The Brain and Movement: How Physical Activity Affects the Brain

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ABSTRACT In recent years, many studies have demonstrated the importance of movement for the human body, from the improvement of cardiovascular efficacy to the enhancement of muscular functions, metabolic balance, and organ systems. The brain is no exception and benefits greatly from movement, both structurally and functionally. Memory, creativity, and intelligence, are only a few of the many things that are regulated by the brain. The literature demonstrates the benefits of physical activity on numerous factors that influence brain functions. The present short review aims to clarify how physical activity affects the human brain. We have identified the influence of movement on the brain, through investigation of this influence according to the close relation of physical activity with cognitive processes and brain development. These findings offer an insight into several conclusions regarding the influence of movement on the brain, which is soundly based on relevant literature.

KEY WORDS motor activity, neurotrophic factors, language, human movement

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Introduction

The influence of movement on the brain, an introduction

Research papers that support the importance of movement for our body are almost countless. These works start from the improvement of heart and lung efficacy to the enhancement of joint function (Padulo, Di Capua & Viggiano, 2012; Padulo et al., 2013; Oliva, Osti, Padulo & Maffulli, 2014; Gheller et al., 2015); from regulating blood sugar and fat to that of the sleep-wake cycle (Matinez-Gomez et al., 2010; Umpierre et al., 2011; Lang et al., 2013). Obviously, among all the organs of our body, the brain is richly benefitted by movement, both structurally and functionally. The literature demonstrates the movement benefit on mood in depression (see, e.g. Schuch et al., 2016; Chen et al., 2016), anxiety (see, e.g. De Souza Moura et al., 2015; Herring et al., 2015), and in bipolar disorder (see, e.g., review by Melo et al., 2016).

It has been widely demonstrated (see the review by Heijnen, Hommel, Kibele & Colzato, 2016) that the motor activity stimulates the so-called brain-derived neurotrophic factor (BDNF), a neurotrophin responsible for neural conservation and differentiation, synaptic plasticity (also for the formation of new synapses), long-term potentiation, and brain neurogenesis (also in adulthood). To this family of proteins also belong NGF (nerve growth factor), NT3 and NT4 (neurotrophin 3 and 4). BDNF exerts its effects on the cognitive (Alesi et al., 2014) sphere through the abilities described above, and it is thought to influence learning (Leckie et al., 2014). Interestingly, an increase in BDNF after exercise is positively correlated with cognitive performance; this was also confirmed recently by Van Dongen, Kersten, Wagner, Morris & Fernández (2016), who demonstrated that physical activity performed four hours after learning improves memory efficiency, showing how the hippocampus improves its efficacy in memory retention.

However, the increase of neurotrophins differs depending both on the type of exercise and gender. Huang, Larsen, Ried-Larsen, Møller & Andersen (2014) published a review in which it was highlighted that only one aerobic exercise session is needed to increase BDNF levels and that frequent aerobic exercise further increases

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this effect. A meta-analysis of the studies that take into account the effects of aerobic exercise on BDNF has confirmed this neurotrophic influence on the brain but it has also shown that effects may be lower in females relative to males (Szuhany et al., 2015). The hypothesis is that this discrepancy is caused by hormonal changes occurring during the menstrual cycle by the hypothalamic-pituitary-adrenal (HPA) axis and subsequent levels of anandamide (AEA; Maccarrone et al., 2001).

Therefore, considering the link between sex hormones and cognitive functions (Colzato et al., 2010; Colzato & Hommel, 2014), it is hypothesized that aerobic exercise can affect mood and cognitive functions in women in a different way, depending on whether they are in the follicular phase (low levels of progesterone) or the mid-luteal phase (high progesterone levels). In particular, during the luteal phase, the increase of AEA induced by exercise is particularly low. In turn, this mechanism leads to a reduction in the amount of BDNF released. Starting from this assumption, we can say that engagement in aerobic exercise during the luteal phase weakens the cognitive benefits of the follicular phase.

