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The effect of acute exercise on cognition

Blanka Dwojaczny[1BCD], Sergii Iermakov[2ADE], Tetiana Yermakova[3ADE], Mirosława Cieślicka[1ADE]

[1]*Collegium Medicum im. L.Rydygiera in Bydgoszcz, Nicolaus Copernicus University in Toruń, Poland*
[2]*Gdansk University of Physical Education and Sport, Poland*
[3]*Kharkiv State Academy of Design and Arts, Ukraine*

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Abstract

Purpose: Several lines of evidence indicate that physical activity has a positive impact on central nervous system. The positive impact is observed in areas of brain related to cognitive processes such as memory, learning and attention. The majority of studies focused on the chronic effects of exercise. Relatively limited number of reports addresses the problem of influence of acute exercise (single bouts of exercise) on cognitive functions.

Material: We examined the influence of a single bout of exercise on cognitive performance of young volunteers (23 males; aged 20,91 ± 1,01). To evaluate the cognitive performance in our subjects we used Face/Name Association Test, Stroop Test and Trail Making Test. Volunteers run for 30 minute at moderate –intensity.

Results: The mean results in the Face/Name Association Test before acute exercise were 63,52 ± 5,65% and after acute exercise 67,34 ± 5,82% ($p<0,005$). Statistically differences results were also observed in duration of the retrieval phase of this test ($p<0,005$). In the Trial Making Test, in part A mean results before acute exercise were 66,26 ±11,24 seconds and after physical training 52,39 ± 11,10 seconds ($p<0,005$). In part B mean results were 80,60 ± 22,52 and 70,47 ± 14,54 seconds before and after acute exercise, respectively ($p<0,05$). We have not observed statistical difference in results of the Stroop Test.

Conclusions: Our data suggest that a single bout of exercise can influence the level of cognitive performance. We demonstrate improvement in cognitive function depending on hippocampus (short-term memory) and prefrontal cortex (attention, cognitive flexibility). We have not observed influence of acute exercise on Stroop test (executive function) results.

Keywords: short-term memory, cognitive flexibility, hippocampus, prefrontal cortex, cognitive tests

Introduction

Regular physical activity exerts beneficial influences on several aspect of the central nervous system. In particular, the positive effects are observed in the areas of brain which are related to cognitive processes such as memory, learning and attention [1-4]. Currently it is accepted that regular physical activity leads to improvement of cognitive function via stimulation of neural stem cells proliferation, increases the survival of newly formed nerve cells [2, 3, 5]. Physical exercise enhances cognitive function in both young and older adults but in elderly humans' regular physical exercise additionally helps reduce the risk of neurodegenerative diseases [6-9].

Majority of research focused on the chronic effects of exercise [10-12]. Relatively limited number of research addresses the problem influence of acute exercise (single bouts of exercise) on cognition [13-16]. Previous research indicates that acute bout moderate aerobic exercise improves choice reaction task [17, 18], simple reaction task [19, 20] and confliction task [21].

Other studies reported the following:

- acute exercise improves only prefrontal cortex function such as attention, concentration, reasoning and planning but not hippocampal function [22-24];
- acute high-intensity exercise may enhance true episodic memories, and possibly, also increase the rate of false episodic memories [25];
- acute moderate-intensity aerobic exercise is not associated with prospective memory performance but provides some suggestive evidence that acute exercise may reduce the rate of false memories [26];
- 20 minutes of moderate-intensity exercise benefits EF (executive function) performance in high school students [27];
- acute exercise demonstrates different time-dependent effects of acute exercise on cognition in TEMP and COLD. Study reveals facilitating effects of exercise on university students' processing speed and working memory in both environments. However, in contrast to TEMP, effects on working memory in COLD are transient [28].

There is still very limited research which showed that acute exercise improves long-term memory, associative memory and learning [15, 29-31].

The potential mechanism through a single bout of exercise can influence on cognitive function is unclear. The effect of acute exercise on cognition seems to be depend on many factors: type of exercise, intensity, duration, time course post-exercise cessation.

Therefore, it seems necessary to carry out further research which clearly indicate that impact of single bout of exercise on cognitive process. In the current study we determine the impact of 30 minutes of running on the

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cognitive function such as: declarative memory, selective attention, ability to inhibit habitual responses, attention and cognitive flexibility before and after acute physical activity.

Material and Methods

Participants.

