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Original scientific paper

Effects of Acute Physical Exercise on Mathematical Computation Depending on the Parts of the Training in Young Children

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A B S T R A C T

The aim of this study was to determine whether acute physical exercise may increase the ability to quickly solve basic mathematical operations in young children. In this way, the children acquired the means to activate a larger area of the brain when necessary. The research sample of 38 preschool and 18 schoolchildren was tested in basic mathematical operations before and after physical exercise. The results showed that children's computational performance was enhanced significantly during exercise and remained stable after relaxation part of their physical training.

Key words: *computational performance in children, cognitive abilities, physical exercise, training, neural networks*

Introduction

The tendency of the development of society in general, as well as of education system, increasingly focuses on the development of children's »cognitive functioning«, largely disregarding the importance of the proper motor activity in children's development, not only from the biological aspect[1]. There have been frequent suggestions that physical education in elementary and secondary schools should be abolished, because this time can supposedly be put to a better use in other subjects, e.g. mathematics, physics etc. Furthermore, although the experts propose minimum three classes of physical education a week[2–3], state institutions are not in favor of this proposal, despite the data which indicate the positive influence of motor activity on the entire biological development and health status, but also on the mental development, i.e. the whole range of conative and cognitive dimensions of personality[4]. A large number of researches indicate this positive connection between the child's motor activities and cognitive dimension, and consequently better success at school[5–8].

The cerebral cortex, which is considered the ultimate learning center in the brain, consists of a large number of different parts, each having its own role in receiving, processing and storing information received by the senses[9]. It was established that what the child experiences through the senses does not reach just one part of the brain. Activation of more than one sense increases activation of a large part of the brain[10]. Children use the brain's ability to strengthen connections between numerous parts of the brain – for sight, hearing, smell, taste, touch, as well as for proprioreceptors – in order to create the system of associations (multi-sensuous associations), which becomes increasingly complex, as well as mental activity, creating the neural network. If the child has difficulties in interpreting, integrating and using sensory information which he receives from his body and the environment, his development will be more or less delayed. It is for this reason that extension of the associative (neural) network is important for the development and maintenance of children's cognitive abilities and should definitely be encouraged[11].

Over 50% of newly formed neural networks, i.e. synapses, are formed until 4–5 years of age, which requires serious commitment in the work with preschool children. Additional 25% of synapses are established until 7–8 years of age[12]. In most countries, this is the age when children start school and from the point of neurophysiology it can be said that this is quite late for the beginning of learning and formation of certain important centers in the brain. If the child is not stimulated on time, some functions are not realized to the full extent. Stimulating environment contributes to the development of a larger

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number of synapses and neural paths, resulting in a rich neural network, which is crucial for achieving innate potentials later on[13].

Approximately 50% of our intelligence is developed until the age of four, additional 30% until the age of eight, and the remaining 20% until the age of seventeen, when the highest level of intellectual capacities is reached[14]. It can be reasonably assumed that this is the so-called general intelligence. Practically, this means that intellectual development in preschool children represents an important period in the overall developmental process of this ability.

We come across the similar situation in children's motor abilities, where general motor ability is also manifested, which can be called »motor behavior«[15]. Quantitative levels of manifestation of such ability increase, and the structure of that latent ability develops in significant mutual correlation of potential motor components. It is only at the age of 12 that children experience the so-called »explosion of differentiations« of motor abilities into distinct and relatively independent motor components[16]. At a young age, motor components improve quantitatively, but their interconnection (structure) changes and, depending on the engagement in kinesiology activities, they are formed as basic and specific motor abilities[17].

Motor planning, also known as praxia, represents the ability of conceiving, planning and execution of an unknown motor activity[18]. Apraxia and dyspraxia are the states of impaired abilities. The term dyspraxia is used at a young age, when difficulties in motor planning are of developmental nature. A dyspraxic child has a difficulty in understanding how to plan and organize what his body needs to do or how to sequence and perform movements. Quite often, children with difficulties in acquiring school skills, also have difficulties in motor processing[19]. For this reason, most children with dyslexia (disorder of acquiring reading skills) and dyscalculia (disorder of learning and comprehending mathematical terms and operations) are additionally diagnosed with developmental dyspraxia.