Furthermore, physical activity can be closely related to a person's environment (Vando et al., 2013) and emotions. The environment, and in particular environmental enrichment, is able to stimulate physical activity (De Giorgio, 2017), and physical activity is also able to regulate both emotions and health outcomes (De Giorgio, 2016; Hoying & Melnyk, 2016). Chakrabarti, Scafidi, Gallo, and Haydar (2011) highlighted how physical exercise and environmental enrichment increase neurogenesis, cellular proliferation, and gliogenesis both in a particular part of the hippocampus, the dentate gyrus, and in the forebrain sub-ventricular zone. These two structures are known as places where neurogenesis in the adult mammalian brain occurs (Ming & Song, 2011).

Physical activity and cognitive processes: what changes in "the moving brain"

In the last twenty years, research regarding the effects of movement on the brain in children and adolescents has increased (Alesi et al., 2015). According to these studies, motor activities should gain a significant role in preventing metabolic, respiratory, and cardiovascular diseases as well as in the ability to support, increase and re-activate the cognitive processes useful for each type of learning. Significantly, these human studies have confirmed the results of research on experimental models (Gheller et al., 2015), demonstrating once again their importance in scientific research (Padulo, Maffulli & Ardigò, 2014). Physical activity positively contributes to human growth and development, thus preparing children for the mental and physical challenges of adolescence and emerging adulthood, which require stamina. (Felfe, Lechner, & Steinmayr, 2016; Prakash, Voss, Erickson, & Kramer, 2015). There is a huge body of research indicating that physical activity has, indeed, both physiological and psychological benefits, being associated with better mental health and enhancement of brain function and cognition (Donnelly et al., 2016).

Chaddock et al. (2010a) conducted a study on children aged 9 and 10 demonstrating that physical activity is able to increase the volume of the striatum, one of the structures belonging to base ganglia which are related to both the motor and cognitive tasks, in particular regarding attentive functions. The same research group (Chaddock et al., 2010b) demonstrated through functional magnetic resonance a positive correlation between increased hippocampal volume and mnestic performance in pre-adolescent children who performed regular exercise (Alesi et al., 2015). Whiteman, Young, Budson, Stern and Schon (2016) further demonstrated how aerobic activity affects a particular area in the hippocampus called the entorhinal cortex. Researchers have shown that aerobic activity is related to an increase in grey matter in the entorhinal cortex, through which information travels.

Physical activity also influences the process of myelination. Myelin is a substance that envelops the axons of the neurons and allows, among other things, an efficient conductor of electrical signals throughout the central nervous system. In general, when the grey matter increases in the brain, it is also possible that myelination process begins due to the creation of new axons (Bechler, Swire & Ffrench-Costant, 2017). However, myelination is a complex mechanism that is also related to how much neurons fire. In other words, when a gesture is performed, impulses are sent along axons, and when impulses increase on the same pathway, due to repetitions of the same gesture, more myelin is created. In this way, the signal among brain areas is faster, and the brain can use reduced energy to perform that gesture. However, this mechanism is present in all motor and cognitive functions, which can be linked during the decision-making process, which is a vital skill in many sports. Increased efficiency in making decisions is also due to a myelination mechanism: if neural signals among brain areas are more effective and faster, athletes can make decisions faster than their opponents can. Also noteworthy is a review by Tomlinson, Leiton, and Colognato (2016) in which the authors document how physical activity, environmental enrichment, and motor experiences promote more efficient neuronal myelinization and, conversely, that social retreat, inadequate physical activity, and poor environmental experiences reduce it.

Wens et al. (2016) report an increase in BDNF in subjects with multiple sclerosis as a result of aerobic activity over the course of six months. Have et al. (2016) wanted to test the effects of motor activity on creative performance, as well as executive and math functions in primary school children, and correlate it with their body mass index. Again, in this case, the correlation was positive (i.e. the children who carried out physical activity improved their school performance), and the authors conclude by stating (2016, p. 8):

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> [...] The results of this study will expand the current evidence on the relationship between physical activity and academic achievement in schoolchildren. We expect the results to stimulate the debate about whether the integration of physical activity into the classroom can enhance children's cognitive skills and creativity, and will help educational practitioners to design learning environments that are optimal for cognitive development and academic achievement.

