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13. ABSTRACT *(Maximum 200 words)*

This study evaluated performance after lowering core temperature at different rates while local tissues were either cooled (lower body) or not cooled (upper body). METHODS: Ten men volunteered to perform up to eight cold water immersions (CWI) at combinations of two water temperatures (10° C and 15° C), two depths (waist (W), chest (C)) and two walking speeds (0.44 or 0.88 m/s) until their core temperature fell to 35.5° C, stabilized above that temperature, or they requested to stop. They also completed a control trial (120 min rest in 19° C air; CON). Immediately following each CWI and CON, cognitive and physical performance tests were performed in cold air (10° C; CAE). RESULTS: Overall, the CWI protocol lowered rectal temperature by 0.3°-1.0° C. Mean skin temperature was ~26° C and finger temperature was ~15° C during CAE. No statistical differences were observed across trials for any cognitive test. On the physical performance tests, step test performance was degraded ~12% on CWI trials, compared to CON, but there were no differences in manual dexterity, hand grip strength, marksmanship, or pull-ups. CONCLUSIONS: These results indicate that cognitive performance can be maintained despite mild hypothermia, and that physical performance is related to local tissue temperature, without being altered by moderately reduced core temperature.

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RESEARCH ARTICLE

Cognitive, Psychomotor, and Physical Performance in Cold Air After Cooling by Exercise in Cold Water

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Introduction: This study evaluated performance after lowering core temperature at different rates while local tissues were either cooled (lower body) or not cooled (upper body). ***Methods:*** There were 10 men who volunteered to perform up to 8 cold water immersions (CWI) at combinations of 2 water temperatures (10°C and 15°C), 2 depths [waist (W), chest (C)], and 2 walking speeds (0.44 or 0.88 $m \cdot s^{-1}$) until their core temperature fell to 35.5°C, stabilized above that temperature, or they requested to stop. They also completed a control trial (120 min rest in 19°C air). Immediately following each CWI and control, cognitive and physical performance tests were performed in cold air (10°C; CAE). ***Results:*** Overall, the CWI protocol lowered rectal temperature by 0.3–1.0°C. Mean skin temperature was ~26°C and finger temperature was ~15°C during CAE. No statistical differences were observed across trials for any cognitive test. On the physical performance tests, step test performance was degraded ~12% on CWI trials compared with control, but there were no differences in manual dexterity, hand grip strength, marksmanship, or pull-ups. ***Conclusions:*** These results indicate that cognitive performance can be maintained despite mild hypothermia, and that physical performance is related to local tissue temperature, not a moderately reduced core temperature.

Keywords: immersion, temperature, prediction.

COLD STRESS IS known to adversely affect both cognitive and physical performance (9). Although much data exist, it remains difficult to predict performance degradation in cold environments. One reason may be the large variety of performance tasks used, which differ in requirements for simple vs. complex mental calculations, fine vs. gross motor skills, muscle power vs. endurance, etc. For this reason, the U.S. Special Operations Command developed a standardized test battery of cognitive (23) and physical (28) skills, the Mission-Related Performance Measures (MRPM). The tasks were chosen by their relevance to mission requirements, accuracy and reproducibility, and logistics for administration, allowing use in both laboratory and field studies. Despite the use of standardized tests, conflicting results have still been observed during cold exposure, highlighting other potential confounding factors, such as varied environmental conditions and exposure duration, as well as additional mental or physical stressors (10,22,27,28).

Rate and magnitude of fall in core or local tissue temperatures are important factors for predicting performance degradation, yet these have not always been controlled or reported in previous studies. Although manual dexterity typically deteriorates as skin temperature falls below 15°C (8), greater performance degradation is observed with slow cooling compared with fast cooling, since deeper tissues cool more under those conditions (5). Furthermore, some performance tasks, such as cognitive function, appear to be primarily altered by central cooling (6), while others, such as muscle strength or manual dexterity, may be more dependent on local tissue cooling (8,14). Core cooling is difficult to achieve during cold air exposure alone, due to the combined effects of peripheral vasoconstriction and shivering. During cold water immersion, the high rate of heat transfer rapidly lowers core temperature, and physical activity may actually increase heat loss. A cold stress that reduces core temperature while allowing skin temperatures to remain above the threshold where performance degradation occurs may clarify the role of hypothermia on performance.

