater physical demands on other troop members. Those may not be options in some circumstances. Clearly, there is a need for effective portable methods of cooling.

Current cooling devices either must be frozen or contain a form of cooling crystals or gel packs that are enclosed within a fabric and are activated by soaking in water or by pressing a sensor attached to the cooling vest. The cooling effects provided are minimal and are not sustained, especially when ground troop soldiers are exposed to hot, humid conditions for long periods.

Furthermore, bandanas or neck straps connected to a core-cooling vest are not strategically placed directly over the right or left common carotid artery. The cooling vest requires a generator to be worn in the backpack to sustain a continual cooling effect. The water or gel necessary for the cooling vest adds additional weight. Current devices to prevent heat illness are therefore ineffective for Battlefield Airmen exposed to extremely hot, humid conditions. The Arctic Ease® cooling shirt could provide sustained cooling effects, would not necessarily add weight to the Airmen's backpack, would not require maintenance, and could be used by a large number of Airmen.

4.0 METHODS

4.1 Subjects

Twelve healthy, active duty, male military members between the ages of 19 and 30 were recruited for participation in this study (age: 25.42 ± 2.84 years; height: 178.9 ± 7.92 cm; weight: 78.25 ± 9.61 kg; VO_{2max}: 57.96 ± 1.96 mL/kg/min; body fat: 10 ± 0.03%). Each provided written informed consent in accordance with the Air Force Research Laboratory Institutional Review Board. Eligibility for study participation was determined during a physical screening evaluation on the first visit. Body composition was assessed using a three-site skinfold measurement of the chest, abdomen, and thigh [20]. Aerobic fitness was assessed using a single-stage submaximal treadmill walking test [21]. Subjects ranking in the top 80th percentile for aerobic fitness and top 60th percentile for body composition, according to American College of Sports Medicine normative data [22], were eligible for study entrance.

4.2 Experimental Protocol

Subjects meeting the inclusion criteria returned to the laboratory for four additional testing sessions, each separated by a minimum 72-hour recovery period. For each testing session, subjects wore a novel cooling garment and military issue fatigue pants and boots. The cooling garment consisted of a custom-designed, form-fitting shirt made from moisture-wicking fabric with a pocket over the chest and back for the placement of a cooling, cryotherapy insert. Two hours prior to each testing session, subjects were asked to swallow a core body temperature pill (CorTemp; HQ Inc., Palmetto, FL) with a glass of tepid water. Subjects returned to the laboratory 72 hours after each test to confirm that the CorTemp Core Body Temperature Sensor was properly expelled from the digestive track.

During the first and second testing sessions, subjects completed a 70-minute, 50-pound weighted treadmill walking test. One session was performed with the cooling inserts loaded into the shirt (loaded) and one session was performed without the cooling inserts (unloaded). Treatment order was counterbalanced by the subjects to minimize order effect. First, subjects were fitted with a 50-pound weighted vest (Better Fitness, Inc., Baton Rouge, LA) and heart rate monitor with chest strap (POLAR® Heart Rate Monitor System; HQ Inc., Palmetto, FL). Next, subjects performed a 5-minute aerobic warm-up on the treadmill (WOODWAY USA, Waukesha, WI) at 0% grade. During the warm-up period, subjects self-selected a comfortable walking speed. After the 5-minute warm-up, treadmill grade was increased to 2%. Subjects then walked continuously for 60 minutes at the pace selected during the warm-up. Finally, subjects performed a 5-minute recovery walk at a self-selected treadmill speed. Exercise heart rate and core body temperature were captured continuously using the CorTemp Data Recorder (HQ Inc., Palmetto, FL). Perceived exertion was assessed every 3 minutes using the 6 (very, very light) to 20 (very, very hard) graded scale [23]. Capillary blood lactate was assessed with the Lactate Pro Blood Lactate Test Meter (YSI, Inc., Yellow Springs, OH) within 3 minutes of the recovery period.

During the third and fourth testing sessions, subjects completed a 10-minute, 50-pound weighted lift and carry shuttle test. Again, loaded and unloaded sessions were counterbalanced by the subjects. Subjects were instructed to lift a 22-kg sandbag from the ground and carry it 10 meters, placing it onto a platform at a height of 1.45 meters. Subjects then returned the sandbag to the floor at the start line, signifying one complete shuttle. Subjects completed as many shuttles as possible in 10 minutes while wearing a 50-pound weighted vest (BetterFitness, Inc.) and POLAR heart rate monitor. Exercise heart rate and core body temperature were captured continuously using the CorTemp Data Recorder. Perceived exertion was assessed every 2 minutes using the 6 (very, very light) to 20 (very, very hard) graded scale [23]. Capillary blood lactate was assessed with the Lactate Pro Blood Lactate Test Meter within 3 minutes of completing the shuttle test.

4.3 Statistical Analysis

Analysis was performed using SPSS software for Windows (version 19; IBM, Armonk, NY). Means and standard deviations were calculated. Differences were assessed using a two-factor (insert x time) repeated-measures analysis of variance. When a significant F-ratio was obtained, paired t-tests were used to isolate differences among treatment means. Pearson correlations were used to evaluate associations among variables. An alpha of $p \leq 0.05$ was considered statistically significant.

