Effect of Single Physical Load of Different Duration and Intensity on Cognitive Function

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Key words: *physical load; fatigue; cognitive function.*

Summary. *The aim of this study was to determine the effect of a single physical load of different duration and intensity on cognitive function.*

Material and Methods. The study population comprised 90 male soldiers. The subjects were randomly divided into two groups: experimental (n=60) and control group (n=30). The soldiers in the experimental group undertook 3 specific loads of different types, durations, and intensities. Attention concentration and tapping tests were carried out, and the reaction time was measured.

Results. After the physical load, the soldiers in the experimental group performed the attention concentration test faster, the number of committed mistakes decreased, and the rate of processing information increased as compared to the corresponding values before physical load (all $P<0.05$). However, the indices of fatigue, such as the tapping test score and reaction time, in the experimental group were found to be worse than before physical loads ($P<0.05$). No significant changes were observed in the control group of soldiers.

Conclusion. Despite fatigue, a single physical load of different duration and intensity improved the cognitive function.

Introduction

Studies on humans and animals showed that aerobic exercise could improve some aspects of cognition and mental working capacity (1, 2). Regular physical activity invokes not only biochemical but also long-term morphological as well as functional changes in various systems of the human body. A beneficial aerobic effect of physical activity on the cerebral function was noted in specialized literature (3). For elderly people, physical activity diminishes the deterioration of the cognitive function and the development of dementia (4). A study by Liang et al., which examined cognitively normal older adults with a 10-year history of walking, running, and jogging activity, demonstrated the findings supportive of associations between physical exercise engagement and the levels of biomarkers of Alzheimer's disease (5). Recent studies aimed at revealing the effect of physical exercise on the cerebral function and cognitive activities demonstrate a growing scientific interest in this field of research (6). A positive effect of physical activity is observed at molecular and cellular levels, and it influences human behavior (1). Scientists emphasize the benefit of regular physical activity concerning the improvement of mental work capacity.

The data about structural changes in the brain caused by a sedentary lifestyle, i.e., lack of physical activity, are scarce (3). Many scientific studies deal with the effect of an aerobic physical load on the cognitive function when observations are carried out after several months or a year. There is a lack of studies investigating how engagement in physical activity within a period of several years may have an impact on cognitive function although it is known that it may take years to affect brain health (7, 8).

In scientific literature, we were unable to find any data about the effect of a single physical load on cognitive function. We hypothesized that a single physical load improves attention concentration. Thus, the aim of our study was to determine the effect of a single physical load of different duration and intensity on cognitive function.

Material and Methods

The study population comprised 90 physically active male soldiers with a mean age of 19.5 years (SD, 1.5), a mean body height of 181.5 cm (SD, 4.4), and a mean body weight of 76.2 kg (SD, 7.1). The subjects were randomly divided into two groups: experimental group (n=60) and control group (n=30). The reaction time (RT) and tapping test (TT) scores were determined with the aim to evaluate fatigue generated by the physical load. The rating of perceived exertion (RPE) performing the physical load was recorded for the evaluation of the intensity of the physical load. An attention concentration test (ACT) was taken with the aim to evaluate the cognitive function.

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The research was performed complying with the principles of ethics regarding the experiments with humans as laid down in the Declaration of Helsinki concerning the ethics of experiments performed on humans. The protocol of research was approved by the Kaunas Regional Ethics Committee for Biomedical Research.

Assessment of Reaction Time. The reaction time was measured using a reaction meter (UAB "Baltec CNC Technologies," Lithuania). The measurements were performed before and after each physical load. Typically, a subject was seated in front of the device and asked to press the button as soon as the light appeared. The RT was measured as the interval of time (ms) between the appearance of the light and pressing the button. The mean value of 5 repetitions was calculated each time and was taken for the analysis.

Attention Concentration Test. A special table having 256 Landolt rings was used. Landolt rings were grouped into 16 quadrangles each containing 16 rings. The rings were laid out in a random order with the probability of 8 possible ring gap positions being equal. The subject had to cross out all the rings of the type indicated as accurately and quickly as possible in the given table. The assessment was made according to the time spent on fulfilling the task and the number of mistakes made. The information-processing rate in bits per second was calculated according to the formula (9):

$$S=139.2-(2.807\times n)/T$$

Where S stands for the information-processing rate in bits per second; 139.2 represents the quantity of information available in the table measured in bits; 2.807 is loss of information in bits after failing to cross out the ring of the type indicated; n denotes the number of rings a subject failed to cross out; and T is the time spent on fulfilling the task in seconds.