Parts of the cerebral cortex are connected by the multitude of different neural paths, which can store information in an almost infinite number of combinations. Due to the fact that this system is so complex and the number of possible combinations of neural paths is really enormous, children, as well as adults, use only a small part of the possible combinations. Using as many senses as possible, frequently activating the brain in different and unusual situations, performing different and unusual (non-routine) activities, particularly motor activities of higher intensity, can considerably increase the number of created and realized combinations[20]. This creates larger and more dense neural network in the brain, which is the basis for better cognitive, i.e. intellectual functioning of children.

Tomporowski et al. conclude that physical exercise has an effect on specific cognitive functions, most likely those that define the role of the central executive processor (CEP). This processor represents the part of an individual's self in the prefrontal cortex and is responsible for using information, engagement of working memory, strategic planning and control of behavior[21]. In this way, a person regulates everyday behavior, i.e. adapts to the requirements of the environment, including their own intellectual abilities. Nevertheless, these abilities represent only the potential, but whether this potential will be engaged and to which extent depends on the CEP efficiency. For example, recent researches of adults showed that brisk walking three times a week within 6 months had significant effect on the improvement of the efficiency of executive functions such as abilities of planning and inhibition[22]. Some other researchers have also reported similar findings, leading to the conclusion that the hypothesis of the effect of physical exercise on the CEP functions has gained increasing support[23].

Gabbard and Barton assessed the mathematical computation performance of 106 6th-grade boys and girls before and immediately following 20, 30, 40, and 50 min. of vigorous physical activity[24]. Contrary to the researcher's predictions, children's computational performance was enhanced significantly following 50 min. of exercise.

McNaughten and Gabbard, evaluated the mathematical computation speeds of 120 6th-grade boys and girls and found that performance was significantly better after paced walks of 30 and 40 min. duration than after 20 min. of excercise[25]. Kawashima found in his researches that simple daily calculations activate the brain more effectively than any other activity. He also discovered that the best way to activate the largest regions of the brain was to solve these calculations quickly. That is why he created the easy-to-solve problems[26].

It is well known that more intense physical exercise, not only chronic (several months or years), but also acute (one or a couple of hours of exercise), can increase the brain activity. Therefore, the brain activity increased by exercise, can increase the ability for mathematical functioning, which integrally influences the activity of the cerebral cortex, and probably the functioning of the entire nervous system, consequently influencing the functioning of cognitive abilities in children[27].

Bala showed that children's computational performance was enhanced significantly in the preschool and school groups with 30, or 45, or 60 min. of physical exercise, even in the group of slightly mentally-retarded children (ages 13–14). The results showed that there was no statistically significant increase in mathematics test results between means before and after class without exercise training in appropriate groups. In a few preschool groups the children even had impaired results[28]. This indicates that the classes where there was no physical exercise did not produce a significant improvement in mathematics test results, nor probably in the activation of brain function in these children.

The aim of this study was to determine whether acute physical exercise may increase the ability to quickly solve basic mathematical operations in small children The authors believe that even acute intensive physical training can yield positive effects on children's mathematical ability, not only through aerobic exercises, but through variety of exercises that are common in preschool and school gyms. Furthermore, these physical exercises will create better conditions for increasing the quality of neural networks in young children.

Material and Methods

The research samples of 38 preschool children (5–6) and 18 schoolchildren (7–8), who attended the »Children Sport School – Luka« of The Agency for Physical Culture »Kinesis« in Novi Sad, were tested for basic mathematical operations before and after the physical exercise. Since the previous research of young children from the same geographical area and with similar socio-economic status found that there was no statistically significant differences in cognitive abilities between boys and girls 4 to 10 years of age[29], analyses were carried out for boys and girls together.