This study used a series of cold water immersions (CWI) to elicit different rates of core cooling through various combinations of water temperature, immersion depth, and exercise intensity. The effect on performance of these three independent factors has not previously been studied. The CWI conditions were chosen according to immersion guidelines that represent a range of conditions where soldiers may be wading through water either waist- or chest-deep with arms not immersed (26). This model is based on water-crossing scenarios used in military training and operations, such as the conditions that contributed to the hypothermia deaths of four Army Ranger students in 1995 (29). Understanding the cognitive and physical performance degradation associated with hypothermia can provide insight into how hypothermia may alter the capability of sol-

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diers to complete a mission or to contribute to rescue efforts.

The objective of this study was to use an experimental design of pre-cooling to increase body heat loss while not directly cooling the upper body. The following hypotheses were examined: 1) reduced body core temperature will impair memory and learning; 2) direct tissue cooling in the lower body will degrade performance on a step test by reducing the strength and power of muscle contractions; 3) performance on upper body physical performance tasks will not deteriorate despite mild hypothermia, since the upper body is not pre-cooled.

METHODS

This protocol was approved in advance by the U.S. Army Research Institute of Environmental Medicine Scientific and Human Use Review Committees. Written informed consent was obtained from each person who volunteered to participate after being informed of the purpose, experimental procedures, known risks of the study, and their right to withdraw from the study at any time without prejudice or penalty. Investigators adhered to Army Regulation 70–25 and U.S. Army Medical Research and Materiel Command Regulation 70–25 on the Use of Volunteers in Research.

Experimental Design

There were 10 male enlisted soldiers who participated in this study. Their physical characteristics (mean ± SD) were: age 20 ± 2 yr; height 178 ± 7 cm; weight 73 ± 7 kg; body fat 16 ± 4%; and $\dot{V}O_{2peak}$ 47 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$. Subjects were asked to complete nine trials: one control (2 h resting at normal room temperature, 19°C, 40–50% RH) and eight CWI trials at combinations of two water temperatures (10°C and 15°C), two depths [waist (W), chest (C)], and two walking speeds (0.44 or 0.88 $m \cdot s^{-1}$) on an underwater treadmill. The arms and hands were not immersed during any trial. Trials were denoted by water temperature, depth, and speed: e.g., 10C44 or 15W88. The trials were counterbalanced among subjects. Only one trial was completed each day, and there was at least 1 d in between trials for each subject.

In each of the CWI trials, subjects were removed from the water when their rectal temperature (T_{re}) reached 35.5°C, if they requested to stop for any reason, or after a maximum of 4 h of immersion. They then changed into dry shorts, socks, and shoes. After the control trial and each CWI trial, the subject proceeded to the cold air exposure (CAE, 10°C, 40% RH, wind speed ~0.2 $m \cdot s^{-1}$) chamber where the MRPM cognitive (23) and physical (28) performance tasks were conducted. In addition, a self-paced cycle ergometer task was performed after the MRPM. Completion of all tasks during CAE took approximately 1 h.

Measurements: Body composition was determined by dual X-ray absorptiometry (Lunar DPXL densitometer, GE Healthcare Lunar, Madison, WI). Volunteers with body fat greater than 20% were excluded from participation in the study because subcutaneous fat provides insulation against body core cooling and core cooling was desired in this study. Fitness level was determined using an incremental cycle ergometer test. Subjects exercised at 60 W for 2 min, 120 W for 2 min, and 180 W for 2 min, after which the workload was increased 15–30 W every 2 min until volitional exhaustion. Peak aerobic power ($\dot{V}O_{2peak}$) was measured using an online metabolic analysis system (Sensormedics, Yorba Linda, CA).