Tapping Test. The TT was performed by using a reaction meter (UAB "Baltec CNC Technologies," Lithuania). The subject sat at a table in front of the device, took a small stick in his right hand, and tapped the base of the device with the stick as frequently as he could for 5 seconds. The same TT was repeated with the left hand. Finally, the subject had to perform the TT using his faster hand for 40 seconds divided into 8 equal intervals, and only the blows struck on the base of the device were counted.

Rating of Perceived Exertion. The Borg's 6–20 point scale was used to assess the volume of exertion made during the physical load (10). Based on the presented scale, the soldiers themselves had to assess the exertion made at the beginning, in the middle, and close to the end of the physical load.

Physical Loads. The soldiers undertook 3 loads of different types. The environmental temperature was 19°C–20°C.

When undertaking the first special load (17±3 min), the soldiers had to do a 2-km distance with various obstacles (overcoming wall bars 6 m high, creeping through a trench line 500-m long, crossing the river on a hanging rope from one bank to the other, and hitting the target); during the second special load (85±5 min), the soldiers had to do a 15-km distance with various obstacles (running on firing ground, getting into trenches, hitting targets, doing the "move-cover" task in trenches, and destroying an engineer obstacle with a grenade and running); the third special load was of the same duration as the second one with some extra weight carried by a soldier (personal military equipment and a rucksack of approximately 20 kg in weight).

Experimental Protocol. At least one week before the experiment, the soldiers were acquainted with the procedure of the experiment. All the 3 special loads were undertaken with 6-month intervals. Besides, the ACT and the TT were performed, and the RT was measured before the physical load and immediately after it. The ACT, the TT, and the RT were also carried out with the control group of soldiers. The subjects of the control group were tested twice with intervals of 20 and 90 minutes; however, no physical load was applied.

Statistical Analysis. Descriptive data are presented as means (SD). The significance of differences between arithmetic averages was established using the two-sided Student t test for independent samples. Differences were considered significant with a P value of <0.05. Statistical analysis was carried out by applying Microsoft® Excel 2003 and SPSS statistical packages.

Results

Attention Concentration Test. A comparison of the results concerning errors made by the soldiers in the experimental group before and after the physical load showed that the number of errors significantly decreased after the physical load ($P<0.05$): by 57.1% (SD, 7.5%) after the first load, by 33.8% (SD, 4.3%) after the second load, and by 29.7% (SD, 6.1%) after the third load. Moreover, significant differences were observed when comparing the results of the first load with those of the second and third loads (Fig. 1A) ($P<0.05$). The analysis of the results also showed that the soldiers in the experimental group performed the test significantly faster after the physical loads ($P<0.05$): by 19.7% (SD, 3.1%) after the first load, by 11.8% (SD, 4%) after the second load, and by 9.1% (SD, 4.7%) after the third load. There were significant differences comparing the results of the first load with those of the second and third loads (Fig. 1B) ($P<0.05$). Moreover, an increase in the information-processing rate was evident after the physical load in the experimen-

