International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 07 – Issue 11 || November 2022 || PP. 73-82

Cognitive Functioning and Well-Being Effects of Physical Activity: Biological and Psychological Benefits

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Abstract: Numerous studies demonstrate that physical activity (PE) is a potent gene modulator that alters the structure and function of the brain, having a significant positive impact on both cognitive function and overall health. PE is also a safeguard against neurodegeneration. Uncertainty exists over whether this defense is provided by alterations to the biological processes driving neurodegeneration or by improved defense against assaults. This succinct review discusses the biological and psychological benefits of physical activity, describing the findings on brain plasticity and epigenetic mechanisms in studies on humans and animals. It aims to make it clear how to maximize these benefits while avoiding drawbacks, such as exercise addiction. The research is presented in terms of how children develop physically, as well as emotionally, socially, and cognitively. According to the review, PES has the ability to significantly and uniquely contribute to advancement in each of these fields. The development of children's fundamental movement abilities and physical competences, which are crucial prerequisites for involvement in later lifestyle and sporting physical activities, is believed to benefit significantly from PES. Additionally, they can aid in the growth of self-esteem and pro-school attitudes, as well as, in certain cases, academic and cognitive development, when presented in an appropriate way. The review emphasizes the fact that many of these advantages may not come directly from participation; rather, they may be mediated by the way in which children interact with their coaches, parents, and teachers. The nature of these physical activities are greatly influenced by contexts that place an emphasis on positive experiences, ones that are defined by enjoyment, diversity, and the engagement of all, and that are managed by committed and trained teachers, coaches, and parents who are also supportive and knowledgeable.

Keywords: Cognitive Functioning, neurodegeneration, Physical Activity, Biological and Psychological Benefits

Introduction:

Numerous studies have shown that physical activity (PE) alters brain plasticity, affecting cognition and wellbeing (Weinberg and Gould, 2015; for review see Fernandes et al., 2017). In reality, research from both experimental and clinical settings has shown that PE alters the structure and function of the brain, resulting in significant medical and psychological advantages. In general, it is common to distinguish between the biological and psychological components of claimed PE effects. In fact, the majority of studies showed that PE had positive benefits on either mental health or overall wellbeing (in terms of physical and mental health). These two factors are examined in this review along with how they interact. In actuality, choices that are behaviorally suitable depend on effective cognitive functioning. Additionally, limbic and prefrontal brain regions involved in specialized cerebral circuitry that affects emotional states have an impact on cognitive abilities (Barbas, 2000).To properly define PE, it is first required to examine its advantages. Physical activity (PA), which is defined as "any physiological action produced by skeletal muscles that involves energy expenditure," is frequently mistakenly used interchangeably with PE (World Health Organization, 2010).Then, PA is defined as any motor behavior, such as daily and recreational activities, and it is a lifestyle factor for overall health status (Burkhalter and Hillman, 2011). PE, on the other hand, is "a subclass of PA that is planned, structured, repeated, and has as a final or an intermediate purpose the improvement or maintenance of one or more components of physical fitness" (World Health Organization, 2010). Aerobic and anaerobic exercise is examples of PE, which have a specific frequency, duration, and intensity. With evidence from both animal and human studies, this review aims to demonstrate the biological and psychological advantages of PE on cognition and wellbeing in both health and sickness. Numerous studies have been done on the biological foundation at the molecular and supramolecular levels. The other objective of the current research is to offer the actual data on the epigenetic processes that control or regulate the biological effects of PE on the brain. While the physiological mechanisms are adequately understood at the molecular and supramolecular levels (see Lista and Sorrentino, 2010), less is known about the ones involving epigenetics. Finally, the mode of PE practice that will yield these benefits while mitigating its drawbacks will be described. There are many advantages to participating in physical education and sport (PES), according to proponents of these activities. For instance, Talbot argues that physical education promotes respect for both one's own and other people's bodies, aids in the integration of mind and body development, fosters an understanding of the importance of both aerobic and anaerobic exercise for health, positively boosts self-confidence and self-esteem, and improves social, cognitive, and academic achievement. According to a Council of Europe report that specifically discusses sport, it offers opportunities to interact with others, adopt various social roles, learn specific social skills (such as tolerance and respect for others), adapt to team/collective objectives (such as cooperation and cohesion), and experience emotions that are unavailable in everyday life. According to this report, there is "strong evidence" that physical activity has positive effects on self-concept, self-esteem, anxiety, depression, tension and stress, self-confidence, energy, mood, efficiency and well-being. It also emphasizes the significant role that sport plays in personality development and psychological well-being.