The study was conducted in accordance with the Declaration of Helsinki for Human Studies. The study protocol was approved by a local Ethics Committee.

Volunteers (23 males; aged 20, 91±1, 01) were recruited from the Kazimierz Wielki University in Bydgoszcz (Poland). The volunteers were students from the Faculty of Physical Education. In order to limit the influence of hormonal factors on the obtained results only boys were qualified in this study. In order to limit the differences in their level of education, physical activity and socioeconomic background, all volunteers were students of the same faculty. All students were regularly engaged in weakly schedule at least 9 hours of supervised intense physical activity (including soccer, competitive swimming, volleyball, track athletics).

Research Design.

Evaluation of cognitive abilities was based on scores obtained by participants in Face/Name Association Test, Stroop Test and Trial Making Test. All cognitive tasks were conducted both before and after acute exercise session. The detailed experimental protocols for these tests were described previously [32]. Shortly, in the acquisition phase of the face/name association test, subjects were exposed to 100 faces associated with a single name on a computer screen. Each face/name pair was presented for 2 seconds. After 10 min from the end of acquisition phase the retrieval phase began. During this phase test subjects were presented with the same faces as in acquisition phase but each face was associated with two names, one of which was the same name as in acquisition phase. The task of the subject was to indicate the name associated with the face during acquisition phase. No time limitations for retrieval phase were imposed by the protocol. The percent of correctly answered names, and the duration of the retrieval phase were monitored for each subject. Face/name test evaluating short-term declarative memory associated with hippocampal activity [33].

The Stroop test consisted of four pages. The first test page contained the names of colours written in two columns in black ink (20 words in each column). The task was to read the names of colours. The second page contained the rows of cross marks in two columns (20 rows in each column). The rows of cross marks were displayed in different colours. A colour of each row was recognized and pronounced by each participant. The third and fourth pages contained the names of colours written in two 20-word columns. An ink colour was different than the name of a colour. The written name of colour (third page) or the colour of the ink (fourth page) were recognized and pronounced by each subject. For each page the time of reading duration was recorded. In the statistical analysis we used the reading time of the last page expressed as a percentage of the first page reading time. The Stroop test measure multiple cognitive processes such as executive control, selective attention and ability to inhibit habitual responses [34, 35]. These abilities are strongly associated with the activity of prefrontal and anterior cingulate cortical areas [36].

The Trail Making Test consisted of two pages. The first page contained numbers from 1 to 25 which are randomly arranged on a piece of paper. The task of the subject is to connect numbers of a continuous line (without revealing a paper and pencil). The second page contained numbers (from 1 to 13) and letter (from A to L) which are randomly arranged on a paper. The task of the subject is to connect alternately numbers and letters (without revealing paper and pencil). The result of the test is the time it took to complete part A and part B, respectively. TMT test measures prefrontal cortex-dependent attention and cognitive flexibility [37].

Volunteers were engaged in 30 minutes running at moderate-intensity (16 km/h). Physical activity session with 5-min.warn up and 5-min. cool down period for a total of 40 min. of exercise. Cognitive tests took place 20-30 minutes after physical training.

All tests were performed between 9:00 am and 14 pm.

Statistical Analysis.

Statistical significance of the differences between before-exercise tests and after-exercise tests was assessed using two-tailed paired T-Test. The results are presented as means with standard deviation. $p<0.05$ was considered statistically significant.

Results

The mean score of Face/Name Association Test before acute exercise was 63, 52 ± 5, 65%, after the exercise the scores were 67, 34 ± 5, 82 %. 19 volunteers improved their score. The score decreased in 4 volunteers (Fig.1). In the same test before acute exercise the mean retrieval duration equalled 301, 21 ± 78, 97 seconds, after acute exercise mean retrieval duration equalled 259, 26 ± 55, 83 seconds. 19 volunteers improved their score. The score decreased in 4 volunteers (Fig. 2). Statistically significant differences were observed between percentage of correctly recognized pair face/name and the duration of the retrieval phase of this test.

We also observed statistically differences in a Trail Making Test ($p<0.005$). The mean results in TMT A before acute exercise were 66, 26 ± 11, 24 seconds, after acute exercise the mean results were 52, 39 ± 11, 10 seconds. 20 volunteers improved their score. The score decreased in 3 volunteers (Fig.3). The mean results in TMT B before acute exercise were 80, 60 ± 22, 52 seconds. After the acute exercise the mean results were 70, 47 ± 14, 54 seconds. 18 volunteers improved their score. The score remained unchanged in 1 and decreased in 4 volunteers (Fig.4). Statistically differences were observed between results before and after for TMT A ($p<0, 005$) and for TMT B ($p<0, 05$).

