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REVIEW ARTICLE

Physical activity improves cognition: possible explanations

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Abstract Good cognitive abilities (CA) enable autonomy, improve social inclusion and act preventively. Regular physical activity (PA) reduces the risk of developing Alzheimer's disease (AD) and, at the same time, it reduces the decline of CA and stimulates neurogenesis. So PA in connection with cognitive training, nutrition and social interaction has a positive effect on general CA and the central nervous system, the central executor, memory and attention, and reduces the likelihood of developing dementia. Our objective was to examine which sort and intensity of PA is preferred. We did a review, restricted only to human studies, of transparent scientific articles and sample surveys carried out and published in the period between 2001 and 2016 based on the keywords: age, aging, physical activity, physical abilities, cognitive abilities, memory and Alzheimer's disease. According to results CA and PA interact, as an increasing PA of only 10% reduces the risk of dementia and AD significantly. However, there is a question of appropriate intensity of exercise. Low-intensity aerobic exercise has a positive effect on the visual spatial perception and attention, whereas moderate PA has a positive impact on general CA, working memory and attention, verbal memory and attention and vice versa. While the majority of experts recommends vigorous or moderate exercise, many of them warn that higher intensity requires more attention to PA and less to cognitive processes, particularly in terms of reducing reactions, selective attention and flexibility to tasks. There is also a further question what PA should be like. Although some experts believe that the best combination is aerobic PA and exercises against resistance, it is not entirely clear whether the improvement in CA is a result of cardiac vascular fitness. On the other hand, for most elderly it is more suitable to perform an alternative form (not anaerobic) of PA due to comorbidity and actual fragility. We can conclude that PA has a positive effect on CA, but an appropriate intensity and the type of exercise remain unsolved. For the relevant findings it is absolutely necessary to have an interdisciplinary approach.

Keywords Physical activity · Cognition · Memory

Introduction

The quality of aging is a complex process determined by social, natural and physical components (Fratiglioni et al. 2004), intertwining one with another greatly. Knowledge about the connection of physical activity (PA) and cognitive skills is not new, since the latter was already mentioned by Cicero 65 years BC (McCrory 2007). The consequence of the decrease in physical and mental abilities, characterized by age-related changes (Cassilhas et al. 2007), reduces the quality of life of elderly people (Vaughan et al. 2012).

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The whole body is subject to age-related changes, and thus the central nervous system and, consequently, CA, as well. Within the age in the brain occur biological changes, such as shrinkage of neurons, losses of myelination, reduced dendritic branching reduced cerebral blood flow and decreased availability of certain neurotransmitters (McDaniel et al. 2008). Most affected by age-related changes are attention, short-term and long-term memory and central executive (Cassilhas et al. 2007). Although the decline in cognitive functions is a normal process and is a part of aging in some elderly patients this decline deviates slightly from the expected one.

Well, CA change with the age (Costarella et al. 2010; Zuccaro et al. 2012), decrease rapidly to some degree (at the age between 60 and 70), and then the changes, as long as there are no signs of disease processes, become only trifling (Zuccaro et al. 2012). However, the decline can be reduced (Baker et al. 2010; Doi et al. 2015) or the brain can be stimulated to form new cells (Mohorko 2014) by PA (Scherder et al. 2005; Erickson et al. 2011; Chang et al. 2014), therefore for a quality life of elderly people it is important to consider what kind of and how intense PA would be most suitable (Kelly et al. 2014).

The importance of physical activity for cognition

CA and training of cognitive skills are important because PA slows down the cognitive decline (Kemoun et al. 2010), in addition, individuals with reduced CA and decline of memory (without dementia) often develop AD (Lautenschlager et al. 2008) which is approximately in 70% of the cases of dementia (Albert 2008). Therefore, when getting old, it is important to stimulate thought processes that have a positive impact on reduction or prevention of dementia (Christensen et al. 1996). However, at the same time Fong et al. (2015) emphasize the importance of maintaining cognitive functions also to perform the necessary daily activities (e.g. driving an electric wheelchair in case of weaker physical condition). In the study reveals that many daily activities (e.g. dealing with money, medication, using the telephone, preparing a meal) are primarily a cognitive problem while some daily activities (e.g. walking, transfer, moderate PA, climbing stairs) depend rather more on PA than CA.