Physical exercise, brain, and cognition:

The biological consequences of PE that are related to "neuroplasticity" are particularly significant. The neural system's ability to alter itself in response to experience is known as neuroplasticity (Bavelier and Neville, 2002). PE could therefore be viewed as an enhanced environmental component that supports neuroplasticity. According to studies conducted on animals, structural changes are examined at the cellular (neurogenesis, gliogenesis, synaptogenesis, and angiogenesis) and molecular levels (alteration in neurotransmission systems and increase in some neurotrophic factors), whereas functional activity has been measured by levels of performance on behavioral tasks, such as spatial tasks that allow for the analysis of various aspects of spatial cognitive functions (Mandolesi et al., 2017). Examples of structural change indicators in humans include changes in neurotrophin levels, white matter integrity measurements, and brain volume (by correlation with tropic factors plasma levels). These measurements can be used to define the functional brain efficiency and correlate them to cognitive performances (Serra et al., 2011). In this regard, it is important to stress that any morphological alteration modifies the functional characteristics of a neural circuit, and vice versa, any change in the effectiveness and functionality of a neuron is dependent on morphological changes (Mandolesi et al., 2017).Studies in both experimental and clinical settings have demonstrated that PE causes significant structural and functional alterations in brain function.

Animal Studies:

Animals frequently substitute "motor activity" or "motor exercise" for PE. In rodents, the benefits of motor exercise are primarily investigated by assessments of locomotor activity or through specialized training on wheels. Studies on healthy animals have shown that vigorous motor activity increases the rate of proliferation of neurons and glia cells in the hippocampus and the neocortex as well as induces angiogenesis in the neocortex, hippocampus, and cerebellum (van Praag et al., 1999a,b; Brown et al., 2003; Ehinger and Kempermann, 2003; Steiner et al., 2004; Hirase and Shinohara (Black et al., 1990; Isaacs et al., 1992; Kleim et al., 2002; Swain et al., 2003; Ekstrand et al., 2008; Gelfo et al., 2018). Motor activity alters the molecular levels of neurotransmitters such serotonin, noradrenaline, and acetylcholine (Lista and Sorrentino, 2010; see Lin and Kuo, 2013 for a review) and triggers the release of BDNF (Vaynman et al., 2004; Lafenetre et al., 2011) and insulin-like growth factor-1 (IGF-1; for a review, van Praag, 2009).