Statistically differences were not observed in Stroop test conducted before and after acute exercise. The mean

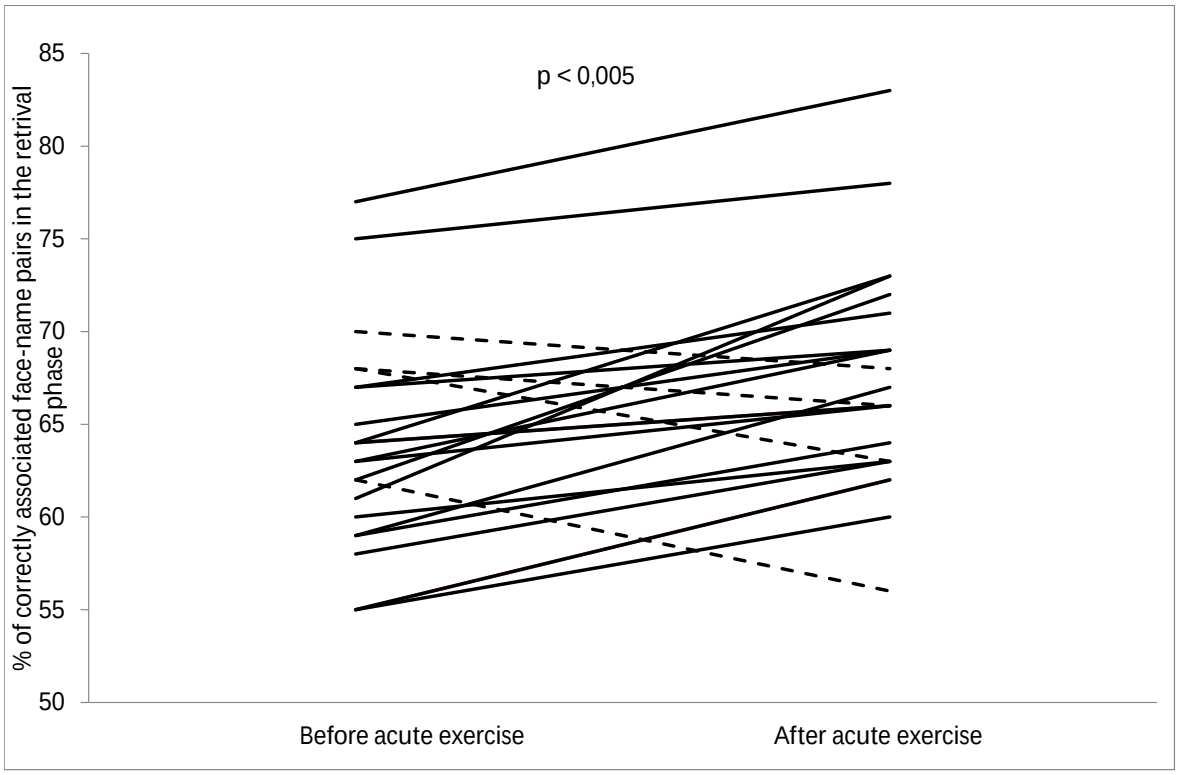

Fig.1. Individual scores in the face/name association test - % correctly associated face-name pairs. Each subject's results from before and after acute exercise are connected by a line. Solid line depicts subjects who fared better on the post-exercise test, dashed lines those who fared worse after acute physical exercise.