On the morning of each trial, the subjects placed a rectal temperature probe (Yellow Springs Instruments, Inc., Yellow Springs, OH) 10 cm past the anal sphincter, and placed an esophageal temperature probe (Yellow Springs Instruments, Inc.) at approximately the level of the heart, estimated as 1/4 of the height of the individual. Although it is well established that esophageal temperature (T_{es}) is more responsive and a better representation of central temperature than rectal temperature (T_{re}) (16), not all subjects can successfully tolerate probe placement, and in these cases the subjects performed the trials using only the rectal temperature probe. Esophageal temperature was measured in five subjects during all trials, in two subjects during five of the trials, and in the remaining subjects during one to two trials. The esophageal probe was removed prior to the performance tasks to avoid tangling the wires, particularly during weapon disassembly/reassembly and marksmanship tasks. Heat flow/thermistor sensors (Concept Engineering, Old Saybrook, CT) were attached at 11 skin sites: foot, calf, anterior thigh, abdomen, chest, triceps, anterior aspect of the forearm, subscapular, forehead, dorsal hand, and the dorsal middle phalange of the middle finger. Holes were cut in the tape used to attach the sensors (Tegaderm, 3M, St. Paul, MN) to securely attach the sensors to the skin without directly covering the disks themselves. Mean weighted skin temperature was calculated as $T_{sk} = 0.06T_{foot} + 0.17T_{calf} + 0.28T_{thigh} + 0.14T_{chest} + 0.07T_{tricep} + 0.07T_{forearm} + 0.14T_{subscapular} + 0.07T_{hand}$. Mean weighted heat flow (H_c, $W \cdot m^{-2}$) was calculated using the same weightings.

Performance tests: The MRPM consists of six cognitive tests, two psychomotor tests, and three physical performance tests described in detail below. Tasks were completed in order of increasing metabolic activity in order to maintain reduced body temperatures as long as possible. Cognitive tests were completed first, followed by weapon disassembly/reassembly, marksmanship, hand grip strength and endurance, pull-ups, and step test. On separate days prior to experimental testing, five practice sessions were completed at a neutral room temperature for each task to ensure consistent performance, based on data from previous studies (10,22). Following the step test, subjects completed a self-paced cycle ergometer task that is not part of the MRPM. The cycle ergometer task was practiced at a neutral temperature on three occasions before testing began. A *t*-test conducted on the last two practice sessions indicated no further learning effect on any performance task.

Cognitive tests: The computer-based cognitive tests are described in detail by Thomas & Schrot (23).

Match-to-Sample evaluates short-term spatial memory and pattern recognition. On subject initiation, an

8×8 matrix appears with a random pattern of red or green squares. After 3 s, the screen blanks for either a short (1-s) or long (15-s) delay, after which 2 matrices appear, only 1 of which matches the original (the other differing in 1 or 2 of the 64 squares). Time to make a response and which matrix is chosen are recorded. Completion of 20 trials takes ~5 min.

Complex Reaction Time displays a set of boxes in the same orientation as the four arrow keys on the keyboard. A red square appears randomly in a box, and the subject must press the corresponding arrow key, after which the red square immediately appears in another square. The task lasts ~1 min. Response time and accuracy are measured.

Logical Reasoning measures general reasoning ability using true or false statements about the sequence of two letters presented on the screen, "AB" or "BA." The statements may be positive/negative, active/passive, and refer to whether one letter precedes or follows the other. This task takes ~3 min for 32 presentations.

Visual Vigilance evaluates sustained visual attention and choice reaction time. Letters or numbers appear briefly (0.5 s) in the center of the screen, with random delays (1–5 s) between presentations. The subject must press the down-arrow when only "A" or "3" appear. This task takes ~6 min for 100 presentations.

Serial Addition/Subtraction measures the ability to perform simple calculations. Two digits are presented with either a plus or minus sign. If the answer is positive, the last single digit of the answer is to be entered. If the answer is negative, the subject must add 10, and then enter the resulting single positive number. This task takes ~2 min for 50 presentations.

Repeated Acquisition assesses the subject's ability to learn, decode, or acquire a key press sequence. There are 12 blocks presented and the subjects must learn the sequence of up, down, right, or left arrow keys by trial and error over 15 total presentations. This task takes ~8 min.