Animals who engaged in motor activity displayed increases in spatial cognition (van Praag et al., 2005; Snigdha et al., 2014) as well as other cognitive domains like executive skills (Langdon and Corbett, 2012), demonstrating the improvement of cognitive processes by motor activity. According to Kronenberg et al. (2006) and Nithiantharajah and Hannan (2006), similar structural and functional changes were seen in older animals as well as in animal models of neurodegenerative diseases. This evidence suggests that motor exercise is a potent neuroprotective factor against pathological and physiological aging (Gelfo et al., 2018). In this context, one can use transgenic models to pinpoint the precise moment at which a structural change takes place, and then examine the ideal time for the animals to receive motor instruction to maximize its benefits. In this regard, accumulating evidence suggests that in order for motor activity to exert its protective effects, it must occur before the onset of neurodegeneration (Richter et al., 2008; Lin et al., 2015), such as before the development of beta amyloid plaques in Alzheimer's disease (Adlard et al., 2005). However, some experimental evidence suggests that performing motor exercise after neurodegenerative lesions allows for the improvement of spatial abilities, making it also a powerful therapeutic agent (Sim, 2014; Ji et al., 2015). It's interesting to note that PE causes changes that the offspring can inherit. Positive maternal experiences can actually affect the offspring's behavior and biochemistry (see Cutuli et al., 2017, 2018). Preclinical research also suggested that a mother's exercise regimen during pregnancy may have an impact on her unborn child (Robinson et al., 2012). It is unclear, though, whether the chances of inheritance are just restricted to motor training. In this regard, it has been observed that pregnant rats exposed to motor exercise during treadmill and wheel running produce offspring with enhanced spatial memory and elevated levels of the neurotransmitter BDNF in the hippocampal region (Akhavan et al., 2008; Aksu et al., 2012). Further research is required, though, as it is yet unknown whether these advantageous benefits come from epigenetic alterations to the developing embryo or physiological changes to the in utero environment (Short et al., 2017). However, there aren't many researches that can be used to investigate the effects of paternal motor training over generations because they are inconsistent and difficult to repeat (Short et al., 2017).

Human Studies:

Even in humans, neuroplasticity events following PE have been seen. Numerous studies have shown that PE affects structural changes in adults, including increased gray matter volume in the frontal and hippocampal areas and decreased gray matter damage (Colcombe et al., 2006; Erickson et al., 2011) (Chaddock-Heyman et al., 2014). PE also boosts blood flow, enhances cerebrovascular health, decides benefits on glucose and cholesterol metabolism, and encourages the release of neurotrophic factors such peripheral BDNF, transporting "food" to the brain (Mandolesi et al., 2017).Cognitive functioning is affected by these consequences (for a summary, see Hötting and Roder, 2013). In fact, the findings of cross-sectional and epidemiological studies showed that PE improves memory skills, the effectiveness of attentional processes, and executive-control processes in both young and older adults (Lista and Sorrentino, 2010; Fernandes et al., 2017). (Kramer et al., 1999; Colcombe and Kramer, 2003; Grego et al., 2005; Pereira et al., 2007; Winter et al., 2007; Chieffi et al., 2017). Additionally, in comparison to inactive persons, structural alterations following PE have been linked to academic attainment (Lees and Hopkins, 2013; Donnelly et al., 2016). Additionally, it has been demonstrated that children who engage in regular aerobic activity outperformed sedentary peers of the same age on verbal, perceptual, and arithmetic tests (Sibley and Etnier, 2003; Voss et al., 2011). Numerous studies have shown that PE lowers the risk of dementia (Colberg et al., 2008; Mandolesi et al., 2017), the degree of decline in executive functions (Hollamby et al., 2017), prevents cognitive decline associated with aging (Yaffe et al., 2009; Hötting and Roder, 2013; Niemann et al., 2014), and enhances quality of life (Pedrinolla et al., 2017). Additionally, research using positron emission tomography showed that PE dictates alterations in metabolic networks linked to cognition (Huang et al., 2016). PE impacts network structure, according to studies on magneto encephalography-based (MEG) functional connectivity (Foster, 2015). It is crucial to recognize that MEG, which has the advantage of combining high spatial and temporal resolution, is a far more accurate way to assess brain activity than fRMI. PE was linked to improved intermodular integration and enhanced cognitive abilities in healthy persons (Douw et al., 2014) (Huang et al., 2016). PE appears to have benefits even in people who are at risk for AD (Deeny et al., 2008), highlighting the protective nature of PE. PE may boost blood flow in the brain circuits involved in cognitive function, which could account for these ameliorative structural and functional effects (Erickson et al., 2012). Another explanation could be found in the idea of "cerebral reserves" (Stern, 2002, 2012), a process that could explain why people differ greatly in the severity of cognitive aging and clinical dementia despite neurodegenerative alterations that are comparable in type and amount (Petrosini et al., 2009). There are two distinct categories of reserves: cognitive reserve and brain reserve. The former is based on the ability of anatomical characteristics like brain size, neuronal density, and synaptic connection to provide protection, whereas the latter is based on the effective connectivity between neural circuits (Stern, 2002; Mandolesi et al., 2017). We may argue that PE is an environmental component that makes it possible to gain reserves in accordance with the reserves hypothesis and taking into account the multiple evidences discussed above. However, it is important to note that while PE enhances cognitive performance and creates reserves that can be used in the event of a brain lesion, the changes to the clinical manifestation of neurodegeneration cause a delay in diagnosis. Patients with greater cognitive reserves have been observed to delay the onset of memory loss symptoms (Zanetti et al., 2017). A brain compensation system that enables the performance of complex activities has been suggested (Stern, 2009). These findings undoubtedly raise significant questions more relevant to the diagnosis of neurodegenerative diseases than to the practice of PE. From childhood to old age, the impacts of physical activity on cognitive functioning have been demonstrated (Hötting and Roder, 2013). It has been demonstrated that the most sensitive cognitive processes to PE are those that depend most heavily on experience, such as memory, and those that are most influenced by brain maturation, such as attention or cognitive flexibility. Overall, these research, along with those looking at the combined impact of environmental factors, indicate that up until middle age, maintaining a "enriched lifestyle" is important for a good effect on cognitive performance. In fact, exposure to PE combined with a variety of other experiences offers a "reserve"-like benefit that promotes the long-term maintenance of cognitive function in old age (Chang et al., 2010; Loprinzi et al., 2018).

