PHYSICAL AND COGNITIVE PERFORMANCE DURING LONG TERM COLD WEATHER OPERATIONS

By
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A Thesis
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CHAPTER I. OVERVIEW

ABSTRACT

During extended cold weather operations, humans are subject to decrements of physical and cognitive performance. Performance has been shown to decline during short term and long term cold exposure. Previous studies have shown a decrement in muscle strength, dexterity, and complex mental tasks during short term cold exposure. Long term cold exposure studies have examined cognitive performance, but no physical performance or physiological parameters were measured. Studies were generally conducted in laboratory settings.

A study was developed to examine the effects of extended cold weather operations on physical and cognitive performance, and physiological responses, where testing was conducted under field conditions. We studied five groups participating in nine-day cold weather survival courses offered by the Canadian Forces School of Survival and Aeromedical Training. Subjects (28 men) were instrumented for continuous field measurements of core temperature (T_{co}) and heart rate. Finger tip temperature (T_{finger}) was measured only at time of testing. Physical performance was evaluated with tests of strength (i.e. hand grip and upper body strength) and dexterity (i.e. lace-tying, nut-bolt, and a GPS entry test). Cognitive performance consisted of tests of logical reasoning, planning, and vigilance. Subjective scales of exertion, cold sensation, and mood were also used.

Results indicated that hand grip strength (-12%) and dexterity [i.e. lace-tying (-31%), nut-bolt (-16%) and GPS] were detrimentally affected by cold. Cognitive tests showed no performance decrements.

These results demonstrate that the cold exposure of the survival courses (-24.4 °C to +4.4 °C) was sufficient to induce a decline in strength and dexterity, but not in cognitive performance.

INTRODUCTION

Long term cold weather operations present several challenges to the participants, including achieving physical comfort, maintaining a positive mental attitude, and preserving the ability to perform tasks adequately. Understanding the factors that affect human performance during prolonged operations in the cold is of importance to military personnel who operate in the cold, and to rescue personnel during the rescue of cold injury victims. Advances in military technology (like night-vision devices, and firepower) and changes in doctrine (like an around-the-clock capability) dictate that military members continue to be prepared to operate under adverse conditions. Some of the factors that may affect performance in long term cold weather operations are: cold, exertional fatigue, sleep deprivation, dehydration, and nutritional deficit. Outdoor enthusiasts and military planners will be interested in knowing which, and how, these factors affect both cognitive and physical performance.

The present literature that examines the effects of exposure to cold on humans can be divided into two main categories: short term and long term. Short term studies were generally conducted in a laboratory setting and did not normally expose subjects to more than three hours of cold stress. The effects of cold on performance are of two kinds, peripheral effects, which influence strength and manual dexterity (17,20), and central effects which influence cognitive performance (38). It is known that cold exposure results in a decrement of physical and cognitive performance (11,19,20,38). Physical performance can be evaluated with physical strength and dexterity tests.

Studies that examined physical strength have reported decreased strength with cold exposure (19,20,28,40). Gaydos (16) and Gaydos and Dusek (17) have shown a decrement in dexterity when the hand was cooled. Giesbrecht and Bristow (19) showed a decline in manual dexterity with whole body cooling. These studies have shown that local arm temperature played a significant role in both manual strength and dexterity. Physiological responses of core temperature (19,20) and heart rate (19) were also examined during cooling.

The effects of cold on mental performance have been examined with various cognitive tests (8,11,18,38). Overall, more complex tasks were more detrimentally affected by cold exposure than simpler tasks.

Only two long term studies have examined the effect of cold on performance (2,37). These studies were limited in that only a small number of cognitive responses were examined.

Exertional fatigue can lead to an impairment of performance and increase the perceived effort necessary to complete a task (29). Sleep deprivation has been shown by Angus and Heslegrave (1) to decrease cognitive performance, and by McCann and Pointing (25) to detrimentally affect planning. Dehydration is a significant threat to cold weather operations as a major contributing cause of cold injury and loss of effectiveness. As a result of dehydration, the decrease in circulating blood volume could lead to less oxygen and nutrient delivery to the peripheries, thus impairing physical performance (13,21). Nutritional deficit may be of concern to performance, because normally, during cold weather operations, there is a restriction of food and water intake, and without proper nutrition, energy stores decrease and eventually, so will task performance.

Despite the extensive work done on cold and performance, two main limitations remain: first, the studies that included physical, cognitive and physiological responses, were short term studies, second, the long term studies examined a limited number of cognitive responses, and no physical performance or physiological data were presented. All the above short-term and long-term studies were conducted in a laboratory setting.

STATEMENT OF THE PURPOSE

The purpose of the present investigation was to examine physical and cognitive performance and physiological responses to cold during long term cold weather operations, where testing was conducted under actual field conditions.

IMPORTANCE OF THE STUDY

This study is important on two accounts: first, it examined a relationship that had not yet been reported, that of both physical and cognitive performance, and physiological responses during prolonged operations in the cold; second, testing was conducted in the field while subjects were training in field operations. This is of importance to military personnel who operate in the cold, to rescue personnel during the rescue of cold injury victims, and to outdoor enthusiasts.

Over two winter seasons we studied five groups participating in nine-day cold weather survival courses offered by the Canadian Forces School of Survival and Aeromedical Training (CFSSAT) in Winnipeg, Canada.

HYPOTHESES

We expected both physical and cognitive performance to decrease in the field compared to baseline testing, and that performance decrements would be greater when the average air temperature of survival courses was lower.

ASSUMPTIONS

Military operation schedules were assumed to remain the same throughout the range of the testing period. The military requirements and activities should remain relatively equal during the period of the study. Cold was expected to be the most variable factor to affect performance during testing because the survival courses were given the same tasks, sleep time, water, and food. The factor not necessarily common throughout the seasons was cold.

LIMITATIONS

This study was conducted in a non-laboratory setting with military personnel. This limited the amount and type of equipment that could be used to test the hypotheses. All equipment had to be portable and endure transport between test sites. The schedule of the military operation had to be adhered to, this limited the time available to test the subjects. Also, adverse environmental conditions like air temperature may affect the co-operation and willingness of the subjects to participate in this study.

REVIEW OF RELATED LITERATURE

INTRODUCTION

This review is intended to serve four purposes. First, a brief discussion of thermoregulation and homeostasis of humans will be presented. Next, physical and cognitive responses during short term cold exposure will be discussed. Third, an examination of the effect of long term cold exposure on cognitive performance is presented, and finally, the effects of exertional fatigue, sleep deprivation, dehydration, and nutritional deficit on human performance are briefly examined.

THERMOREGULATION AND HOMEOSTASIS

The human is a homeotherm, which means it is designed to maintain a constant core body temperature independent of the environmental temperature. Temperature regulation in man is primarily the role of the hypothalamus. The hypothalamus acts as a thermostat that keeps the human body within narrow limits of a set temperature (14). In order to regulate body temperature, the hypothalamus integrates sensory information form three sources: 1) peripheral thermal receptors; 2) thermal sensitive cells in the central nervous system; and 3) core thermal receptors (34). In general, the hypothalamus responds to changes in the temperature of the blood that reaches it, and to nerve impulses from temperature receptors in the skin and in the core of the body. The anterior area of the hypothalamus is sensitive to an elevated body temperature and responds by increasing heat loss, whereas the posterior area is sensitive to a lowered body temperature by reducing the rate of heat loss and increasing the rate of heat production .

Body temperature is maintained at a constant level because of the balance between heat production and heat loss. Some factors that increase heat production over the basal metabolic rate are exercise, shivering, and fever. Sweating, vasodilation, and exposure to a cooler environment are some factors that can enhance heat loss. Heat is lost from the body by conduction, convection, radiation, and the evaporation of water (33,34). Heat loss through the skin depends on the temperature gradient between the skin and the air or objects surrounding the skin. The temperature of the skin is regulated by the blood flow to the skin and by evaporation (34). Blood flow to the periphery is regulated by alterations in the caliber of the blood vessel. Contraction or relaxation of the spiral smooth muscles in the vessel wall determines the size of the vessel. Vasoconstriction occurs as a result of increased sympathetic activity mediated by the stimulation of alpha receptors by norepinephrine. Beta receptors stimulated by epinephrine result in vasodilation (14). Vasoconstriction maintains low skin temperature and minimizes heat loss to the environment, whereas vasodilation increases skin temperature and maximizes heat loss to the environment (34).

Conduction refers to heat lost due to physical contact between the skin and fixed objects. Convection refers to heat transferred to a circulating medium such as air or water (27,34). Convective heat loss increases as the movement of the air or water increases over the body.

Radiation refers to heat lost by the transfer of electromagnetic infrared waves between objects. The amount of heat loss depends on the temperatures of the objects. For example, if a person sits near a large window on a cold winter day, the temperature of the glass may be 2 °C, even though the air temperature in the room is higher, say, 24 °C. Radiation that leaves the person's body is higher than that returning from the glass because the glass temperature is lower than that of the body, and the body experiences a net heat loss.

Heat lost by the evaporation of water falls under three types: 1) insensible perspiration; 2) thermal sweat; and 3) non-thermal sweat (emotional sweat). Insensible perspiration is constantly leaving the body unless the surrounding relative humidity is 100 %. This moisture leaves the body through pores of the sweat glands by diffusing through the strata of the skin, and from the lungs during exhalation. Thermal sweating occurs from the eccrine sweat glands in the skin. Non-thermal sweating occurs from the eccrine sweat glands in the palms of the hands and soles of the feet, and the apocrine sweat glands in the axillae and forehead. This type of sweating is triggered when the person is not necessarily under heat stress but is experiencing emotional disturbances. Once a liquid is on the surface of the skin, it is then subject to evaporation if the relative humidity is less than 100 % (39). The phase change from a liquid to a gas in evaporation is exothermic and takes heat away from the body. This evaporation lowers skin temperature (34).

EFFECTS OF COOLING

The human is a bare-skinned animal with a limited amount of subcutaneous fat, leading to susceptibility to cold. However, man can control cold environments with clothing and shelter. A physiological adaptation to cold seen in humans is a rise in metabolic rate as an acute response to cold (32). If the cold exposure is repeated, a metabolic adaptation may develop where the resting metabolism at thermal neutrality is increased (27).

Exposure to a cold environment can affect motor and cognitive performance. Motor responses include body movements like strength, coordination and dexterity. Cognitive responses are those that include reasoning, planning, and vigilance.

PHYSICAL RESPONSES DURING SHORT TERM COLD EXPOSURE

Numerous short term studies have been conducted on humans examining various aspects of physiological, physical, and cognitive performance under cold stress. Physical performance can be evaluated with physical strength and dexterity tests.

Physical Strength: Studies that examine physical strength normally report decreased strength with cold exposure (6,7,19,20,31,32). Giesbrecht and Bristow (19) measured hand grip strength which requires static contraction of the forearm flexor muscles, the tests were conducted before and during immersion in cold water. There was an immediate, but not significant decrease in hand grip strength upon water immersion, and strength continued to drop as core temperature decreased during immersion. The authors describe the following as possible mechanisms for their results, first, local cooling may increase viscosity of synovial fluid and tissues of the hands, this could interfere with joint movement. Likewise, there could be an increase in the viscosity of the flexors and extensors of the fingers and their tendon sheaths. The muscles could also be suffering from a decrease in the metabolic rate, enzyme activity, excitability of nerve membranes, decreased nerve conduction velocity, and decreased calcium and acetylcholine release.

There is evidence that manual arm performance is unrelated to body core temperature. Giesbrecht et. al. (20) developed a protocol that allowed for core and peripheral temperatures to be changed independently. Arm performance could then be examined under varying temperature combinations. Temperature in the biceps muscle was measured while subjects were immersed in water under three conditions, 1) cold body-cold arm; 2) warm body-cold arm; and 3) cold body-warm arm. Hand grip strength decreased by 68 % from baseline after 70 minutes of immersion in the conditions where the arms were cooled, regardless of a warm or cold body core. The cold body-warm arm condition did not result in significantly different scores from baseline. The authors report that muscle temperature was the main predictor of performance, which accounted for 85-98 % of the decrease in test scores (20).

Oksa and Rintamaki (28) explain that muscle cooling decreases force production during exercise and that a decrease in core temperature is not a prerequisite for a decrement in performance. Cooling decreases the ability of certain components of physical performance to function, namely, power, force production, velocity, and co-ordination. Some of the mechanisms which may account for decrement in performance are decreased peripheral circulation, ATP hydrolysis, conduction velocity, rate of calcium release and absorption, and increased muscle stiffness and shivering. The decrement in performance is likely the combination of several of these mechanisms (28).

Dexterity: Some of the tests used to measure dexterity in the arms and hands are knot tying, block stringing, and nut and bolt assemblies (16,17,19,20,24,35). Gaydos (16) examined the effect of cooling the body while maintaining the hands at normal temperature on complex manual performance. Gaydos (16) used a controlled temperature room with an electrically heated box to enclosed the hands and forearms to a temperature that was independent from the rest of the room. Subjects were clad in shorts, T-shirt, socks, and shoes. Ambient room temperature was kept at 8 °C for both experiments. For the condition with warm hands, the warming box was maintained at 30-35 °C. A thermocouple on a fingertip indicated hand temperature. The dexterity tests used in this study were knot tying and block stringing. Subjects had 30 seconds to tie as many knots as possible in one length of 2.5 meter cord for one the tests. The other test consisted of stringing cubed blocks of wood with a hole in the center onto a cord. Gaydos (16) found that manual performance degraded if both the body and the hands were cooled, and that no change occurred in performance when the body was cooled, if the hands were kept warm. Gaydos (16) explained that task performance deteriorated to an extent which seemed to depend on the degree of hand cooling. Hand skin temperature was described as being the primary factor associated with a decrement in performance. Gaydos (16) relates this relationship to practical field conditions where hand temperature may be lower than the rest of the body and that special care should be taken when working outdoors.

Gaydos and Dusek (17) tested manual dexterity with two experiments using the same equipment as described above (16). In the first, only the hands and wrists were cooled, while the rest of the body was exposed to a room temperature of 20-25 °C. In the second, subjects were fully clothed in a cold environment (-10 °C) but with bare hands. Manual performance degraded in both experiments, but no differences were reported between the two experiments. Knot tying and block stringing were performed as described above for Gaydos (16). This study did not measure mean skin temperature or core temperature, but did measure fingertip temperature during both experiments. The authors arrived at the conclusions that the performance of a complex manual task is adversely affected by lowering the temperature of the hands, and that the decrement in performance is a function of local hand and forearm temperature, regardless of the thermal environment surrounding the body (16).

Giesbrecht and Bristow (19) used two dexterity tests to analyze manual arm performance during whole body cooling. The tests used were speed of flexion and extension of the fingers, and manual dexterity. Subjects opened and closed the dominant fist as quickly as possible five times. This was a dynamic movement that required contractions of the forearm flexor muscles. The manual dexterity test comprised of a peg and ring board with ten rings on one peg. Subjects moved the rings from one peg to another peg, then back to the original peg as quickly as possible. These tests were performed at three times: 1) Prior to immersion in 8 °C water; 2) just after immersion; and 3) every 15 minutes thereafter until termination of immersion. The dexterity tests did not show a significant decrease immediately after cold water immersion. The decrease in test performance was greater during the first drop of 1 °C in core temperature. The decrement in the speed of movement was greater than that of the peg test as core temperature decreased by 1 °C. The authors attributed increased joint viscosity of synovial fluid and tissues of the hand as a possible mechanism for the results (19).

The results presented indicate that the relative decrement in the speed of movement test was greater than that of the peg test. This may be because the speed test relies on fast movements of cold joints. Cold did not affect manual dexterity of the peg test to same extent as the speed test because larger, more central upper arm and shoulder muscles were required to move the arm during the peg test. These larger muscles may not have been cooled as much as the forearm muscles (19).

Using the previously described protocol, Giesbrecht et. al. (20) independently controlled peripheral and central body temperature. They examined arm performance with a variety of dexterity tests: speed of finger flexion and extension, finger dexterity, hand and finger dexterity (nut and bolt test), manual movement (peg and ring test), and speed of arm movement. Speed of finger movement, finger dexterity, and the nut and bold tests were classified as fine motor tests. The peg and ring, and speed of arm movement tests were considered gross motor tests. Tests were administered four times during each of the three conditions. The gross motor test followed similar trends as the warm body-cold arm and cold body-cold arm conditions. Data for these two conditions did not differ from each other as performance decreased until the third or fourth trial. During the cold body-warm arm condition scores did not differ from baseline in any of the tests. This same pattern was seen in the fine motor tests, where no change from baseline was recorded in the conditions with cold arms as performance decreased until the third or fourth trial (20).

This study has controlled the temperature of the local tissue involved in task performance and isolated it from the rest of the body. It has demonstrated that the majority of the decrement in arm performance during mild hypothermia is due to the local effects of cooling on arm tissue (20).

In summary, it has been shown by the above studies that peripheral arm temperature plays a significant role in manual performance, in both strength and dexterity. Local cooling in the arm, regardless of a warm or cold core results in degradation of manual performance. Lowering of hand temperature has two effects, first it numbs cutaneous sensitivity, and second, it attenuates manual dexterity (15).

The explanations put forth on the local effects of cooling may be physical or neuromuscular in nature (20). Overall, high arm muscle and hand temperatures are critical in maintaining good performance in the hand.

COGNITIVE RESPONSES DURING SHORT TERM COLD EXPOSURE

Moderate cold refers to an environmental temperature that is above freezing, and even though it does not normally induce core hypothermia, it can induce physiological and behavioral effects (38). Some of the physiological and physical effects of cold have been discussed, this review will now focus on the cognitive effects of cold exposure.

Various cognitive tests have been used to examine the effects of cold on mental performance (4,10,12,15,30,36). Ellis (10) and Enander (12) examined the effect of cold on reaction time. Ellis (10) exposed subjects for 1.5 hours to −12 °C air while they performed simple reaction time tests and found a decrease in performance due to low skin temperature and not to low core temperature. Enander (12) examined reaction time in the cold with two experiments. The first was done at an ambient temperature of 5 °C and the second at 21 °C. The average fingertip temperatures for the two conditions were 14 °C and 30 °C respectively. Enander (12) reported a decrease in performance of complex tasks, including reaction time.

Teichner (36) tested the effect of cold on reaction time at ambient temperatures of –37 °C, and –26 °C with wind speeds of 5, 10, 15, and 20 mph. Subjects were 620 males that watched a light on a screen and responded when they saw the light. No decrement in performance was observed at low wing speeds (5,10 mph), but there was a linear decrement with higher wind speeds (15, 20 mph). The authors attributed the results to psychological factors (36).

Ellis et. al. (11) designed a study to examine where and how cold affected serial choice reaction time (SCRT). SCRT requires the subjects to quickly decide if a digit is odd or even by pressing one of two buttons. As soon as a response is made, another randomly selected digit is presented to the subject. To examine the effect of cold on SCRT, two experiments were used. In the first, fast cooling experiment, analgesics were administered to reduce the distracting effects of cold. Subjects wore shorts and were exposed to an ambient temperature of –5 °C. Skin and rectal temperatures were measure with thermistors. Two types of SCRT were used, 8-choice (i.e. digits 1-8), and 4-choice (i.e. digits 1-4). Overall, 8-choice SCRT trials produced more errors than 4-choice trials. Also, errors in the cold were greater than either before or after cold exposure. In the second, slow cooling experiment, subjects were slowly cooled to the level of the fast cooling experiment over a period of 3 hours in a cold room at 8 °C. Subjects were clad in shorts and a sweater and again, skin and rectal temperatures were measured. No changes in 8-choice SCRT were noted in the slow cooling experiment. Therefore, the authors concluded that it is not slow cooling that causes performance changes, but fast cooling, since fast cooling affects peripheral muscles more dramatically than slow cooling (11).

The fast cooling experiment demonstrated that more complex tasks were detrementally affected by cold exposure. Thomas et. al. (38) have examined the effect of moderated cold exposure on complex cognitive performance. The cognitive test used in this study was a complex conditional discrimination known as matching-to-sample. This task requires a correct choice from two simultaneously presented matrices which matches a previously presented sample matrix. The authors wanted to identify acute and repeated effects of moderate cold exposure on matching-to-sample performance. Subjects were clad in shorts, t-shirts, and socks during the experiments. Skin and rectal temperatures were measured. Subjects were tested after 60 minutes of exposure to an ambient temperature of 22 °C, and moderate cold of 5 °C. Skin temperature was significantly lower during cold than during ambient conditions. Accuracy on the matching-to-sample procedure was lower during moderate cold (5 °C), than during 22 °C exposure. This study reported impaired performance of matching-to-sample cognitive performance during exposure to a moderate cold temperature of 5 °C (38).

Giesbrecht et. al. (18) have also examined the effects of task complexity on performance in the cold. Several tests of varying complexity were administered. The auditory attention continuous performance test was used to evaluate sustained vigilance for simple auditory stimuli. The subject listened to a sequence of letters on an audio tape and indicated the frequency that a certain letter was heard. The Benton visual recognition test evaluated complex visual perceptual organization ability, and short term visual memory. The subject was presented with a plate with four figures on it for 10 seconds. The plate was removed for 15 seconds, then another plate was presented, also with four figures on it. The subject was asked which of the four figures was identical to the original figure (18).

The stroop word and color test was used to test the subject's susceptibility to interference by competing response tendencies. In the first test, the word test, the subject read as many words as possible (eg, red, green, and blue) in 45 seconds. In the second test, the color test, "XXXX" was printed in red, green, or blue ink. Subjects were asked to name the color of the ink. The third test, the word-color test, asked subjects to read a word that was printed in an ink color that did not match the word itself (18).

The final cognitive test was the digit span task. This test measured attention, concentration, vigilance for auditory stimuli and short-term memory. In the first part of the test, the examiner read out a series of numbers ranging from three to nine digits in length. The subject was then asked to repeat the numbers in the same order as the examiner had read them. In the second part of the test, the subject was again read a series of digits, but this time, the subject was asked to repeat the numbers in the reverse order the examiner had read them (18).

Tests were administered on three occasions: 1) prior to cold water immersion; 2) after immersion in 8 °C water but before any decrease in core temperature; and 3) after 55 to 80 minutes of immersion when core temperature had decreased 2-4 °C. Auditory retention, Benton visual recognition and Forward Digit Span tests did not differ in the three trials. The Stroop word test had higher raw scores than the color test, which in turn had higher scores than the word-color test. This indicates that this test presents progressively increasing difficulty. Neither the Stroop, nor the Backward Digit Span tests were significantly affected by cold water immersion, prior to reduction of core temperature. Scores on the Stroop word, and color naming tests were lower at the final end cooling, than prior to water immersion (18).

The authors concluded that simple cognitive tests such as auditory attention, visual recognition, and forward digit span, were not affected by peripheral or central cooling. However, more complex cognitive tests that require mental manipulation, like the backward digit span, or mental process and analysis, like the Stroop test, are detrementally affected by central cooling (18). The above studies lead to the conclusion that complex cognitive tasks are more adversely affected by cold than simple tasks.