According to Benedict et al. (2013) PA is associated with the increase in the volume of the brain resp. with the reducing of atrophy. In a cross-sectional study (2001–2003) it was found that PA has an impact on gaining brain volume (metric MRI) and CA. PA, in connection with CA, is also important as a protective function, since, according to Barnes and Yaffe (2011), the increase of PA by 10% reduces the risk of developing AD significantly, whereas reducing inactivity by 25% would reduce the incidence of dementia in 1 million individuals a year. Also, Larson et al. (2006), on the basis of self-reporting, find that regular PA reduces the chance of developing AD by as much as 32%, which is very important given the fact that the decline of CA is often a precursor of AD (Abbott et al. 2004). The fact that PA affects forgetting and the development of dementia is also agreed by Abbott et al. (2004), who in their study confirmed the influence of PA (walking) on reducing the likelihood of developing dementia.

The decline of PA which coincides with the age has an impact on modified functioning of the neurotransmitters in the dopaminergic system (Jay 2003; Loprinzi et al. 2013). Being aware that dopamine is important for both, the hippocampus and the prefrontal cortex, the absence of dopamine can anticipate problems with working memory and learning (Abdulrahman et al. 2015).

Due to deposition of amyloid-β plaques in the form of oligomers can lead to impaired synapse communication, contribute to oxidative stress, impair cellular glucose metabolism, and induce gliosis can result cognitive decline (Wang et al. 2006) as a consequence of chronic microglia activation (Perry et al. 2010). PA has indirect effect on the body, reduces chronic stress, oxidation and inflammation and so has impact on reduced dementia risk and better cognition function (Barnes and Lautenschlager 2013).

Neuroplasticity and neurogenesis of the brain can be demonstrated by the increased number of neurotrophins deriving from the brain (*brain-derived neurotrophic factor-BDNF*) (Mohorko 2014; Piepmeier and Etnier 2015). BDFN, which can be measured in blood serum or blood plasma and peripheral BDFN–pBDFN (Pareja-Galeano et al. 2015), belongs to those most important proteins in the brain that play an important role in neurogenesis, synaptic plasticity, learning and memory (Vaughan et al. 2012; Erickson et al. 2010). On the other hand, a lower concentration of pBDFN, a smaller hippocampal volume and poorer execution of cognitive tasks associated with spatial memory (Kisner and Colby 2007) have been noticed. Baker et al. (2010) detected an increase of pBDFN in the elderly with minor cognitive impairment after aerobic exercise.

A suitable PA to improve cognition

Health-related fitness which defines aerobic capacity, muscle strength, speed and skills, and body composition (Ruiz et al. 2009; Sergi et al. 2011) has become more and more important. Fitness (decrease in muscle mass, muscle strength, worse performance of tasks) decreases with the age even in a population with good fitness (Lawlor and Hanratty 2001).

Kelly et al. (2014) think it is difficult to define what the appropriate PA should be like, because the elderly are often prone to restriction of PA due to various reasons. Doctors therefore recommend PA for elderly people, but Lawlor and Hanratty (2001) found, the recommendation on performing PA which the elderly get at the doctor is inefficient, what was the same that found Orrow et al. (2012).

Makizako et al. (2015) established in their study that moderate PA has an impact on the increase in the hippocampus. In the years from 2003 to 2013 Erickson et al. (2014) came to a conclusion by reviewing published scientific literature on the connection between PA, cardio vascular fitness and exercise and the volume of the gray brain in the elderly population, that there is a positive link between PA and increasing the volume of the gray brain in the prefrontal cortex and hippocampus in elderly adults, resulting in a better attention and memory. Kennedy et al. (2009) also agree with the above mentioned, adding that the decline in the brain gray is especially noticeable in the sensory part of the hippocampus. PA improves memory. Cox et al. (2009) found in their study after 6-month of PA in the home environment, on the basis of self-reporting, that there was an improvement of memory in people with mild memory problems, compared with the control group. In their study Flöel et al. (2010) also confirmed the link between the PA and improving of the memory as well as increasing the gray brain in the prefrontal and limbic cortex (testing, MRI, blood test of neutrophins).