Physical exercise and wellbeing:

PE appears to have numerous advantages for people of all ages, enhancing psychological health and quality of life (Zubala et al., 2017). High levels of self-efficacy, task orientation, and perceived competence are associated with physical education in kids (Biddle et al., 2011). Most studies have shown that physical activity (PE) improves health outcomes in youth and adults, including mood and self-concept (Berger and Motl, 2001; Landers and Arent, 2001; Penedo and Dahn, 2005). PE supports social connections and mental health in the elderly population by assisting with maintaining independence (Stessman et al., 2009). It was now widely acknowledged that PE-related biological and psychological mechanisms interact to improve wellbeing (Penedo and Dahn, 2005). PE's positive biological effects are primarily mediated by an increase in cerebral blood flow and maximal oxygen consumption, oxygen delivery to cerebral tissue, a reduction in muscle tension, and elevated serum levels of endocannabinoid receptors (Thomas et al., 1989; Dietrich and McDaniel, 2004; Querido and Sheel, 2007; Gomes da Silva et al., 2010; Ferreira-Vieira et al., 2014). Additionally, it is known that neuroplasticity phenomena like modifications in neurotransmitters have an impact on health. For instance, PE raises serotonin and beta-endorphin levels, including anandamide (Young, 2007; Korb et al., 2010) (Fuss et al., 2015). A feeling of control (Weinberg and Gould, 2015), competency and self-efficacy (Craft, 2005; Rodgers et al., 2014), an improved self-concept and self-esteem (Marsh and Sonstroem, 1995; Fox, 2000; Zamani Sani et al., 2016), positive social interactions, and opportunities for fun and enjoyment (Raedeke, 2007; Bartlett et al., 2011) have all been highlighted among the psychological According to psychological studies, PE can even influence personality and self-development (Weinberg and Gould, 2015). PE has also been linked to hardiness, a personality trait that makes it possible for someone to endure or deal with stressful circumstances (Weinberg and Gould, 2015).