Baddeley (3) developed a logical reasoning test based on grammatical transformation that has been used in cognitive performance studies (1,4,9). This logical reasoning test consists of sentences that claim to describe the order of two letters, A and B. The subject's task is to read each sentence and to decide whether that sentence is a true or false description of the letter pair which follows it. Subjects are instructed to work as quickly as possible without making mistakes. There are 64 possible combinations that describe the arrangement of A and B. This test can be performed rapidly and yet it is demanding enough to be sensitive to any fall in intellectual capacity (3).

Monk (26) has designed a Visual Analogue Scale (VAS) technique to detect changes in mood. Questions have been developed to quickly and easily assess the subject's affective state (such as feelings, and mood), and the level of vigor (such as alertness, and vigilance) (26). The test used by Monk (26) is based on the VAS. VAS techniques have a history of being used in the evaluation of mood. These tests involve a question, below which is a line, normally 10 cm long, where the subjects mark their response. Labels at either end of the line indicate opposite extremes of the mood, and the mark made by the subjects represents their feelings at the time of testing. Monk showed the mood scales to be sensitive enough to detect various changes in the mood of subjects.

LONG TERM COLD EXPOSURE

Teichner and Kobrick (37) tested the visual-motor performance of five soldiers in a constant temperature chamber for 41 days. For the first 16 days, the temperature was held at 22 °C, for the next 12 days at 12 °C, and for the remaining 13 days at 22 °C. Subjects were clad in shorts, T-shirts, and socks. No physiological measurements were taken. The visual-motor test measured time–on-target for the apparatus. Subjects were given 15 practice trials per day, each trial was 20 seconds long, and there was a 10 second interval between trials. Visual-motor performance was markedly and immediately impaired in the cold, and recovered gradually, but to a lower limit than during 22 °C. An immediate recovery in performance was seen at the onset of the recovery period (22 °C on day 29). The authors explain the impairment in performance as a result of a lowering of the final limit of performance rather than a reduction of the rate or limit of learning. This study shows that there is an impairment in cognitive performance even in 12 °C ambient temperature (37).

Angus et. al. (2) investigated the effect of cold exposure on vigilance performance in men working and sleeping under arctic conditions. Training, baseline, and recovery sessions were conducted in a laboratory. The field sessions were conducted in a room in the arctic with an ambient temperature ranging from 0 °C to 5 °C. The testing apparatus consisted of a screen which occasionally displayed small diffuse spots of light only slightly brighter than the background. The subjects wore headphones that sounded with "white noise" and masked out any external noises that could otherwise distract them from the screen. Subjects could record their detection of a signal on the screen by a hand-held button. The subjects were tested eight times in the field on alternate days. Each test period lasted 40 minutes with the subjects continuously watching the screen for the occasional appearances of the signal (2).

The authors examined the relation between detection performance on a demanding visual vigilance task and changes in REM sleep in men required to sleep and perform under arctic conditions.

Sleep measurements were done on the experimental nights. The subjects wore electrode montages for the sleep recordings and sensors for body temperature. Sleep data was recorded continuously. During the baseline and recovery sessions in the laboratory, subjects detected 75 % of the signals presented. The test following the first night of sleep in the cold presented with 50 % detection of the signals presented. This represents the subjects' poorest performance during the experiment. From this day, performance gradually improved, returning to baseline during the final two field sessions. The decreased performance in the field may be related to the mean overnight temperature during nights preceeding each field session. The amount of REM sleep was decreased during colder nights. Subjects performed better following sleep on a night of warmer temperatures than following colder nights (2). Angus et. al. (2) have shown that performance of a demanding visual task declines under arctic conditions and decreased sleep quality (i.e. REM sleep).

The two studies described above (2,37) have shown that cognitive performance is negatively affected by prolonged exposure to cold. These studies add valuable information to the field, but they are limited in that they did not report continuous physiological measurements like core temperature and skin temperature. No physical tasks were performed, only cognitive responses were measured. Testing was also conducted in a laboratory setting and was not performed daily.

EXERTIONAL FATIGUE

Exertional fatigue can lead to an impairment of performance and increase the perceived effort necessary to complete a task (29).

PERFORMANCE RESPONSES DURING SLEEP LOSS

Sleep loss has been shown to decrease cognitive performance by Angus and Heslegrave (1). Twelve female subjects were continuously monitored during a 54 hour period of wakefulness. This study maximized performance degradation by applying continuous, high demand, mental workload and by using sensitive cognitive tasks. Subjects were isolated during testing periods and worked alone in single 3 x 4 m operator work stations with a video display terminal. Their duty was to monitor a communication network and perform certain cognitive tasks.

The 54 hour period of sleep deprivation consisted of nine identical 6 hour performance blocks, with the same sequence of activities occurring in each block. Two main types of tests were administered, self-report scales, and cognitive tests. Self-report scales examined the subject's fatigue and sleepiness levels and mood. The serial reaction time task required the subjects to cancel an illuminated light by pressing a corresponding button as quickly as possible. Once the light was extinguished, another light was illuminated, and the sequence was repeated (1).

Angus and Heslegrave (1) used the logical reasoning task devised by Baddeley (3). They presented the subjects with sixteen logical reasoning sentences for completion. Short term memory was tested with a digit span for the subjects to memorize and repeat once the last digit had been exposed. Auditory vigilance was tested with clearly audible tones presented over headphones. The subjects' task was to detect the tones and respond by pressing a key on a response panel (1).

The analyses revealed significant changes in all self-report scales during the study. Subjective fatigue, sleepiness, and mood all changed significantly during the 54 hour wakefulness period. Serial reaction time performance significantly changed during the study. This decrease in performance is attributed to the declining number of correct responses made per minute rather than to an increase in the number of errors. Results of the logical reasoning task are similar to those of the serial reaction time in that declines in performance are attributed to the declining number of correct responses rather than to changes in the number of errors. Logical reasoning results dropped to 57 % and 26 % of baseline after 24 and 48 hours of sleep loss respectively. Auditory vigilance also presented with a significant decline in performance of 66 % and 38 % of baseline after 24 and 48 hours respectively (1).

McCann and Pointing (25) examined how sleep deprivation affected planning. Planning is a fundamental and critical aspect of military missions. Planning can be done in advance of some operations, but depending on the situation, planning may be done under extreme time pressure. Typically, military planning problems involve space and time, and many units of varying capabilities. Thirty four Canadian Forces personnel participated in this study. The planning task presented to the subjects was to determine an efficient dumping order of 15 types of ammunition required at different locations in a military area. The ammunition was distributed between two vehicles with different carrying capacities and travelling speeds. The aim in planning was to make the most efficient use of the vehicles and have them take the shortest possible route through the military area (25).

The area of the planning test was based on three layouts of dumping sites. Comparable but different problems were created by varying the capacity of the vehicles and by rotating and/or reflecting the map layout (25). Subjects completed one planning problem every two hours during 50 hours of sleep deprivation. McCann and Pointing (25) reported that performance on the planning task was affected detrimentally by sleep deprivation.

RESPONSES TO DEHYDRATION

Dehydration is a significant threat in cold weather operations and is a major contributing cause of cold injury and loss of effectiveness (32). Physical performance in the cold is closely related to water balance in the body. Water balance is tightly coupled with nutrition and depends on both the quality and quantity of food consumed.

Normally, there is restriction of food and water intake during cold weather operations. Water balance is disturbed in the cold as a result of many factors, namely: metabolic rate increases in cold due to heavy clothing, and increased costs of movements in snow; abundant sweating due to heavy exercise; and, increased respiratory water loss due to dry inspiratory air. Dehydration results in increased blood viscosity and decreased blood volume which may decrease blood flow to the periphery, thus decreasing the body's ability to adjust to cold stress, possibly due to an inability to maintain peripheral skin temperatures. The combined diminution effect in circulation of increased viscosity and decrease blood volume especially to cooled arm muscles could impair physical performance (32).

Jimenez et. al. (22) examined plasma volume changes during and after acute exercise-induced dehydration and heat-induced dehydration. Exercise-induced dehydration was accomplished with a treadmill exercise at 60 % of V_{O2max}, and heat-induced dehydration was accomplished by passive dehydration of body mass. In both conditions subjects were dehydrated to 2.8 % loss of body mass. Blood hematocrit (Hct), hemoglobin concentration (Hb), plasma protein concentration, and plasma osmolality were measured before, during and after changes in body hydration. Under euhydration status, blood hematocrit (ratio of volume of red cells to volume of whole blood) is close to 42 %, and hemoglobin concentration is about 150 $g \cdot l^{-1}$ (5). The authors report an increase in all of the above factors, confirming that dehydration causes concentration of plasma volume (22).

Dehydration results in concentrated plasma, with increased viscosity. If this is not alleviated, the viscosity of the blood makes it harder to push through the vessels, and more cardiac power is needed to move blood through the circulatory system (5). For persons who are active in the cold, and under the effects of dehydration, like participants in the survival course, more cardiac power leads to higher energy requirements.

NUTRITION

Nutritional deficit may be of concern to performance (23), because normally, during cold weather operations, there is a restriction of food and water intake, and without proper nutrition, energy stores decrease and eventually, so will task performance.

SUMMARY AND CONCLUSIONS

Extensive research has been conducted examining physical, and cognitive performance, and physiological responses to short term cold exposure under controlled conditions. Long term cold exposure studies have been limited to cognitive responses in a laboratory setting. Cold exposure degrades physical and cognitive performance. The effects of long term cold exposure on physical and cognitive performance, and physiological responses remain unclear.

The present study was conducted in a field setting to better understand the effects of long term cold exposure on physical and cognitive performance and its relation to physiological responses.

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CHAPTER II. PHYSICAL AND COGNITIVE PERFORMANCE DURING LONG TERM COLD WEATHER OPERATIONS

ABSTRACT

The effects of long term cold weather operations on physical and cognitive performance were studied. Some of the factors that may affect performance in long term cold weather operations are cold, exertional fatigue, sleep deprivation, dehydration, and nutritional deficit. Most of the previous work that examined physical and cognitive performance and physiological responses to cold was conducted in a laboratory setting, and exposure was short term. Two long term investigated limited aspects of cognitive performance and testing was conducted in a laboratory. The present study examined physical and cognitive performance, and physiological responses during long term cold weather operations where testing was conducted in a field setting.

We studied five groups of males (total 28 subjects) who participated in cold weather survival courses. Physical performance was evaluated with strength (i.e. hand grip and upper body) and dexterity (i.e. lace-tying, nut-bolt, and GPS entry). Cognitive performance was evaluated with tests of logical reasoning, planning, and vigilance. Subjective scales of exertion, cold sensation, and mood were also used. Continuous physiological measurements of core temperature and heart rate were recorded. Finger tip temperature was recorded only at time of testing.

Results indicate that strength tended to decrease in the field and was predicted by air temperature, finger tip temperature, and/or rating of perceived exertion. Cognitive performance did not change during field testing. Most mood responses were different from baseline in the field and were generally consistent with the rating of perceived exertion.

The results demonstrate that the cold stress during the survival courses (-24.4 °C to +4.4 °C) was sufficient to induce significant decrements in strength and dexterity of small muscles of the hand and forearm, but not in cognitive performance. While there were significant differences in group mean core temperature, subjects were not hypothermic (less than 35 °C) at any time during the field trials.

INTRODUCTION

Long term cold weather operations present several challenges to the participants, including achieving physical comfort, maintaining a positive mental attitude, and preserving the ability to perform tasks adequately. Understanding the factors that affect human performance during prolonged operations in the cold is of importance to military personnel who operate in the cold, and to rescue personnel during the rescue of cold injury victims. Advances in military technology (like night-vision devices, and firepower) and changes in doctrine (like an around-the-clock capability) dictate that military members be prepared to operate under adverse conditions. Some of the factors that may affect performance in long term cold weather operations are: cold, exertional fatigue, sleep deprivation, dehydration, and nutritional deficit. Outdoor enthusiasts and military planners will be interested in knowing which, and how, these factors affect both cognitive and physical performance.

The present literature that examines the effects of exposure to cold on humans can be divided into two main categories: short term, and long term. Short term studies were generally conducted in a laboratory setting and did not normally expose subjects to more than three hours of cold stress. The effects of cold on performance are of two kinds, peripheral effects, which influence strength and manual dexterity (12), and central effects which influence cognitive performance (21). It is known that cold exposure results in a decrement of physical and cognitive performance (5,11,12,21). Physical performance can be evaluated with physical strength and dexterity tests.

Studies that examined physical strength have reported decreased strength with cold exposure (11,12,18,22). Gaydos (8) and Gaydos and Dusek (9) have shown a decrement in dexterity when the hand was cooled. Giesbrecht and Bristow (11) showed a decline in manual dexterity with whole body cooling. These studies have shown that local arm temperature played a significant role in both manual strength and dexterity. Physiological responses of core temperature (11,12) and heart rate (11) were also examined during cooling.

The effects of cold on mental performance have been examined with various cognitive tests (4,5,10,21). Overall, more complex tasks were more detrimentally affected by cold exposure than simpler tasks.

Only two long term studies have examined the effect of cold on performance (2,20). These studies were limited in that only cognitive responses were examined. Angus et.al. (2) investigated the relation between detection performance of a visual vigilance task and changes in REM sleep of six men living and sleeping in arctic conditions. Vigilance was tested every second day for 16 days in a room at 0-5 °C (2). Visual vigilance was detrimentally affected by initial cold exposure and on days following cold overnight temperatures with less REM sleep. Teichner and Kobrick (20) tested visual-motor performance of five men living in a temperature chamber every day for 41 days. Air temperature was 22 °C for the first 16 days, followed by a cold period at 12 °C for 12 days, and a recovery period for the last 13 days at 22 °C. Visual-motor performance was examined with a pursuit-rotor that measured the subjects' time on target. Teichner and Kobrick (20) reported a marked and immediate impairment of performance with the onset of the cold period and an immediate recovery at the onset of the recovery period. Neither of these studies examined physical performance or physiological responses.

Exertional fatigue can lead to an impairment of performance and increase the perceived effort necessary to complete a task (19). Sleep deprivation, has been shown by Angus and Heslegrave (1) to decrease cognitive performance, and by McCann and Pointing (17) to detrimentally affect planning. Dehydration is a significant threat to cold weather operations as a major contributing cause of cold injury and loss of effectiveness. As a result of dehydration, the decrease in circulating blood volume could lead to less oxygen and nutrient delivery to the peripheries, thus impairing physical performance (6,13). Nutritional deficit may be of concern to performance, because normally, during cold weather operations, there is a restriction of food and water intake, and without proper nutrition, energy stores decrease and eventually, so will task performance.

Despite the extensive work done on cold and performance, two main limitations remain: first, the studies that included physical, cognitive and physiological responses, were short term studies, second, the two long term studies examined a limited number of cognitive responses, and no physical performance or physiological data was presented. All the above short-term and long-term studies were conducted in a laboratory setting.

The purpose of the present investigation was to examine physical and cognitive performance and physiological responses to cold during long term cold weather operations, where testing is conducted under field conditions.

Over two winter seasons we studied five groups participating in nine-day cold weather survival courses offered by the Canadian Forces School of Survival and Aeromedical Training (CFSSAT) in Winnipeg, Canada. Cold was expected to be the most variable factor to affect performance during our testing because the survival courses had the same schedule and content. Therefore, participants of each survival course were given the same tasks, sleep time, water, and food. The factor not common throughout the seasons was cold.

We expected both physical and cognitive performance to decrease in the field compared to baseline testing, and that performance decrements would be greater when the average air temperature of survival course groups was lower.

METHODS

Subjects: With approval from the Faculty and DCIEM Human Ethics Committees, and written informed consent, twenty eight healthy men in good physical condition participated in this study. The nine-day Survival Evasion Resistance and Escape (SERE) course exposes its military members to scenarios of survival in hostile environments and is designed to prepare members for survival in dangerous situations. Several SERE courses are run from October to April of each year in Nopiming Provincial Park, in eastern Manitoba, Canada. Subjects were recruited from participants of five courses from January 2000 until February 2001.

Anthropometric and Fitness Measurements: Subject anthropometric characteristics were taken in a laboratory setting prior to deployment to the field. These included: height, weight, and percent body fat [skinfold (15), and hydrostatic weighing (7)]. Skinfolds of triceps, biceps, subscapular, and suprailiac areas were used. A progressive submaximal treadmill test was used to estimate maximal aerobic fitness by extrapolating predicted $\dot{V}O_{2max}$ from the predicted maximal heart rate (16).

Environmental Conditions: Baseline air temperature was not measured as it was assumed to be approximately 22 °C for each day. During field trials *Air temperature* (T_{air}) at the time of testing was measured with a digital thermometer (Doric 450-TH Temperature Indicator, Doric Scientific).

Tests of physical performance: All physical performance scores, except GPS (see below), were recorded during baseline and field testing sessions. Physical performance was measured with tests of muscle strength and dexterity. Strength was evaluated with a *hand grip strength* test which measured maximal isometric contraction of the forearm muscles. Subjects were instructed to grasp the hand dynamometer (Takei Kiki Kogyo, Japan) in the dominant hand, hold the forearm at the level of the thigh, away from the body, and squeeze vigorously in order to exert maximum force. Isometric *upper body strength* was measured with a shoulder-arm push apparatus (14). This apparatus consists of two vertical handles that are pushed together. It is held firmly at the chest level with the forearms parallel to the ground, and squeezed vigorously so as to exert maximum force. Three trials were completed with 30 second rest intervals between trials for both strength tests. Readings were recorded to the nearest 0.5 kg.

Hand and finger dexterity were evaluated with lace-tying and nut-bolt tests, and with a global positioning system (GPS) entry. The *lace-tying* apparatus consisted of 25 one meter long pieces of cord draped under a 100 mm diameter plastic tube. The cords were compressed between the plastic tube and a base board to prevent displacement of the cords. Subjects had two minutes to tie as many "shoe lace" knots as possible around the plastic tube. The *nut-bolt test* consisted of a wooden board (33 x 26.5 cm) that stood perpendicular on a base. The upright board had twelve 14-mm holes in a 4 x 3 pattern. Bolts (11 mm x 45 mm) were inserted through all the holes, with corresponding nuts hand tightened, before the task began. Subjects had two minutes to unthread the nuts, turn the bolts around to the other side of the board and re-thread the nuts onto the bolts. Scores for the lace-tying and nut-bolt assembly tests were based on the number of completed repetitions during the two minute period.

The *GPS entry* task made use of a GPS unit (Garmin 12XL, Kansas City) and was created to mimic a survival relevant test. Subjects were scored on the time required to input a reference waypoint into the GPS unit. This was done with an ungloved dominant hand while the non-dominant gloved hand held the GPS unit. While each test presented a different assignment, all trials required 50 key presses to complete the task. Baseline scores for the GPS entry task were not recorded because all subjects performed the task at the same time in an instructional setting.

Tests of cognitive performance: Cognitive performance was evaluated with tests of logical reasoning, planning, and vigilance. All cognitive performance scores were recorded during the field sessions. Only the logical reasoning test scores were recorded during baseline since the first encounter with the other two cognitive performance tests was only meant to be a familiarization. *Logical reasoning* was evaluated with a grammatical transformation test that could be performed rapidly and yet was demanding enough to be sensitive to any fall in intellectual capacity (3). Baddeley (3) developed a logical reasoning test based on 64 combinations of the placement of the letters A and B. Subjects answered true or false to a question pertaining to the arrangement of each combination. The questions were arranged in random order so that each testing day had a different combination of questions. Subjects were given two minutes to answer as many questions as possible.

The *planning task* examined the ability of the subjects to develop a plan for the most efficient pickup of highlighted shopping items from a supermarket grid layout using two carts. The subjects were required to plan in accordance with cart capacity. This task was comprised of two different supermarket grid layouts, the appearance of the layouts was manipulated in three ways (rotation of 90 °, horizontal flip, as well as horizontal flip and 90 ° rotation) to produce three additional orientations that were topologically equivalent to the original problems (17). The items to be picked up corresponded to the same location as on the original problems. The subjects had 5 minutes to prepare a route through the layout where every highlighted item was picked up by either of the two carts. Problems one, three, and five were created from one common layout, while problems two and four were created from another more complex layout, each with different perfect solutions (17). The test was scored based on the number of steps exceeding the perfect plan that each cart covered to complete the task.

Subject vigilance was monitored with a vibrating wrist watch (Watch Minder) that was programmed to vibrate four times randomly throughout the day, at which time a message of "write" or "practice" was displayed on the watch face. Subjects were instructed to record the time when the message "write" appeared. Scores were based on percentage of "write" responses recorded at the appropriate time.

Subjective Scales: All subjective measures were recorded during baseline and field testing sessions. *Visual analog scales* were used for exertion, cold sensation, and mood. *Rating of perceived exertion*, whole body *cold sensation scale*, and finger and toe cold sensation scales were rated from 0 to 10; "0" being "not tired" and "warm", to "10" being "extremely tired" and "so cold I am helpless", respectively. Subject *mood* was established for a series of attributes (alertness, sadness, tenseness, fatigue, enthusiasm, weariness, calmness, and sleepiness), to which subjects indicated by a tick mark on a ten centimeter line with "very little" and "very much" at the leftmost and rightmost edges of the line respectively. Scores were recorded to the nearest tenth of a centimeter.

Physiological Measures: Subjects were instrumented for continuous field measurement of core temperature and heart rate during each course. *Core* *temperature* (T_{co}) was measured with a radio pill (Human Technologies, Inc., Palmetto, FL) encapsulated by a biologically inert shell about 6 mm in diameter, and 13 mm in length. The pill was swallowed and passed through the gastrointestinal track harmlessly. It emitted a temperature-dependent frequency signal that was captured by a receiver (BCTM3, Personal Electronic Devices, Inc., Wellesluy, MA) which was held in a nylon chest holster. Continuous *heart rate* was measured and stored at one minute intervals using a Polar heart rate monitor (Polar Accurex plus, North York, ON). The receiving unit (i.e., heart rate watch) was also worn in the chest holster.

Finger tip temperature (T_{finger}) was only recorded at the time of field testing. Thermistors were sewed to the inside medial aspect of fingertips one, three, and five of standard issue Canadian Forces (CF) olive drab wool gloves. These gloves were worn on the non-dominant hand during testing sessions and were assumed to provide representative finger tip temperatures of the dominant hand used for testing. Gloves of various sizes were instrumented to ensure a comfortable, yet snug fit for each subject. Thermistors were connected to a data recorder (Smart Reader Plus 8 unit, 12 bit data logger, ACR Systems Inc., Vancouver) for data storage. T_{finger} is given as an unweighted mean of the three finger tip values.

Protocol: On Monday, the day before each course started, subjects reported to the Laboratory for Exercise and Environmental Medicine at the University of Manitoba for one day of familiarization, anthropometric measurements, and metabolic exercise testing. Subjects were shown all instrumentation to be used in the field and performed enough physical and cognitive tests until no further improvements in the scores were noted. Once this plateau was reached, baseline measurements were taken on all subjective and physical tests (except the GPS entry test) and the logical reasoning test. All testing was conducted at an air temperature of approximately 22 °C.

