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ARCTIC MILITARY CONFERENCE IN COLD WEATHER MEDICINE

Cognitive Performance changes during a 20-day Winter Military Training Course and the Following 10-day Recovery Period

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ABSTRACT

Introduction: The purpose of the present study was to investigate the effects of a winter military field training course consisting of strenuous physical stressors (e.g. physical activity, sleep deprivation and cold weather) on cognitive performance among Finnish soldiers.

Methods: Fifty-eight (age 19 ± 1 years, height 182 ± 6 cm, body mass 78.5 ± 7.2 kg) male soldiers took part in a 20-day military field training course in northern Finland. Cognitive performance was assessed before, during, and after the course four times on a tablet computer. Sustained Attention to Response Task (SART) was used to assess soldier's executive and inhibitory function. Baddeley's 3-min reasoning task (BRT) was used to assess grammatical reasoning, and Change Blindness (CB) task was used to assess visual perception.

Results: Strenuous winter field training had detrimental effects in all performance tests compared to baseline. SART response rate decreased 27.3% ($p < 0.001$), and BRT and CB task scores decreased 20.6% ($p < 0.01$) and 14.1% ($p < .05$), respectively.

Conclusion: The present study showed a decline in soldier's cognitive performance after 20-days of physically demanding winter military field training. To be able to optimise field training, it is important to be aware of how cognitive performance changes during military exercises and missions.

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Introduction

Military operations and field exercises often involve high levels of stress [1]. In the Arctic and other cold-weather operations, environmental conditions in terms of low ambient temperature, wind and snow are additional stress factors imposed upon soldiers. To survive in harsh environments, soldiers must be able to maintain good physical performance and act rationally and consistently in mentally and physically stressful situations [2]. Cognitive performance in a military context refers to a soldier's ability to perform various mental functions such as perception, learning, memory, understanding, awareness, reasoning, judgement, intuition, and language [3,4]. Impaired cognitive performance caused by physical, environmental, and other stressors can have serious consequences for the success of military operations. Therefore, it is important to understand the effects of stress on cognitive functioning during military operations and exercises.

Several studies suggest that high levels of physical and/or mental stress can interfere with cognitive performance. It has been found, for example, that physical and mental stress can increase an employee's susceptibility to mistakes and accidents [5] and weaken decision-making efficiency [6]. In the context of military field training, stressful situations have often been seen as a result of prolonged and/or particularly intense combat or training. Stress burden consists of a wide range of factors in terms of lack of sleep, mental pressure, cognitive and physical strain, as well as malnutrition and environmental conditions (cold/heat, darkness, difficult terrain) [7–9]. Several studies have shown that restriction or complete lack of sleep can impair working memory and attention, visuomotor performance, alertness and decision-making [10–12]. Studies have also suggested that sleep deprivation may have an additive effect with cold exposure, degraded attention and reaction time, and trending towards this pattern in aspects of executive functioning [13].

With regard to physical stress and cognitive performance, laboratory and field studies have shown a decline in cognitive function as a result of increased physical activity [14–17]. Regarding the interaction between physical and cognitive load, our previous study showed an association between physical stress markers (cortisol and insulin-like growth factor–1 (IGF

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−1) levels) and cognitive executive function [18]. Impaired cognitive performance was associated with high cortisol and low IGF−1 levels due to cumulative physical stress. Studies have also shown unclear effects on cognitive performance during cold exposure. Some studies suggest a decline in cognitive performance during cold exposure [19,20], while others have found mixed [21] or no effects [22]. This may suggest that the effect of cold exposure on cognition can be indirect through mechanisms related to distraction or arousal. The effects of hypothermic cold temperatures (body temperature falls below 35°C) on cognitive performance and mood are well documented (e.g. impairments in cognitive performance, vigilance and mood). However, evidence for non-hypothermic effects on cognition has been inconsistent [14]. Some studies have also investigated the combined effects of several stressors, such as sleep disturbances, physical and mental stress, and cold. These studies have reported declines in cognitive performance during and after sustained military operations and simulated combat training in multi-stress environments [e.g 23–25].