Depression and Anxiety:

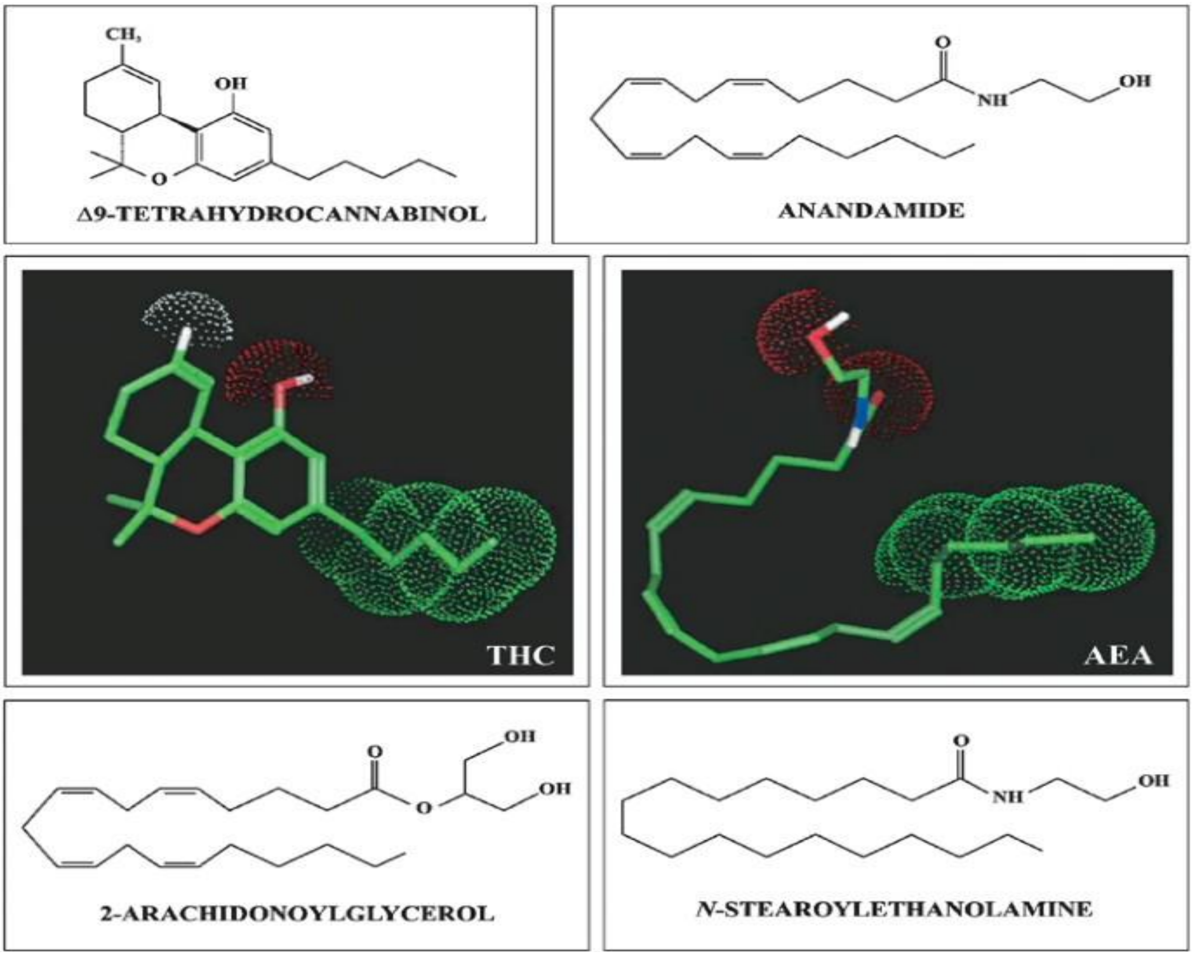
Anxiety disorders, which rank among the most common mental illnesses worldwide, are similar in nature (Weinberg and Gould, 2015). Epidemiological studies have consistently shown that PE has a positive impact on lowering anxiety and depression (Mammen and Faulkner, 2013) (DeBoer et al., 2012). Exercise may be used as a treatment for these illnesses, as it has been observed that people who participate in PE regularly are less depressed or anxious than those who do not (De Moor et al., 2006) (Carek et al., 2011). Regardless of the specific activity, the majority of research on the connection between PE and positive mood state changes has shown positive effects (Knapen et al., 2009), even though it is debatable what level of aerobic PE is necessary to control and reduce symptoms (de Souza Moura et al., 2015). For instance, it has been found that people with major depressive disorder (MDD) significantly reduced their depressive symptoms after about 16 weeks of an aerobic exercise program (Craft and Perna, 2004). However, there is evidence to support the claim that even anaerobic exercise is effective in treating clinical depression (Martinsen, 1990). Independent of the type of exercise, it has been demonstrated that PE has positive effects on anxiety disorders even with brief bursts of activity (Scully et al., 1998).Modulation of peripheral levels of BDNF was found to be a physiological mechanism linked to the improvement in depressed mood post-exercise PE (Coelho et al., 2013). Recently, it was proposed that exercise prescriptions for mood improvement should be made on an individual basis rather than based on the patient's preferred intensity (Meyer et al., 2016a,b). On the other hand, being inactive led to worsening depressive symptoms and subsequently lower peripheral levels of BDNF (Brunoni et al., 2008). Lower oxidative stress may also contribute to post-PE mood improvement (Thomson et al., 2015). This competition provided evidence that those with MDD or bipolar disorder experience abnormal oxidative stress (Cataldo et al., 2010; Andreazza et al., 2013), and that PE, particularly at higher intensities, reduces oxidative stress and improves mood (Urso and Clarkson, 2003).

