Acute Exercise and Your Brain

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While the physical improvements from exercise have been well documented over the years, the impact of physical activity on mental health has recently become an object of interest. Physical exercise improves cognition, particularly attention, memory, and executive functions. However, the mechanisms underlying these effects have yet to be fully understood.

Keywords: age groups ; attention ; brain

1. Introduction

Physical activity (PA) is defined as “any bodily movement produced by skeletal muscles that requires energy expenditure” [1] (p. 126) and can encompass several activities, such as housework, sports, and active recreation [2]. Limitations to or, often, a complete absence of exercise cause various health problems, including postural and somatic disorders, diabetes, overweight, obesity, cardiovascular disease, and even premature death [3][4][5]. Existing literature suggests that regular PA, particularly aerobic activity, promotes physical and mental improvements in healthy and impaired people [6].

While several papers have dealt with exercise-induced benefits on body health, only in recent years has the study of the relationship between PA and cognition received considerable attention. This relationship directly influences cognitive functioning associated with structural and functional changes in the brain and improves psychophysical well-being [7]. Although a definition of cognition has yet to be standardized [8], the term cognition includes a series of mental abilities that enable us to perceive, process, and store valuable information in daily life. It has been widely demonstrated that PA can positively influence different cognitive functions (e.g., attention, memory, and executive functions) and has more generic effects on the mechanisms involved in learning. Pioneering research on rodents demonstrated how PA could induce growth factor production and changes in the hippocampus, improving memory [9]. These favourable outcomes on mice have spurred research on humans.

The first human studies indicated that these benefits are mediated by complex neurophysiological and biochemical systems, such as the brain-derived neurotrophic factor (BDNF), which over time, leads to a more efficient, adaptive, and plastic brain [10]. In humans, circulating BDNF and vascular endothelial growth factors are acutely and chronically enhanced after aerobic exercise, leading to brain structure and function changes and neurogenesis [11]. Considering recent mouse studies, the expression of BDNF and cytokines following a systemic administration of myokines released during muscular contraction, such as irisin, could have an anti-depressant effect [12]. However, these neurobiological mechanisms have yet to be understood entirely [13], primarily due to a need for suitable procedures for evaluating brain function in vivo during a dynamic motor task.

Cognitive functioning is commonly assessed through mental status examinations, which evaluate the level of consciousness, orientation, constructional ability, and cognitive abilities. Nowadays, neuroimaging methods detail the link between exercise and cognitive function, provide the physical-exercise-induced changes in the neural correlates of cognition in both short-term and long-term practice, and assess brain health [14]. Among the methods available to investigate the impact on functional brain activation, functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), and structural and functional magnetic resonance imaging (MRI) have been used in previous research [15][16]. fNIRS and EEG have a limited spatial resolution and may only allow for the evaluation of brain activation patterns in superficial cerebral areas. However, functional magnetic resonance imaging (fMRI) has recently overcome these shortcomings.

fMRI is a fundamental non-invasive instrument of investigation to acquire high-definition images of whole brain activity during different motor tasks and to estimate the brain activation changes in cortical and subcortical areas (cerebral networks) via the blood oxygenation level-dependent (BOLD) signal [17][18][19]. The human brain comprises anatomical regions (nodes or hubs) and synaptic connections among the various regions (edges) [20]. The cerebral networks may change after PA and usually encompasses all body muscles, or after jaw-related therapeutic interventions that involve especially masticatory muscles [21]. Task-based fMRI and resting-state fMRI examine BOLD changes obtained during a cognitive task and while performing no straightforward task, respectively. These two methods are suitable for exploring the modification in neural correlates driving cognitive improvements and measuring brain functional connectivity after exercise or other environmental factors, such as thermal stress [22]. Functional connectivity relates to areas of the brain that are spatially separated but temporally connected in their signalling [23]. A good use of fMRI is in the preclinical models [24]. Indeed, fMRI may even detect abnormal mitochondrial functions, especially in severe inheritable metabolic diseases with neurological manifestations [25].

2. Acute Exercise

Previous studies have targeted cognitive abilities as evidence suggests that a single exercise session may temporarily alter them [26]. A 2001 study observed that older patients with chronic obstructive pulmonary disease (COPD) showed better verbal fluency following 35 min of acute aerobic exercise (20 min cycling and 15 min recovery period) [27]. **Therefore, acute exercise positively impacts both healthy and impaired people.** Although previous papers recommended acute physical exercise [28], the relationship between acute PA and cognition remains to be determined.