Psychomotor tests: An M-16 rifle was disassembled in 12 specific steps then reassembled. Time for disassembly and reassembly was recorded, typically 1–2 min. Rifle marksmanship speed and accuracy were measured using a single stationary target laser system (Noptel, Oulu, Finland). Note that this task differs from the marksmanship task in the MRPM, as previously described (28), due to space limitations in the cold air chamber. However, this task has previously been demonstrated to be sensitive to a variety of environmental stressors, including hypoxia (20) and operational stress in a cold-wet environment (21). Subjects waited with the rifle below waist level, then took their shot after a red LED light appeared at a random time (1–10 s). Three sets of five shots fired from a standing, unsupported posture at a target simulating 46 cm at a distance of 50 m were analyzed. Calculated parameters included distance from center of mass (mm), which was the distance between the average shot location of a five-shot series from the center of the target; shot group tightness (SGT, mm^2), which was the area in which the five shots were clustered; and sighting time (min), which was the time from appearance of the red LED until the trigger was pulled. This task took ~2 min.

Physical performance tests: Right hand grip strength was measured on three maximal efforts, followed by a measure of handgrip endurance. Because tissue cooling can affect muscle strength, the hand grip endurance task used the force determined as 50% of the average maximum grip strength obtained during the last practice session (normal room temperature). Thus, even if cold stress on any trial altered maximum grip strength, grip endurance was still measured at the same absolute force. Hand grip strength and endurance took ~5 min.

Pull-ups were performed from a hanging position with knees bent. The maximum number of pull-ups (full arm extension to chin over the bar) was recorded. Also, a single step test was performed while wearing a 20-kg weight vest. This task differed from the MRPM as previously described (28), in that only one step was used due to height limitations in the cold air chamber. Subjects were instructed to complete as many steps (up with one foot, then the other and down with one foot, then the other, all together counting as one step) as possible in 1 min.

Immediately following the step test, subjects completed a self-paced cycle ergometer test of a fixed amount of work ($3\ kJ \cdot kg^{-1}$ bodyweight). The initial work rate was set for each subject to reflect a 50% $\dot{V}O_{2peak}$ exercise intensity at a pedal cadence of 60 rpm, but the subjects could thereafter alter the work rate according to their preference throughout the test. Subjects were instructed to complete the task as quickly as possible.

Statistical analyses: Data were analyzed with repeated measures analysis of variance using a general linear model procedure (SAS Institute, Cary, NC). Missing data were replaced with the harmonic mean. When main effects or interactions were significant, Tukey's honestly significant difference post hoc test was applied to determine where significant differences between means existed. Significance was set at the $p < 0.05$ level. Because the large number (27) of performance test analyses increases the probability of a Type I error, i.e., finding significant differences when they do not exist, a Bonferroni correction was used which requires a significance level of $p < 0.001$ to maintain a $p < 0.05$ level of significance after the correction was applied. Data are presented as mean ± SD.

RESULTS

Out of 80 possible cold water immersion trials, 70 trials were completed. Two subjects voluntarily withdrew from the study before completing all trials and one subject was withdrawn after six trials for medical reasons.

A representative subject's response of rectal, mean skin, hand, and finger temperatures during CAE is shown in **Fig. 1**. The fall in T_{re} on movement associated with marksmanship, pull-ups, and step test is expected after cold water immersion as the blood circulates through the cooled tissues of the lower body. The increase in T_{re} and T_{finger} toward the end of the CAE reflect