Addictive and Unhealthy Behaviors:

PE has a strong track record of success in treating a variety of addictive and unhealthy behaviors. PE tends to control the urge for hunger and satiety as well as behaviors like drinking, gambling, and smoking (Vatansever-Ozen et al., 2011; Tiryaki-Sonmez et al., 2015). In this context, numerous studies have shown that regular physical activity helps increase healthy behaviors in substance abusers (Giesen et al., 2015). Regular physical activity has been shown to lessen cigarette cravings and use (Haasova et al., 2013). Although physical activity has benefits for psychological health, it is important to note in this context that PE can occasionally reveal unhealthy behaviors that have a detrimental effect on health (Schwellnus et al., 2016). It is the case of exercise addiction, a dependence on a regular exercise regimen that is characterized by withdrawal symptoms, such as anxiety, irritability, guilt, muscle twitching, a feeling of being bloated, and nervousness, after 24-36 hours without exercise (Sachs, 1981) (Weinberg and Gould, 2015). According to Scully et al. (1998), there is a significant correlation between exercise addiction and eating disorders, pointing to the co-morbidity of these disorders and a shared biological underpinning. Recent research in particular has demonstrated that these unhealthy behaviors are linked to decreased prefrontal cortex volume, activity, and oxygenation, which results in cognitive impairment, such as the loss of inhibitory control, which in turn leads to compulsive behaviors (Asensio et al., 2016; Wang et al., 2016; Pahng et al., 2017). Additionally, it has been observed that a few days of PE increase prefrontal cortex oxygenation, improving mental health (Cabral et al., 2017).

What kind of physical exercise is recommended?