Along with the cognitive training, nutrition and social interaction, PA stimulates neurogenesis (Voss et al. 2013; Cox et al. 2013). Vaughan et al. (2012) say, that besides the brain, according to the cognitive strain, cognitive processes (cognitive plasticity) may also change. Above all, PA (aerobic), beside its positive effect on CA, also has a positive effect on the maintenance of healthy brain in most populations (Smith et al. 2013). The importance of PA (moderate to intense) for quality aging and reducing of brain atrophy has been confirmed by Doi et al. (2015) in their study. At the same time moderate PA also affects the overall CA (Weuve et al. 2004; Lautenschlager et al. 2008; Chang et al. 2012), working memory and attention, and verbal memory and attention. The decrease in the memory is significantly influenced by BDFN and IGF-1 as important factors of neurogenesis (Pareja-Galeano et al. 2015). A smaller decline in the concentration of BDFN over the years is normal and expected, but also furtherly reduced by age-related degenerative diseases and a deteriorating physical condition (Coelho et al. 2013). In their study Cassilhas et al. (2007) experience an increase in serum insulin (IGF-1) with those who practiced PA, most likely in connection with the transfer into the central nervous system and, consequently, better cognitive functions. IGF-1 belongs together with the above mentioned BDFN and neutrophins 3 and 4/5 to the most important neutrophic factors that influence neurogenesis (Coelho et al. 2013). Erickson et al. (2011) find that PA influences mostly a better spatial memory, as due to the increased concentration of BDFN there is a consequent increase of the hippocampus. It is also necessary to consider the fact that elderly people have inherently less BDFN (Coelho et al. 2012), which is not in favor of a long life since an appropriate level of BDFN also belongs to key factors important for our survival (Failla et al. 2015).

Genetic predisposition has to be considered as well. There are numerous genes that can potentially influence on cognitive functioning; Apolipoprotein E (ApoE), Angiotensin I converting enzyme, Catechol-O methyltransferase, Methylenetetrahydrofolate Reductase, Methionine Synthase, Klotho, Cayhepsin D, Lactotransferrin, Nicastrin, Prion gene, Serotonin Transporter and DISC (Mcgue 2008). The ApoE-ε4 genotype is the largest genetic risk factor for the late-onset AD (Karch and Goate 2015) and the effects on it on neuropathology and cognitive decline might be aggravated by PA (Rovio et al. 2005; Poedewils et al. 2005). According to numerous studies, epigenetics events that include changes in DNA methylation patterns, histone modification and alterations in microRNA are some of changes that occur within aging (Kaliman et al. 2011). High intensity PA has been shown to reduced global DNA methylation (Zhang et al. 2011), therefore more genomic stability, on histones (Nakajima et al. 2010) and on microRNA (Flynn et al. 2003).

Endurance training (Chodzko-Zalko et al. 2009; Volčanšek and Pfeifer 2014; Failla et al. 2015) provides a better cardiovascular fitness and a positive effect on angiogenesis (Colcombe et al. 2004) and verbal fluidity (Gates et al. 2013). However, it is also necessary to consider co-morbidity and fragility since the presence of at least one chronic disease increases with the age and about 70% of elderly people older than 70 have at least one disease (Rossi et al. 2013).

The question is why better cognition occurs in connection with the PA. In addition to increased blood flow to the muscles (Busse et al. 2009; Schiaffino and Reggiani 2011), according to some, this is due to a better blood supply to the brain, reduction of cardiovascular diseases and reduction of the negative stress (Fratiglioni et al. 2004). Even Alosco et al. (2014) perceive in their study, within a period of 12 months, worse CA in those who were less physically active. Lautenschleger et al. (2008) believe that the most likely reason lies in the increase in blood flow and perfusion of the brain in the prefrontal cortex and parietal areas and the increased influence of the environment, which has a positive impact on synaptogenesis and neurogenesis.

