Effect of Motivation and Physical Fitness on Cyber Tasks

K. Helkala, S. Knox and M. Lund

Norwegian Defence Cyber Academy
e-mail: {khelkala; sknox; maslund}@mil.no

Abstract

Today, and especially in the future, soldiers have to be able to operate and maintain a large variety of devices connected to the cyber domain in whatever environment they are operating in. This places a high demand on soldiers' cognitive abilities and mechanisms that humans use to process and store information. In this paper we study how motivation, gained by understanding the purpose of tasks connected to the cyber domain and level of physical conditioning affect cognitive abilities. A cognitive test designed for this study contains tasks that are similar to real cyber operations or incidents. The test was conducted three times during a two-week long military exercise where sleep and nutrition were highly reduced and physical activity significantly increased. We show that both motivation (given by task explanations) and high physical fitness has a positive effect on performance in cyber tasks.

Keywords

Motivation, physical fitness, cognitive abilities, cyber solder, military exercise

1. Introduction

The threats in the cyber domain do not only apply to civil society, they also apply to the military (Lynn III 2010, Gertz 2014). Military ICT services are to be secure and functioning in times of peace as well as in times of conflict. In addition, the services have to be operational from the combat edge to headquarters, not just from headquarters to home. Therefore, today's soldiers have to be capable of handling large amounts of information received and sent via the cyber domain. They also need skills and knowledge to operate and maintain a large variety of devices connected to the cyber domain in whatever environment (inside, outside, conflict or peace) they find themselves. This requires that the soldiers have high levels of cognitive ability.

Our academy delivers a four-year cyber warrior education program: sergeants with a bachelor degree in computer science and telematics combined with good physical fitness. Good physical fitness is an issue under discussion; Andress and Winterfeld (2011) see it as not a necessary skill for a cyber-warrior.

Existing research results have shown that physical activity and positive motivation have positive effect on cognitive abilities. In this paper, we want to verify if the existing research results also apply to our adult students – who, generally, have better condition than an average citizen - in a military exercise, where the amount of food and sleep are significantly limited and physical activity is heavily increased. This paper reports the results of cognitive tasks related to the cyber domain during a two-week military exercise called Exercise Cyber Endurance. Military exercises are an appropriate environment to study human performance and physiology as was shown by Leiberman et. al (2006) who studied soldiers' cognition, mood and physical performance during a 96-hour sustained operation. The rest of the paper contains the following section: State of Art, Experiment setup, Results, Discussion, Conclusion, and Future Work.

2. State of Art

Humans make errors. The nature of an error defines the damage a wrong decision or an action based on the error causes. In a critical situation a human error might have fatal consequences. Psychological factors divide human errors as intentional or unintentional. Unintended actions can cause errors as slips; attentional failures, or lapses; memory failures. Intended action can cause mistakes; rule-based and knowledge-based mistakes, or violations; routine violations, exceptional violations and acts of sabotage (Angles, 2004).

Education and training reduce knowledge-based mistakes and rule-based mistakes as well as violations. However, avoiding unintended actions, especially occurring with environmental stresses, anthropometric factors and human sensory factors (size, shape, strength, and senses (Angles, 2004)) cannot be achieved with pure academic education. Unintended actions are a declination of cognitive abilities. Cognitive abilities such as perception, attention, memory, motor, language, visual-spatial processing and executive functions are mechanisms used to process and store information (Pascale 2006). Our actions are then based on the processed information.

Cognitive incapability is often thought to be a problem for a person with old age. Even if there exists clear generalities on age-related changes, the individual variance is large (Glisky, 2007), and the age is definitely not the only attribute that changes human's cognitive abilities. For example; fatigue (Hartzler, 2014), hunger (Gailliot, 2013) and stress (Harris, 2007), have a negative effect.

Physical activity, on the other hand, has a positive effect (Fisher et al. 2011, Gregory et.al 2012, and Reed et.al 2013). Also environmental attributes (Dahlman et. al, 2012) and motivation (Gaillard, 2007) have shown to affect cognition. Some studies such as Lees and Hopkins, (2013) and Koch and Hasbrouck (2013) imply that good physical condition has a positive effect on academic achievement.