Hematocrit was taken as a measure of hydration status. On Monday (baseline), Saturday, and Wednesday, a 1cc blood sample was taken from the antecubital fossa of the preferred arm of the subjects and transferred to micro-capillary tubes. After the sample was centrifuged (International Equipment Company, MA), hematocrit was read on a micro-capillary reader (IEC, MA) and recorded to the nearest 0.5 %.

Each nine-day SERE course began on Tuesday and ended on Wednesday of the following week. Students were continuously exposed to environmental conditions during the nine course days except when classroom lectures took place in a heated trailer. Sleeping accommodations during the first six nights consisted of four-person unheated cabins (Tue-Thur, and Sun), or four-person unheated tents (Fri and Sat). Classroom lectures occupied most of the first five days of the course. The last four days were spent mostly outdoors doing activities like navigation, improvised shelter building, and pyrotechnics exercises. During the last two nights (Mon and Tue), students were alone in the forest, where they built improvised shelters and had a limited amount of food (450 Kcal). Students obtained water by melting snow. Investigators moved to the course location, instrumented the subjects, and administered the first field test on Friday evening. T_{co} and heart rate readings were manually checked on the receivers immediately prior to testing, if no T_{co} reading was obtained, a new radio pill was administered, then the testing session began. Testing was conducted at about the same time (1700-1900 hr) each day from Friday until Tuesday and at 0800 hr on Wednesday, just before the course ended. Students and staff returned to Winnipeg on

Wednesday morning. Table 1 shows a schematic of the SERE course schedule and testing protocol.

Table 1. SERE course schedule and testing protocol. Testing was done between 1700-1900 h each day (Friday-Tuesday). Testing sessions were shortened Wednesday morning since subjects left the training area to return to Winnipeg in the morning.

Mon	Tues - Thurs	Fri	Sat	Sun	Mon	Tues	Wed
U of Manitoba Blood Test # 1 Baseline Testing	SERE Course Starts No Testing	Test #1	Blood Test # 2 Test #2	Test #3	Test #4	Test #5	Test #6 Blood Test # 3 Leave CFSSAT

For each testing session, investigators moved all the testing equipment to the subjects' location, where subjects sat on a vinyl fold-out chair and wrote on a fold-out table. A 9 v flashlight was set on a tripod and shone at the table if ambient light was not sufficient to read and write. Subjects remained seated for all the subjective and cognitive tests, but were able to stand during the muscle strength tests (hand grip, and shoulder-arm push).

The test sequence was arranged as follows so subjects were not sitting for the entire duration of the testing session:

1. Cold Sensation Scale (whole body, fingers and toes),
2. Rating of Perceived Exertion,
3. Mood Inventory,

4. Nut-bolt,
5. Hand grip strength,
6. Logical reasoning,
7. Lace-tying,
8. Shoulder-arm push,
9. Planning,
10. GPS entry.

On Wednesday morning the subjects broke camp and met briefly at a staging area before transport back to the main camp. Because of this limited access to the subjects the test battery was shortened to include only subjective scales, hand grip strength, and GPS entry. Blood samples for hematocrit determination were taken on Saturday morning and again on Wednesday morning.

Data Analysis: Variables were grouped into physiological responses, physical and cognitive performance, and subjective scales. Physiological responses included core and finger tip temperature, heart rate, and hematocrit. Core temperature was presented as a mean during the testing session (~20 min). In cases where a radio pill was given immediately prior to testing, a delay of approximately 10 – 15 minutes was imposed until an accurate T_{co} could be read. Physical performance tests included strength (i.e., hand grip strength and shoulder-arm push) and dexterity (i.e., lace-tying, nut-bolt, and GPS entry) ~~tests.~~ Cognitive performance was evaluated with logical reasoning, planning, and vigilance tests. Subjective scales consisted of the self-report scales of exertion, cold sensation scale for whole body, toes, and fingers, and the eight mood questionnaires.

As well, air temperature was used to indicate environmental conditions at each testing time. For each variable, individual and mean scores were plotted for each group.

One way analysis of variance compared the group mean baseline scores for most performance and all subjective responses. As stated earlier baseline values were not recorded for planning, vigilance, or GPS entry.

Two way analysis of variance for repeated measures was conducted for all variables except heart rate. The two sources of variation were test day (effect of time) and group (effect of group). The 0.05 level of significance was chosen and post hoc analysis for significant differences was done with the Tukey-Kramer multiple-comparison test.

Stepwise regression analysis was conducted between the independent, predictor variables and the dependent, response variables in an effort to develop predictive models for cognitive and physical performance. Independent variables were selected as: air temperature, age, V_{O2max}, core temperature, finger tip temperature, and rating of perceived exertion. Although the latter three variables depend on environmental conditions and activity, these were, for the purpose of this study, considered predictive variables which could affect the outcome of the dependent variables (physical and cognitive performance, and subjective scales). Rating of perceived exertion may be considered a dependent variable that is affected by T_{air} and activity, as such it was regressed against T_{air} in an effort to predict perceived exertion.

RESULTS

The 28 male subjects that participated in this study were (mean ± S.D.) 28.6 ± 5.6 years old, 179.8 ± 6.7 cm tall, weighed 89.0 ± 11.2 kg, had 21.9 ± 8.3 percent body fat (with hydrostatic weighing), and a predicted $\dot{V}O_{2max}$ of 47.4 ± 8.3 $ml \cdot min^{-1} \cdot Kg^{-1}$. Mean anthropometric characteristics for each group are shown in Table 2.

Table 2. Anthropometric characteristics of subjects.

Group (n)	Age (yrs)	Ht (cm)	Wt (Kg)	%Fat (skinfold)	%Fat (hydrostatic)	Predicted $\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	Predicted $\dot{V}O_{2max}$ ($ml \cdot min^{-1} \cdot kg^{-1}$)
1 (6)	25.0 (4.5)	179.0 (6.6)	81.7 (4.3)	14.2 (5.3)	18.5 (9.4)	4.4 (0.9)	53.4 (10.7)
2 (6)	30.3 (5.1)	177.7 (6.4)	93.2 (11.0)	23.1 (6.1) †	20.8 (8.8)	4.3 (0.5)	46.6 (8.9)
3 (6)	26.5 (2.3)	184.1 (4.0)	96.2 (8.6)	14.4 (3.0)	20.1 (6.4)	4.4 (0.4)	45.9 (5.6)
4 (4)	37.5 (2.4)*	180.5 (7.1)	95.0 (10.6)	27.9 (6.3)**	28.5 (6.8)	3.8 (0.6)	39.7 (5.0)
5 (6)	26.8 (5.1)	178.1 (9.2)	81.2 (12.1)	22.4 (5.2)	24.0 (9.1)	4.1 (0.8)	51.6 (11.2)

Values are shown as mean (S.D.)
* Indicates age of group 4 was significantly greater than groups 1, 3, and 5 ($P < 0.01$).
** Indicates percent body fat (skinfold) of group 4 was significantly greater than groups 1 and 3 ($P < 0.01$).
† Indicates group 2 percent body fat (skinfold) was significantly greater than group 1 ($P < 0.01$).

No significant differences were found between groups for height, weight, percent body fat (measured with hydrostatic weighing), or predicted $\dot{V}O_{2max}$. Group 4 was significantly older than groups 1, 3, and 5 ($P < 0.01$), and had significantly more percent body fat (measured with skinfolds) than groups 1 and 3 ($P < 0.01$). Percent body fat measured with skinfolds was significantly greater for group 2 than group 1 ($P < 0.01$).

The average T_{air} in the field was different between all courses ($P < 0.001$) with values being -5.5 ± 1.8, -9.5 ± 5.1, +4.4 ± 2.5, -24.4 ± 3.9, and -11.9 ± 6.9 °C for courses 1 to 5 respectively. T_{air} had a tendency to decrease as the field testing sessions progressed from Friday to Wednesday. Wednesday morning T_{air} was significantly lower ($P < 0.0001$) than all other testing sessions. This is likely because early morning tends to be colder than early evening. Group mean T_{air} for each group for each day are presented in Figure 1.

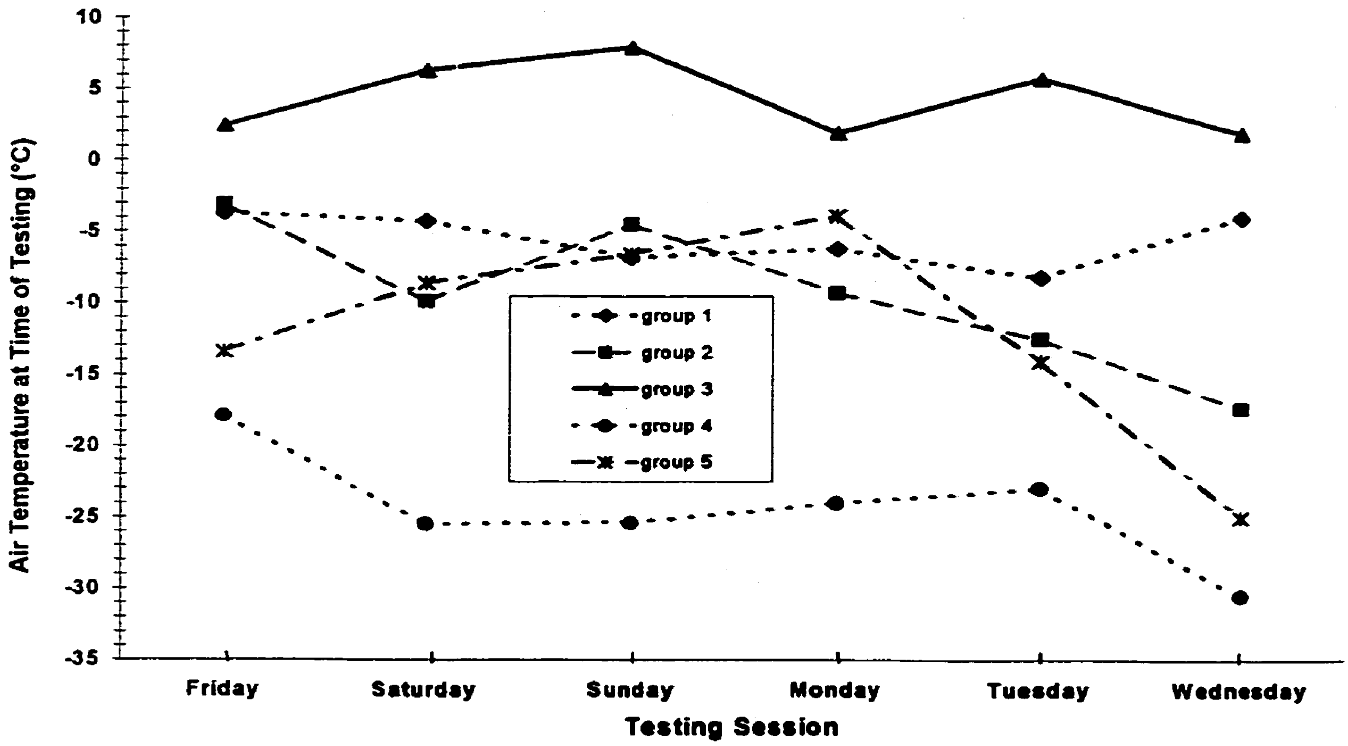

Figure 1. Mean T_{air} for each group during field testing sessions. All groups were significantly different from each other ($P < 0.001$).

Physiological responses: Continuous core temperature data followed a circadian pattern with night-time lows of approximately 35.6 °C, and day-time highs of 38.2 °C. T_{co} was not consistently available for Friday and Wednesday testing sessions. Radio pills were administered on Friday evening and on 17 occasions the pills had not been in the gastrointestinal track long enough to be detected by the receiver. For the Wednesday morning testing session, 15 T_{co} readings were not available because pills were expelled prior to testing time. On earlier testing sessions a new pill would have been administered. For the remaining days (Saturday to Tuesday), T_{co} did not differ from day to day testing sessions. Group 3 had a significantly lower average T_{co} (37.1 ± 0.3 °C, $P < 0.05$) than groups 1 (37.5 ± 0.3 °C) and 5 (37.5 ± 0.5 °C) (Fig. 2).

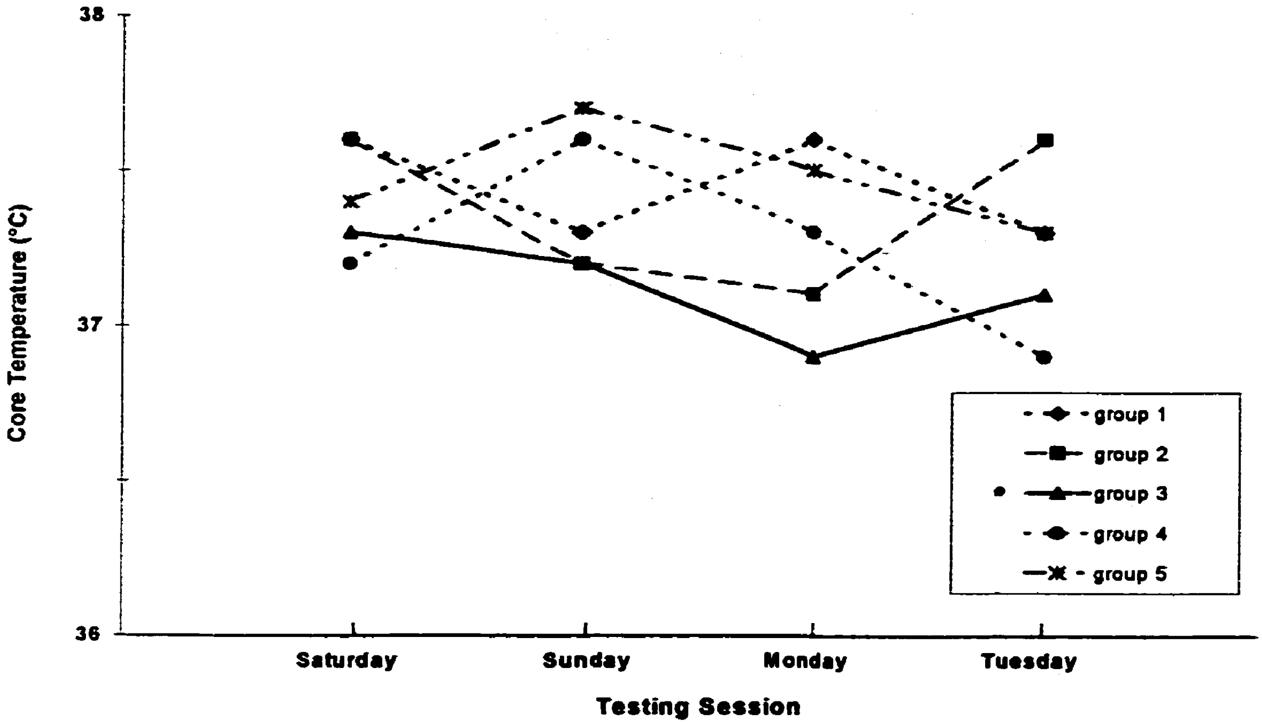

Figure 2. Mean T_{co} for each group during field testing sessions. * Indicates the average Tco of group 3 was lower than groups 1 and 5 ($P < 0.05$). Group 4, n=4; other groups, n=6.

T_{finger} had a significant but small correlation with T_{air} (r=0.53, P=0.0001, $T_{finger} = 16.73 + 0.2840 \times T_{air}$). T_{finger} was not significantly different throughout the field testing sessions, but group 4 (9.4 ± 3.4 °C) was significantly lower than the other groups (15.7 ± 3.7, 13.9 ± 3.7, 18.0 ± 4.2, and 15.3 ± 5.6 °C for groups 1 to 5, respectively, P < 0.001). Group mean responses for each group for each day are presented in Figure 3.

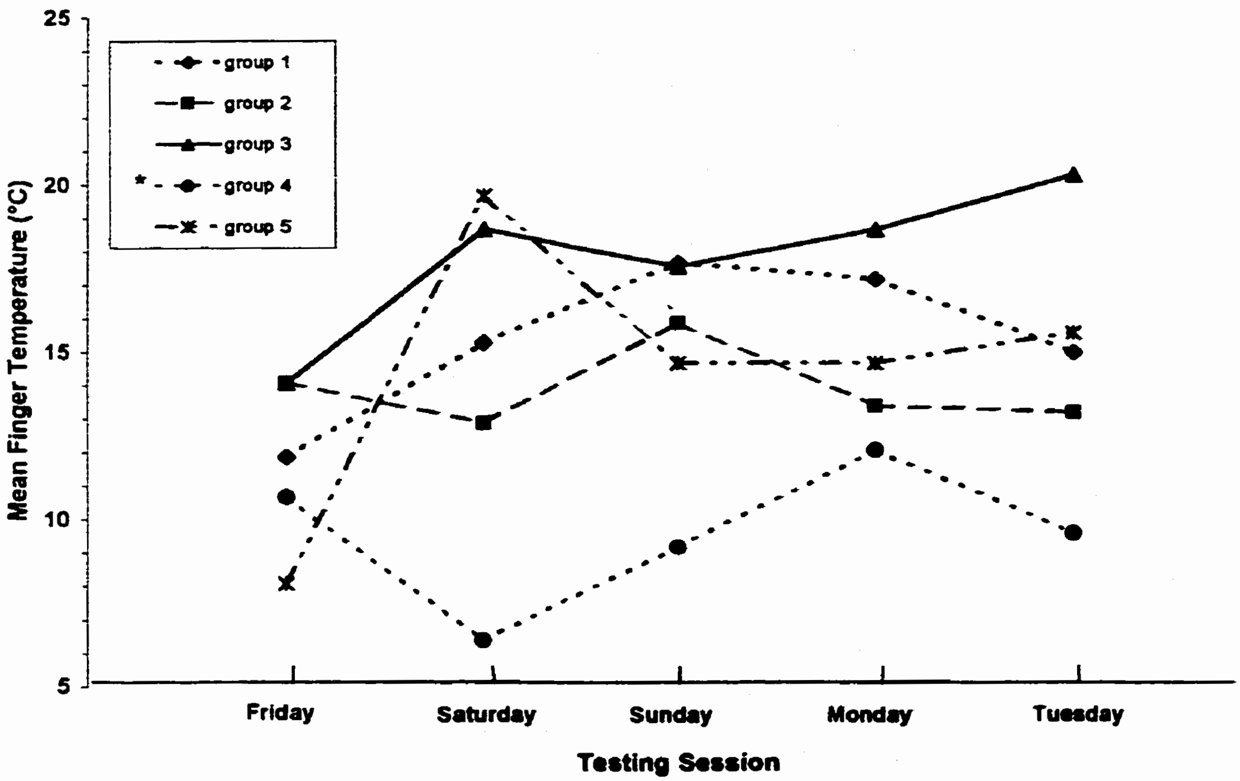

Figure 3. Mean T_{finger} for each group during field testing sessions. * Indicates group 4 had a mean T_{finger} lower than all other groups (P < 0.001). Group 4, n=4, other groups, n=6.

Heart rate could not be analyzed since out of a possible 140 individual test days for the 28 subjects, only 29 complete days of data were successfully recorded (~ 21%). Therefore, heart rate was of limited value. Data collection may have been interrupted because of instrumentation faults or subject compliance. Contact between the chest and electrode surfaces may have been lost as the subjects went about their daily routines. The heart rate watches beeped when contact was not ideal, and some subjects may have inadvertently pushed buttons on the watch and stopped data collection.

There were no significant differences in hematocrit between baseline (44.9 ± 5.1) and the initial (44.2 ± 2.2) and final (44.8 ± 2.4, $P < 0.05$) field tests. Also, groups were not different from each other ($P < 0.05$).

Physical Performance: **Scores of hand grip strength, upper body strength, lace-tying, and nut-bolt tests were standardized so that baseline values represented 100 percent of performance. Hand grip strength group mean responses for each day are presented in Figure 4. For group 3, the mean hand grip strength in the field (98.4 ± 5.7 %) was significantly greater than groups 1, 4, and 5 (91.9 ± 5.9, 87.5 ± 9.0, and 88.9 ± 9.7 % respectively, P < 0.001). Group 4 mean hand grip strength was significantly lower than groups 2 (93.9 ± 10.4 %) and 3 (P < 0.001). Hand grip strength decreased during field sessions, and Sunday through Wednesday scores were significantly lower than those at baseline (P < 0.001).**

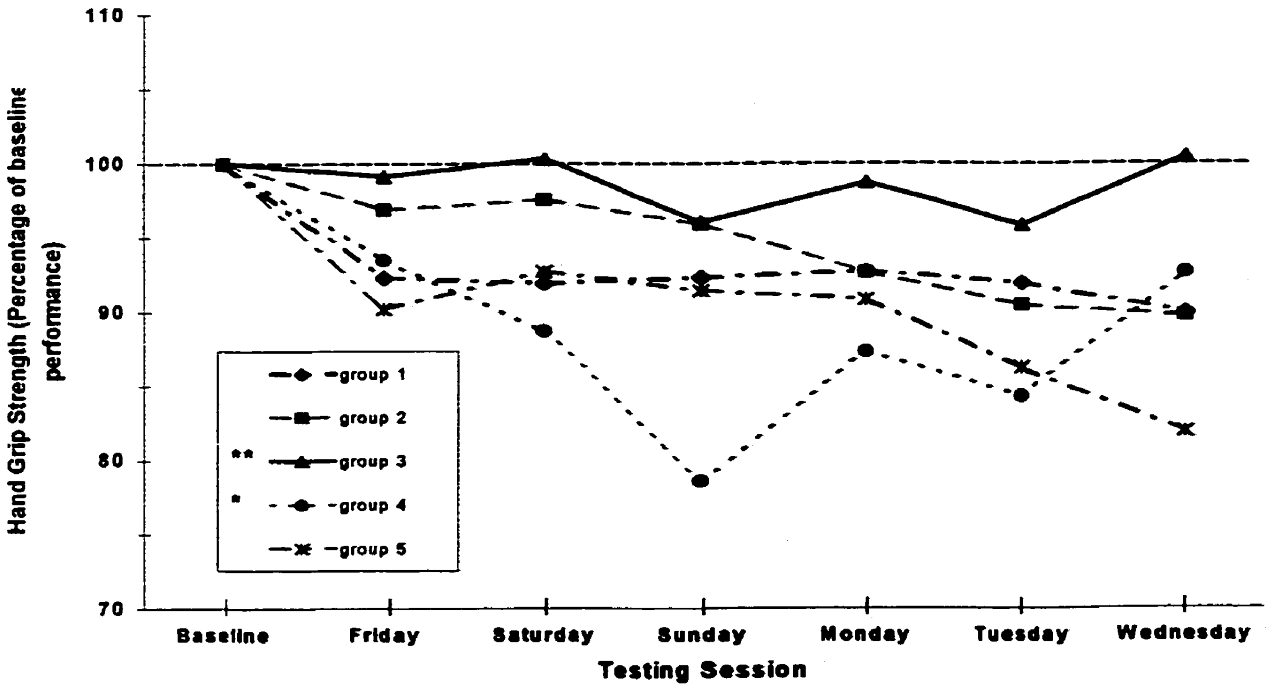

Figure 4. Mean hand grip strength for each group. Scores were standardized so that baseline represented 100 % of performance. * Indicates group 4 mean hand grip strength was significantly lower than groups 2 and 3 (P < 0.001). ** Indicates group 3 mean hand grip strength was significantly greater than groups 1, 4, and 5 (P < 0.001). Group 4, n=4, other groups, n=6.