Test to assess the success in solving basic mathematical operations consisted of 40 tasks with the operations of addition and subtraction (same difficulty level for preschool children), and multiplication and divisions (same difficulty level for school age). Each task had only 2 members, the corresponding mathematical operation symbol and an equal sign (e.g. 3+5=, 10–7=, 2x3=, 6:2=), and the respondents were asked to solve and write down solution for each task as soon as possible within 2 minutes. The test result was the number of correct answers.

The training class lasted for 60 min and structure of the training was as follows:

- I – introductory part – lasts for 5 min. and includes: warm-up, various movements with changeable speed, exercises that correct and prevent flat feet;
- II – preparation part – lasts for 10 min. and includes: stretching, corrective and preventive exercises for bad posture, proper sense of good performance;
- III – main part – lasts for 40 min. and includes: revision and practice of previous skills, teaching and practicing new skills, competitive practice, conditioning (apparatus activities, running, jumping, throwing, games and team sports) and
- IV – cool-down (relaxation) part – lasts for 5 min. and includes: stretching, coaching comments, conversation).

Every part of the training lesson was run in a positive, warm and friendly atmosphere, with appropriate music (particularly during the introduction and preparation).

For each group of children, parental consent was required before testing. The same test with 40 tasks, with short appropriate instructions, was applied prior to the physical training. Each child received a single sheet of printed tasks and an eraser pencil. In case of an incorrect response the child was able to erase an answer, or cross it out and then enter another result. Children from each group started the test at the same time. After 2 minutes, the examiner finished the testing and collected all the tests. Afterwards, the trainers began the implementation of relevant activities in the training class. At the end of the third part of the training, the children were given the same mathematical tasks. After 2 minutes, the testing was finished. They had 5 minute relaxation and were then given again the same mathematical tasks to be solved within the same time frame of 2 minutes.

Before and after the third part of the training, as well as after 5-minute relaxation, basic statistics of the test scores were calculated (mean – $\overline{X}$, standard deviation – SD, standard error of the mean – SEM, minimum – MIN and maximum – MAX score in the test). Significance of differences between the test results before and after class activity, as well as after the third part of training and 5 minute relaxation, was analyzed by nonparametric technique of Wilcoxon Sign Test and Signed Test, and by parametric technique of Paired-samples t test (t). Since both techniques gave synonymous results, only the results of the last analysis technique were shown.

Results

The results showed that preschooler's computational performance was significantly enhanced between initial testing and after the 55-minute physical exercise, i.e. during the physical exercise (Table 1). The calculated standard errors of means (SEM) can be applied in assessing the range of possible results of the means in the case before and after application of the appropriate types of activities in exercise class at preschools for the population from which small samples of respondents were drawn. After a 5-minute relaxation children's computational performance remained stable, as there were no significant changes.

Since the standard deviations in all three cases in the sample of preschool children were higher than the arith-

TABLE 1
DIFFERENCES IN THE SUCCESSFUL SOLVING OF ELEMENTARY MATHEMATICAL PROBLEMS DURING THE PHYSICAL EXERCISE TRAINING CLASS- PRE-SCHOOL AGE

Part of training	MIN	MAX	$\overline{X}$	SD	SEM	t	p
Before physical exercise	0	40	7.47	10.61	1.72	–4.54	0.00
After 55 min physical exercise	0	40	9.63	11.40	1.85		
After 5 min relaxation	0	40	9.97	11.65	1.89	–0.81	0.42

metic means, and it can be seen that there were children with maximal number of correct answers, but also children with no correct answers, it was necessary to establish if there was a statistically significant difference between mathematical abilities of boys and girls. The results of this analysis are given in Table 2. It can be easily noted that girls were significantly better at solving basic arithmetic operations. This was the case when the analyses were conducted under the assumption that variances of the achieved results were equal. Such an assumption was made at the beginning of the experiment based on the research results of general cognitive ability of boys and girls 4–10 years of age, indicating that there were no statistically significant differences regarding this ability[29]. Fast and accurate solving of short mathematical problems using basic arithmetic operations is undoubtedly one form of manifestation of general cognitive ability in children. However, when the analysis was conducted under the assumption that they were not equal, there were no statistically significant differences between boys and girls, which confirms findings of the mentioned authors. (Table 2)

In the group of schoolchildren, the results showed that computational performance was also significantly enhanced between initial testing and after 55 minutes of physical exercise (Table 3). After 5-minute relaxation schoolchildren's computational performance also remained stable. However, differences between boys and girls were not statistically significant in any of the cases (Table 4).