Physical activity and brain development are closely related

Language is maybe the most significant skill in humans, and the study of motor activity linked to the development of language yields much information regarding the link between these two characteristics that influence each other. There are two language areas of the brain in humans: Broca's area and Wernicke's area. In the vast majority of the population (9 out of 10), these areas are present solely in the left hemisphere. It is rarely possible to find these areas in the right hemisphere alone, while bilingual or multilingual have dedicated areas in both hemispheres. Broca's area is defined as the area to "say what you understand"; it is where a motor language program can be established. Wernicke's area is for "understanding what is said"; this area enables the understanding of language.

The ability of the humans to connect the information in a word by moving the lips that produces the sound of the work is a very early ability, evident at two months of age. In an interesting article, Patterson and Werker (2003) show that an infant can detect a discrepancy between the movement of the lips and the sound heard when an adult pronounces a word that does not match the expected sound. In addition, this discordance elicits more attention in the child rather than when he can observe an adult moving his lips in accordance with the word spoken.

Further evidence of the link between the development of motor skills and the development of language skills emerge from a rich series of studies. For example, research performed by Mervis and Velleman (2011) took into account canonical babbling, which characterizes the early developing stages of the articulation of sounds in the child. In particular, the authors describe how in Williams syndrome vocalization by the baby, usually accompanied by rhythmic movements of hands characterized by the same temporal profile, is delayed perhaps because of a motor delay of hand-clapping. In other words, in children with normal development, hand-clapping seems to promote babbling, and vice-versa. The use of hands for development and improving language is also demonstrated by Iverson and Goldin-Meadow (1998; 2005). In particular, the researchers published in Nature (1998) an experiment in which they asked people to speak with their hands free to move or to talk with their hands motionless, held under their thighs. The cognitive performance of the latter group of people was significantly worse than the former group. Bernardis and Gentilucci (2006) conducted an interesting experiment in which people had to move their arms through three motor conditions: *hello*, *no*, or *stop*. The researchers studied the gesture, lips movement, and sound quality when the subject pronounced and simultaneously moved the arm with *hello, no,* or *stop*. When *hello*, *no*, or *stop* were pronounced, the corresponding gesture slowed down. These studies, among others, show us that present a similar or even overlapped neural circuit for both spoken and non-verbal language probably exists.

In addition to the cerebral cortex, the basal ganglia and cerebellum are structures also involved in both motor and cognitive aspects, including language. For example, the basal ganglia circuits are essential in some motor aspects of language such as planning, learning, and control of speech production (Macoir et al., 2013; Hanakawa & Hosoda, 2014). Moreover, these structures are very connected to each other. The basal ganglia receive a large amount of input both from the cerebral cortex (Haber, 2016), and cerebellum (Bostan & Strick, 2010; De Bartolo et al., 2011), and their role in cognition is well established (Middleton & Strick, 2000).

It has also been demonstrated that all these structured are impaired in intellectual disabilities. The cerebral cortex (Tavian, De Giorgio & Granato, 2011; Granato, Palmer, De Giorgio, Tavian & Larkum, 2012; Granato & De Giorgio, 2014; De Giorgio & Granato, 2015; Granato & De Giorgio, 2015), basal ganglia (De Giorgio, Comparini, Intra & Granato, 2012) and cerebellum are very sensitive to environmental factors during the development of the brain. However, physical activity is able to repair, at least in part, damage that has occurred during brain development (see for review, De Giorgio, 2017).

Conclusion

In this short review, we have brought together some of the findings relevant to the influence of the movement on the brain or, more precisely, we offered presented articles which discuss how physical activity affects the human brain. These articles indicate that the use of movement and environment enrichment contribute to the development of the central nervous system and can repair several cerebral structures that have encountered damage during the development period. Furthermore, it can be concluded that physical activity is closely related to cognitive processes and brain development. These findings are especially significant in the cognitive and motor development of infants and children. Effects of physical activity on some cognitive processes in children and the connections between the development of motor and language skills are evidenced in many studies conducted in recent years.

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