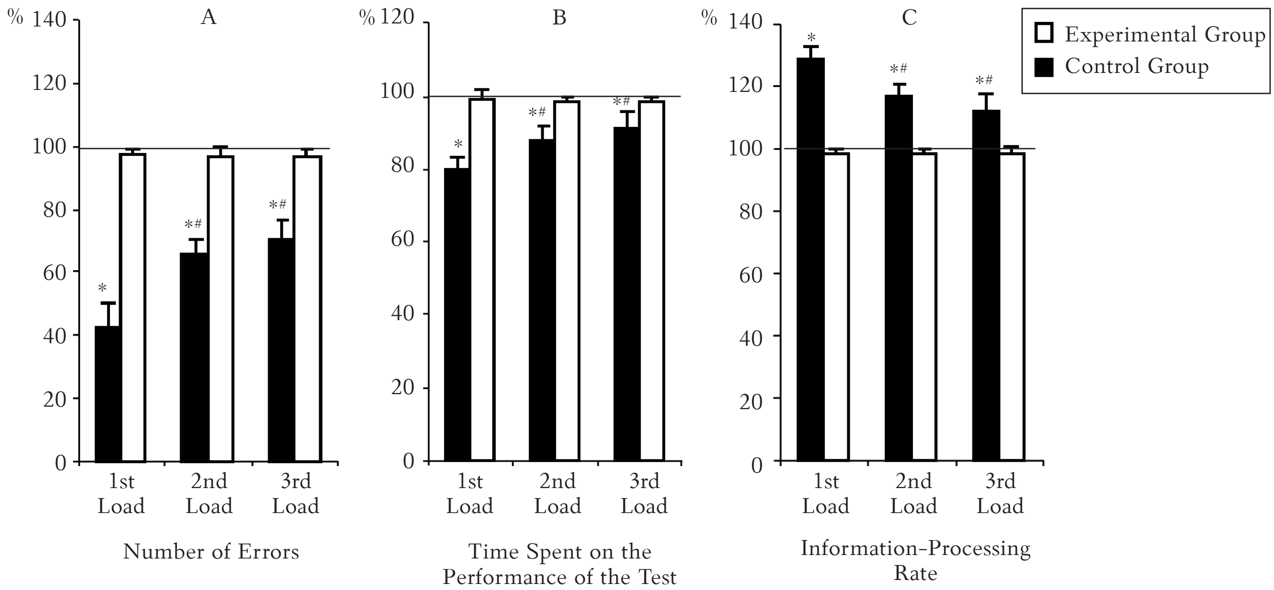

Fig. 1. Percentage changes in the number of errors (A), time spent on the performance of the test (B) and information-processing rate (C) after the physical load

The results before each physical load are considered as 100% (——); the subjects of the control group were tested twice at the same time as the test group, and no physical load was applied.
*P<0.05 vs. corresponding values before the physical load; #P<0.05 vs. corresponding values of the first load.

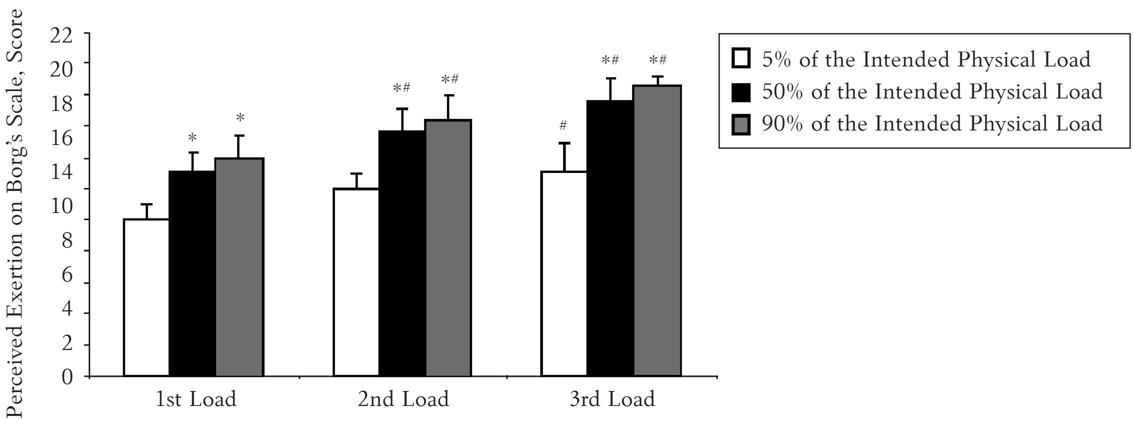

Fig. 2. The rating of perceived exertion during each physical load

Each bar represents the rating of perceived exertion (mean and SD) for each physical load;
5%, a person performed 5% of the intended physical load; 50%, a person performed 50% of the intended physical load; 90%, a person performed 90% of the intended physical load.
*P<0.05 vs. corresponding values after performing 5% of the indented physical load;
#P<0.05 vs. corresponding values of the first load.

tal group (P<0.05), i.e., it increased by 28.9% (SD, 3.5%), 16.3% (SD, 4.6%), and 12.2% (SD, 5.2%) after the first, second, and third loads, respectively. Differences in this parameter comparing the results of the first load with those of the second and third loads were significant as well (Fig. 1C) (P<0.05). There were no significant changes in the ACT results in the control group.

Rating of Perceived Exertion. The RPE significantly increased after the first, second, and third loads (Fig. 2).