There is a big difference in the average number of achieved correct answers at the mathematical test between preschool children and schoolchildren, both according to samples taken together and separately for boys and girls. This difference does not need to be tested, since it is attributed to the development of the central nervous system, especially brain functions associated with normal biological growth and development of children. An increased homogeneity around the average number of correct answers in schoolchildren compared to preschool can easily be noted. This indicates that there were extreme cases in both directions in preschool children, either those with incorrect answers in all tasks, or those with correct

TABLE 2
DIFFERENCES BETWEEN BOYS AND GIRLS IN THE SUCCESSFUL SOLVING OF ELEMENTARY MATHEMATICAL PROBLEMS DURING THE PHYSICAL EXERCISE TRAINING CLASS – PRE-SCHOOL AGE

Part of training	Boys (N=27)				Girls (N=11)				t	p
	MIN	MAX	$\overline{X}$	SD	MIN	MAX	$\overline{X}$	SD		
Before physical exercise	0	38	5.19	7.60	0	40	13.09	14.75	–2.18[a]	0.03
									–1.69[b]	0.12
After 55 min physical exercise	0	40	7.00	7.72	0	40	16.09	16.16	–2.36[a]	0.02
									–1.78[b]	0.10
After 5 min relaxation	0	40	7.48	8.01	0	40	16.09	16.66	–2.16[a]	0.04
									–1.64[b]	0.13

[a]Equal variances assumed
[b]Equal variances not assumed

TABLE 3
DIFFERENCES IN THE SUCCESSFUL SOLVING OF ELEMENTARY MATHEMATICAL PROBLEMS DURING THE PHYSICAL EXERCISE TRAINING CLASS – SCHOOL AGE

Part of training	MIN	MAX	$\overline{X}$	SD	SEM	t	p
Before physical exercise	9	40	24.28	10.87	2.56	–3.16	0.01
After 55 min physical exercise	12	40	27.44	10.05	2.37		
After 5 min relaxation	13	40	27.39	10.77	2.54	0.071	0.94

TABLE 4
DIFFERENCES BETWEEN BOYS AND GIRLS IN THE SUCCESSFUL SOLVING OF ELEMENTARY MATHEMATICAL PROBLEMS DURING THE PHYSICAL EXERCISE TRAINING CLASS – SCHOOL AGE

Part of training	Boys (N= 13)				Girls (N= 5)				t	p
	MIN	MAX	$\overline{X}$	SD	MIN	MAX	$\overline{X}$	SD		
Before physical exercise	9	39	22.69	10.54	13	40	28.40	11.80	–0.99	0.33
After 55 min physical exercise	12	40	25.85	9.55	17	40	31.60	11.19	–1.09	0.29
After 5 min relaxation	13	40	26.00	10.73	16	40	31.00	11.18	–0.87	0.39

answers in all tasks. On the other hand, there were no schoolchildren with all incorrect answers, and according to the arithmetic means and standard deviations, there was a higher number of children with correct answers in the maximal number of mathematical tasks. According to the obtained results, this means that the intellectual level of boys and girls of the school age was not only on the higher level of mathematical functioning, but they were also more homogenous compared to boys and girls of the preschool age. Of course, one should not ignore the fact that the samples of children were small in both analyses, with proportionally significantly smaller number of girls, so the obtained results do not have a greater external validity, i.e. they cannot apply to preschool and school age population of children in general.