Upper body strength measured with the shoulder-arm push decreased significantly from baseline for groups 2 (82.6 ± 22.5 %) and 3 (77.2 ± 10.5 %, P < 0.001) (Fig. 5). Groups 4 (100.3 ± 11.4) and 5 (102.2 ± 8.3 %, P < 0.001) showed no difference from baseline, and group 1 (115.6 ± 11.5 %) actually improved in the field. In the field, no day to day changes were found for any group.

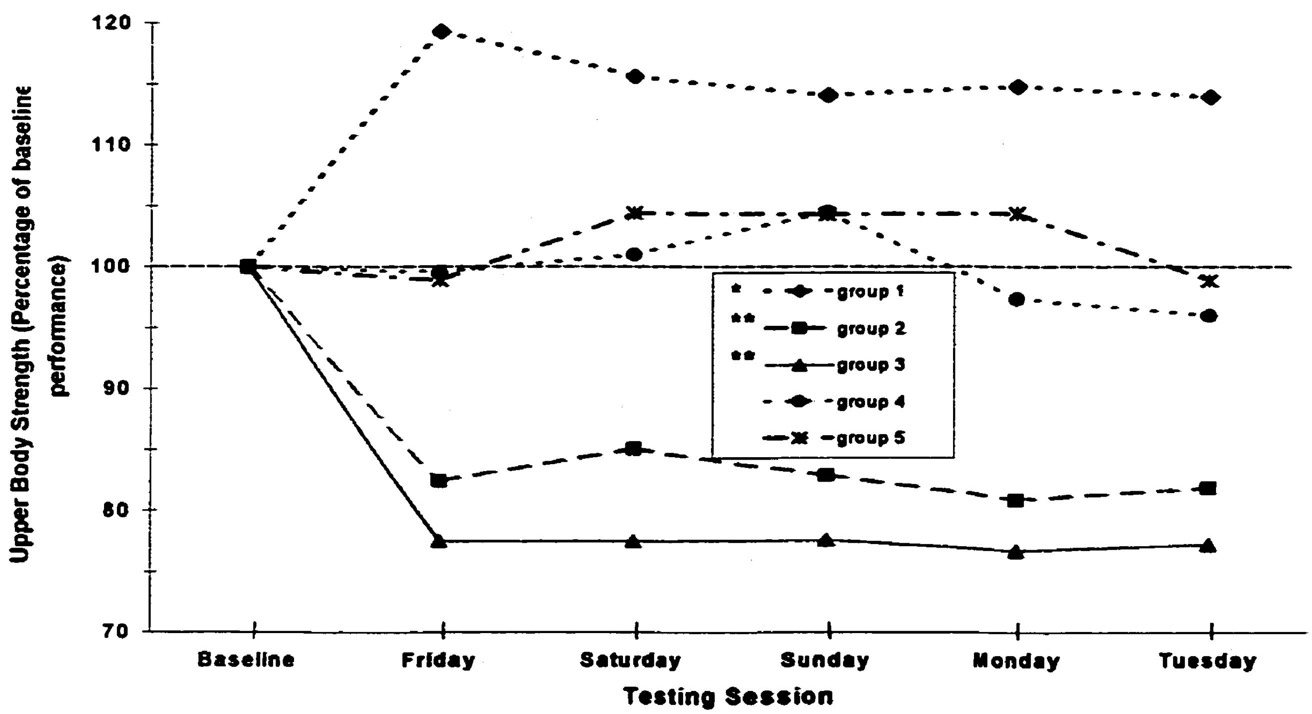

Figure 5. Mean upper body strength (measured with the shoulder arm push apparatus) for each group. Scores were standardized so that baseline represented 100 % of performance. * Indicates group 1 was significantly greater than all groups (P < 0.001). ** Indicates groups 2 and 3 were significantly lower than groups 1, 4, and 5 (P < 0.001). Group 4, n=4, other groups, n=6.

Lace-tying scores for group 1 in the field (105.2 ± 19.7 %) actually improved from baseline and were significantly greater than groups 2, 4, and 5 (87.2 ± 16.7, 69.2 ± 12.1, and 87.8 ± 18.0 % respectively, P < 0.001). Groups 2, 3 (93.9 ± 14.4 %) and 5 were significantly greater than group 4 (P < 0.001). Group 4 scores were significantly lower than all other groups (P < 0.001). Group mean responses for each group for each day are presented in Figure 6. Field sessions did not differ from one another, but Friday (86.1 ± 19.3 %) and Saturday (89.2 ± 17.5 %) were significantly lower than baseline (100 %, P < 0.05).

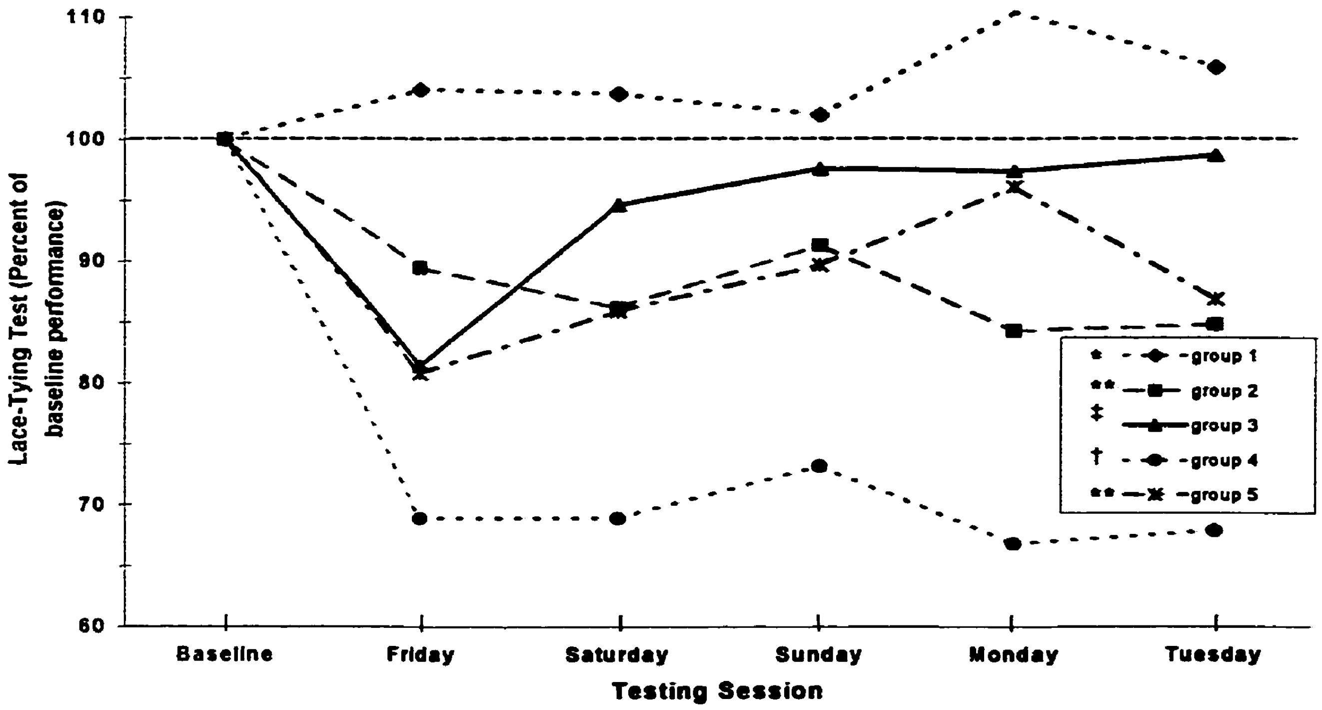

Figure 6. Mean lace-tying scores for each group. Scores were standardized so that baseline represented 100 % of performance. * Indicates group 1 was significantly greater than groups 2, 4, and 5 (P < 0.001). ** Indicates groups 2 and 5 were different from groups 1 and 4 (P < 0.001). ‡ Indicates group 3 was significantly greater than group 4 (P < 0.001). † Indicates group 4 was significantly lower than all groups (P < 0.001). Group 4, n=4; other groups, n=6.

The field nut-bolt test scores of groups 1 (112.0 ± 25.1 %), 2 (106.2 ● 11.5 %), and 3 (104.6 ± 14.9 %) were greater than baseline. Group mean responses for each group for each day are presented in Figure 7. Group 1 was significantly greater than groups 4 (83.8 ± 18.1 %) and 5 (99.1 ± 11.8 %, P < 0.001). Group 4 performed significantly lower than any other group (P < 0.001). There was no change in performance in the field except in group 1, where Tuesday scores were significantly greater than those on Friday (P < 0.05). This test had a time-group interaction (P < 0.05) because of the steady performance improvement of group 1 which may have been caused by the high motivation of this group.

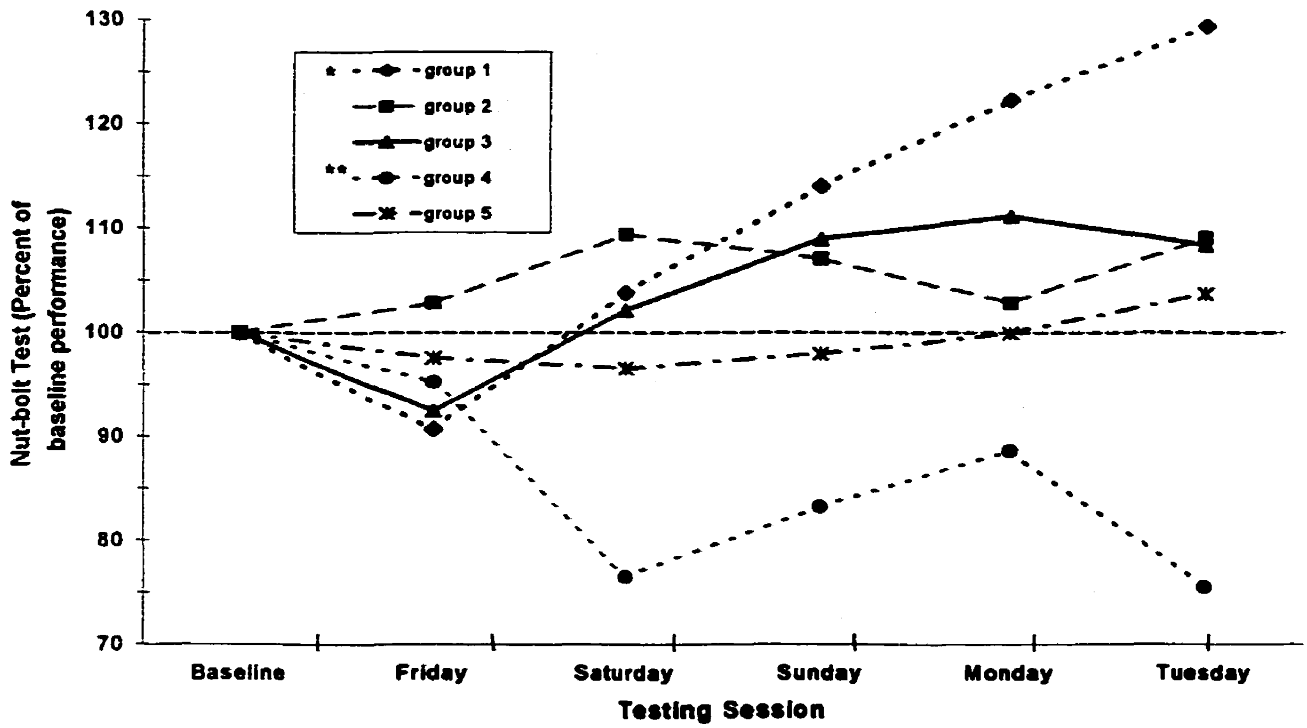

Figure 7. Mean nut-bolt scores for each group. Scores were standardized so that baseline represented 100 % of performance. * Indicates group 1 mean nut-bolt scores were significantly greater than groups 4 and 5 (P < 0.001). ** Indicates group 4 mean nut-bolt scores were significantly lower than all groups (P < 0.001). Group 4, n=4; other groups, n=6.

The mean GPS entry times for group 4 (55.6 ± 17.8 sec) were significantly greater than all other groups (42.5 ± 11.4, 43.4 ± 12.4, 43.9 ± 8.2, and 45.6 ± 10.6 sec for groups 1 to 5, respectively, $P < 0.001$). Group mean scores for each group for each day are presented in Figure 8. The field testing sessions of Sunday, Monday, and Tuesday required significantly less time than either Saturday or Wednesday ($P < 0.05$). No day to day differences were found for any group except group 3 where the test on Saturday required significantly more time than all other testing sessions ($P < 0.05$). The GPS test follows the pattern seen in the other two dexterity tasks, in that group 4 had significantly greater performance decrements than all of the other groups ($P < 0.001$).

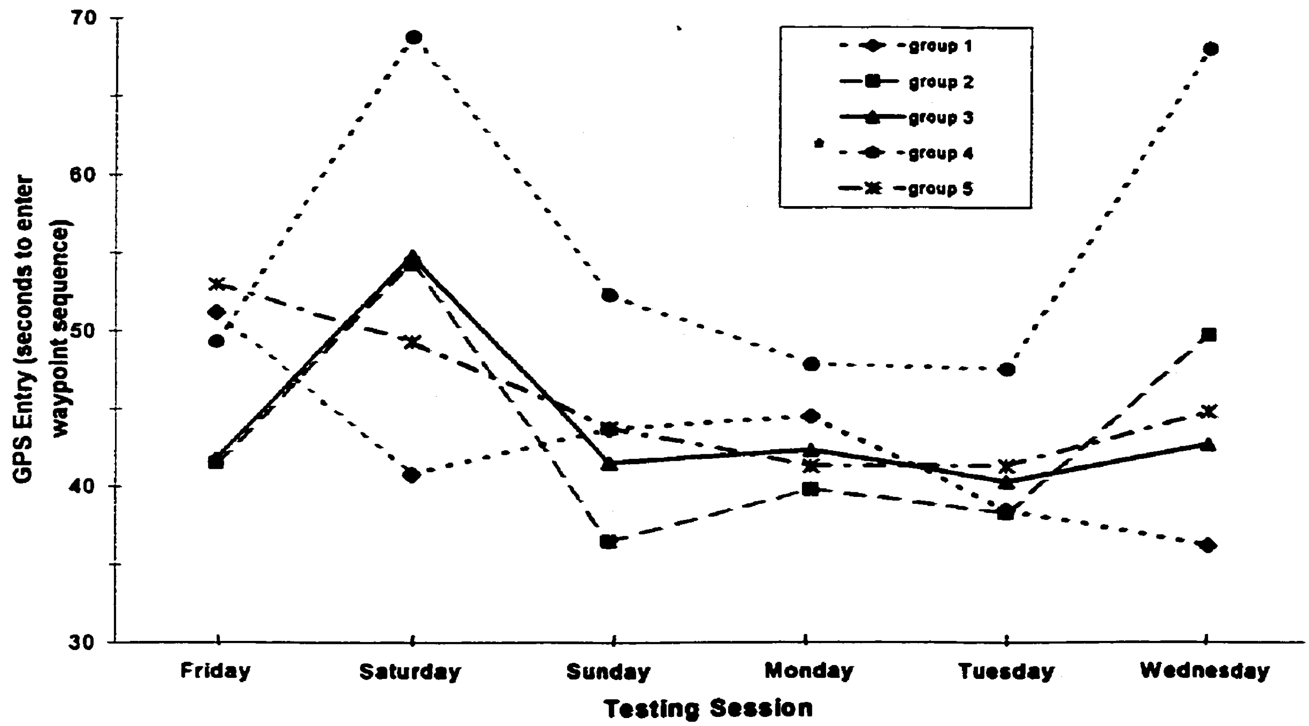

Figure 8. Mean GPS entry times for each group. * Indicates group 4 required significantly more time to enter the waypoint sequence into the GPS unit than all other groups ($P < 0.001$). Group 4, n=4; other groups, n=6.

***Cognitive performance*:** The cognitive responses of logical reasoning and vigilance showed no effect of time or course group.

The planning task results were not different between groups. The two versions of the planning task were administered on alternate field testing sessions. Figure 9 shows that tests 1, 3, and 5, were similar to each other but significantly better than the more complicated tests 2 and 4 ($P < 0.001$).

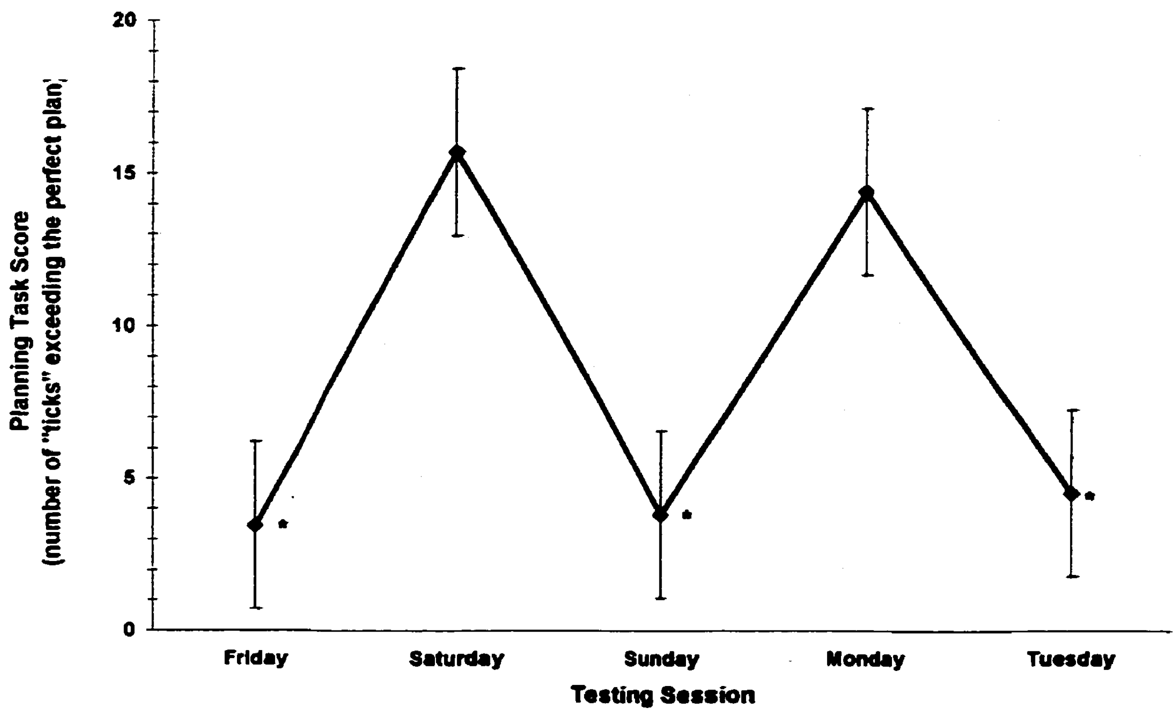

Figure 9. Mean (± S.E.) planning task scores for all groups combined. Tests 1, 3, and 5 were administered on Friday, Sunday, and Tuesday, tests 2, and 4 were performed on Saturday and Monday. * Indicates scores of tests 1, 3, and 5 were significantly lower than tests 2 and 4 ($P < 0.001$). Group 4, n=4; other groups, n=6.

Subjective Scales: Rating of perceived exertion was significantly greater in the field than during baseline ($P < 0.001$) (Fig. 10). There was a progressive increase in rating of perceived exertion during the first two days of field testing, followed by a plateau on the last four field sessions. Group 1 (4.3 ± 2.4) had the greatest average rating of perceived exertion of all courses and was significantly greater than groups 3 (3.0 ± 1.9) and 5 (2.9 ± 1.7, $P < 0.05$). For predictive purposes, a reasonable approximation of RPE can be obtained with the equation: $RPE = 4.7 \times [1-e^{(-\ln 2 \times ND/2)}]$, where ND is the number of days in the field (r=0.90, S.E.=0.7).

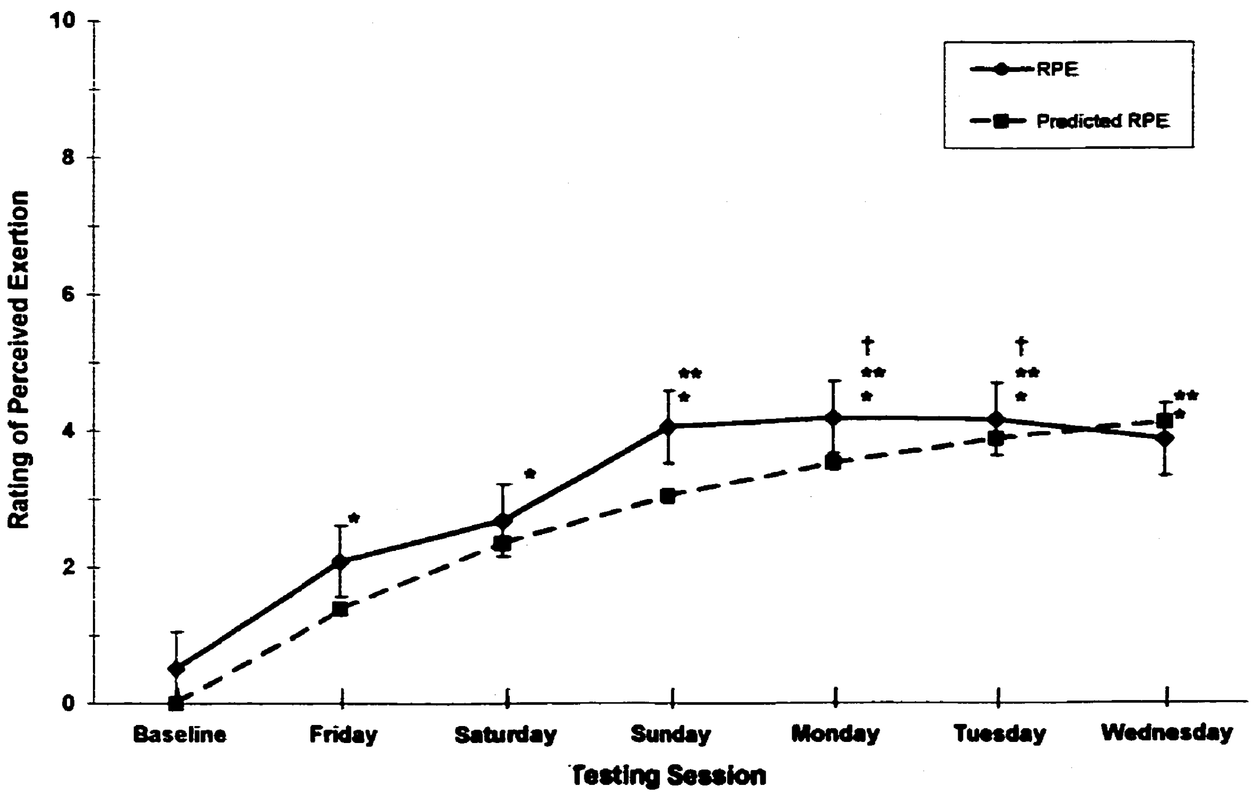

Figure 10. Mean (± S.E.) rating of perceived exertion scores of all groups combined during each testing session. * Indicates different from baseline ($P < 0.001$). ** Indicates different from Friday ($P < 0.001$). † Indicates different from Saturday ($P < 0.001$). Predicted rating of perceived exertion (i.e. $RPE = 4.7 \times [(1-e^{(-\ln 2 \times ND/2)}]$ is also shown.