Military field exercises typically consist of activities with an inseparable coexistence of cognitive functions, such as observing the environment and detecting changes and objects (perception, working memory), maintaining good situational awareness and adjusting plans and actions (working memory, reasoning, language) and executing or inhibiting actions (executive function, for example, the decision to shoot or not to shoot at the target). Because military performance utilises multiple cognitive functions simultaneously, it is challenging to assess soldiers' cognitive functions by assessing their task performance. Another challenge of the evaluation is that the exercises are done in field environments and with precise training goals that can be disturbed by research measurements. One way to minimise training interference while still assessing specific cognitive functions is to use a simple, brief, and well-validated self-administered cognitive test and select tests based on relevance to military performance (e.g. based on recommendations from training instructors). Previous studies suggest that visual perception and reasoning problems may occur as a result of prolonged sleep deprivation and cold [24–26] and that loss of inhibitory control could be responsible for some friendly-fire incidents [27].

In the present study, we investigated the effects of strenuous winter military field training and recovery from stress on the cognitive performance of Finnish soldiers. We expected that multi-stressors (such as cumulative physical stress, sleep deprivation, energy deficit, and cold exposure) would lead to decreased cognitive performance after 20 days of field training (Hypothesis 1). We also expected that 10 days recovery after the exercise would restore cognitive performance to the pre-exercise levels (Hypothesis 2).

Methods and design

The present study was conducted during a military field exercise in February–March in Northern Finland. Throughout the exercise, the soldiers were exposed to winter conditions and performed various tasks, which included long-distance skiing carrying 30–40 kg of equipment. The exercise was planned to become progressively harder, proceeding from lighter training phase to a more strenuous field phase with accumulating stress (i.e. cold, physical load, sleep and energy deprivation). The first 10 days of the exercise included basic winter skills training, and the second phase started with a parajump with full equipment to be continued with reconnaissance and other tasks for 10 days. The exercise concluded with a 24-hour ski march. The weather details [28] during the exercise are shown in Table 1 for the beginning (0–10 d), the later part of the exercise (11–20 d) and for the whole exercise (0–20 d).

Subjects

Fifty-eight conscript male soldiers participated in the training exercise. Soldier's average age was 19 ± 1 years, height 182 ± 6 cm and weight 78.5 ± 7.2 kg. The subjects were informed about the design of the study prior to beginning. All subjects provided written informed consent. The study was conducted according to the Declaration of Helsinki, granted an approval from the Ethical Committee of the University Hospital of Helsinki (HUS/1020/2019) and approved by the Finnish Defence Forces (AP12498).

Procedures

During the military field training, cognitive performance was assessed with three cognitive tests that were performed before the exercise (PRE measurement), after 10 days from the start of the exercise (MID measurement), immediately after the field exercise (POST measurement, i.e. 20 days from the beginning of the exercise) and after a 10 day recovery period after of the field exercise (RECO measurement). In this study, we reviewed and selected the Sustained Attention to Response Task (SART [29,30]), to assess executive/inhibitory function, Baddeley's 3-min Reasoning Task (BRT

Table 1. Weather details during the exercise.

	0–10 d	11–20 d	0–20 d
Average snow depth (cm)	92	79	85
Average daily temp (°C)	−14.5	−5.2	−9.6
Average daily max temp (°C)	−6.5	−0.7	−3.5
Average daily min temp (°C)	−22.6	−12.8	−17.5

[31]) to assess reasoning and the Change Blindness task (CB [32,33]) to assess visual perception.

SART was used to assess the soldier's inhibitory and executive cognitive function. It is a test that requires the participant's continuous attention and measures the speed and accuracy of a soldier's responses to NoGO (inhibit) and GO (execution) stimuli. In the test, subjects were shown a continuous stream of numbers in the middle of the tablet screen. The participant's task was to follow the screen and press the answer button as quickly as possible whenever something other than the number 3 was on the screen (i.e. one of the numbers 1, 2, 4, 5, 6, 7, 8, 9; GO stimulus) and refrain from pressing the button in the presence of the number 3 (NoGO stimulus). One round of the test lasted approximately 5 min and contained 225 stimuli, of which the proportion of NoGO stimuli was 25%. The number of commission errors (responses to NoGO stimuli) was used as a measure of lack of behavioural inhibition, whereas the number of omission errors (omitted responses to Go stimuli) and response time (in connection with correct responses to Go stimuli) was used as a measure of execution performance.

