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Influence of Physical Activity on Cognitive Functions - Potential Mechanisms and Benefits

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Abstract.

Background and Study Aim. The positive impact of physical activity on the proper functioning of the musculoskeletal, respiratory and circulatory system has been demonstrated and confirmed by numerous studies. The results of many research indicate that systematic physical activity has also positive effect on functions of the central nervous system. For example, improvement of the cognitive functions level, such as memory and learning, under the influence of systematic physical training has been demonstrated. The positive effect of physical activity on the central nervous system is especially visible and widely described with regard to elderly people, who develop many adverse remodeling changes in the structure of the brain. Physical activity seems to be a useful tool that may help in limiting and reducing the effects of those changes. However, particularly interesting are the studies which show that also among young people (learning youth, university students), a positive effect of physical activity on cognitive processes is observed. Currently, several hypotheses are proposed, presenting potential mechanisms underlying the beneficial effects of physical activity on the central nervous system. The first hypothesis assumes the beneficial effect of physical activity on the expression of hippocampal genes related to synaptic plasticity. The second hypothesis assumes that physical effort *per se* is an inducer of the secretion of the growth factors (e.g., BDNF, IGF-1), which have a trophic effect on the nervous system. In addition, the results of the latest scientific studies indicate that the positive effect of physical activity on the central nervous system may be due to the action of phospholipase (Gpld-1), released to the bloodstream from the liver under the influence of physical exercise.

The aim of this work is to describe the positive impact of physical activity on the central nervous system. This work indicates that due to the influence on cognitive functions, physical activity is absolutely essential to both elderly and young people population. In addition, this paper describes potential mechanisms related to the impact of physical activity on the central nervous system.

Conclusions. The results of many modern studies have confirmed and proven the observations of the beneficial effect of physical exercise on central nervous study, including the cognitive functions. It seems necessary to

educate both young and elderly people that the proper level of physical activity is a key factor allowing to maintain both physical and mental health at an appropriate, desirable level.

Keywords: young people, physical activity, cognitive function, learning, neurogenesis

Introduction

Modern human genome has been evolutionarily programmed for an active lifestyle [1,2]. However, modern Homo sapiens, despite being genetically programmed and phenotypically adapted to an active lifestyle, more and more often choose a sedentary lifestyle, limiting their physical activity to the necessary minimum. Research conducted by World Health Organization (WHO) showed that more than a quarter of the world's adult population is insufficiently active. Globally, over 27,5% of adults and 81% of young people lead typically sedentary lifestyle [3,4]. Physical activity is recognized as a biological need of the body, necessary for the proper functioning of many genes [5,6]. Lack of physical effort causes changes in gene expression, and thus leads to the development of civilization diseases such as: cardiovascular diseases [7], diseases of the musculoskeletal system [8], cancer [9], diabetes [10], and consequently increases the risk of the premature death. The appropriate level of physical activity is the factor that allows to maintain both physical and mental health at a correct level [5,11,12]. Among the human population aged from 18 to 65 World Health Organization recommends at least 150–300 minutes per week of moderate-intensity aerobic physical activity or at least 75–150 minutes per week of vigorous-intensity aerobic physical activity. Additionally, WHO recommends muscle-strengthening activities at least 2 days per week [13].

Influence of physical activity on cognitive function.

It is well known and widely described that physical activity has beneficial influence on the circulatory, respiratory, musculoskeletal system and on metabolic processes. Research conducted in the last few years demonstrated that systematic physical activity has also a positive effect on the functioning of the central nervous system. For example, several studies conducted among both animal and human models indicated that systematic physical activity has positive effect on cognitive functions such as learning, memory, time of reaction or attention [14,15,16]. It is very important to indicate that the positive impact of physical activity on cognitive processes seems to be independent regardless of age. In elderly people many unfavorable changes are observed along with the advancing aging process [17,18]. These changes are usually degenerative and involve a systematic and progressive reduction in the number of nerve cells amongst brain structures [19]. Neurodegenerative processes frequently affect brain structures that play crucial role in cognitive processes, such as memory, association, learning ability, leading to their impairment [20,21]. Physical exercise seems to be a valid factor that may delay or even reduce the formation of adverse changes in the central nervous system within age. In elderly, regular exercise may be a key factor to reverse age-related declines in cognitive functions [22]. Furthermore, among older population, physical activity influences both physical and mental health and thus affects on the quality of life. Although among young healthy people there are no negative functional and structural changes in the central nervous system, it has been demonstrated that physical activity may also improve their level of cognitive abilities. The results of the studies, conducted so far, has shown that among young individuals, physical activity can intensify the process of neurogenesis, increase synaptic plasticity and stimulate gene expression for factors having a trophic effect on the nervous system [23,24,25]. Additionally, in animal model studies, it was observed that among young animals, compared to older individuals, the impact of physical activity on the formation of new nerve cells and the survival of newly formed neurons is stronger [22,26]. The role of newly formed neurons in the hippocampus is yet not fully understood. One current hypothesis proves that hippocampal neurogenesis is crucial for memory consolidation and learning [27]. This hypothesis is confirmed by the results of studies conducted on rodents, which showed that an increase in the level of hippocampal neurogenesis leads to an improvement in spatial memory [22], whereas reduced proliferation of neural stem cells is linked with age-related cognitive decline [19]. Furthermore, inhibition of neuronal precursors of cell proliferation leads to memory impairment and learning disorders [28]. Positive impact of adult neurogenesis on learning and memory processes turns out to be very important for young people, high school and university students [29,30]. WHO emphasized that physical activity enhances thinking processes,