Whole body cold sensation scale was significantly greater during all field testing sessions than during baseline (P < 0.001) (Fig. 11). Field testing sessions did not differ from one another. Group 4 (2.5 ± 1.2) had significantly greater whole body cold sensation scores than groups 1 (1.5 ± 1.0) and 3 (1.6 ± 1.0, P < 0.001). A score of 2 was "slightly cool".

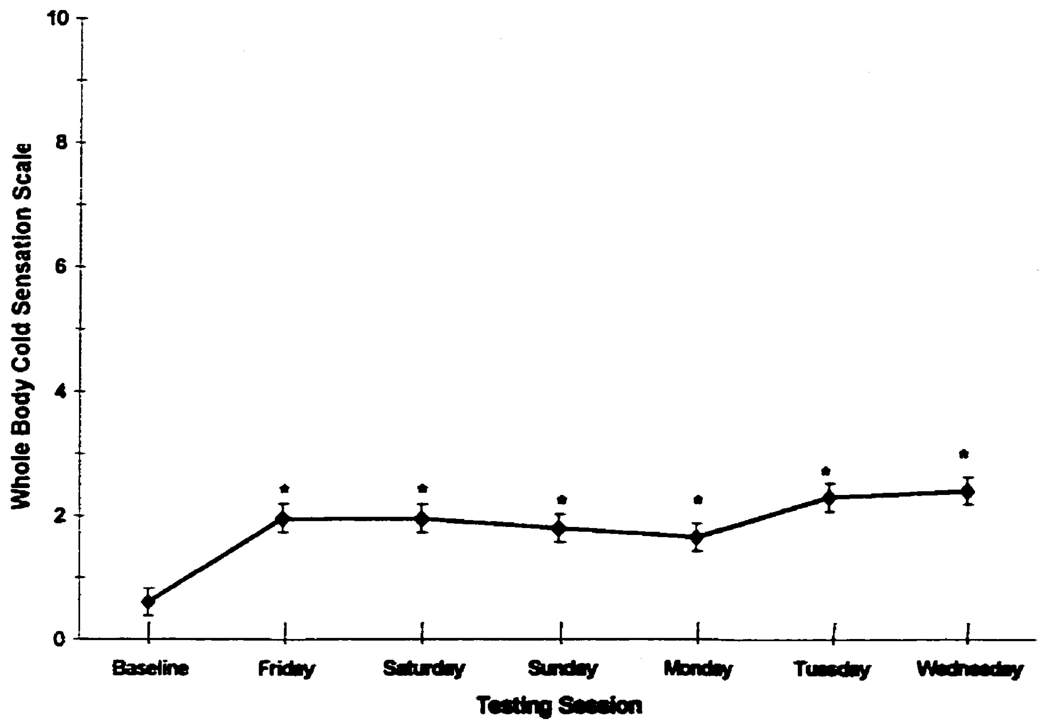

Figure 11. Mean (± S.E.) whole body cold sensation scale for all groups combined.
* Indicates scores of all field testing sessions were significantly greater than baseline (P < 0.001).

Cold sensation scale of the toes was not significantly different between groups, but Saturday (1.6 ± 1.4), Tuesday (1.7 ± 1.0), and Wednesday (2.5 ± 1.9) scores were significantly greater than baseline (0.5 ± 0.5, P < 0.001). Likewise, cold sensation scale of the fingers at baseline (0.5 ± 0.6) was significantly lower than all of the field testing sessions which ranged from 1.5 ± 0.9 to 3.0 ± 2.5 ($P < 0.001$). Group 4 (2.5 ± 1.7) had the highest cold sensation scale scores of the fingers and was significantly greater than groups 1 (1.5 ± 1.3) and 3 (1.2 ± 0.8, $P < 0.001$).

Of the eight mood attributes, tenseness and calmness did not differ between baseline and field testing sessions. Sadness was not significantly different between groups, and tended to increase during field testing sessions (Fig. 12). However, only Sunday and Tuesday scores were significantly greater than baseline ($P < 0.05$). Enthusiasm did not differ between groups and decreased in the field compared to baseline, but only Sunday, Monday, and Tuesday, were significantly lower ($P < 0.01$) (Fig.12). Alertness did not differ between courses. Scores had a tendency to decrease during field testing sessions, but only Sunday, Monday, and Tuesday scores were significantly lower than baseline ($P < 0.001$) (Fig. 13). Fatigue did not differ between groups. The last four field testing sessions (Sunday to Wednesday) were significantly greater than baseline, Friday, and Saturday ($P < 0.001$) (Fig. 13). Weariness scores for Sunday to Wednesday (4.7 ± 2.9, 5.0 ± 3.2, 5.3 ± 2.9, and 4.1 ± 2.7 respectively) were significantly greater than baseline (1.9 ± 2.5, $P < 0.001$). Mean responses for each group on each day are presented in Figure 14. Group 5 had the lowest weariness scores and was significantly lower than groups 1 and 2 ($P < 0.01$) (Fig. 14). Sleepiness scores for the field sessions (4.1 ± 2.3, 4.6 ± 2.7, 5.9 ± 2.6, 6.0 ± 2.1, 5.4 ± 2.5, and 5.4 ± 2.7 for Friday to Wednesday respectively) were significantly greater than baseline (2.0 ± 2.5, $P > 0.001$). Sleepiness was significantly lower in group 5 than all other groups ($P < 0.01$) (Fig. 15).

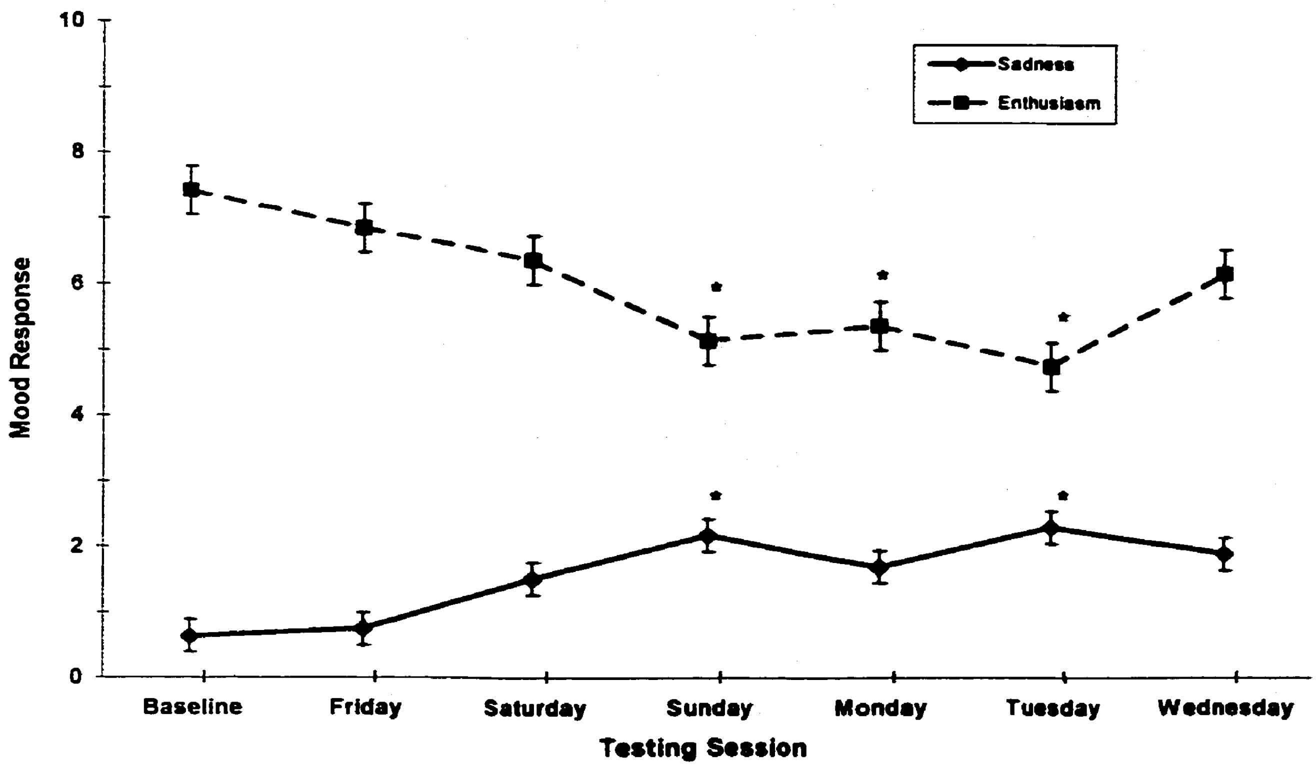

Figure 12. Mean (± S.E.) sadness and enthusiasm scores for all groups combined.
* Indicates scores were different from baseline ($P < 0.05$).

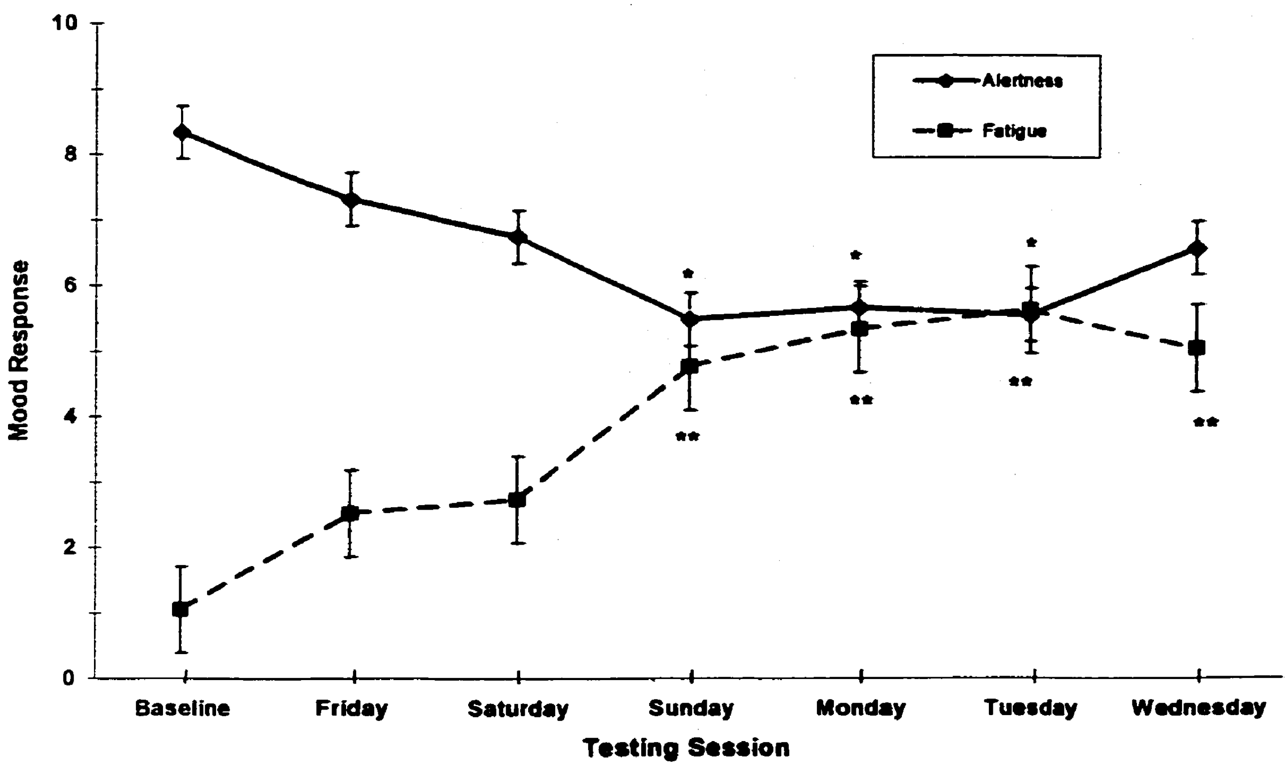

Figure 13. Mean (± S.E.) scores of alertness and fatigue for all groups combined.
* Indicates scores were different from baseline ($P < 0.001$). ** Indicates scores were different from baseline, Friday, and Saturday ($P < 0.001$).

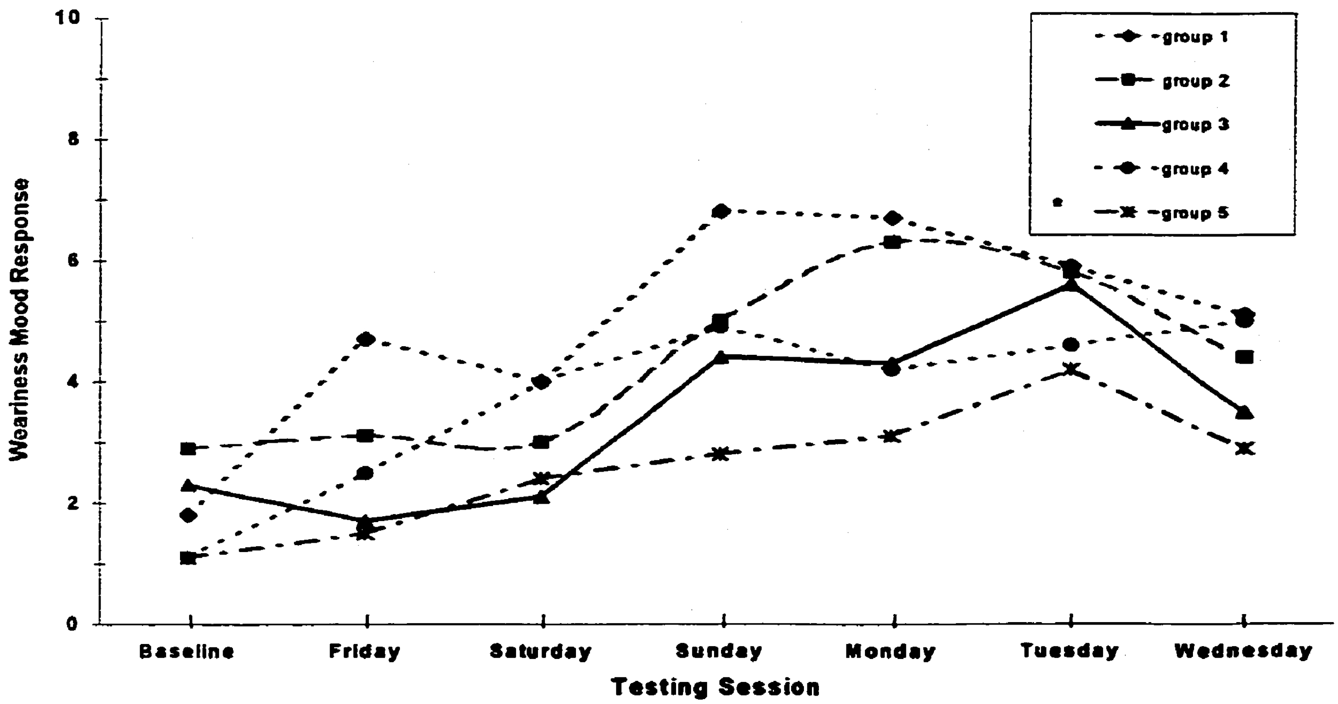

Figure 14. Mean weariness scores for each group for each testing session. * Indicates group 5 average weariness scores were significantly lower than groups 1 and 2 ($P < 0.01$). Group 4, n=4; other groups, n=6.

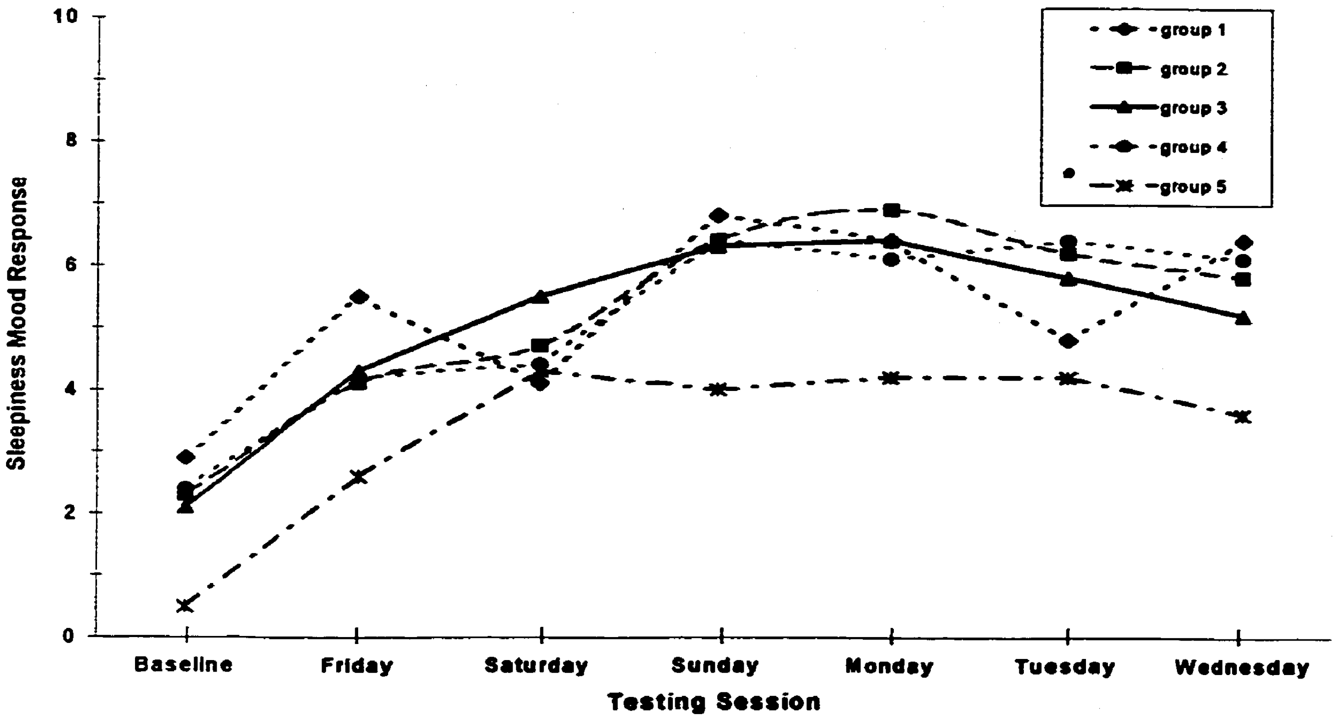

Figure 15. Mean sleepiness scores for each group. * Indicates group 5 mean sleepiness scores were significantly lower than all groups ($P < 0.01$). Group 4, n=4; other groups, n=6.

Predictive equations of response variables are shown in Table 3. Stepwise regression analysis indicated that the two physical performance variables (hand grip strength, and shoulder-arm push) had common predictors of T_{air} and rating of perceived exertion. Upper body strength had additional predictors of age and $\dot{V}O_{2max}$. The dexterity task of nut-bolt assembly was related to T_{finger} and $\dot{V}O_{2max}$. GPS entry and lace tying were both predicted by T_{air}, lace tying had a second predictor of $\dot{V}O_{2max}$. Whole body cold sensation scale was predicted by T_{finger} and rating of perceived exertion, whereas cold sensation of the fingers was predicted only by T_{air}. Rating of perceived exertion was a common predictor for all the mood questionnaires, except sadness. Interestingly, tenseness, enthusiasm, alertness, fatigue, and sleepiness were also predicted by $\dot{V}O_{2max}$; positive mood indicators were negatively correlated to fitness. Along with rating of perceived exertion and $\dot{V}O_{2max}$, fatigue was also predicted by T_{air}, T_{co}, and age. These predictions are valid for our range of data, and if the predictive variables of rating of perceived exertion or of T_{finger} are not available, they can be predicted by T_{air} ($RPE=3.37 - 0.0158T_{air}$; $T_{finger}=16.73 + 0.2840T_{air}$). Furthermore, rating of perceived exertion can also be predicted by the number of days spent in the field [i.e. $RPE = 4.7 \times (1-e^{-\ln 2 \times ND/2})$, where ND is the number of days in the field].

All the response variables were regressed against T_{air} for practical considerations (i.e., other variables such as age, fitness, and fatigue levels of accident victims may be unknown by search and rescue personnel). Highlighted R^2 are suggested as the best prediction based on closeness of fit and practical considerations. The relationship of upper body strength with T_{air} seems to be counterintuitive, that is, the predictive equation indicates that upper body strength is expected to decrease with an increase in T_{air}.

Table 3. Summary of stepwise regression prediction for response variables. Variables were also predicted by only T_{air} for practical considerations. Highlighted R^2 are suggested as the best predictors based on practical considerations.