Tapping Test and Reaction Time. The results of the TT after the application of the physical load significantly (P<0.05) were worse in the experimental group by 9.9% (SD, 2.4%) after the first load, by 18.0% (SD, 5.2%) after the second load, and by 21.5% (SD, 9.1%) after the third load (Fig. 3A). The mean RT of the soldiers in the same group also increased after the physical load (P<0.05): by 13% (SD, 3.5%) after the first load, by 20% (SD, 4.6%) after the second load, and by 33.4% (SD, 8.2%) after the third load (Fig. 3B). Moreover, significant differences in both parameters were found comparing the values of the first load with those of the second and third loads (P<0.05). The control group showed no significant differences.

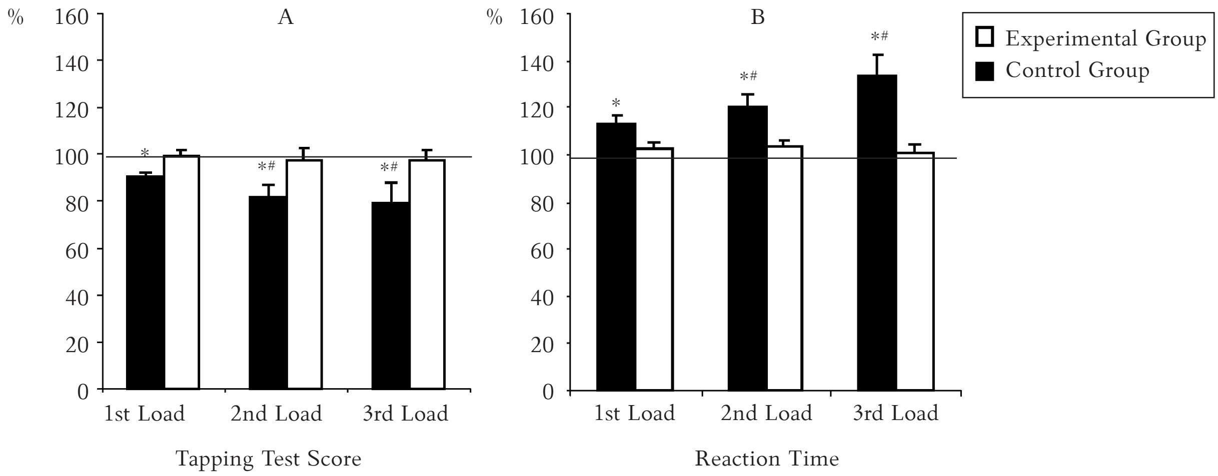

Fig. 3. Percentage changes in the tapping test scores (A) and reaction time (B) after the physical load

The results before each physical load are considered as 100% (——); the subjects of the control group were tested twice at the same time as the experimental group, and no physical load was applied.

$^{*}P<0.05$ vs. corresponding values before the physical load; $^{\#}P<0.05$ vs. corresponding values of the first load.

Discussion

The aim of this study was to show that despite the efforts to carry out a physical load, decreased functional lability of the neuromuscular apparatus, and increased reaction time, mental working capacity (shorter attention concentration time, lower number of mistakes, and greater information-processing rate) improved after a single physical load of different duration and intensity.

Great RPE correlates with great physical fatigue (11). Great exertion (RPE), increased time of reaction, and worsened results of the tapping test indicate high physical fatigue of the soldiers. In spite of that, the cognitive function improved after the physical loads.

For the assessment of attention concentration of the soldiers, the ACT was used. This test generally characterizes the information-processing rate as well as the changes in it in the process of work. A decrease in the information-processing rate reflects fatigue of the central nervous system. In our experiment, after all the 3 loads, the soldiers of the experimental group performed the ACT faster and with a decreased number of errors; moreover, their information-processing rate was also faster. This is indicative of the fact that even undertaking a onetime physical load contributes to the improved indices of attention concentration. The best results were achieved after the first load, which lasted for 15–20 minutes. When the physical load was extremely intensive and even exhausting (during the third load when the soldiers had to carry an extra weight of 20 kg), according to the Borg's scale, the ACT indices were the worst of all, especially in comparison with the indices of the other two cases; however, they were still better than those before undertaking the physical load.