5.0 RESULTS

This study examined the effects of a cooling shirt on core body temperature during physical activity with a 50-pound weighted vest, military issue boots, and fatigue pants. Participants completed two rigorous physical tests, with and without cooling gel inserted into a lightweight shirt with pockets located on the front and back: a 70-minute treadmill weighted vest walking test where only core body temperature was measured (Figure 1) and a sandbag shuttle test that required participants to carry a 50-pound sandbag for 10 minutes or until reaching volitional fatigue.

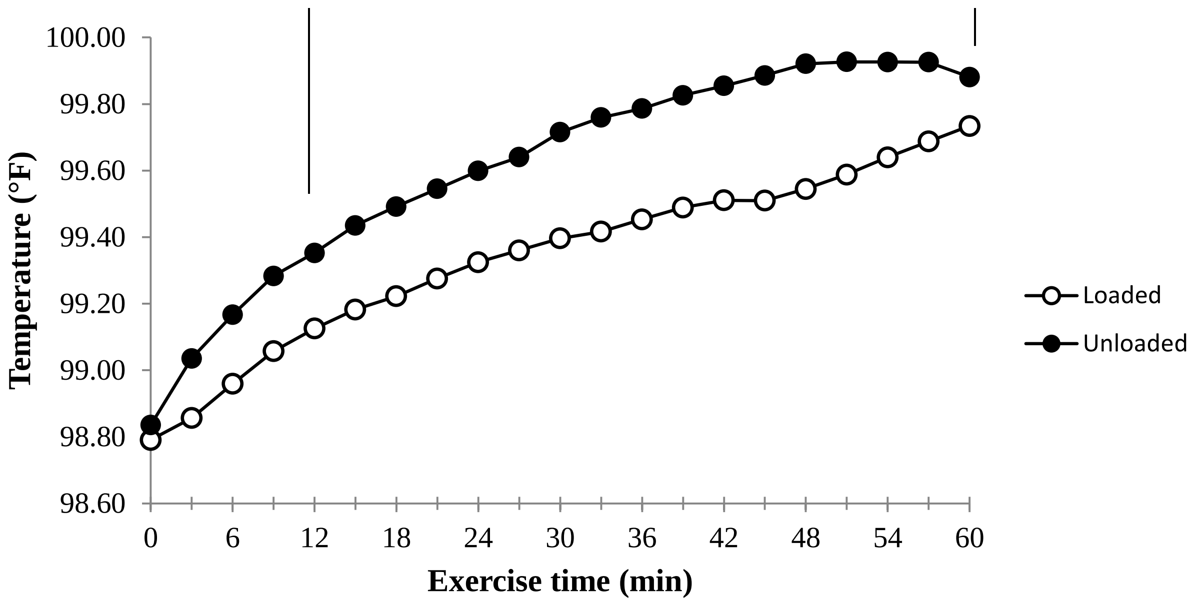
The two physiological tests chosen for this study simulated “real” time field performance tests typically required of Special Operators during training and in the battlefield. Special Operators may be exposed to harsh environmental conditions such as hot, humid climates [11]. The cooling shirt is a practical device for the Special Operators both in training and on the battlefield. Hence, testing this product’s effectiveness in reducing core body temperature and enhancing human performance fulfilled an Air Force Special Operations Command research gap related to exertional heat illness.

The independent variable for this study was the cooling shirt technology and the dependent variables for this study included (1) core body temperature, (2) exercise heart rate,

(3) physical work capacity test, (4) capillary blood lactate, and (5) subjective ratings of perceived exertion.

There were two statistically significant findings ($p<0.05$). There was a significant difference in core body temperature during the 70-minute weighted vest walking test with the cooling shirt "loaded" ($p=0.001$) and peak core temperature ($p=0.038$) during the 70-minute treadmill weighted vest walking test with the cooling shirt "loaded."

No statistically significant differences were found in participants' subjective ratings of perceived exertion, blood lactate, or number of sandbag shuttles completed in 10 minutes.



6.0 DISCUSSION/CONCLUSIONS

The primary aim of this study was to determine the effects of a cooling shirt with cooling gel inserts on core body temperature during high-intensity physical activity on a treadmill.

A secondary interest was to determine the effects of a cooling shirt on physical work capacity (e.g., sandbag shuttle) and various other physiological parameters related to physical performance. Examination of the effects of this cooling technology substantiated its role in mitigating heat-related illnesses and improving physical performance in a like group of Special Operators in a controlled laboratory environment. However, additional studies should examine this cooling shirt in the field during training while completely covered.

Current cooling technologies must either be frozen or contain a form of cooling crystals or gel packs that are enclosed within fabric and are activated by soaking in water or by pressing a sensor attached to the cooling vest. The cooling effects provided are minimal and are not sustained, especially when ground troop soldiers are exposed to hot, humid conditions for long periods.

Since results indicate a significant impact on core body temperature and peak core body temperature, future plans are to present the results to the Air Force Special Operations Command and to test a newer version of the shirt in the Human Performance laboratory and then expand to field testing at Hurlburt Field, Florida. Additional plans are to test the effectiveness of the cooling shirt on aircrew, flight maintainers, and emergency room doctors in non-air-conditioned rooms overseas.

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