PA therefore does not have the same impact on all cognitive functions, but rather on thinking, working memory and cognitive flexibility (Davranche et al. 2015).

Proactive aging

The fact is that the number of elderly people has been increasing which consequently increases the significance of the research in this field. As previously mentioned, both CA and PA function mutually and their reduction may lead to deterioration in the quality of life of elderly people. That is why the identification of the impact on the reduction of cognitive function in the aging population is very important (Kelly et al. 2014). The importance of the decline of CA with the age is essential for individual, economic and social levels (Vaughan et al. 2012) and increases the importance of finding appropriate solutions. Although regular PA in all stages of life belongs to positive factors influencing PA and CA, and at the same time preventing the onset of many diseases, inactive lifestyle is often still in the lead (Hötting and Röder 2013). It is important to deal with the age proactively, which means the ability to predict negative changes in the life course and preparing for them. Among proactive strategies there are healthy lifestyle habits (giving up smoking, balanced diet, regular exercise etc.). Through active participation in the process of aging the effects of stressors can be reduced, coping with age can be strengthened and social exclusion can also be reduced. Unfortunately, there arises a paradox, since the compensation processes and optimization, which improve the quality of aging, are often more difficult to be implemented because of aging processes themselves (Ouwehand et al. 2007). In addition, according to Vrdoljak et al. (2014), healthy lifestyle habits can also depend on economic status (e.g. a healthy diet), which may represent an additional problem for an old person, since they often consume low quality foods. It is also important to recognize that each individual is responsible for his functional age and all health determinants (Železnik 2010).

The intensity and the type of physical activity

The biggest dilemma is still the appropriate exercise intensity. While the majority of experts recommend vigorous to moderate exercise (Cassilhas et al. 2007; Chang and Etnier 2009; Chang et al. 2012), many of them warn that higher intensity requires more attention to PA and less of it to cognitive processes, particularly in terms of reducing reactions, selective attention and flexibility to perform tasks (Davranche et al. 2015) or however, the result may even be negative (Eggermont et al. 2006; Mc Morris et al. 2015). The ideal dose varies and it should be based on age, fitness level, comorbid illness, and other factors (Barnes and Lautenschlager 2013). Vidoni et al. (2015) found in their study that even low-intensity aerobic exercise has a positive effect on the visual spatial perception and attention. In order to ensure health and CA they recommend 75 min of moderate aerobic activity per week and conclude that there is no need for more intense workout. The main focus is, in their view, on maximal aerobic power, therefore it is necessary to create specific workout for each individual, because due to his lifestyle and genetic influences each individual reacts differently to a training (Chodzko-Zalko et al. 2009; Bouchard et al. 2011). Aerobic exercise also affects the normalization of N-acetyl aspartate (NAA), a metabolite of the central nervous system, the size of which is reduced in the elderly (Erickson et al. 2012) over the years. Kozlovskiy et al. (2012) found in their study that high concentrations of NAA in the hippocampus provoke improved working memory.

It is necessary to consider some external conditions in which physical exercise is performed, such as higher outdoor temperature and dehydration, which may also affect the implementation of cognitive tasks (Jiménez-Pavón et al. 2011). Some randomized control studies also claim greater improvement in cognitive functions due to the involvement of several cognitive domains while dancing than functional aerobic activity (Coubard et al. 2011; Kim et al. 2011; Hackney et al. 2015; Eggenberger et al. 2015), while others don't (Merom et al. 2016).

Conclusion

By studying the impact of PA on CA of elderly people, there are still a lot of open questions. When selecting the population, it is possible to choose among a population that already has cognitive problems and the healthy one. The effects of PA on cognitive functions of the elderly could be the result of improved blood circulation and oxygenation of the brain (Williams and Kemper 2010), which is expected to form more neurons and thereby maintain the brain volume (Etnier et al. 2006). PA could or should be used as a supportive therapy in clinical syndromes of dementia in neurodegenerative disorders, since that individuals who are physically active are less likely to develop cognitive impairment and dementia and have improvement in at least some aspect of cognitive function, brain volume, and functional brain connectivity.

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