Emotional arousal has also shown to have a positive effect on cognitive abilities and especially memorability. Positive or negative emotional arousal helps maintain a readiness to respond (McPherson, 2011) which helps them notice and recall incidents or details. For example Lee and Sternthal (1999) showed that a positive mood enhanced learning in relation to a neutral mood, when participants learned names of different brands and Dietrich et al. (2001) outlined the influence of emotional contents on recognition performance. Also positive password sentences seemed to have a higher recall rate than sentences with a negative content (Helkala, 2014).

3. Experiment context and setup

The experiment took place in Exercise Cyber Endurance (a two week long military exercise containing three simulated military field operations), in the 4th semester. During the exercise students lived in an outdoor military base, their nutrition and sleep were reduced and physical exhaustion was increased from the normal level. Each day the students either practiced previously taught military and engineering skills or learned new skills. The students were tasked to integrate military and civilian based ICT systems to solve varying operational needs. For example; they were instructed to build, and program, a static intrusion alarm system for their base that was networked to a their deployable Battle Management System (BMS).

3.1. Study design

40 students took voluntarily part to the study (4 women and 36 men, 21-27 years). The cognitive test set was combined with combat conditioning training in the following-way: the participants conducted 2 x 14 minute long training sessions with 2 minutes pauses; after which they commenced the individual cognitive test. The test was conducted three times. The first test was two days before the actual start of the exercise. The participants had slept normally, received normal nutrition and were still living indoors. The second test was on the 3rd day of the exercise. The third and final test run was on the 10th day of the exercise. The second and third tests took place between 9pm and midnight. Between the first and second tests, the sleeping hours had been limited to maximum five hours per night and the feeding had been reduced slightly. Between the second and third test, the sleeping hours were reduced to a couple of hours per night due to the operational scenario. Three days before the third test the feeding was reduced to max 1400 kcal per student per day. The day of the third test, the students were not provided with any food. The students had unlimited access to water during the entire exercise period.

3.2. Test groups

Motivation has earlier been shown to strengthen the ability to remain concentrated (Gaillard, 2007). In order to see if the students gained motivation based on the importance of a task, they were divided into two groups and conducted tests with different instructions. The control group (CG) did the test with the neutral instructions. The explanation group (EG) conducted the same tasks, but this time also the purpose of each task was explained as an act or incident in the cyber domain.

In the analysis phase, both control and explanation groups were further divided into two smaller groups. This division was based on students' physical fitness level. Their physical fitness level was determined based on their overall progression in physical performance during pre-exercise tests; combination of upper body strength and speed in running a distance of 3000 meters. The students with the character B or above in physical tests formed the high physical level groups (CHL and EHL). The lower physical level groups (CLL and ELL) contained student with characters C or lower.

(The requirements to receive B for men (women) in tests are: 3000 m: 10 min 55 sec (12:05), sit-ups: 53 (53), push-ups: 34 (20), and hang-ups: 10(15).)

3.3. Cognitive test

The cognitive test followed the general lines of the Montreal Cognitive Assessment test (Moca) and the test-set used in the study of Leiberman et. al (2006). However, the tasks were modified so that they reflected cyber operations or incidents. No knowledge of cyber operations is needed to conduct the tasks. The test consisted of five tasks and takes 30-40 minutes to complete.

1st task measured attention by visual vigilance test and is similar to the study of Leiberman et. al (2006). The test demanded that students detect bars taller or equal to 3000 in a continuously moving diagram, see Fig. 1. The bars appeared for 7,5 seconds with 0,25 second intervals with random heights. The explanation group were told to monitor network traffic data and raise an alarm when a traffic peak was taller or equal to 3000. The task lasted 20 minutes and the amount of "alarm" bars varied between 115 and 120. Detection was correct if the bar was visible on the screen.

2nd task measured attention and short-term spatial memory. In this task we combined two tasks from the study of Leiberman et. al (2006): four-choice reaction time and matching-to-sample tasks. In our task, see Fig. 2, a single-colour or two-colour basic geometric figure was presented for one second. After that, a 2 x 2 matrix appeared and the students had to identify and locate the figure in the matrix. The matrix was visible of 3 seconds. In total, 75 single figure and corresponding matrix pairs were presented. The task lasted 5 minutes. The explanation group was told that the purpose of the task was to detect different states of different network devices in a very unstable environment.