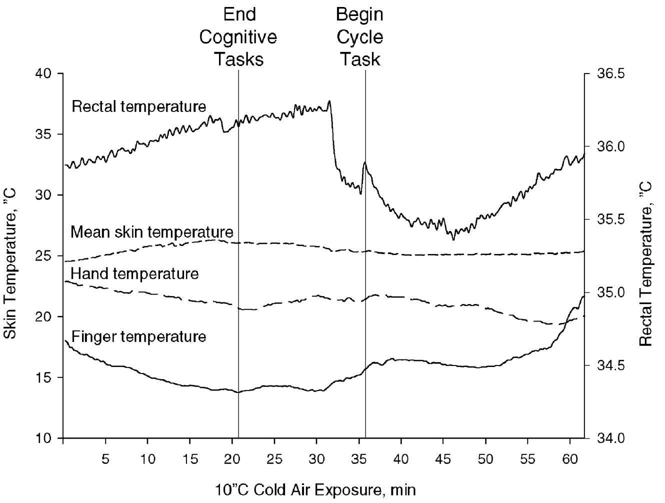

Fig. 1. Mean skin, hand, finger temperatures (left hand axis) and rectal temperature (right hand axis) during cold air exposure for subject 5 following chest-deep walking at 0.44 m · s^{-1} in 10°C water. Vertical lines indicate the time the subject completed the cognitive tasks and when he began the final cycle exercise task.

the elevated metabolic heat production during the cycle ergometer task.

On 26 trials the target T_{re} (35.5°C) was reached. Four subjects reached the intended core temperature limit of 35.5°C on all trials, with the exception of 15W88, during which only one subject cooled to 35.5°C. On the trials where the core temperature limit was not reached, T_{re} either stabilized above 35.5°C (39 trials), or subjects were removed from the cold water due to foot or leg discomfort associated with continuous underwater treadmill walking (1 subject on 5 trials). Overall, initial T_{es} (36.4 ± 0.2°C) was lower ($p < 0.05$) than initial T_{re} (36.7 ± 0.2°C), but final T_{es} (35.8 ± 0.5°C) and T_{re} (35.9 ± 0.4°C) did not differ ($p = 0.055$).

Table I presents the number of subjects completing each trial, duration of immersion on each trial, change in T_{re} during CWI, T_{re} at the beginning of CAE, T_{sk} during CAE, lowest finger temperature during CAE, and H_c during CAE. There was a significant main effect ($p < 0.0001$) for T_{re} at the beginning of cold air exposure, with post hoc analysis indicating that T_{re} was lower ($p < 0.05$) on all cold trials compared with control, but not significantly different among cold trials. Similarly, there was a significant main effect ($p < 0.0001$) for T_{sk}, with post hoc analysis indicating that T_{sk} was ~2–2.5°C lower ($p < 0.05$) on all of the cold water trials compared with control, with no difference among cold trials.

Step test performance was degraded ($p < 0.0001$) due to CWI, with post hoc analysis indicating a decline in number of steps completed on all CWI trials (pooled value: 46 ± 4 steps) compared with control (52 ± 4 steps), with no significant difference among CWI trials. No statistical differences were found for any other performance test; therefore, data from CWI trials and control were pooled for presentation of the results. Cognitive test performance scores (percent correct) were: Match-to-Sample (59 ± 12); Complex Reaction Time (91 ± 11); Logical Reasoning (81 ± 21); Visual Vigilance (93 ± 8); Serial Addition/Subtraction (95 ± 5); and Repeated Acquisition (66 ± 20). Weapon assembly/disassembly time was 103 ± 22 s. Results for marksmanship parameters were: distance from center of mass, 5.3 ± 1.2 mm; SGT, 84 ± 38 mm^2; and sighting time, 6.7 ± 2.9 s. Grip strength was 44 ± 13 kg; grip endurance was 59 ± 16 s; pull-ups numbered 11 ± 5; and the self-paced cycle ergometer test time was 22.8 ± 3.1 min.

DISCUSSION

The purpose of this study was to examine the effects of reduced body core temperature and lower-body precooling on cognitive and physical performance. The CWI protocol was intended to reduce rectal temperature to 35.5°C, and this target temperature was reached on about one-third of the trials. Overall, the CWI protocol lowered rectal temperature 0.3–1.0°C, with T_{sk} ~26°C and finger temperature ~15°C during CAE. It was hypothesized that lowered core temperature would impair cognitive performance on memory and learning tasks, and that reduced local tissue temperature would degrade physical performance only on the step test, since the legs cooled during CWI whereas the upper body did not. While step test performance was degraded by ~12% and there was no performance degradation in upper body tasks, cognitive performance was not impaired by the cold stress. The results of this study indicate that cognitive performance can be maintained despite moderate core cooling, and that physical

TABLE I. IMMERSION TIME AND CHANGE IN RECTAL TEMPERATURE (ΔT_{RE}) DURING COLD WATER IMMERSION (CWI); INITIAL T_{RE} AT THE START OF COLD AIR EXPOSURE (CAE); MEAN SKIN (T_{SK}) AND LOWEST FINGER (T_{FMIN}) TEMPERATURE AND MEAN HEAT FLOW DURING CAE.