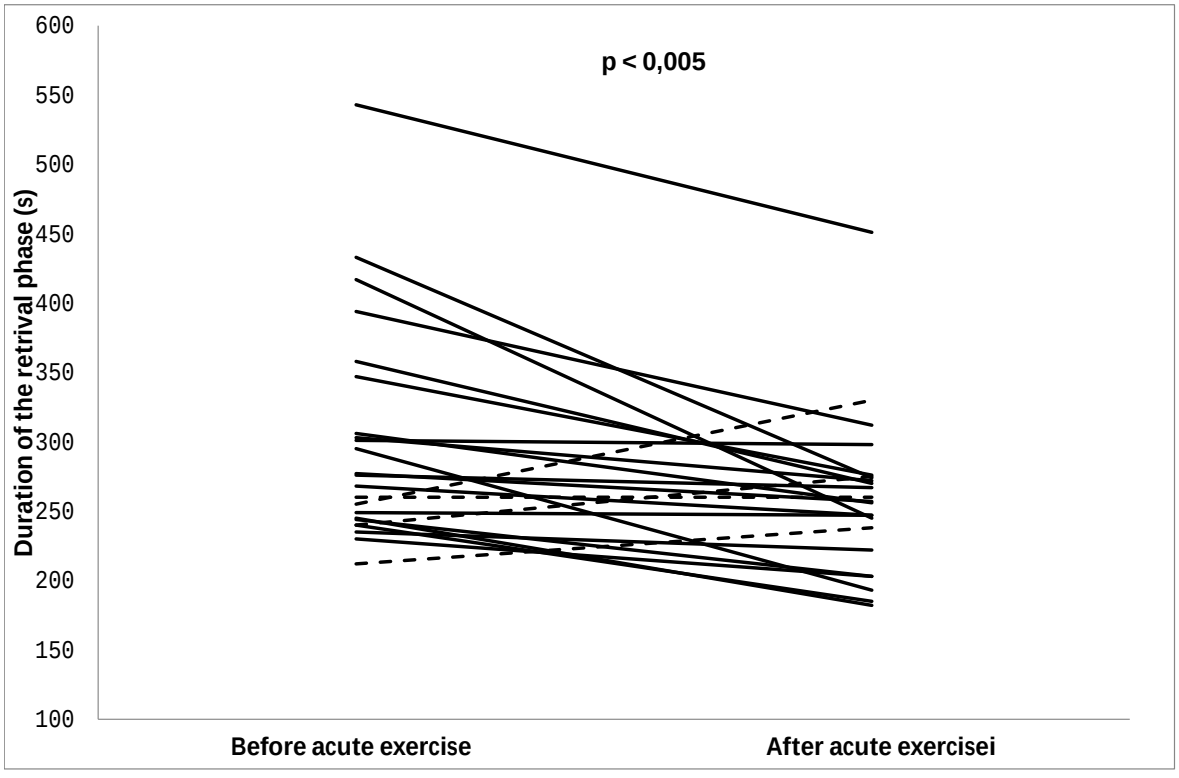

Fig.2. Individual scores in the face/name association test – duration of the retrieval phase. Each subject's results from before and after acute exercise are connected by a line. Solid line depicts subjects who fared better on the post-exercise test, dashed lines those who fared worse after acute physical exercise.