3rd task measured short-term memory and the ability to learn by trial-and-error. The task was a variation of the task used in the study of Leiberman et. al (2006). In our task, a student had to memorize a random 12 digit long sequence, see Fig. 3. The digits from one to five were used to form the sequence. An empty 1 x 12 matrix was shown to the students. A digit was entered into the first square and "enter" was pressed. If the digit was correct it stayed visible, and the cursor moved to the next square. If not, the digit vanished. Using the trial-and-error method, the student filled the whole 1 x 12 matrix. When the last digit was correct and "enter"-key pressed, an empty 1 x 12 matrix appeared again. The same sequence was to complete again.

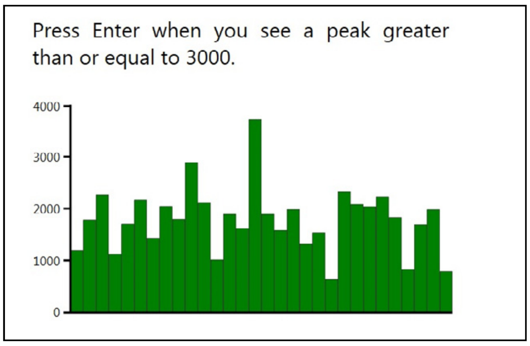

Figure 1: Visual vigilance task (1)

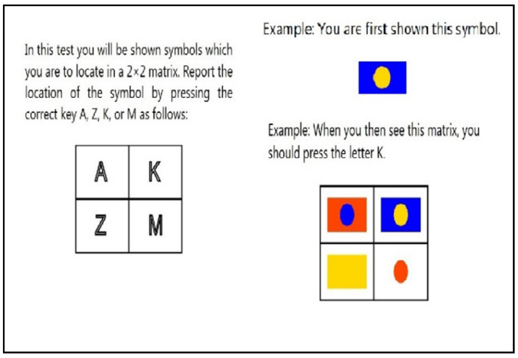

Figure 2: Matching-to-sample task (2)

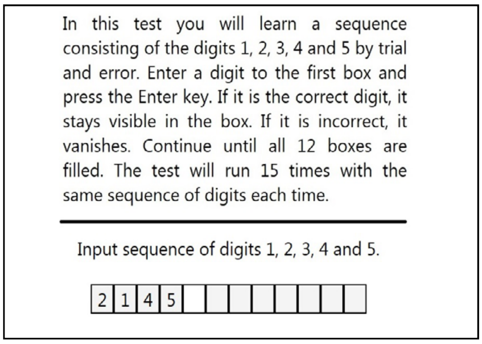

Figure 3: Trial-and-error method (3)

Figure 4: Example of memory task (5)

This was repeated 15 times. The explanation group was told to memorize an encryption key. In each of the three test runs, the student had a different sequence to learn. We recorded the amount of incorrect digits for each 1 x 12 matrix.

4th task confirmed if the 12 digit long sequence really had been memorised. The students only had one chance to type the sequence. We recorded if the sequence was correct or not.

5th task measured visual-spatial, executive memory and language abilities. The students memorized three Norwegian (students' mother tongue) sentences with a total of 13-14 words and a picture of five single-colour basic geometric figures in one minute, see Fig. 4. Subsequently, they had to write down the sentences and draw the figures with coloured pencils. The sentences and the figures were different in each test run. The correct words, forms and colours were counted. The word was correct if placed in the correct place in the correct sentence. The form was correct, if it had the correct shape and was positioned in the correct place on the figure. For the colour to be correct it had to be in the correct place in the figure. The explanation group were instructed to memorize coded messages sent from a terrorist grouping.

4. Results

A comparison of performance rates was conducted between control group (CG) and explanation group (EG). Additionally, comparison between high physical and low physical level subgroups in both control group (CG) and explanation group (EG) was conducted.

Performance was shown as average success rates for each group for each test run. When studying cognitive abilities, behavioural statistics analysis is recommended. Therefore, Cohen's effect size is used for comparison between different groups (Cohen, 1988). If *Cohen's d* is 0.8 or above, the effect size is large. Effect size is medium if *d* is 0.5 or above and small if *d* is 0.2 or above. The results, when appropriate, were also roughly compared to the findings in the study of Leiberman et. al (2006). The participants in both our and Leiberman et. al's study were the same age and had completed their first year of military service. However, our sample size was larger (40 vs. 13 soldiers) and the duration of our exercise was 3.5 times longer.