BRT test was used to assess soldier's level of grammatical reasoning. It consisted of 64 statements about the order of letters A and B that were presented in the screen either in order AB or BA (e.g. "B follows A", "B is not following A", "B precedes A", etc.). The participant's task was to answer correctly as many statements as possible in the fixed 3-min period. The number of correct answers and response rate was used as a measure of verbal reasoning performance.

CB task was used to assess the soldier's visual performance. In the test, the participants were shown two picture collages of 3–13 objects (e.g. clock, shoe, saw, chicken, etc.). In the latter picture collage, one of the objects was replaced by a new object. The participant's task was to indicate both the replaced and the replacement object from among the answer options. The test included 5 practice tasks and 28 actual test tasks. The number of correct answers in the test was used as a measure of perception accuracy.

Cognitive tests were adopted from the millisecond.com test library [34] and performed using Inquisit stimuli presentation software via a Panasonic FZ-G1L2114T3 tablet. The order of the execution of the tests was always the following: SART, BRT, and then CB.

Statistical analysis

Data for each cognitive performance parameters (i.e. number of SART commission errors, number of SART omission errors, SART reaction time for GO stimuli, BRT test score and response rate and CB test score), were analysed by the General Linear Model (GLM) Repeated Measures procedure in SPSS statistical program version 25 with Measurement (PRE, MID, POST, RECO) as within-subject comparison. Contrasts (e.g. POST vs. PRE, RECO vs. POST measurement) were analysed to assess differences in cognitive performance after recovery and before and immediately after the field training.

Results

The GLM Repeated measures analysis revealed a significant main effect for the Measurement (PRE, MID, POST, RECO) in all three tests as follows: in predicting SART omission error rate, $F(3,160) = 8.70$, $p < 0.001$ and reaction time, $F(3,132) = 16.57$, $p < 0.001$; in predicting BRT score, $F(3,130) = 20.06$, $p < 0.001$ and response rate, $F(3,135) = 16.35$, $p < 0.001$ and in predicting CB test score, $F(3,133) = 13.51$, $p < 0.001$. Analyses showed no effect for the SART commission (false response to NoGO stimuli) rate.

As illustrated in the Table 2, analyses showed that SART omission errors ($M_{PRE} = 1{,}2\%$ and $M_{POST} = 4.0\%$; $p < 0.01$), SART reaction time ($M_{PRE} = 332$ ms and $M_{POST} = 423$ ms; $p < 0.001$), and BRT response rate ($M_{PRE} = 4612$ ms and $M_{POST} = 5564$ ms; $p < 0.01$) increased and BRS score ($M_{PRE} = 35.0$ and $M_{POST} = 30.1$; $p < 0.05$) decreased after 20 days of training (POST) compared to before training.

As also illustrated in Table 2, analyses showed that SART omission errors ($M_{RECO} = 0.6\%$ and $M_{POST} = 4.0\%$; $p < 0.001$) and BRT response rate ($M_{RECO} = 4323$ ms and $M_{POST} = 5564$ ms; $p < 0.001$) decreased, while BRT-score ($M_{RECO} = 38.9$ and $M_{POST} = 30.1$; $p < 0.05$) and CB ($M_{RECO} = 31.0$ and $M_{POST} = 25.8$; $p < 0.001$) increased after 10 days of recovery (RECO) as compared before recovery (POST).

Results show that SART omission error rate, SART reaction time and BRT response rate were highest and BRT and CB scores lowest in POST measurement (i.e. right after the 20-day field exercise) therefore indicating that the strenuous exercise impaired cognitive performance in terms of reaction and error rate, grammatical reasoning and visual perception. Results also showed that omission error and BRT response rate decreased, and BRT and CB scores increased from POST to RECO measurement, therefore indicating significant cognitive recovery in 10 days.