Variable	Predictive Equation	R^2	F	P
Strength				
Hand grip	$98.87 + 0.3560(T_{air}) - 0.9969(RPE)$	0.21	22.59	0.0000
	$95.51 + 0.3718(T_{air})$	**0.16**	32.02	0.0000
SAP	$87.75 - 0.9723(T_{air}) - 0.6436(age) + 0.5441(\dot{V}O_{2\,max}) - 2.0719(RPE)$	**0.26**	11.66	0.0000
	$90.83 - 0.6116(T_{air})$	0.07	11.14	0.0010
Dexterity				
Lace Tying	$77.20 + 0.7886(T_{air}) + 0.3877(\dot{V}O_{2\,max})$	0.19	19.23	0.0000
	$96.35 + 0.8711(T_{air})$	**0.15**	25.22	0.0000
Nut Bolt	$55.36 + 1.2070(T_{finger}) + 0.6399\ (\dot{V}O_{2\,max})$	**0.21**	15.04	0.0002
	$106.78 + 0.6122(T_{air})$	0.08	12.58	0.0005
GPS entry	$42.52 - 0.3610(T_{air})$	**0.08**	14.18	0.0002
Cold Sensation				
CSS-Whole Body	$2.16 - 0.0514(T_{finger}) + 0.1397(RPE)$	0.12	7.83	0.0006
	$1.58 - 0.048(T_{air})$	**0.13**	24.35	0.0000
CSS-Fingers	$1.42 - 0.0768(T_{air})$	0.32	90.51	0.0000
Mood				
Tense	$-1.94 + 0.060(\dot{V}O_{2\,max}) + 0.2455(RPE)$	**0.16**	14.94	0.0000
	$1.62 - 0.0237(T_{air})$	0.01	2.34	0.1280
Calm	$8.99 + 0.0323(T_{air}) - 0.5253(RPE)$	**0.16**	15.61	0.0000
	$7.20 + 0.0392(T_{air})$	0.02	2.95	0.0880
Enthusiastic	$10.80 - 0.058(\dot{V}O_{2\,max}) - 0.6555(RPE)$	**0.31**	36.42	0.0000
	$5.69 - 0.0039(T_{air})$	0.00	0.03	0.8500
Alert	$11.04 - 0.0418(\dot{V}O_{2\,max}) - 0.8123(RPE)$	**0.57**	104.01	0.0000
	$6.01 - 0.0166(T_{air})$	0.01	0.79	0.3750
Sad	$-0.76 + 0.0517(\dot{V}O_{2\,max})$	**0.06**	10.19	0.0020
	$1.61 - 0.0122(T_{air})$	0.00	0.58	0.4400
Fatigue	$13.58 - 0.071(T_{air}) - 0.3587(T_{co}) - 0.064(age) + 0.044(\dot{V}O_{2\,max}) + 0.9028(RPE)$	**0.55**	27.92	0.0000
	$3.86 - 0.0516(T_{air})$	0.04	5.92	0.0160
Weary	$5.57 - 0.042(T_{air}) - 0.1547(age) + 0.7526(RPE)$	**0.34**	26.60	0.0000
	$4.13 - 0.0062(T_{air})$	0.00	0.07	0.7800
Sleepy	$0.72 + 0.0369(\dot{V}O_{2\,max}) + 0.7838(RPE)$	**0.44**	63.49	0.0000
	$5.40 + 0.0152(T_{air})$	0.00	0.56	0.4500

Abbreviations: SAP; shoulder arm push (measured upper body strength). CSS; cold sensation scale. RPE; rating of perceived exertion.

DISCUSSION

New contribution of this study: This study is the first to examine the effects of cold during long term cold weather operations on physical and cognitive performance where a large battery of both physical and cognitive tests were conducted in the field under continuous physiological assessment.

Summary of result highlights: This study provided an excellent opportunity for determining the predictive effects of cold on physical and cognitive performance. Groups were continuously exposed to various air temperatures ranging from -24.4 °C to +4.4 °C. Under these field conditions, physical performance mostly decreased and was predicted by T_{air}, T_{finger}, $\dot{V}O_{2\,max}$, and/or rating of perceived exertion. On the other hand, cognitive performance was not affected during any of the courses. All mood attributes (except "sadness" and "tenseness") were different in the field from baseline, and were generally related to rating of perceived exertion.

Possible mechanisms for results: These results are in general agreement with previous laboratory based studies. The decrease in hand grip strength during field sessions seen in our study is in agreement with several other studies (11,12,18,22). Giesbrecht and Bristow (11), and Giesbrecht et.al. (12) measured hand grip strength before and after immersion in 8 °C water (11), and with independent cooling of the core and periphery (12), and found decreased strength with cooling of the limb. They proposed (12) that cooling interferes with joint movement and can cause increased viscosity of synovial fluid and tissues of the hand, and decrease the efficiency of muscles by decreasing metabolic rate, enzyme activity, ATP utilization, slowed calcium and acetylcholine release, and delayed cross bridge formation, as well as increase time to achieve maximal force production. Cooling can also decrease excitability of nerve membranes, decrease number of muscle fibers recruited, and finally, initiate antagonistic muscle excitation. Some of the above studies also showed that strength and dexterity performance decrements were related to local hand and forearm cooling alone, regardless of core body temperature (8,9,12). Corroborating the above studies, Oksa and Rintamaki (18) explained that muscle cooling decreases force production during exercise, and that a decrease in core temperature is not a prerequisite for a decrement in performance.

Cooling decreases the ability of certain components of physical performance to function, namely, power, force production, velocity, and co-ordination. Some of the mechanisms which may account for a decrement in physical performance are decreased peripheral circulation caused by dehydration and vasoconstriction, and increased muscle stiffness and shivering. The decrement in physical performance is likely a combination of these factors. Unlike hand-grip strength, our upper body strength test which used larger muscles of the upper arm and shoulder did not differ from baseline during field testing. Upper body strength of two groups (2 and 3) decreased in the field, two groups (4 and 5) did not change, and one group (1) actually improved compared to baseline. Subjects were fully clothed during the survival courses, as such, the upper arms may not have cooled to the same extent as the forearms and hands, thus not affecting the ability of the upper arm and shoulder to generate force. Stepwise regression analysis indicated upper body strength was expected to decrease with an increase in T_{air}. This was an unexpected, anomalous result and we are unsure as to why this negative correlation occurred.

Giesbrecht and Bristow (11) also tested manual dexterity of larger muscles of the upper arm and shoulder (peg and ring test), and smaller muscles of the forearm (speed of movement test). Both dexterity tests were detrimentally affected by cold when T_{co} decreased by 0.5 °C, however, performance of the speed of movement test was lower than the peg and ring test (11). Performance of dexterity tests using muscle groups ranging from the hands to the upper arm and shoulder was dependent on temperature of the arm (12). Gaydos (8) and Gaydos and Dusek (9) have also demonstrated a decrease in manual dexterity performance (knot-tying, and block stringing) when the hands were cooled, regardless of body cooling. The conclusions from these studies and others (22) was that strength and dexterity of hands and arms using small, peripheral muscle groups were more detrimentally affected by local limb cooling than tasks that used larger muscle groups. Our lace-tying, nut-bolt, and GPS entry tests which used small muscles of the hand and forearm were detrimentally affected by cold, and the coldest group (group 4) had a significantly lower performance in the field than all groups. During the lace-tying test, subjects held their arms above the table to reach the laces and often complained of sore shoulders, this added burden may have also contributed to the decline in performance seen in this test.

Cognitive performance examined with logical reasoning, planning, and vigilance showed no decrements during field sessions. Coleshaw et.al. (4) support our findings of no decrement in logical reasoning in that they also used Baddeley's test of grammatical transformation (3) to examine logical reasoning, and found no decrement in performance with exposure to cold. Coleshaw et.al. (4) lowered core temperatures with immersion in 15 °C water and tested logical reasoning after rewarming had started in 41 °C water when skin temperature was warm but T_{co} remained low (4). They reported no loss of accuracy provided that adequate time for completion of the task was allowed. Coleshaw et.al. (4) attributed this slowed response to a slowing of synaptic transmission, and viewed it as a possible hazard when quick responses are needed in emergencies. Angus and Heslegrave (1) examined the effects of sleep loss on cognitive performance. They examined the cognitive performance of 12 female subjects during 54 hrs of sleep deprivation. Self-report scales, and logical reasoning were part of the test battery. Angus and Heslegrave (1) also used Baddeley's test of logical reasoning (3) and found a decline in the number of attempted questions, but no increase in errors. Our results agree with the above two studies in that we showed no changes in logical reasoning accuracy. However, our number of attempted logical reasoning questions was not affected during any of the courses.

Our planning task results did not differ between groups. McCann and Pointing (17) examined the effects of alerting drugs on planning performance during sustained operations on 34 CF personnel. Their planning task used a grid layout of a military area to dump ammunition at different locations in the area. Three layouts of the dumping area were replicated to create 36 topologically equivalent problems that looked quite different to the subjects. Planning problems were administered every two hours during 58 hrs of sleep deprivation. Their results indicated that planning quality degrades only slightly under conditions of sleep deprivation(17). We are not aware of similar planning work on the effects of cold. During the survival courses, our subjects may have suffered from sleep deprivation on the last two nights of the course, where they were alone in the forest. "Sleepiness" was not different between field testing sessions, but there was a slight effect of group in that group 5 was significantly less sleepy than all other groups. However, this had no effect on the planning performance on the final two days of the course.

Cognitive performance decrements are usually accompanied with drops in T_{co}, not just in skin temperature (10). The cold stress our subjects were exposed to may not have been sufficient to induce decrements in cognitive performance. We did not find a drop in T_{co} over time, or during the colder courses. Indeed core temperatures at time of testing were above values reported where cognitive performance decrements occurred. Paradoxically, the group exposed to the warmest air temperature (group 3, with a T_{air} of +4.4 ± 2.5 °C) had a lower mean T_{co} than two other groups that experienced a lower T_{air} (groups 1 and 5 with mean T_{air} of –5.5 ± 1.8, and –11.9 ± 6.9 °C, respectively). While the range in T_{air} was large (-24.4 to +4.4 °C), the mean range in T_{co} was relatively small (37.1 to 37.5 °C). The lower mean T_{co} of group 3 may be related to subject behavior. Subjects may have had a tendency to dress less warmly when the ambient temperature was warmer. Also, all groups had to perform the same tasks, as such, the group with greater T_{air} may have perspired more than other groups and the resultant wetter clothing may have induced core cooling.

The effects of cold on cognitive performance become more substantial with increasing task complexity. Giesbrecht et.al. (10) have shown that tests requiring minimal cognitive demands were unaffected by cold water immersion or central cooling. Our planning task had two levels of complexity, but it might not have been complex enough to be detrimentally affected by cold.

Response to our subjective scales of rating of perceived exertion, cold sensation, and mood were expected. Subjects were more tired, colder, and their mood declined in the field compared to baseline. Angus and Heslegrave (1) used subjective scales in their cognitive performance study and also found declines in mood as the study progressed.

Practical Implications: Of the predictive variables used in this study (T_{air}, age, $\dot{V}O_{2max}$, T_{co}, T_{finger}, and rating of perceived exertion), T_{finger} and rating of perceived exertion can be predicted by T_{air}. In a case where performance is to be predicted, and only T_{air} is known, other predictive variables may themselves be predicted, thus giving a more complete prediction of the response variable. Our results have practical implications for military operations, rescue personnel, and outdoor enthusiasts. Training conditions of the survival courses were not extreme enough to cause a loss of function, decrements in cognitive performance, or to induce hypothermia on the participants. It is reasonable that training for, and participating in military operations at the cold stresses presented in this study will allow the members to maintain the ability to plan, and reason, but not to utilize full strength and dexterity. If conditions during actual survival scenarios are similar to those presented here, members should have the ability to perform without serious difficulty.

The ability to use equipment during cold weather operations is vital for survival. Clothing should be equipped with "velcro" or large zippers with strings so they may be easily reached and drawn with gloves on. Signaling and communication equipment should be simple to use, with buttons and controls large enough for operation with gloves on. Finally, food should be easily accessible in packaging with pre-cut tags that can be removed with gloves on.

The present results are of interest to rescue personnel because a reasonable amount of co-operation and self-help can be expected if the victims are not suffering from severe trauma. For example, if provisions can be delivered to the victims and minimal dexterity of the hands and fingers are required to access the provisions, then rescue may not have to be immediate to ensure survival of the victims. For outdoor enthusiasts these results offer reassurance that with proper food and equipment, the risk of loss of cognitive performance is minimal compared to those of strength and dexterity.

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APPENDIX A. Sample Testing Instruments: Subjective scales [rating of perceived exertion, cold sensation scales (whole body, fingers, and toes), and mood attributes], and cognitive tests (logical reasoning and planning).

CFSSAT Field Trial
Daily Data Sheet

Day #: ____

Subject: ____________
Date: ____________
Time: ____________
Temperature (°C): ____________

Cold Sensation Scale

0	Warm
1	Comfortable
2	Slightly cool
3	Cool but comfortable
4	Uncomfortably cool
5	Cold
6	
7	Very cold
8	
9	Numb with cold
10	So cold I am helpless
•	Collapse

Rating of Perceived Exertion

0	Not tired
1	Barely tired
2	Slightly tired
3	Moderately tired
4	Somewhat tired
5	Tired
6	
7	Very tired
8	
9	Very, very tired
10	Extremely tired
•	Collapse

Strength Tests

Grip Strength
1 ______
2 ______
3 ______
______

S.A.P
1 ______
2 ______
3 ______
______

Manual Dexterity

Lace Tying ______

Nut/Bold Assembly ______

GPS ______

Toe Sensation Scale

0	Warm
1	Comfortable
2	Slightly cool
3	Cool but comfortable
4	Uncomfortably cool
5	Cold
6	
7	Very cold
8	
9	Numb with cold
10	So cold I am helpless
•	Collapse

Finger Sensation Scale

0	Warm
1	Comfortable
2	Slightly cool
3	Cool but comfortable
4	Uncomfortably cool
5	Cold
6	
7	Very cold
8	
9	Numb with cold
10	So cold I am helpless
•	Collapse

Please complete carefully:

How alert do you feel? (wide awake, vigilant)	**Very little**	**Very much**
How sad do you feel? (sorrowful, blue)	**Very little**	**Very much**
How tense do you feel? (uptight, nervous, jittery)	**Very little**	**Very much**
How much of an effort is it to do anything?	**Very little**	**Very much**
How enthusiastic do you feel? (motivated)	**Very little**	**Very much**
How weary do you feel? (tired and fed-up, beat)	**Very little**	**Very much**
How calm do you feel? (relaxed, laid back)	**Very little**	**Very much**
How sleepy do you feel? (ready for bed)	**Very little**	**Very much**

LOGICAL REASONING (Page 1 of 9)

PROVIDE ANSWERS TO THE FOLLOWING GRAMMATICAL REASONING PROBLEMS. ANSWER EACH QUESTION BY CIRCLING EITHER "T" FOR TRUE OR "F" FOR FALSE.

B A	**A FOLLOWS B**	**T**	**F**
B A	**A IS NOT FOLLOWED BY B**	**T**	**F**
A B	**B DOES NOT FOLLOW A**	**T**	**F**
B A	**A DOES NOT PRECEDE B**	**T**	**F**
B A	**B PRECEDES A**	**T**	**F**
B A	**B DOES NOT PRECEDE A**	**T**	**F**
A B	**A IS PRECEDED BY B**	**T**	**F**
B A	**B IS NOT PRECEDED BY A**	**T**	**F**
B A	**A IS NOT PRECEDED BY B**	**T**	**F**

			gum	lemon drops				scrub brush	brillo pads		EXIT ↑		
bananas			pretzels	crakers				laundry soap	dish soap				mayo
kiwi			mints	nuts				wax	window cleaner				vinegar
melons													mustard
plums				Cottage cheese	yogurt			bacon	sausage				pepper
apples				butter	cream			roast beef	turkey				ketchup
oranges				eggs	sour cream			wurst	chicken legs				relish
pears													
grapes				beans	lettuce			kool aid	tea				cocoa
				cabbage	spinach			piña colada	fruit juice				suger
				tomato	radishes			beer	water				salt
→ ENTER				carrots	onions			coffee	cola				yeast
													flour
			pie	bread	biscuit	muffins	rolls	donuts	cookies	cake			oil

Problem #1:

You have two carts:

The first travels 1 square per clock tick and holds 7 items.

The second travels 2 squares per clock tick and holds 8 items.

Create an efficient plan!

CONFIDENCE RATINGS:

________ %

	wurst	turkey	bacon	ham	sausage	roast beef		piña colada	water	beer	tea	fruit juice	kool aid
EXIT													
													yeast
lemon drops	corn chips	nuts		cake	pie	rolls		apples	oranges	grapes	plums		salt
gum	pretzels	crackers		donuts	muffins	cabbage		kiwi	bananas	melons	pears		sugar
													flour
													vanilla
				eggs	ice cream	sour cream		pepper	mayo	ketchup	mustard		baking powder
window cleaner	brillo pads	laundry soap		whipped cream	cottage cheese	yogurt		relish	tabasco	jam	vinegar		cocoa
bleach	wax	scrub brush											oil
	beans	carrots	onions	spinach	tomato	radishes	lettuce	cabbage				ENTER	

Problem # 2:

You have two carts:

The first travels 1 square per clock tick and holds 10 items.

The second travels 2 squares per clock tick and holds 5 items.

Create an efficient plan!

CONFIDENCE RATINGS:

________ %

Problem # 3:

You have two carts:

The first travels 1 square per clock tick and holds 7 items.

The second travels 2 squares per clock tick and holds 8 items.

Create an efficient plan!

CONFIDENCE RATINGS:

________ %

			dish soap	bleach	brillo pads	scrub brush	wax	laundry soap	window cleaner	mop			chicken legs
													ham
ENTER				vinegar	pepper			melons	plums				pork chops
				ketchup	mayo			pears	oranges				sausage
				mustard	tabasco			grapes	apples				roast beef
sugar				relish	jam			bananas	kiwi				turkey
yeast													
baking powder				gum	corn chips			muffins	biscuits				sour cream
vanilla				crackers	lemon drops			bread	cookies				cottage cheese
flour				popcron	nuts			rolls	pie				yogurt
salt													butter
cocoa			carrots	beans				pina colada	fruit juice				ice cream
oil			tomato	onions				tea	water				cream
			lettuce	cabbage				beer	kool aid		EXIT		

			swiss cheese	cottage cheese	cream	whipped cream	eggs	butter	sour cream	yogurt			wax
ENTER													scrub brush
				carrots	lettuce			mustard	tabasco				mop
				beans	tomato			pepper	mayo				dish soap
				spinach	cabbage			jam	vinegar				laundry soap
coffee				onions	radishes			ketchup	relish				bleach
beer													
kool aid				popcorn	nuts			bread	cookies				sausage
pina colada				crackers	gum			rolls	cake				ham
water				corn chips	pretzels			donuts	muffins				wurst
fruit juices													pork chops
tea			cocoa	baking powder				melons	kiwi				chicken legs
cola			sugar	oil				plums	pears				turkey
			vanilla	salt				oranges	grapes			EXIT	

Problem # 4:

You have two carts:

The first travels 1 square per clock tick and holds 10 items.

The second travels 2 squares per clock tick and holds 5 items.

Create an efficient plan!

CONFIDENCE RATINGS:

_______ %

pears			onions	tomato	carrots	cabbage	spinach	lettuce	beans	radishes			
melons													
kiwi				fruit juice	beer			donuts	pie				ENTER
apples				water	pina colada			bread	cake				
plums				coffee	kool aid			muffins	cookies				
grapes				tea	cola			rolls	biscuit				nuts
													pretzels
oil				biscuits	muffins			mop	dish soap				corn chips
yeast				cookies	bread			bleach	window cleaner				gum
salt				pie	rolls			wax	brillo pads				mints
sugar													crackers
cocoa				butter	yogurt				wurst	ham			popcorn
flour				cottage cheese	whipped cream				turkey	sausage			lemon drops
		EXIT		cream	ice cream				bacon	roast beef			

Problem # 5:

You have two carts:

The first travels 1 square per clock tick and holds 7 items.

The second travels 2 squares per clock tick and holds 8 items.

Create an efficient plan!

CONFIDENCE RATINGS:

________ %

APPENDIX B. Sample physiological responses and correlation plots

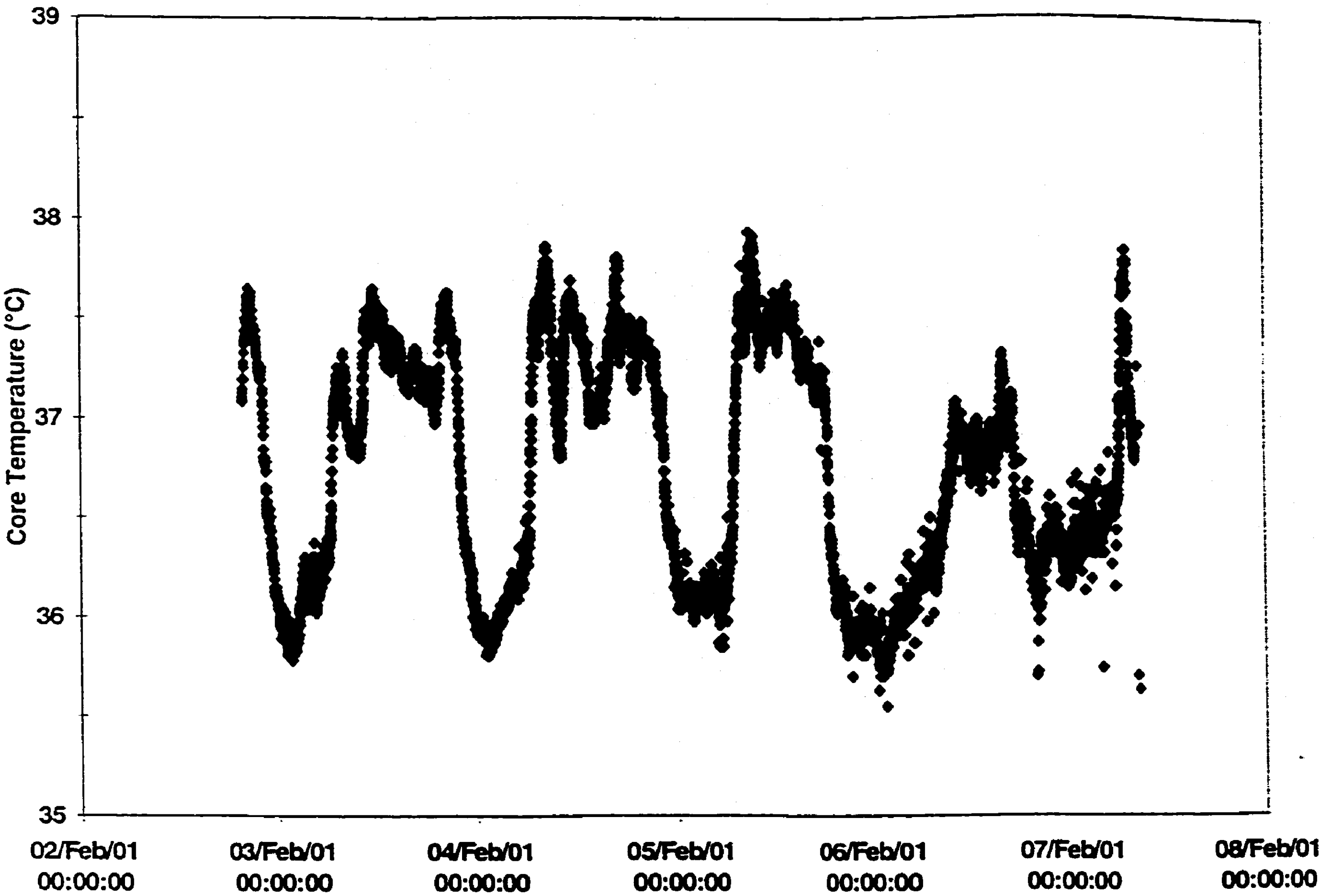

Figure 1. Sample continuous core temperature record of one subject. Subjects were instrumented on Friday evening, and de-instrumented on Wednesday morning.