learning, and judgment skills, ensures healthy growth and young people development as well as generally improves overall well-being [13].
Regardless of age, the beneficial impact of physical activity results from its systematic practice, which leads to an increases of neural stem cell proliferation rate [16], enhances neurite outgrowth, increases progenitor cell survival [26], and increases synaptic plasticity [31]. Additionally, it also increases the gene expression of neurotransmitters and growth factors, which are acting within the central nervous system [32].

The influence mechanisms of physical activity on the central nervous system.

The positive impact of physical activity on cognitive processes has been demonstrated both in animal and human studies. However, the mechanism through which beneficial changes in the central nervous system occur seems to be complex. So far, it has not been possible to clearly explain and describe the mechanisms responsible for the positive impact of physical activity on the central nervous system. Several hypotheses have been proposed to explain potential mechanisms underlying the beneficial effects of physical activity on postnatal neurogenesis. The first one assumes the beneficial effect of physical activity on the expression of hippocampal genes related to synaptic plasticity. This influence applies particularly to genes related with the glutamatergic and GABAergic systems [33]. Under the influence of physical effort, an increased activation of the glutamatergic system genes is observed. This system is the main excitatory neurotransmission system of the brain. Physical activity, within the stimulation of the glutamatergic system, may affect the production and functioning of new neurons within the mature brain structure. In contrast to the glutamatergic system, the GABAergic system genes is the main inhibitory system in the CNS. It has been proven that physical activity inhibits the activity of the GABAergic system [34]. The other hypothesis assumes that exercise per se is an inducer of growth factors secretion. Research indicates that physical activity affects the synthesis and the release of growth factors, which have trophic effect on the nervous system [35,36,37]. Several studies indicate that physical activity may affect on the increase of synthesis and release of vascular endothelial growth factor (VEGF), brain-derived growth factor (BDNF) and insulin-derived growth factor (IGF-1) [38,39,40]. Growth factors are the extracellular signaling molecules that promote increased cell growth and maintenance. During the development of the nervous system, they are important signals, regulating the proliferation and differentiation of stem cells and progenitor cells in the brain [41]. Among adults they play a crucial role in the processes of synaptic plasticity, learning and neurogenesis [42,43]. During mature neurogenesis, growth factors influence the proliferation, differentiation and survival of newly formed cells. The effects of growth factors are complementary, but the outcome of exercise on learning is mainly regulated by IGF-1 and BDNF, while exercise-dependent stimulation of angiogenesis and neurogenesis appears to be regulated by IGF-1 and VEGF [44]. Particularly interesting are the results of the latest studies which shown that positive effect of physical activity on the central nervous system may arise from the influence on secretion of glycosylphosphatidylinositol - specific phospholipase D (Gpld-1) released from the liver under the influence of physical exercise. In animal models, concentration of Gpld-1 increases after physical activity and correlate with the improved cognitive functions. Additionally, among elder active people concentration of Gpld-1 is higher than among the same age population leading sedentary lifestyle [45].

Conclusions

The beneficial effects that physical exercise demonstrate on the body were already noticed in early Greece, where it was believed that physical activity was an essential element of everyday life, ensuring both physical and mental health. The results of many modern studies have confirmed and proven the observations of the beneficial effect of physical exercise on the entire body, including the central nervous system. Unfortunately, the results of the majority of research show that the level of physical activity in modern societies is not sufficient. Therefore, it seems necessary to educate both young and elderly people that the proper level of physical activity is a key factor allowing to maintain both physical and mental health at an appropriate, desirable level.

Conflict of interest

The authors declared not to have a conflict of interest concerning this work, authorship, and/or publications of this paper.

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