Figure 1, illustrates the percentage change in test scores as compared to the "baseline" (PRE measurement). POST SART response rate was 27.3%, POST BRT response rate and test score were 20.6% and 14.1%, respectively, and CB test score was 6.7% lower than baseline. However, cognitive performance levels recovered near or even better than baseline after the recovery period (except in the case of the SART reaction time). The higher scores after recovery as compared to baseline may indicate that some effect of learning by repetition of the tests has occurred.

Discussion

In the present study, we investigated the effects of a winter military field training exercise consisting of strenuous physical stressors (e.g. high physical activity, sleep and energy deprivation and cold weather) on cognitive performance among Finnish soldiers. Previously, we have reported significant decline in physiological and physical performance markers during the present study [35]. Also, the participants were in energy deficit, there was a significant decline in body mass and fat mass, and they only had limited amount of sleep during the exercise. As we expected, all these factors led to soldier's cognitive performance decline during the field exercise: reaction time increased and response accuracy to a target stimulus as well as test scores for visual perception and grammatical reasoning decreased. Thus, the results supported our expectation that cognitive performance would decrease significantly after 20 days of field training (Hypothesis 1) but recover after 10 days rest (Hypothesis 2).

Changes in performance were as high as 20% in some measures. The results supported previous studies that have reported the effects of prolonged exercise [17] and multi-stress environments [23–25] on cognitive performance. Armstrong et al. [17] found 20 to 25%

Table 2. Summary of the cognitive test results.

	PRE (0)	MID (+10 days)	POST (+20 days)	RECO (+30 days)
Test result				
SART omission error (%)	1.2$^{\#\#}$	0.6$^{\#\#\#}$	4.0**	0.6$^{\#\#\#}$
SART reaction rate (ms)	332$^{\#\#\#}$	386***	423***	398***
BRT score (no.)	35.0$^{\#}$	35.8$^{\#\#\#}$	30.1*	38.9$^{\#\#\#}$
BRT response rate (ms)	4612$^{\#\#}$	4537$^{\#\#\#}$	5564**	4323$^{\#\#\#}$
CB score (no.)	27.6	29.0$^{\#\#\#}$	25.8	31.0$^{\#\#\#}$

* = compared to PRE measurement * = p < 0.05, ** = p < 0.01, *** = p < 0.001.
# = compared to POST measurement # = p < 0.05, ## = p < 0.01, ### < 0.001.

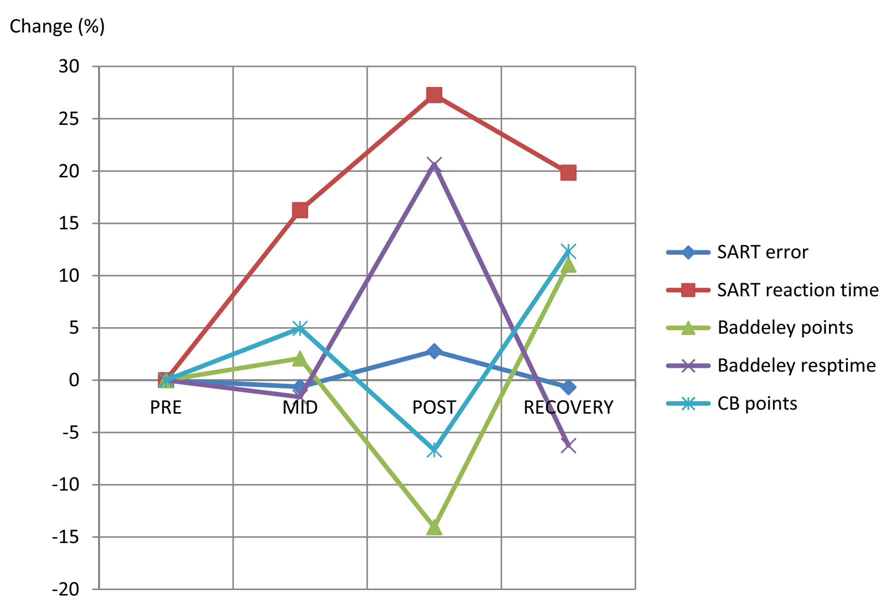

Figure 1. Percentage change in SART omission error rate and reaction time, BRT score and response rate and CB score in the measurements as compared to baseline (PRE measurement).