Discussion

A growing number of researches have suggested that participation in acute physical activity is linked to enhancement of brain function and cognition[30–32]. In spite of this fact, the majority of school systems reduces school time devoted to physical education[33–34]. However, physical activity has been positively correlated to academic achievement when integrated into early childhood educational programs[35]. Evidence from longitudinal studies indicates that only fine motor skills in young childhood predict improvement in reading and math skills in later years[36]. Ericsson showed that children who were assigned to a physical training program for motor skills not only improved their motor skills, but also their native language and mathematic performance[37]. Cognitive deficits, such as learning disabilities, are often associated with coordination and motor skill disorders[31]. Adler states that mathematics cannot be separated from the particular cognitive processes in operation whenever we apply our minds to a mathematical task[38].

The researches by Kawashima, showed that in order to solve short and simple mathematical problems, a large area of the brain was activated[26]. This happened before the first (introductory) part of the training. It is known that physical exercise with high intensity can also increase the brain activity, even acute one (one or a couple of hours of exercise). According to the results obtained in this study, it could be assumed that exercise during introductory (5 min), preparation (10 min) and main (40 min) parts of physical training increased the brain activity which consequently increased the capacity for mathematical functioning. The ability to quickly solve short mathematical problems remained at the end of the third part of the training and after inactivity (relaxation) in the fourth part (5 min) of the training. Physical exercise caused an arousal based on the activity of the sympathetic nervous system, which was associated with an increase in cognitive performance, in this case in mathematical performance[39]. It can be assumed that when the cognitive performance was performed during exercise (as the motor problem tasks), it was strongly related to energetic constraints of the task. Exercise with greater energy demand caused more attention to control movements, as some authors showed[40]. All this affects the integrated activity of the cerebral cortex and, possibly, the entire functioning of the nervous system, the level and quality of concentration, and therefore the cognitive functioning of children. The results of this study confirm the findings of McNaughten and Gabbard who evaluated the mathematical computation speeds of 120 6th-grade boys and girls and found that performance was significantly better following paced walks of 30 and 40 min duration than following 20 min of such exercise. There were no gender-related differences[41].

A study conducted by the California Department of Education evaluated the performance of over one million children on standardized tests of physical fitness, which also includes indices of language arts and mathematics proficiency. Obtained results indicated that physical activity was positively related to various components of cognitive function such as: perceptual skills, verbal skills, mathematic skills, memory, and academic readiness[42].

General results obtained in this study are consistent with the findings of Tomporowski who concluded that physical exercise has an effect on specific cognitive functions and the ones most likely to define the role of the central executive processor[21].

In conclusion, incorporation of physical activity into an early childhood education program would have many beneficial effects. With proper well-designed physical exercises, a child can overcome a wide range of cognitive developmental problems. The authors also believe that even acute intensive physical training can yield positive effects on children's mathematical ability, not only through aerobic exercises, but through variety of exercises that are common in preschool and school gyms. Furthermore, these physical exercises will create better conditions for increasing the quality of neural networks in young children. Generally, physical activity may influence brain health and cognition in children, which could enhance scholastic performance and greater overall cognitive functioning across their lifespan.

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EFEKTI AKUTNOG FIZIČKOG VJEŽBANJA NA SPOSOBNOST MATEMATIČKOG RAČUNANJA OVISNO OD DIJELOVA TRENINGA KOD MALE DJECE

S A Ž E T A K

Cilj istraživanja bio utvrditi da li akutno tjelesno vježbanje povećava sposobnost da se brzo rješavaju osnovne matematičke operacije kod male djece. Na ovaj način, djeca aktiviraju veću površinu mozga kada je to potrebno. Uzorci istraživanja od 38 predškolske i 18 školske djece testirani su u rješavanju osnovnih matematičkih operacija prije i poslije tjelesne aktivnosti. Rezultati su pokazali da je sposobnost matematičkog računanja djece znatno poboljšana tijekom vježbanja i da je ostala stabilna nakon završnog dijela (relaksacije) njihovog tjelesnog treninga.