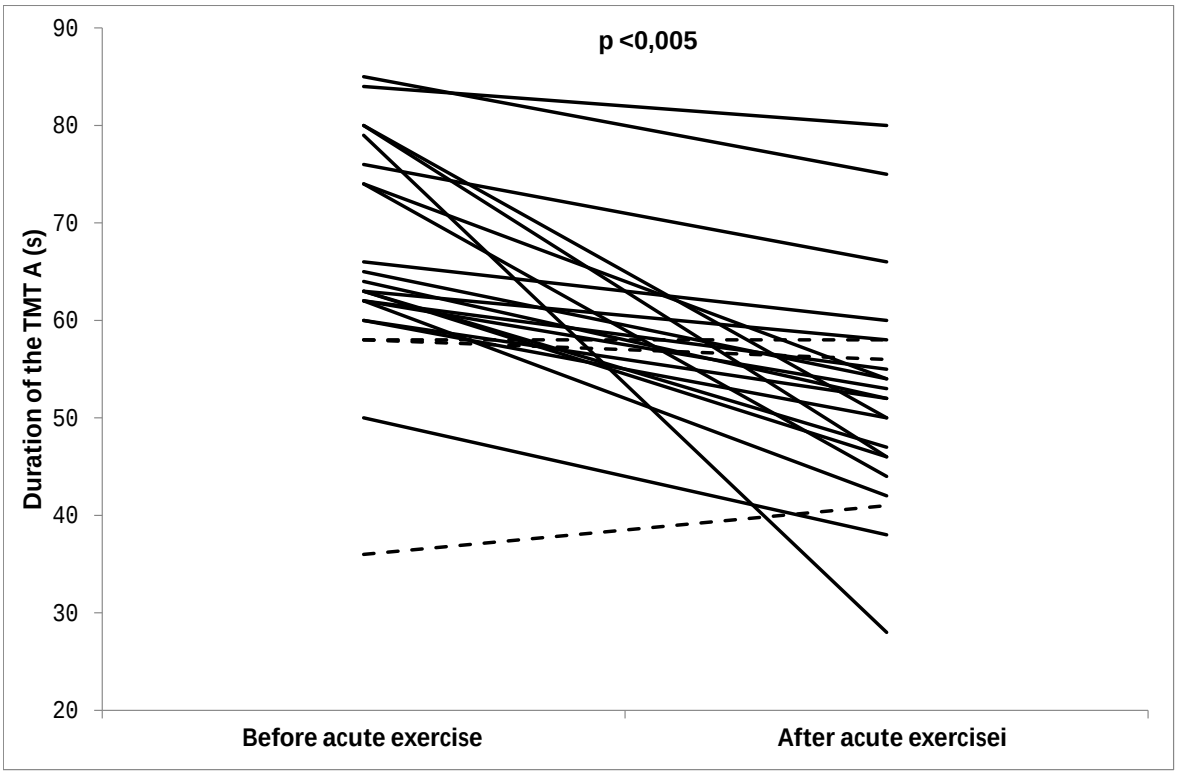

Fig.3. Individual scores in the Trial Making Test – duration of the TMT A phase. Each subject's results from before and after acute exercise are connected by a line. Solid line depicts subjects who fared better on the post-exercise test, dashed lines those who fared worse after physical exercise.

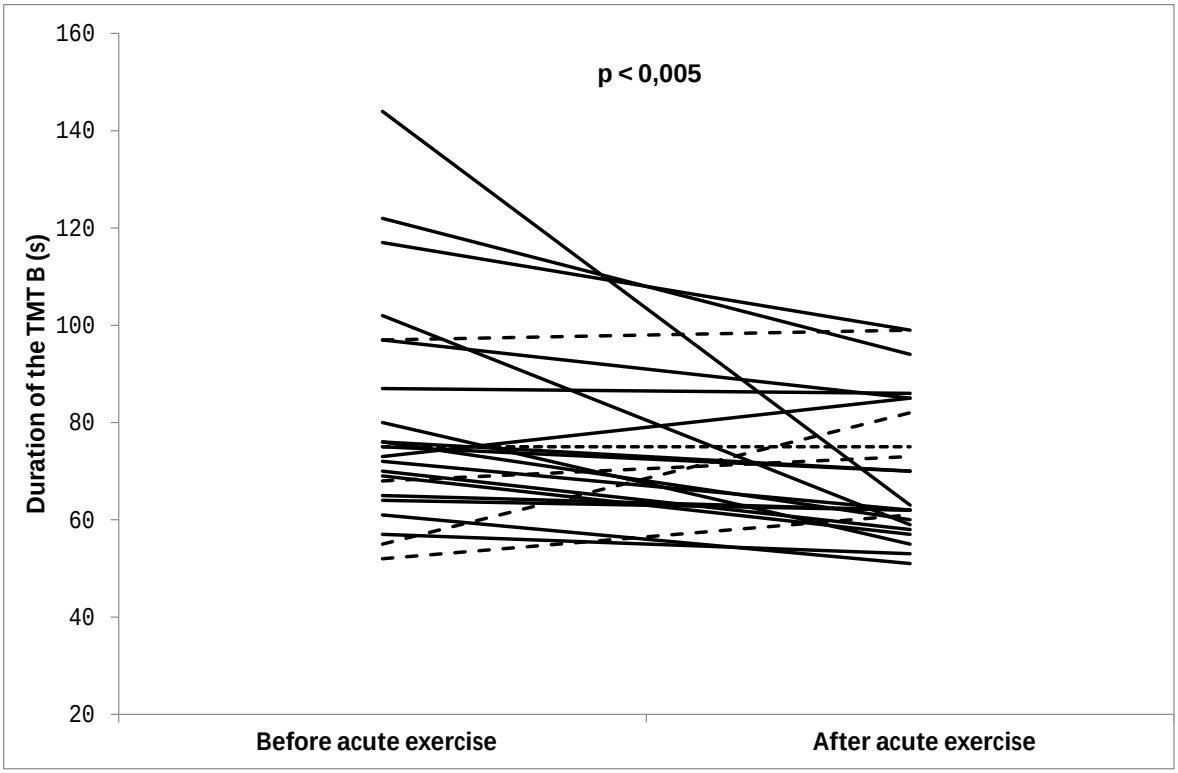

Fig.4. Individual scores in the Trial Making Test – duration of the TMT B phase. Each subject's results from before and after acute exercise are connected by a line. Solid line depicts subjects who fared better on the post-exercise test, dashed lines those who fared worse, dotted lines represents individuals with score unchanged after acute physical activity.

result in the Stroop test was 199, 0 ± 29, 56 % and 200 ± 27, 02% in the before and after acute exercise results, respectively.