An improvement in attention concentration or cognitive function after physical loads has been reported by other researchers as well (12–16). Exercise-induced effects may affect brain neural networks (3). A study by Masley et al. showed that 10-week aerobic activity was associated with improved neurocognitive performance, in particular cognitive flexibility, which is considered a measure of executive function (17).

However, the originality of our research lies in the fact that the dynamics of attention concentration of the soldiers in the experimental group was observed after multiple applications of onetime physical loads. Usually, an improvement in the human physical condition gives a positive cognitive effect, especially in case of mental tasks, which require processing multiple data. The significance of the positive effect depends on a number of factors, such as the duration of training, age, and physical condition, as well as various combinations of training regimens. Increasing evidence suggests that regular exercise improves brain health and promotes synaptic plasticity and hippocampal neurogenesis (2). It is thought that engagement in physical activity is associated with reduced cognitive deterioration and may improve frontal lobe activity (17). Smith et al. carried out a systematic literature review of 29 large-scale, randomized, controlled trials that examined the effects of aerobic exercise training on neurocognitive performance. This systematic literature review revealed that persons who were randomly assigned to undergo aerobic exercise training showed modest improvements in attention and processing speed, executive function, and memory (8).

The improvement in the cognitive function after a physical load is related to the majority of mechanisms. First, exercise increases blood circulation in the brain, thus, supplying oxygen and nutrients to it. It has been suggested that physical activity is related to changes in the brain through overall cardiovascular conditioning and enhances cerebrovascular blood flow and oxygen supply to neurons (4). Previous studies carried out in animal models have shown that prolonged aerobic exercise induces angiogenesis in motor areas of the cerebral cortex and promotes cell proliferation in the dentate gyrus of rats (18, 19). Skeletal muscle exercise increases β-endorphin production in mice , and cell proliferation in the hippocampus and dentate gyrus (20–26).

Exercise-induced production of growth factors, such as the brain-derived neurotrophic factor (BDNF), has been shown to enhance neurogenesis and to play a key role in positive cognitive effects (3). BDNF is especially active in the hippocampal area of the brain. The lack of BDNF can have an influence on the development of Alzheimer's disease and depression and, thus, cause problems with memory.

There is also a growing body of evidence that aerobic exercise training in older humans increases (serum) BDNF levels, the size of the (anterior) hippocampus, and improves spatial memory, as well as the plasticity of brain networks (25, 27). Hippocampal and medial temporal lobe volumes are larger in higher-fit adults, and physical activity training increases hippocampal perfusion. Aerobic exercise training increases the size of the anterior hippocampus, leading to improvements in spatial memory (25). Increased hippocampal volume is associated with greater serum levels of BDNF, a mediator of neurogenesis in the dentate gyrus. Aerobic exercise training is effective in reversing hippocampal volume loss in late adulthood, which is accompanied by improved memory function (25, 26).

Indeed, exercise may also mediate its effects on cognition via movement as seen in other neurophysiopathological processes, e.g., proprioception (28).

The enhancement of neurogenesis and learning in exercising animals may be related to increased levels of BDNF (29, 30). Therefore, BDNF is believed to play a key role in exercise-induced positive cognitive effects although the underlying mechanisms remain to be elucidated (3).

Scientists suggest that physical exercises of different intensity have different effects on information processing in the central nervous system. In 2007, Kamijo et al. investigated the interaction between the intensity of physical exercises and the complexity of tasks (cognition) with respect to the human cognitive process (31). P3 components of endogenous potentials generated in the brain, which are attributable to the indices reflecting the cognitive function, were studied. The results obtained by Kamijo et al. showed that the P3 amplitude increased after performing physical exercises of light and moderate intensity, whereas after major physical loads, the results were reverse. P3 latency was also recorded. P3 latency was established to be shorter in conditions of light and moderate physical load and longer after heavy physical load with respect to the results demonstrated by the control group (31).

An increasing number of studies suggest that physical activity is a lifestyle factor that might improve physical and mental health (1). The intensity of physical activity is linked to the function of the cognitive process. Regular physical activity markedly improves information-processing rate, memory, mental flexibility, and other cognitive functions. We suppose that even a single physical load can improve mental working capacity, which is very important to athletes in certain branches of sports as well as to soldiers and people in other professions.

Conclusions

Despite fatigue, a single physical load of different duration and intensity improved the cognitive function.

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Statement of Conflict of Interest

The authors state no conflict of interest.

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