	Control n = 10	15W88 n = 10	15W44 n = 9	15C88 n = 9	15C44 n = 9	10W88 n = 9	10W44 n = 8	10C88 n = 8	10C44 n = 8
Immersion time, min	N/A	158 ± 48	150 ± 59	118 ± 41	119 ± 39	82 ± 27	92 ± 39	88 ± 41	87 ± 39
CWI initial T_{re}, °C	36.7 ± 0.3	36.7 ± 0.2	36.7 ± 0.2	36.7 ± 0.2	36.7 ± 0.2	36.7 ± 0.2	36.7 ± 0.1	36.6 ± 0.4	36.7 ± 0.2
CWI final T_{re}, °C	36.6 ± 0.3	36.3 ± 0.3*	35.8 ± 0.3*	36.1 ± 0.5*	35.9 ± 0.4*	36.0 ± 0.5*	35.9 ± 0.4*	35.8 ± 0.3*	35.7 ± 0.2*
CAE T_{sk}, °C	28.7 ± 0.8	26.9 ± 0.6*	26.1 ± 0.8*	26.2 ± 0.8*	26.0 ± 0.5*	26.3 ± 0.6*	26.2 ± 0.8*	26.0 ± 0.8*	25.7 ± 0.6*
Heat Flow, W · m^{-2}	118 ± 7	119 ± 10	111 ± 9	115 ± 7	110 ± 10	115 ± 12	111 ± 6	106 ± 6	109 ± 6
CAE T_{fmin}, °C	15.6 ± 1.5	14.2 ± 1.1*	14.4 ± 1.3*	14.3 ± 1.1*	14.4 ± 1.2*	14.2 ± 1.1*	14.8 ± 1.3*	14.7 ± 1.1*	14.5 ± 1.3*

During the control trial subjects sat for 120 min in 19°C air before CAE. Other CWI trial abbreviations indicate water temperature (15°C or 10°C), immersion depth [waist (W) or chest (C)], and walking speed (0.44 m · s^{-1} or 0.88 m · s^{-1}). Number of subjects (n) that performed each trial is indicated. Data are expressed as mean ± SD. * $p < 0.05$, compared to control.

performance is primarily related to local tissue temperature, not reduced core temperature.

Cognitive performance during cold exposure has varied among protocols, with some studies showing degradation, while others show no change, and no clear relationships between performance and either skin or core temperature have emerged (9). Such observations have led some investigators to propose other theories for altered performance, rather than changes in body temperature. Teichner (18) suggested the cold environment causes distraction, resulting in inattentiveness to the task at hand, whereas Enander (6) suggested that arousal due to mild cold exposure could account for the improved performance that sometimes occurs (19). Krausman et al. (11) suggested the pressure to perform and/or anxiety associated with a stressor may either degrade or enhance performance, depending on the experience and skill of the individual. It follows, then, that performance degradation could be limited by training under stressful scenarios, such as the cold conditions of the present study, once the task has been learned under ideal conditions to ensure optimal skill development. This strategy has been found to be effective for improving manual dexterity in cold environments (1,13,15).