decrease in visual Go/NoGO task among men and women during prolonged load carriage and Friedl et al. [23] found a 20% decrease in reasoning during multistressor exposure in summer Ranger training. These findings highlight the need to understand, prepare and support cognitive performance in military operations in addition to physical and environmental factors. Support and recovery from stress are especially important in long operations and in tasks where there is a shortage of personnel, because the stress factors tend to cumulate in these situations. Based on some previous research, we could argue that lack of sleep played a large role in the results, although there could also have been cumulative effects of sleep and energy loss, physical exercise and cold. It is well known that when people are extremely tired, their reactions and reasoning are generally slow and the ability to perceive information is impaired [11]. In addition, fatigue and prolonged exposure to cold, which uses the body's stored energy, can increase negative cold-related feelings and make it harder to maintain body and hand temperatures at a comfortable level.

Regarding recovery from training, the results showed that the soldier's cognitive performance fully recovered 10 days after the end of the training (with the exception of SART reaction time). Previous studies [36,37] suggest that even a shorter recovery period (e.g. 1–2 nights of good sleep) may be sufficient to restore cognitive functions. In the future studies, it would be important to measure which cognitive aspects recover quickly and which slowly by measuring them daily during the recovery period.

Limitations of the results

In the present study, military exercise consisted of several strenuous physical stressors. This imposes some limitations on the study. It was not possible to analyse the effects of each stressor (e.g. cold exposure) separately. Therefore, we suggest that in order to support soldiers and alleviate possible performance problems, it is important in further studies to examine the role of various stressors and recovery methods affecting cognitive performance. Interestingly, new technologies enable measuring responses and performance, as well as supporting recovery and performance more efficiently and easily. For example, using different body and environmental sensors and stimulation (e.g. vagus nerve stimulation [38]) offer the potential to study such phenomena in more detail in field environments.

Another limitation of this study is that physical and other stress during exercise was significantly high, and therefore we cannot draw conclusions about the effects of lower levels of stress on cognitive functions. Follow-up studies could also investigate whether moderate and low stress can affect cognitive performance and recovery, and whether there are certain thresholds for cognitive impairment related to exercise duration, stress, and individual abilities. For example, based on our other (currently unpublished) study, we have observed that low levels of stress during exercise did not affect performance in cognitive tests. Thus, we could assume that physical exertion or other stressors would have to be substantial to affect cognitive performance.

Future research

In addition to individual and environmental factors, it is important to consider the military relevance. Optimally, we should assess, evaluate, and support cognitive functions by assessing and/or directly measuring soldier performance. However, as discussed earlier, soldier performance consists of complex cognitive and physical tasks that occur in operations or exercises in harsh and uncontrolled field environments, making assessment challenging. In this study, we sought to select cognitive tests that measured military-relevant cognitive functions (i.e. perception, reasoning, and execution). However, the predictive value of these tests for truly assessing military performance is still unknown. Follow-up studies should investigate whether good performance on these non-military cognitive tests predicts success on military-specific cognitive tasks. Further studies could elaborate more widely the effects of different stressors (e.g. the role of cold temperature), individual differences and stress thresholds, and a wider range of cognitive tasks relevant to soldiers.

Conclusion

The present study showed evidence of negative effects of prolonged and strenuous field training on cognitive performance. As the operating environments and tasks for soldiers are often in many ways highly challenging and stressful, understanding the levels of cognitive performance and recovery as well as effects of various stressors on performance is highly important both for realistic training as well as for preparing and executing successful operations.

Disclosure statement

No potential conflict of interest was reported by the authors.

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