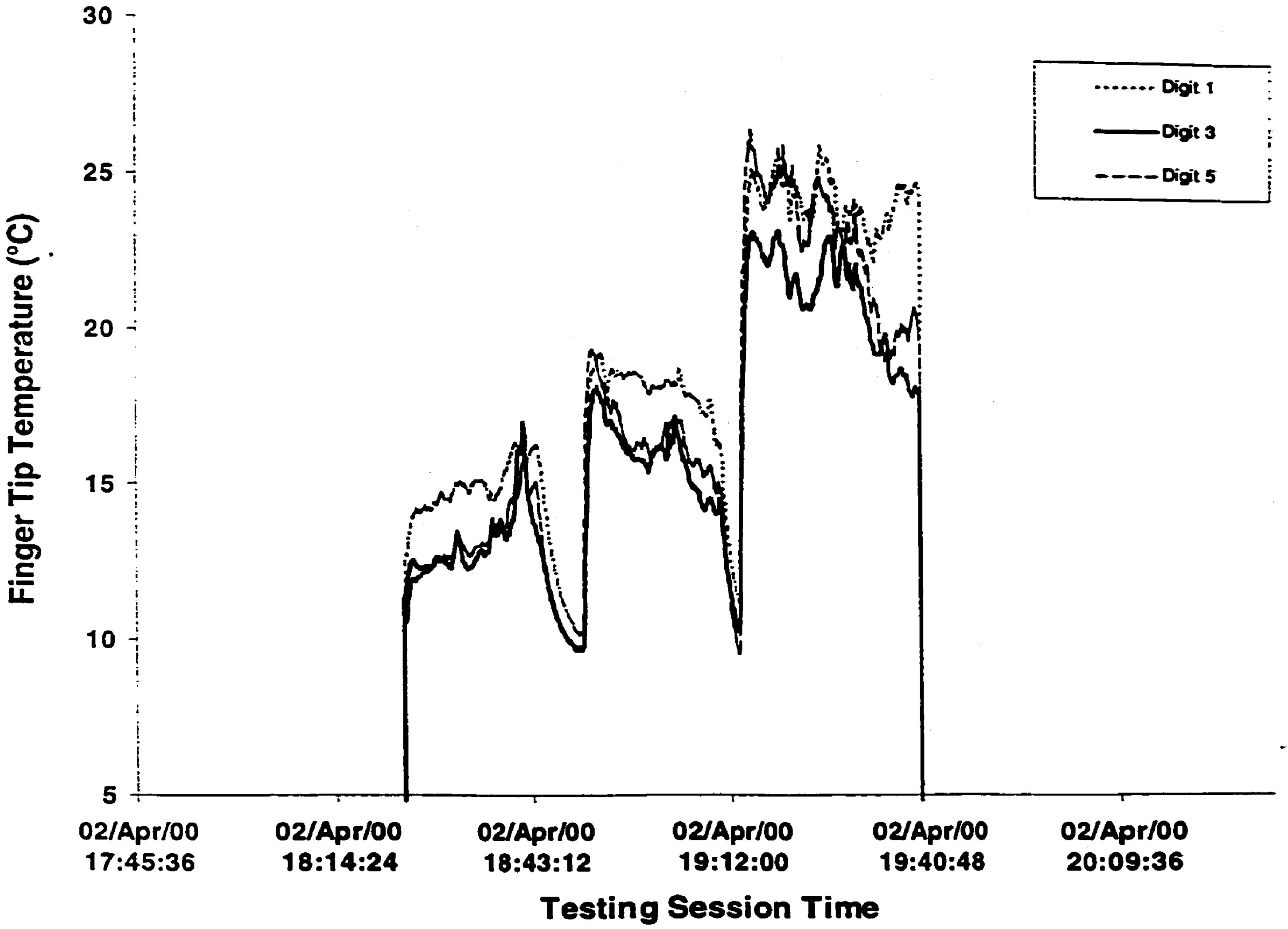

Figure 2. Continuous finger tip temperature at time of field testing of three subjects.

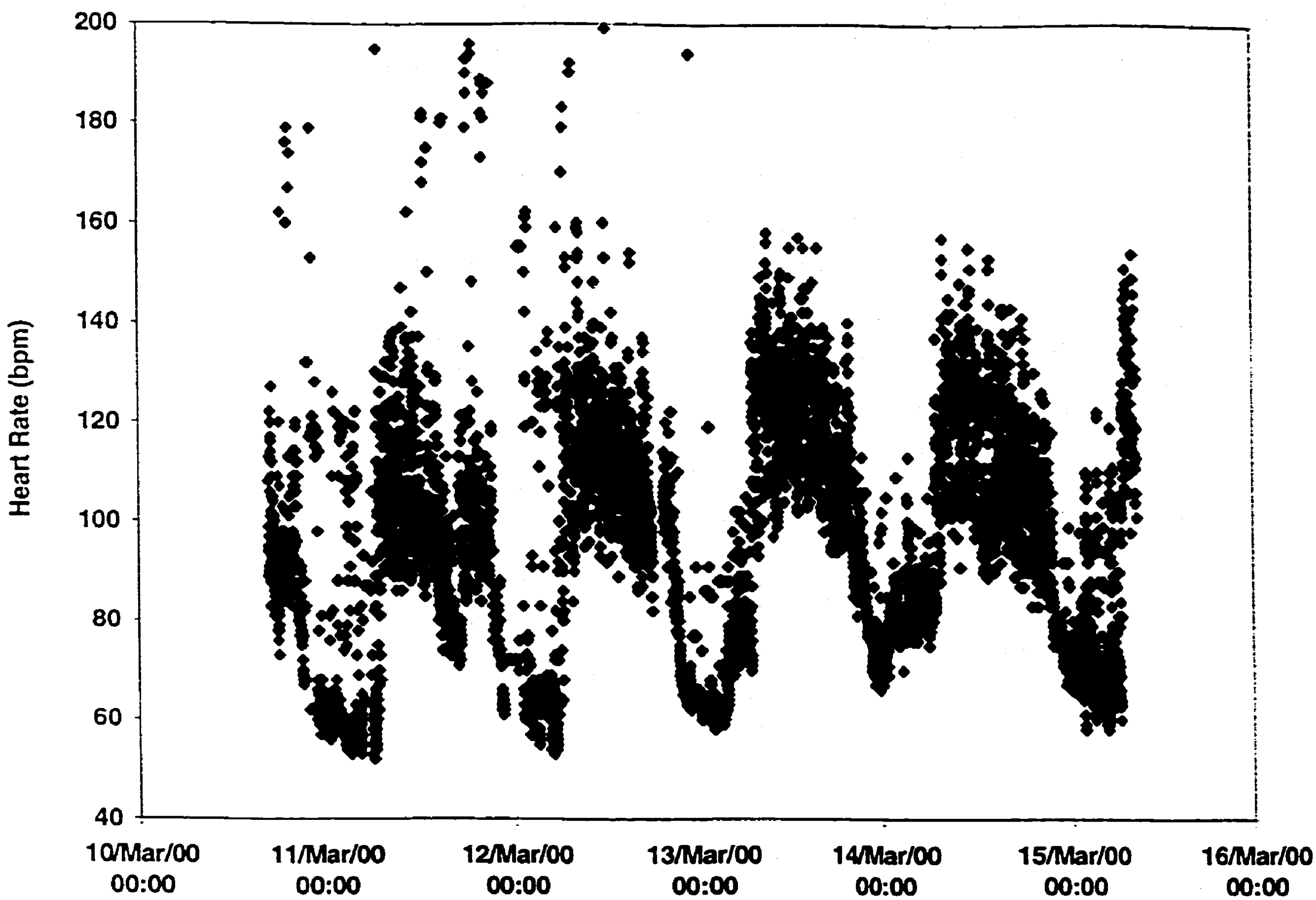

Figure 3. Continuous heart rate record for one subject. Only 29 of the possible 140 full days of data were collected. This figure is representative of complete data collection for heart rate.

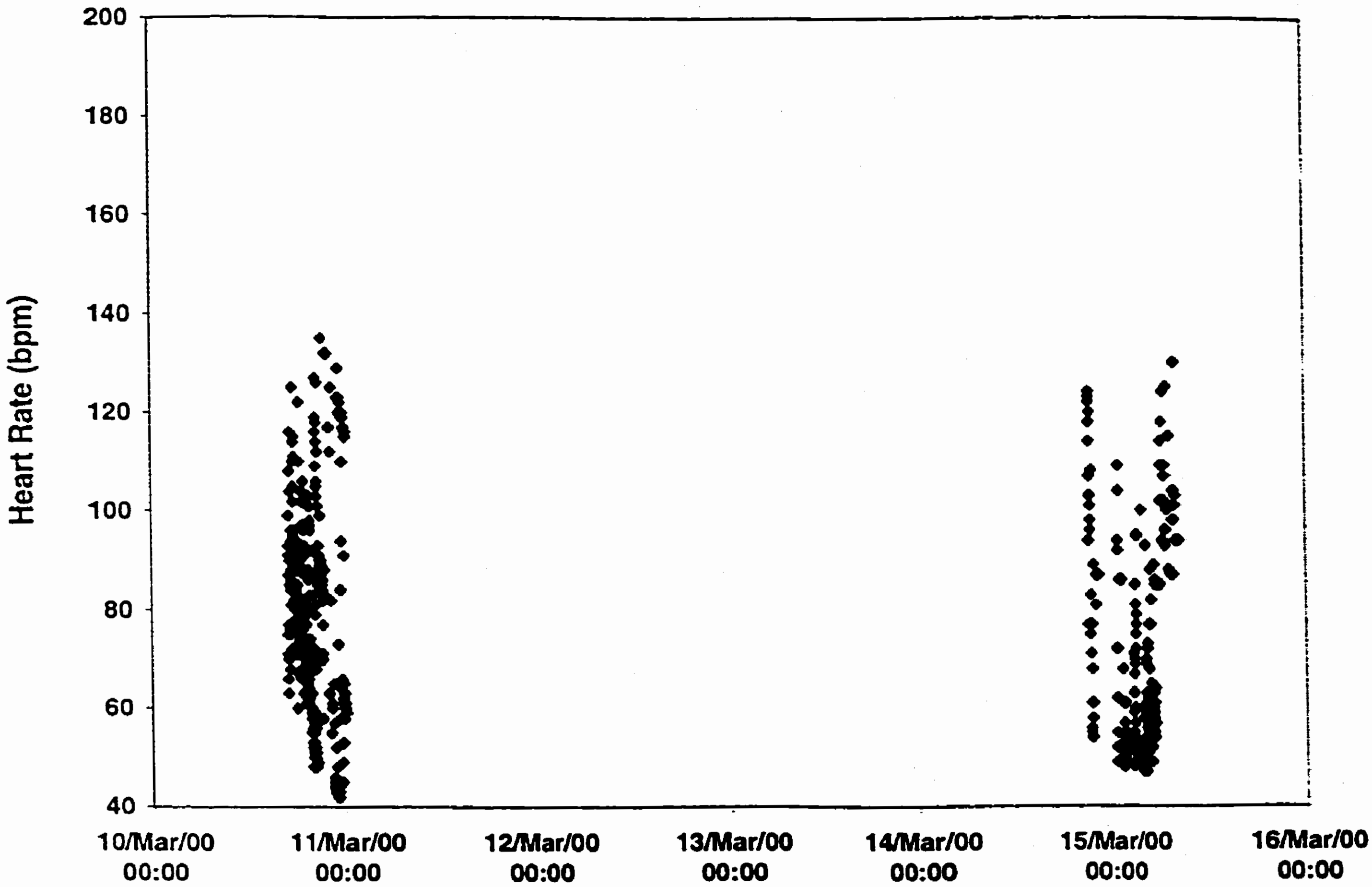

Figure 4. Continuous heart rate record of one subject. This figure is representative of incomplete data collection.

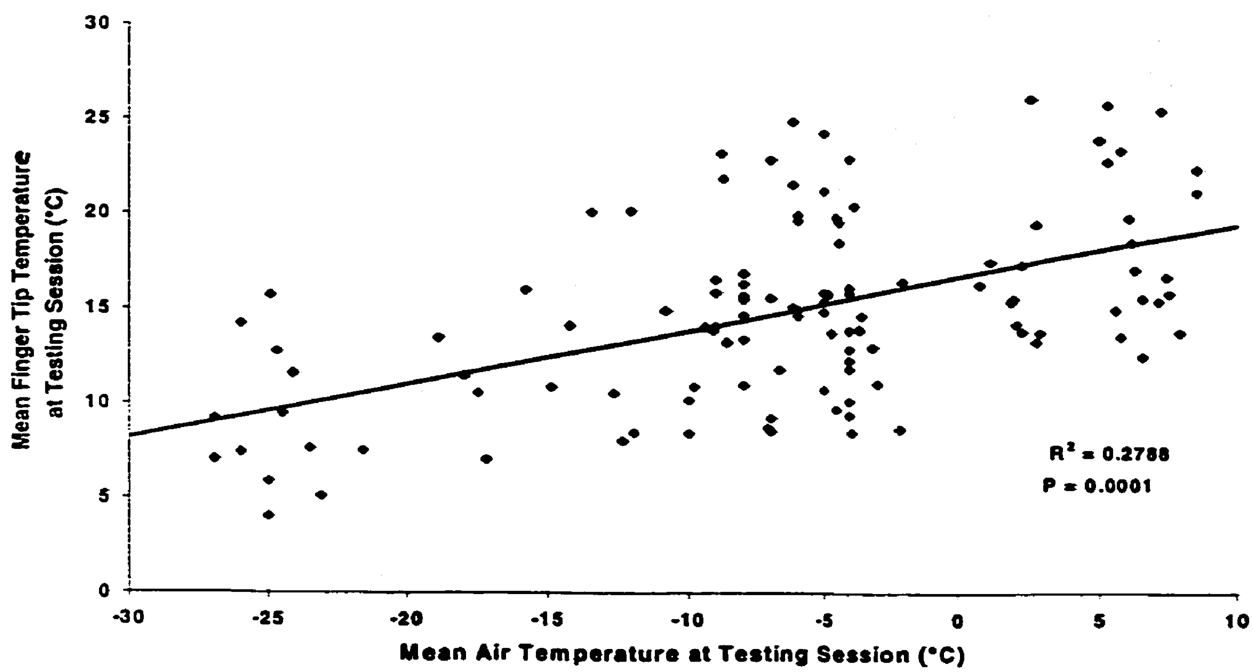

Figure 5. Scatter plot of T_{air} and T_{finger} during field testing sessions.

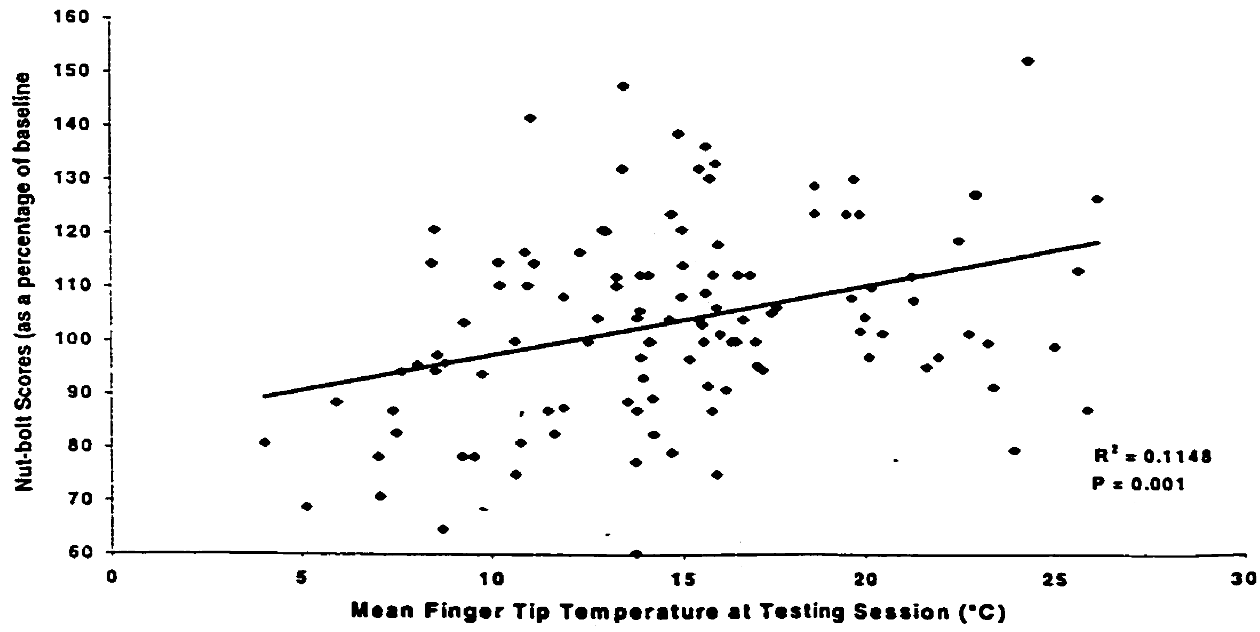

Figure 6. Scatter plot of T_{finger} and nut-bolt scores during field testing sessions.

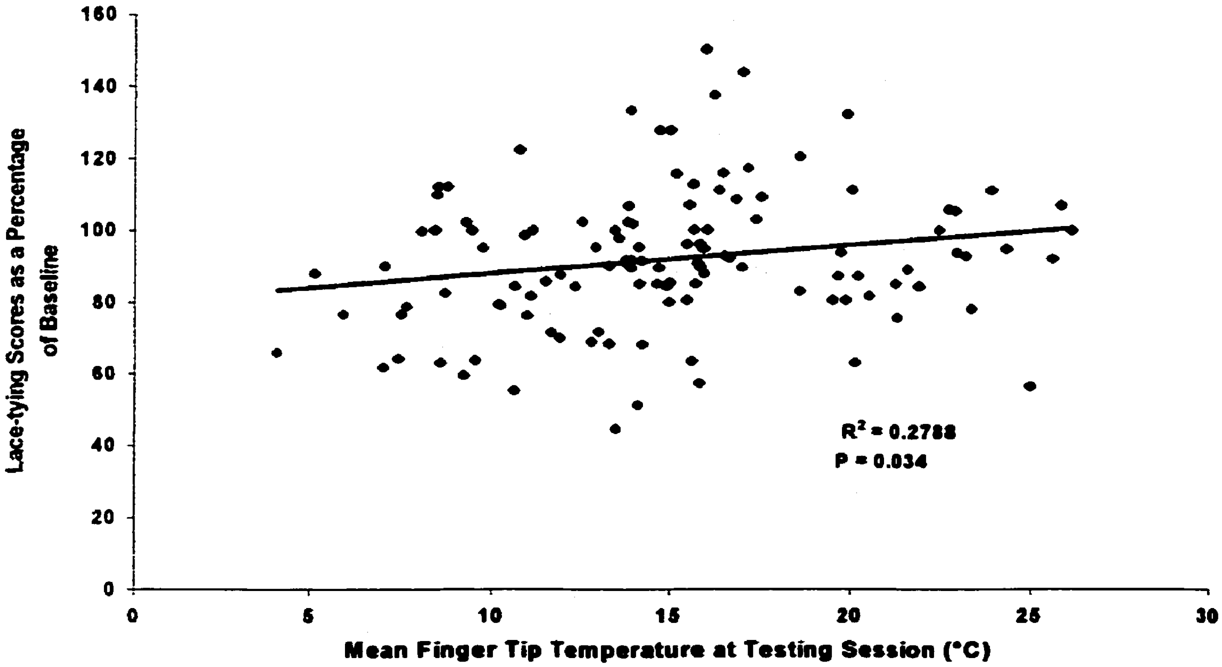

Figure 7. Scatter plot of T_{finger} and lace-tying scores during field testing sessions.

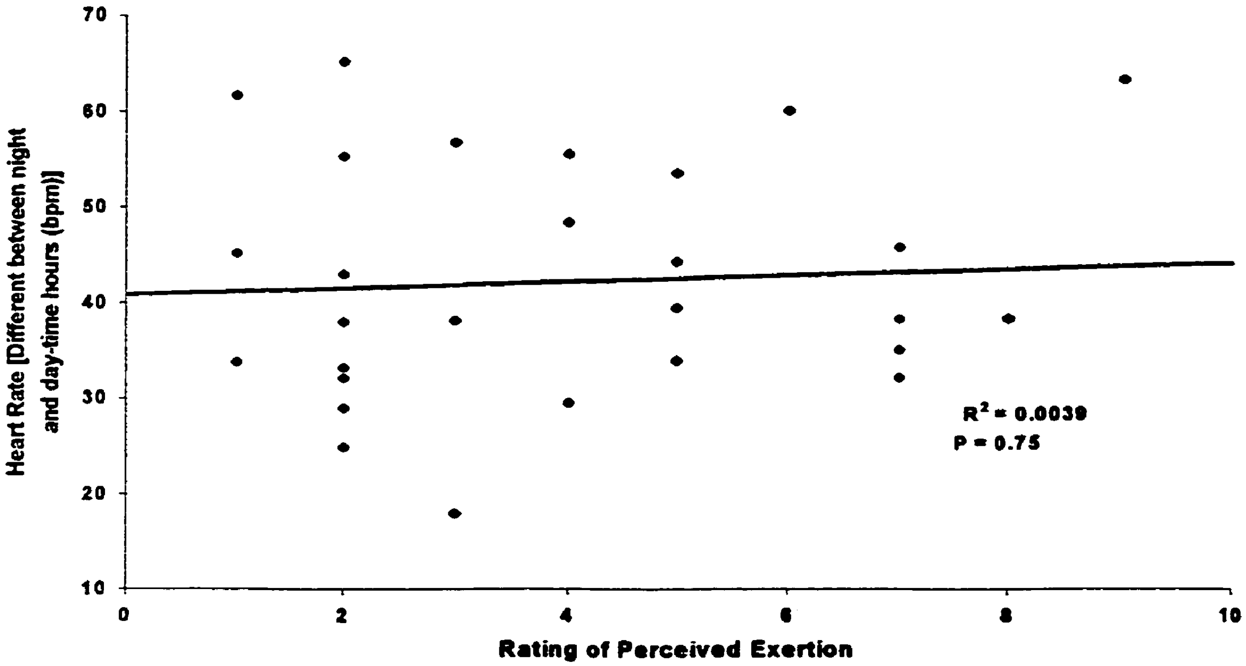

Figure 8. Scatter plot of RPE and heart rate. Night-time (2400-0400 hrs) heart rate was subtracted from day-time (0700 hrs to testing session) heart rate to maintain relative changes in heart rate between subjects. This was an attempt to link RPE to a physiological response, but no relationship existed between these two variables.