Test	Nr	Control (%)	Explanation (%)	Cohen's Effect size
Task 1	1	97	**98**	Small: 0,43
	2	96	**98**	Small: 0,37
	3	87	**93**	Small: 0,37
Task 2	1	90	90	-0,03
	2	95	**97**	Small: 0,35
	3	85	**89**	Small: 0,26
Task 4	1	68	**95**	Medium:0,7
	2	95	85	-0,33
	3	85	80	-0,13
Task 5	1	83	**86**	Small: 0,26
	2	84	**89**	Small: 0,32
	3	82	84	0,09

Table 1: Performance rates and Cohen's effect size for the tasks

4.1. Effect of motivation: control group vs. explanation group

Task 1: Visual vigilance. Cohen's effect size in all test runs shows that explanation has a small positive effect on the amount of correctly raised alarms, see Table 1.

Task 2: Matching-to-sample. The first performance rate (test run 1) for both groups is slightly biased, because three control group and four explanation group students did not stop to read the given example and therefore ended up pushing wrong keys in the beginning of the task. For test runs 2 and 3 Cohen's effect size shows that explanation has a small positive effect, see Table 1.

Task 3: Motor learning. Error-curves for the control and explanation groups in each of the test runs are shown in Fig. 5. The error-curves show the amount of errors the students made when guessing digits for each 15 matrices. It was expected that the students would make plenty of errors the first matrix as they learnt the sequence. Ideally, the amount of errors should decrease for each new matrix, ending in zero errors. As it can be seen from Fig. 5, there is a difference in error-curves in the first test. Cohen's effect size shows that explanation has a medium positive effect (0,55) in the first test run, however it does not have an effect later on.

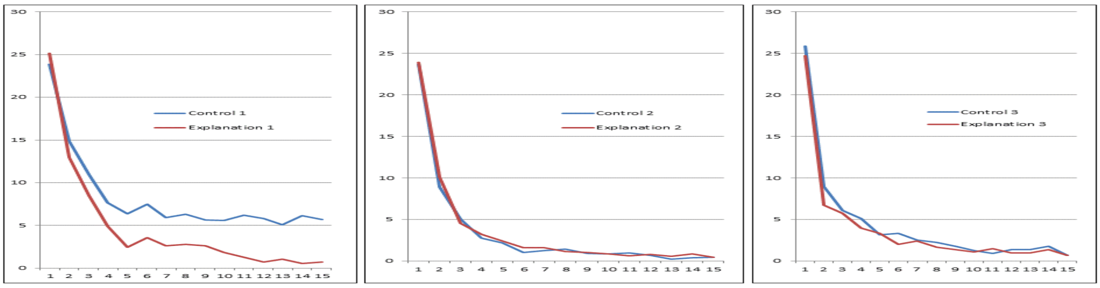

Figure 5: Error-curves of motor learning (task 3)

Task 4: Sequence control. The purpose of this task was to control if the students had really learnt the correct sequence from Task 3. This type of learning was unfamiliar to students and two students from the control group did not understand that the sequence asked in Task 4 was the sequence they have tried to learn in Task 3. That lowered the recall rates in the first test run. Cohen's effect size can now be misleading due to the misunderstanding in the first test run. It shows that explanation has medium positive effect on remembering the sentence. However, the results support the finding in Task 3 in the first test run. In second and third test runs, the explanation did not have an effect anymore, see Table 1.

Task 5: Visual-spatial and executive memory and language ability: Cohen's effect size shows that explanation has a small positive effect on memorizing three sentences and a coloured figure in the first two test runs. In the last run, when students were most tired, the explanation did not have an effect.

4.2. Effect of physical fitness level

Here we analyse the effect on physical fitness. The analysis is done separately for both control and explanation groups due to the different explanations. Our hypothesis is that the students having higher physical fitness level would perform better in the last test run as they would be more robust against physical exhaustion than lower physical fitness level students. Therefore we focus the results of the last test run.

Performance rates for high physical level (HL) and lower physical level (LL) together with Cohen's effect size are shown in Table 2. Error-rate curves are not included to this paper as they are similar to curves in Fig. 5 showing no differences between physical fitness groups in the two last test runs. However, in the first test run, high physical level students in control group performed worse.