Physical performance is closely related to changes in local tissue temperature. Tissue cooling impairs muscle strength, slows nerve conduction velocity, and reduces joint mobility (8), all of which may have contributed to decreased step test performance. Muscle function begins to decline at muscle temperatures below $\sim$27°C (2), and data from previous studies suggest this temperature threshold was reached in the present study. Ducharme and Tikuisis (4) report muscle temperatures of 18–25°C (superficial to deep tissues) during 60 min of forearm cooling in 15°C water, and in our subjects the legs were immersed in 10–15°C water for 82–158 min. This degree of tissue cooling did not occur in the upper body, since the arms were not immersed in cold water, and forearm ($\sim$28°C) and hand ($\sim$20°C) skin temperatures during cold air exposure remained above the thresholds typically associated with performance degradation (8). While manual dexterity may initially be affected at skin temperatures as high as 20°C, there is an abrupt performance degradation when skin temperature falls below $\sim$15°C (8), and a subsequent drop at $\sim$4°C as tactile sensitivity is impaired (14). No performance changes were observed for upper body tasks despite the lowered core temperature. This agrees with the findings of Giesbrecht et al., who report no decrease in hand grip strength with lowered core temperature (35.8°C) when arm temperatures were kept warm (7).

Performance prediction models could improve soldier operational effectiveness by assisting decision-making to determine: 1) whether a particular mission can be completed; or 2) whether it may require additional resources or time. Tikuisis (24) originally designed the Cold Exposure Survival Model to predict cognitive impairment and survival time (to lethal hypothermia), then later modified the model to include motor function impairment of the arms and hands to determine how long an individual would be capable of self-help (25). The model uses threshold temperatures for core, muscle, and finger skin temperatures to determine when performance will be degraded to "moderate" or "severe" levels. Based on the conditions of this model, performance decrements would not have been predicted under the conditions of the present study, with the exception of step test performance due to muscle cooling. Xu et al. (30) developed a model based on finger skin temperature to predict manual dexterity during cold exposure ranging from 1–7 h. This model would predict 20% degradation in manual dexterity based on finger temperatures of 15°C. In the present study, finger temperatures fell to 15.6°C during the control trial and were significantly lower by 0.8–1.4°C during the cold trials, yet no significant differences were found on the weapon disassembly/reassembly task, even when compared with the last practice session that was performed under normal ambient conditions (19–20°C). However, the exposure in the present study was only $\sim$20 min at the time of this task, highlighting the importance of duration of cold exposure that affects the extent to which underlying tissues are cooled.

There are some limitations to this study that could confound data analysis and interpretation. A power analysis (two-tailed test, Statistica software, StatSoft, Tulsa, OK) performed using data from previous studies (22,28) determined that 10 subjects would be required to detect differences in marksmanship performance and 11 subjects would be required for manual dexterity (weapon disassembly/reassembly) at a suggested power of 0.80 and with α set at 0.05. However, not all subjects completed all trials, and core temperature was not consistently reduced to 35.5°C during all trials. Because of this, the statistical power was reduced, which may explain why we did not find performance degradation on the cognitive and psychomotor tasks. In contrast, another study in our laboratory demonstrated 18% degradation in Match-to-Sample and 14% degradation in marksmanship performance after a sedentary CWI that consistently reduced rectal temperature to 35.5°C (12). This indicates that these tasks are sensitive to core cooling, yet neither task was significantly affected by cold stress in the present study. One possibility is that there is a threshold of core temperature reduction for deterioration of cognitive performance that was not achieved in the present study. However, memory registration has been shown to deteriorate at core temperatures as high as 36.7°C (3), and Shurtleff et al. (17) found poorer performance on Match-to-Sample with a cold air exposure (4°C for 60 min) that would not have reduced core temperature. Another factor may be the low statistical power due to the large number of trials. For example, marksmanship shots were dispersed over a 32–59% larger area on all cold trials (pooled data for SGT: 87 ± 39 mm^2), compared with control (59 ± 19 mm^2), yet because of the large inter-individual variability on the marksmanship task, our level of statistical significance was not met. Nevertheless, the degradations observed in the marksmanship measurements represent meaningful differences that are of importance to soldiers operating in cold environments.

In conclusion, this study demonstrates that cognitive performance can be maintained despite mild hypothermia, and that physical performance is related primarily to local tissue temperature, without being altered by reduced core temperature. Soldiers can best limit performance degradation by minimizing body cooling through effective use of cold-weather clothing, using physical activity to increase body heat content, and by conducting training exercises under stressful conditions after skills have been developed in ideal learning environments.

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