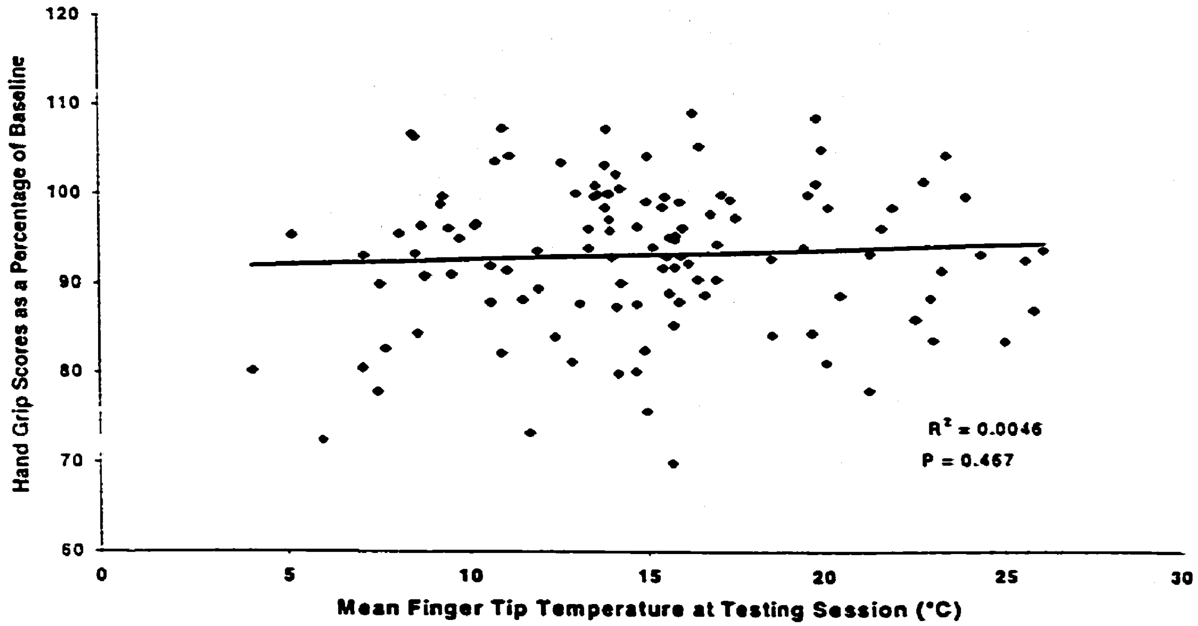

Figure 9. Scatter plot of T_{finger} and hand grip strength during field testing sessions.

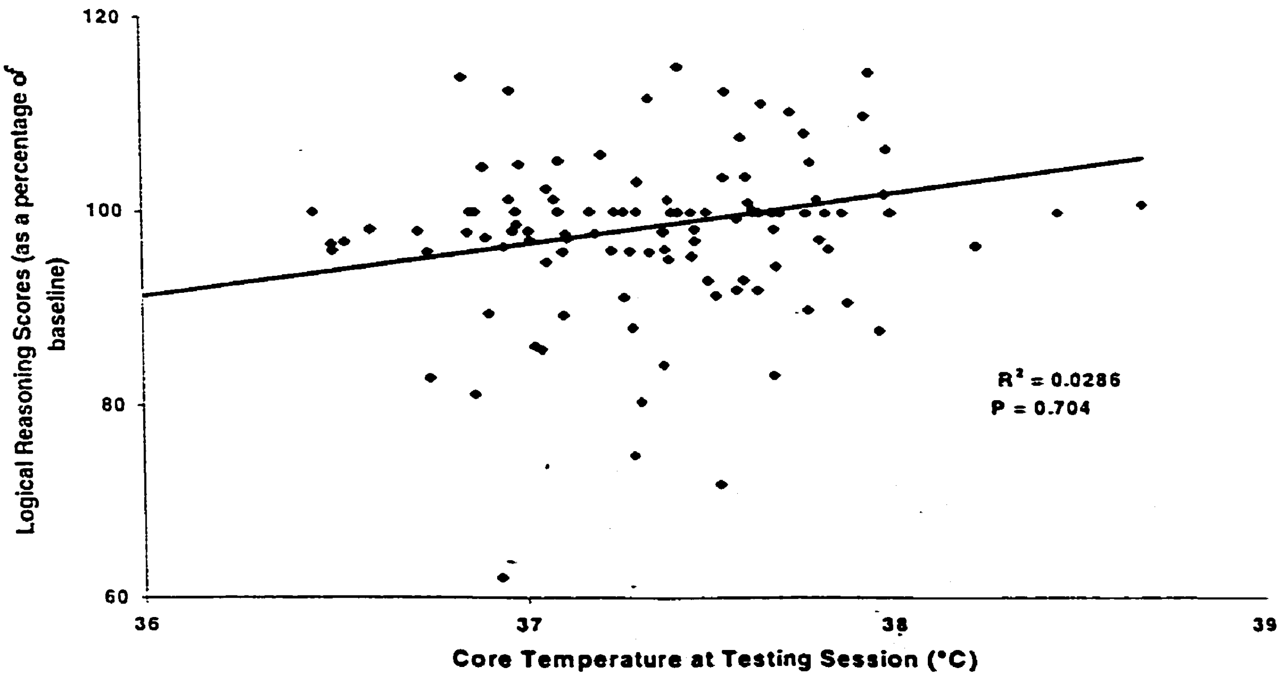

Figure 10. Scatter plot of T_{co} and logical reasoning scores during field testing sessions.

APPENDIX C. Mean data for all variables for each group

Table 1. Mean T_{air} for each group for each testing session. Values are given as °C.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)			-3.7	0.5	-4.3	0.5	-6.8	1.0	-6.2	1.5	-8.2	0.4	-4.0	0.0
2 (6)	NOT		-3.1	0.9	-9.9	1.2	-4.5	0.3	-9.3	2.3	-12.5	1.8	-17.4	1.8
3 (6)	MEASURED		2.4	0.4	6.3	0.6	7.9	0.6	1.9	0.8	5.7	0.6	1.9	0.1
4 (4)			-17.9	0.7	-25.5	1.9	-25.4	0.8	-24.0	1.0	-23.0	1.5	-30.5	0.6
5 (6)			-13.4	0.7	-8.6	0.3	-6.6	0.5	-3.9	0.6	-14.1	1.1	-25.0	0.0

Table 2. Mean T_{co} for each group for each testing session. Values are given as °C.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)					37.6	0.3	37.3	0.3	37.6	0.3	37.3	0.3	37.5	0.3
2 (6)	NOT		37.6	0.3	37.5	0.2	37.3	0.5	37.1	0.6	37.6	0.8		
3 (6)	MEASURED		37.3	0.4	37.3	0.3	37.2	0.2	36.9	0.3	37.1	0.3		
4 (4)					37.2	0.3	37.6	0.4	37.3	0.4	36.9	0.2	37.4	0.4
5 (6)					37.4	0.3	37.7	0.4	37.5	0.4	37.3	0.7	37.6	0.4

Table 3. Mean T_{finger} for each group for each testing session. Values are given as °C.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)			11.9	1.8	15.3	4.6	17.7	3.7	17.2	3.6	15.0	2.1		
2 (6)	NOT		14.1	3.9	12.9	4.1	15.9	4.8	13.4	3.2	13.2	2.3	NOT	
3 (6)	MEASURED		14.1	0.9	18.7	5.2	17.6	3.5	18.7	3.9	20.3	4.5	MEASURED	
4 (4)			10.7	2.7	6.4	2.3	9.2	4.4	12.1	4.1	9.6	2.0		
5 (6)			8.1	0.5	19.7	5.1	14.7	7.2	14.7	4.3	15.7	4.6		

Table 4. Mean rating of perceived exertion for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.7	0.8	3.0	1.7	2.7	1.5	5.2	2.4	4.8	2.1	4.7	2.6	5.7	3.2
2 (6)	0.7	0.8	2.2	1.6	2.8	2.3	4.5	2.4	5.5	2.2	4.0	2.2	3.0	2.2
3 (6)	0.2	0.4	2.0	0.6	2.2	1.0	4.0	2.0	4.0	2.4	3.5	2.0	2.3	2.1
4 (4)	0.8	0.5	1.8	1.5	3.3	1.9	3.8	1.5	3.3	1.3	5.0	2.2	4.5	1.3
5 (6)	0.3	0.5	1.5	0.8	2.5	1.0	2.8	1.9	3.3	1.6	3.7	1.8	3.8	2.3

Table 5. Mean hand grip strength (kg) for each group for each testing session. Scores are given as a percentage of baseline performance.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	100.0	0.0	92.3	4.9	91.9	7.2	92.3	8.1	92.7	7.0	91.9	3.9	90.0	5.9
2 (6)	100.0	0.0	97.0	9.1	97.5	10.0	96.0	10.1	92.6	12.8	90.4	10.0	89.7	11.5
3 (6)	100.0	0.0	99.1	5.6	100.3	4.2	96.0	5.5	98.7	5.6	95.8	5.4	100.4	8.1
4 (4)	100.0	0.0	93.5	5.4	88.7	9.8	78.6	8.0	87.3	6.4	84.3	8.1	92.6	11.1
5 (6)	100.0	0.0	90.2	9.5	92.7	8.2	91.4	6.5	90.8	5.0	86.2	6.9	81.9	17.1

Table 6. Mean upper body strength (kg) for each group for each testing session. Scores are given as a percentage of baseline performance.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	100.0	0.0	119.3	12.9	115.6	11.7	114.1	14.0	114.8	13.5	114.0	7.9		
2 (6)	100.0	0.0	82.4	21.9	85.1	25.9	82.9	24.1	80.9	21.8	82.0	26.9	NOT	
3 (6)	100.0	0.0	77.5	11.3	77.5	10.6	77.6	9.6	76.3	10.7	77.2	13.7	MEASURED	
4 (4)	100.0	0.0	99.6	18.1	104.0	7.5	104.5	10.7	97.4	14.5	96.0	5.7		
5 (6)	100.0	0.0	99.0	10.8	104.4	5.8	104.3	6.4	104.4	7.5	98.9	10.6		

Table 7. Mean lace-tying scores for each group for each testing session. Scores are given as a percentage of baseline performance.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	100.0	0.0	104.1	20.3	103.7	21.7	102.0	9.3	110.4	22.7	105.9	26.9		
2 (6)	100.0	0.0	89.5	6.3	86.2	8.5	91.3	25.8	84.3	21.2	84.8	18.4	NOT	
3 (6)	100.0	0.0	81.4	15.5	94.6	14.5	97.6	13.2	97.3	13.7	98.7	11.8	MEASURED	
4 (4)	100.0	0.0	68.9	22.4	68.9	13.0	73.2	8.8	66.8	9.3	68.0	7.5		
5 (6)	100.0	0.0	80.8	17.5	85.9	12.7	89.7	25.0	96.1	18.0	86.9	17.7		

Table 8. Mean nut-bolt scores for each group for each testing session. Scores are given as a percentage of baseline performance.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	100.0	0.0	90.7	23.0	103.8	24.8	114.0	20.6	122.3	22.7	129.3	21.1		
2 (6)	100.0	0.0	102.8	19.1	109.4	4.9	106.9	10.0	102.8	12.5	109.0	8.4	NOT	
3 (6)	100.0	0.0	92.4	12.0	102.1	13.8	108.9	6.0	111.1	11.3	108.3	22.4	MEASURED	
4 (4)	100.0	0.0	95.2	35.8	76.5	5.3	83.3	6.0	88.6	15.0	75.5	11.6		
5 (6)	100.0	0.0	97.5	10.5	96.5	2.4	98.0	3.0	99.9	24.2	103.7	7.3		

Table 9. Mean GPS entry times (sec) for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)			51.2	13.8	40.8	8.0	43.7	9.8	44.5	9.6	38.5	14.6	36.2	9.6
2 (6)	NOT		41.5	6.5	54.3	15.9	36.5	8.0	39.8	12.9	38.3	12.8	49.7	9.4
3 (6)	MEASURED		41.8	11.3	54.8	6.6	41.5	4.5	42.3	5.5	40.3	3.5	42.7	7.5
4 (4)			49.3	9.8	68.8	30.7	52.3	20.8	47.8	12.4	47.5	7.0	68.0	9.6
5 (6)			53.0	3.3	49.3	15.7	43.8	14.0	41.3	7.8	41.3	6.8	44.8	9.9

Table 10. Mean logical reasoning scores for each group for each testing session. Scores are given as a percentage of baseline performance.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	100.0	0.0	98.5	9.6	98.1	7.0	95.9	6.7	100.1	6.0	101.6	6.8		
2 (6)	100.0	0.0	97.0	6.8	97.7	10.4	103.1	4.9	103.2	6.7	107.2	15.7	NOT	
3 (6)	100.0	0.0	88.9	10.5	92.3	15.5	94.4	6.7	98.8	2.5	96.4	13.1	MEASURED	
4 (4)	100.0	0.0	91.3	4.8	100.4	12.5	83.5	31.5	100.4	5.4	102.3	7.2		
5 (6)	100.0	0.0	99.0	15.3	93.9	5.3	103.1	14.9	96.3	7.5	110.2	30.0		

Table 11. Mean planning test scores for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)			3.2	3.3	14.5	7.1	5.2	4.3	11.5	11.0	5.0	6.5		
2 (6)	NOT		1.7	1.4	14.5	6.4	5.7	6.4	9.7	10.2	4.2	4.4	NOT	
3 (6)	MEASURED		1.0	2.0	15.7	4.5	2.0	2.6	14.7	2.4	3.7	4.7	MEASURED	
4 (4)			1.0	0.8	22.5	9.8	2.8	3.9	21.0	6.6	5.3	4.8		
5 (6)			5.5	3.8	11.3	8.6	3.5	5.0	15.3	4.0	4.5	4.8		

Table 12. Mean percent vigilance response for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)					100.0	0.0	100.0	0.0	77.8	25.1	83.3	40.8		
2 (6)	NOT		NOT		91.7	20.4	94.5	13.6	100.0	0.0	86.1	22.1	NOT	
3 (6)	MEASURED		MEASURED		100.0	0.0	75.0	20.4	91.7	20.4	91.7	20.4	MEASURED	
4 (4)					100.0	0.0	83.3	28.9	88.9	19.2	83.3	28.9		
5 (6)					100.0	0.0	85.2	10.2	90.5	5.8	88.4	15.5		

Table 13. Mean whole body cold sensation scale scores for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.7	0.5	1.8	1.0	1.3	1.0	1.8	1.2	1.7	1.2	1.8	1.0	0.8	0.8
2 (6)	0.7	0.5	2.5	0.5	2.5	1.0	2.0	1.1	2.3	0.8	2.3	0.8	3.0	1.1
3 (6)	0.0	0.0	2.3	1.0	1.8	1.0	1.5	0.8	1.7	1.2	1.5	1.4	1.0	0.6
4 (4)	0.8	0.5	2.0	1.2	3.3	1.3	2.5	1.3	1.3	0.5	3.0	0.8	3.0	1.4
5 (6)	1.0	0.6	1.2	0.8	0.8	0.8	1.2	0.8	1.3	0.8	2.8	1.0	4.3	3.3

Table 14. Mean cold sensation scale of the fingers for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.7	0.5	2.5	1.8	2.2	1.5	1.2	1.2	1.5	1.2	1.8	1.0	0.7	0.5
2 (6)	0.3	0.5	2.3	0.8	1.8	0.8	1.5	1.0	2.0	0.9	2.5	1.5	3.7	0.8
3 (6)	0.5	0.8	1.5	0.8	1.7	0.8	1.3	0.5	1.2	0.8	1.2	0.8	1.2	0.8
4 (4)	0.3	0.5	2.0	0.8	3.5	0.6	3.8	2.2	1.3	0.5	2.5	0.6	4.3	1.5
5 (6)	0.8	0.4	2.0	1.3	1.7	1.2	1.3	1.0	1.7	1.0	2.3	0.8	5.5	3.4

Table 15. Mean cold sensation scale of the toes for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.3	0.5	1.2	0.8	0.7	0.5	1.3	1.4	1.7	1.6	1.2	0.8	1.7	1.0
2 (6)	0.3	0.5	1.2	1.2	1.8	1.0	1.2	1.2	1.7	1.2	2.0	1.3	2.5	1.4
3 (6)	0.2	0.4	2.0	1.4	3.5	1.0	1.0	0.9	1.3	1.0	2.0	1.4	1.7	1.2
4 (4)	0.8	0.5	0.5	0.6	1.0	0.8	1.5	1.0	1.0	0.0	1.5	0.6	2.0	1.2
5 (6)	1.0	0.0	1.0	1.5	0.8	1.2	0.5	0.8	1.3	1.0	1.8	0.8	4.3	3.0

Table 16. Mean tenseness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	1.1	1.8	1.4	2.0	1.2	0.8	3.0	2.6	1.6	2.0	2.0	1.5	1.5	1.8
2 (6)	1.4	2.3	1.2	0.8	1.0	1.2	1.2	0.7	3.1	3.2	2.1	1.8	1.9	2.2
3 (6)	2.5	3.9	1.8	2.0	0.8	0.8	1.2	0.7	2.5	3.3	1.4	1.0	1.5	1.7
4 (4)	0.4	0.4	1.0	1.1	2.2	1.6	2.7	2.2	1.9	0.4	3.8	2.5	2.2	0.6
5 (6)	1.1	1.4	1.6	2.4	1.4	1.8	2.2	2.6	2.0	2.7	2.1	3.2	1.6	2.6

Table 17. Mean calmness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	7.5	3.7	8.1	1.2	7.7	2.0	5.7	3.4	5.5	4.2	6.1	3.6	5.0	3.8
2 (6)	6.9	4.3	6.2	3.0	6.0	4.4	6.8	2.9	6.3	3.1	5.7	3.2	5.9	3.8
3 (6)	6.8	3.9	7.5	3.6	8.8	0.8	7.8	3.2	7.1	2.8	6.9	3.1	6.8	2.5
4 (4)	9.5	0.4	7.1	1.6	5.6	2.5	6.8	1.5	6.2	3.1	5.3	3.0	6.6	2.4
5 (6)	6.8	4.6	7.4	2.9	8.8	1.3	7.3	2.9	8.6	1.8	7.5	3.2	7.1	3.2

Table 18. Mean sadness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.8	0.9	0.8	0.5	0.6	0.4	2.7	2.1	1.7	1.3	0.9	0.6	1.4	1.5
2 (6)	1.0	2.1	1.5	2.1	2.0	2.3	2.7	2.3	2.3	1.1	3.6	3.5	3.0	3.7
3 (6)	0.6	1.0	0.7	1.0	3.0	3.8	1.4	0.7	1.4	1.9	2.0	1.4	1.5	1.4
4 (4)	0.6	0.7	0.9	0.3	1.7	1.1	2.1	2.0	1.5	0.4	3.7	2.3	2.3	1.6
5 (6)	0.2	0.2	0.3	0.5	0.3	0.5	2.0	2.9	1.7	2.4	1.3	2.1	1.3	1.9

Table 19. Mean enthusiasm mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	5.9	1.2	5.7	1.9	6.6	2.0	4.3	3.3	4.9	2.2	4.5	1.9	6.0	2.1
2 (6)	7.5	2.7	4.2	1.6	5.4	2.7	3.6	3.0	3.0	1.5	3.5	2.7	5.4	3.1
3 (6)	6.7	3.5	7.1	1.5	6.8	2.7	5.5	2.1	4.8	3.6	5.0	2.8	6.3	2.6
4 (4)	9.4	0.3	7.0	2.5	5.3	3.0	5.2	3.0	7.3	1.3	4.7	3.1	6.4	3.0
5 (6)	7.6	3.3	7.7	2.3	7.8	2.5	7.1	3.2	6.9	3.0	6.0	2.5	6.7	2.4

Table 20. Mean alertness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		[redacted]		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	8.2	2.1	6.4	3.3	6.9	2.2	4.8	3.3	5.5	2.8	5.9	2.8	5.9	3.1
2 (6)	8.0	2.8	6.2	2.1	5.7	2.2	4.8	2.8	4.2	2.2	5.0	2.3	7.0	1.7
3 (6)	7.7	3.8	8.2	0.8	7.2	1.5	5.1	2.3	5.2	2.9	5.0	0.6	6.9	1.2
4 (4)	9.0	0.8	7.5	1.9	6.9	1.6	6.2	1.6	7.3	1.1	5.4	2.7	6.8	2.0
5 (6)	8.8	1.2	7.7	1.8	7.1	3.0	6.6	3.6	6.1	1.8	6.4	2.0	6.2	2.2

Table 21. Mean fatigue mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	0.7	0.9	2.6	2.0	3.1	1.4	5.6	3.2	5.7	2.9	6.0	2.8	5.4	2.6
2 (6)	1.3	1.6	2.5	1.5	2.7	1.8	5.4	3.2	7.3	1.9	5.9	1.6	5.1	1.6
3 (6)	2.6	3.7	1.0	1.1	1.2	0.9	4.3	2.8	4.9	3.4	5.3	1.6	4.2	2.5
4 (4)	0.4	0.4	3.2	2.8	4.5	2.0	5.6	2.6	5.0	1.7	6.4	2.3	5.6	1.3
5 (6)	0.3	0.4	2.2	3.1	2.2	2.7	2.9	3.0	3.8	2.9	4.5	2.3	4.9	2.8

Table 22. Mean weariness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	1.8	1.4	4.7	2.1	4.0	2.5	6.8	2.3	6.7	2.6	5.9	2.8	5.1	2.7
2 (6)	2.9	3.0	3.1	1.5	3.0	1.6	5.0	2.6	6.3	2.1	5.8	3.0	4.4	2.0
3 (6)	2.3	3.9	1.7	1.1	2.1	1.6	4.4	2.3	4.3	3.8	5.6	1.6	3.5	2.3
4 (4)	1.2	1.6	2.5	2.9	4.0	2.7	4.9	3.6	4.2	3.2	4.6	3.1	5.0	3.2
5 (6)	1.1	1.5	1.5	2.0	2.4	3.3	2.8	3.0	3.1	3.6	4.2	3.8	2.9	3.7

Table 23. Mean sleepiness mood scores for each group for each testing session.

Group	Baseline		Friday		Saturday		Sunday		Monday		Tuesday		Wednesday	
(n)	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
1 (6)	2.9	3.3	5.5	3.4	4.1	3.8	6.8	2.7	6.4	2.7	4.8	3.1	6.4	2.8
2 (6)	2.3	1.7	4.1	2.2	4.7	3.3	6.4	2.5	6.9	1.8	6.2	2.1	5.8	2.5
3 (6)	2.1	3.9	4.3	0.5	5.5	2.1	6.3	1.7	6.4	1.3	5.8	2.7	5.2	1.9
4 (4)	2.4	1.5	4.2	2.2	4.4	2.8	6.4	3.0	6.1	1.5	6.4	2.2	6.1	3.1
5 (6)	0.5	0.9	2.6	1.7	4.3	2.1	4.0	2.9	4.2	2.4	4.2	2.1	3.6	3.1