The results in Table 2 show that physical fitness has a higher effect in the control group than in the explanation group in the last test run. In the control group, high physical level had a large positive effect for the performance rates in Task 1 (visual vigilance), small positive effect in Task 4 (sequence control), and medium positive effect in Task 5 (visual-spatial, executive memory and language ability). Physical fitness did not have effect in Task 2 (matching-to-sample). In the explanation group only small positive effect can be found in the third test run in Task 1 and Task 5.

Similar tests were conducted in a 96-hour sustained operation study in the USA in 2006 by Leiberman et. al (2006). A 96-hour operation is shorter than our exercise and therefore only first and second test run results are somewhat comparable. The results of Leiberman et. al's visual vigilance test (Task 1) were similar to ours. The performance level did not drop between first and second test runs. In matching-to-sample task (task 2) Leiberman et. al found significant declination already on the 3rd day of SUSOPS. This was not the case with our students. Leiberman et. al did not find statistically significant difference between their participants baseline results and results on 4th SUSOPS day in motor learning task (task 3). Our finding is the same. Task 4 and 5 were not included in Leiberman's et. al's study.

		Control Group			**Explan. Group**		
	Nr	**HL %**	**LL %**	**Cohen**	**HL %**	**LL%**	**Cohen**
Task 1	1	98	96	0,60	98	99	-1,26
	2	97	95	0,63	97	99	-0,86
	3	**96**	72	**Large: 1,11**	**96**	90	**Small: 0,49**
Task 2	1	88	93	-0,22	95	81	0,74
	2	96	93	0,23	98	96	0,6
	3	**86**	83	**0,19**	88	**90**	**-0,11**
Task 4	1	58	86	-0,64	100	88	0,53
	2	92	100	-0,43	100	67	1,00
	3	**92**	75	**Small: 0,46**	**82**	78	**0,10**
Task 5	1	84	70	0,56	88	84	0,38
	2	83	87	-0,24	89	89	0,04
	3	**87**	75	**Medium:0,57**	**86**	82	**Small: 0,27**

Table 2: Performance rates of physical fitness groups with Cohen's effect size

5. Discussion

The results indicate that motivation given by explaining the goal and importance of a task has a positive effect on the execution of cyber tasks. This is in line with a finding that information awareness education will be more effective if reasons behind each security action are explained (Parsons et. al, 2014). According to motivation theories a new task can act as motivation alone, as it gives a feeling of personal growth and learning (Ramlall, 2004). When a task is connected to a real work situation, responsibility becomes a motivation factor. Also, emotions towards content of tasks might have an effect (McPherson, 2011).

The results also show that high physical fitness levels have a positive effect on cognitive abilities in neutrally explained tasks when a person is under sleep deprivation, lacks nutrition and is not under (heavy) time pressure. The result supports earlier research (Fisher et al. 2011, Gregory et.al 2012, Reed et.al 2013). It was also noticed that high physical fitness levels did not affect the explanation group. This might indicate that motivation has a stronger effect than pure physical fitness.

6. Conclusion

In this study we designed a cognitive test set to measure students' cognitive abilities. Attention, short-term memory, visual-spatial memory, execution of language skills and ability to learn were all tested at three separate occasions during a two-week exercise. The exercise was physically demanding due to sleep and nutrition being heavily reduced and physical activity being heavily increased.

We found that motivation gained by the explanation of tasks and their importance, helps performance in cyber tasks. We also found that good physical condition has a positive effect when conducting cyber task. This is particularly noticeable in cases where a person has been in a physically demanding environment for an extended period of time. The study encourages us to build on the integration of cognitive engineering tasks with structured military physical training at our academy. Maintaining, operating and defending networks are not only tasks for military personnel. Civil networks are also maintained, operated and defended in similar ways. Based on the results of this study, physical training should not be forgotten in civilian Computer Emergency Response Teams, CERTs. Good physical condition could support analysts' ability to perform when operating under stress.

7. Future Work

In spring 2015 similar cognitive test were conducted for the new second year students. The results will be compared. We also plan to study how to strengthen mental robustness and capacities to carry out effective teamwork under demanding conditions.

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