Discussion

The data presented in this report indicate that a single bout exercise can have significant influence on some cognitive function. 20-minutes of running improved short–term declarative memory expressed by Face/ Name Association Test and attention determined by Trial Making Test. There were no significant differences in the Stroop Test before and after a single bout exercise. Short-term declarative memory is closely associated with hippocampal activity while attention and cognitive flexibility depend on prefrontal cortex. Cognitive processes assessment by the Stroop test remain under control several discrete areas of cerebral cortex and are strongly associated with the activity of prefrontal and anterior cingulate cortical areas.

In contrast to studies of the impact of regular physical exercise on central nervous system, relatively limited number of publications describe influence of single bout exercise on cognitive function. Our findings are consistent with the results from other studies which demonstrated influence of acute exercise on cognitive function [17-21, 38]. However, the results obtained so far are difficult to interpret due to differences in duration, intensity, modality of exercise and the population assessed. Currently, the potential mechanism for the effect of single bout of physical activity on the cognitive function is unclear. Previous research suggests that acute exercise can impact cognitive processing by induced increase brain derived neurotrophic factor (BDNF), insulin-like growth factor (IGF-1) and increase peripheral levels of monoamines such as: dopamine, epinephrine and norepinephrine [39-42]. 30 minutes running at moderate intensity can result in the increase of level BDNF, IGF-1, dopamine and maintain their elevated level up to 90 minutes after the end of exercise. BDNF stimulate growth of new neurons, neuronal differentiation and survival also enhances synaptic plasticity and may promote learning and memory. Studies have shown a positive association between acute exercise- induced peripheral BDNF levels and short-term memory and motor skill memory [43-45]. Studies conducted by Winter et al. showed a significant increase in serum BDNF after anaerobic training. IGF-1 similar like BDNF regulate neurogenesis, neuronal survival and differentiation [39]. Single bout of exercise increase levels of dopamine and serotonin in hippocampus, prefrontal cortex and striatum [46-49]. This neurotransmitters may be a part of positive effect acute exercise has on cognitive functioning [39, 49, 50].

The improvement of result in the Face/Name Association Test and Trail Making Test described in this paper may be a result of influence of 30 minutes running on neurotrophic factors and levels of monoamines. Although research conducted by our team doesn't indicate the mechanism of the observed change of cognitive abilities but they confirm earlier reports about the impact of acute exercise on cognitive function.

Conclusion

The data suggest that a single bout of exercise can influence on level some cognitive performance in young individuals. In our studied acute exercise improves cognitive function depending on hippocampus and prefrontal cortex However, more research is needed to understand the mechanisms of observed changes.

Conflict of interests

The authors have no conflict of interests to declare.

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Information about the authors:

Blanka Dwojaczny; (Corresponding author); https://orcid.org/0000-0002-2253-1502; blanka.dwojaczny@cm.umk.pl; Department of Human Physiology, Collegium Medicum im. L.Rydygiera Bydgoszcz, Nicolaus Copernicus University in Toruń; Toruń, Poland.;

Sergii Iermakov; Doctor of Sciences in Pedagogy, Professor; http://orcid.org/0000-0002-5039-4517; sportart@gmail.com; Department of Sport, Gdansk University of Physical Education and Sport; Gdansk, Poland.

Tatiana Yermakova; Doctor of Sciences in Pedagogy, Professor; https://orcid.org/0000-0002-3081-0229; yermakova2015@gmail.com; Department of Pedagogy, Kharkov State Academy of Design and Arts; Kharkov, Ukraine.

Mirosława Cieślicka; http://orcid.org/0000-0002-0407-2592; m.cieslicka@cm.umk.pl; Department of Human Physiology, Collegium Medicum im. L.Rydygiera Bydgoszcz, Nicolaus Copernicus University in Toruń; Toruń, Poland.

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