Sport psychology has proposed that a number of factors, including exercise intensity, frequency, duration, and whether an individual or a group performs the exercise, determine whether physical activity programs are successful or unsuccessful (Weinberg and Gould, 2015). These factors, which are influenced by individual characteristics, are crucial for maintaining an active lifestyle and obtaining benefits for the brain and behavior. Scientific studies have shown that whether PE is performed in an aerobic or anaerobic modality has different effects on cognitive functioning and wellbeing, even though these factors must be taken into account when training is proposed. Adenosine triphosphate (ATP) can be resynthesized through aerobic mechanisms during exercise by adjusting the exercise's intensity (from low to high intensity), duration (typically long), and oxygen availability. The maximum heart rate (HRmax) or oxygen consumption (Vo2max), which determines an increase in oxygen consumption compared to the resting condition, are dependent on the cardio respiratory effort. Jogging, running, cycling, and swimming are some examples of aerobic exercise. Instead, anaerobic exercise causes the muscles to use up their reserves of ATP and/or phosphocreatine (PCr), shifting the production of ATP to anaerobic energy mechanisms like lactacid or alactacid. Anaerobic exercise also has a short duration, high intensity, and lack of oxygen availability. Weightlifting and 100-meter sprints are two instances of anaerobic exercises. An improvement in cognitive functions and a greater sense of overall wellbeing have been linked to chronic aerobic exercise, according to a body of research (Berger and Tobar, 2011; Biddle et al., 2011). Colcombe et al. (2006), Hillman et al. (2008), Erickson et al. (2009), Mandolesi et al. (2017), and other studies.



Above image showing the endocannabinoid system, anandamide and the regulation of mammalian cell apoptosis

Recent research has shown a link between improved cognitive functions, particularly prefrontal cortex dependent cognition, and acute aerobic exercise, defined as a single bout of exercise (Tomporowski, 2003; Lambourne and Tomporowski, 2010; Chang et al., 2011; Ludyga et al., 2016; Basso and Suzuki, 2017). However, one exercise session typically has minimal effects on cognitive function (Chang et al., 2012). In this line, it was demonstrated that even a single session of moderate-intensity aerobic exercise improves the wellbeing of MDD sufferers by enhancing mood and emotional states (Bartholomew et al., 2005; Basso and Suzuki, 2017). High-intensity exercise increases the speed of information processing, whereas moderate intensity exercise has been linked to improved working memory and cognitive flexibility (Chang and Etnier, 2009). According to this study, peripheral BDNF was found to significantly increase following high-intensity exercise but not following low-intensity exercise (Hötting et al., 2016). In fact, research shows that high-intensity exercise benefits cognitive functions in older people more than low-intensity exercise (Brown et al., 2012). Regarding the psychological benefits of PE, research has shown that longer training programs (several months) are more effective in reducing anxiety and depression than shorter ones (some days) for training sessions lasting longer than 30 minutes. Moreover, aerobic exercise with intensity between 30 and 70% of maximal heart rate can reduce anxiety and depressive symptoms afterward (Weinberg and Gould, 2015). Even anaerobic exercise, like yoga, or all physical activities (PEs) involving rhythmic abdominal breathing, enjoyable rhythmic movements, and relatively little interpersonal competition, play a significant role in affecting mood changes (Berger and Motl, 2001).

Conclusion:

PE identifies beneficial biological and psychological effects that have an impact on the brain and cognitive function and support a state of wellbeing. PE is crucial in the fight against both healthy and unhealthy aging. Recent data have demonstrated that PE activates strong neuroplastic processes, which are partially mediated by epigenetic mechanisms. In fact, PE results in significant changes in the expression of genes and their protein products, known as epigenomic manifestations (Fernandes et al., 2017). A growing body of research suggests that aerobic and chronic PE can both have beneficial effects. These findings ought to cause people to consider the positive effects of physical activity and to advocate for its use as a modifiable factor in prevention, cognitive improvement, and mood enhancement. Despite all these benefits, it must be emphasized that PE should be personalized for each person. Even excessive physical activity (PE) can have a negative effect if it leads to compulsive behavior and encourages addictive behaviors. It's also wise to sound the alarm. The assertion that these effects will take place automatically is not supported by the scientific evidence. There is no reason to think that simply encouraging PES participation will inevitably result in improvements for kids or their communities. Children and young people experience these positive aspects of PES and whether they realize its great potential largely depend on the actions and interactions of teachers and coaches. Fundamentally important are environments that prioritize positive PES experiences, characterized by delight, diversity, and participation of all, and that are run by dedicated and qualified teachers, coaches, and parents.

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