Regarding older adults, a low level of PA is considered a risk factor for dementia. Acute aerobic exercise increased the BDNF plasma levels in patients with Alzheimer's disease and healthy controls. In addition, the BDNF levels had an association with the level of PA [29]. Following 30 min of moderate-intensity exercise in healthy older adults, higher activation was observed in the middle frontal, inferior temporal, middle temporal, and fusiform gyri during a semantic memory task and in the bilateral hippocampus after exercise compared with at rest [30]. Moreover, 30 min moderate-intensity bicycling generated greater activation in the left inferior frontal gyrus and left inferior parietal lobule and deactivation in the right anterior cingulate gyrus [31]. Functional connectivity did not differ significantly between acute light- and moderate-intensity training in cognitively normal older adults. A correlation between the right postcentral/parietal cortex, the right ventral lateral prefrontal cortex, the right posterior superior temporal gyrus, and the right dorsolateral prefrontal cortex was detected after acute exercise [32]. In older adults, 20 min cycling, especially at moderate intensity, improved working memory [32], while 30 min moderate-intensity cycling enhanced executive function and functional processing [31].

Recent papers have reported that a single session of PA increased functional connectivity in specific brain networks. These findings are essential for cognitive and motor functions, often the primary goal of neurorehabilitation strategies [33]. Suwabe et al. observed that young adults showed a higher hippocampal memory function thanks to better functional connectivity between dentate gyrus and cortical networks following a 10 min, very light-intensity PA bout [34]. According to Li et al., in younger adults, a 20 min moderate-intensity physical session slightly improved working memory; however, this single bout generated a greater activation in the right middle prefrontal gyrus, the right lingual gyrus, and the left fusiform gyrus [35]. The improvement in executive control processes after acute exercise was related to activation of the prefrontal and occipital cortexes and deactivation of the anterior cingulate cortexes and left frontal hemisphere. Moreover, motor sequence memory in connection with the hippocampus increased significantly for high-intensity PA while tending towards significance for moderate PA in healthy young males; the bilateral precuneus activity improved for both moderate- and high-intensity PA [36]. The mnemonic discrimination task, working memory, and executive function were enhanced in younger adults after 20 min moderate-intensity cycling, while executive function improved in younger adults with attention-deficit/hyperactivity disorder (ADHD) after 30 min moderate-intensity cycling. A single bout of aerobic exercise significantly improved learning mechanisms in young male adults' visual and motor domains. These benefits could last for at least 30 min after exercise. Moreover, moderate-intensity acute PA could allow for a gradual up-regulation of a functional network due to a constant rise in synapse strength, which could encourage brain plasticity in motor and non-motor areas [37]. Mehren et al. analysed the impact of a 30 min single session of aerobic exercise on attention and executive functions in adult patients with and without ADHD. Moderate-intensity PA significantly improved reaction times in patients with ADHD compared with healthy adults [38]. Although the authors noticed no changes in brain activation between the two groups, they supported the importance of acute exercise for patients with ADHD. In another study, Mehren et al. compared moderate-intensity exercise with high-intensity exercise in healthy younger adults [39]. A better behavioural performance (sensitivity index) and greater activation in areas related to executive function, attention, and motor processes (insula, superior frontal gyrus, precentral gyrus, and supplementary motor area) was noticed following moderate PA. Higher cardiorespiratory fitness was also linked to increased brain activation of the right insult and left rolandic operculum after moderate exercise and decreased brain activation of the right postcentral gyrus after high-intensity exercise. Thirty minutes of low-intensity acute exercise in healthy male athletes led to reduced brain activation in the posterior cingulate cortex/precuneus. In contrast, a 30 min high-intensity acute workout reduced the caudate nucleus and ventral anterior putamen [40]. Schmitt et al. also described a positive interference of intense acute PA in emotion-processing brain regions during fearful face elaboration [40]. The authors concluded that single acute exercise sessions are usually beneficial for mood. Moreover, after 30 min acute aerobic exercise, Li et al. noticed that the right cerebellum played a decisive role in processing simple executive tasks [41]. At the same time, the subcortical regions were involved in the processing of relatively complex executive tasks.

A few papers dealt with acute PA's impact on adolescents and children. Acute aerobic stretching and moderate-intensity exercise affected the theta and alpha waves of the EEG and, thus, had beneficial effects on brain maturation and development of children aged 12 to 14 years, especially those with ADHD [42]. Executive function and working memory performance improved in healthy children after 30 min moderate-intensity cycling [43][44]. During a working memory task, a more significant change in functional brain haemodynamics was also detected in the bilateral parietal cortexes, the left hippocampus, and the bilateral cerebellum. A 30 min cycling session also led to higher brain connectivity between the right dorsolateral prefrontal and left cerebellum, inversely associated with improved cognitive performance. Metcalfe et al. observed no significant modifications in the attentional task after 20 min moderate-intensity cycling in adolescents with and without bipolar disorder [45]. In adolescents with bipolar problems, the authors noticed a reduced functional activation in the orbital part of the left inferior frontal gyrus, the right frontal pole extending to the temporal pole, the bilateral hippocampus, and the right amygdala.

Regardless of age, brain changes following acute exercise were mainly found in the frontal and temporal lobes, the cerebellum, and the hippocampal regions. Moreover, executive functions associated with the frontal lobe and hippocampus could be selectively maintained or enhanced in humans with higher fitness levels. Herold et al. underlined that different acute exercise protocols (cycling or treadmill running) and various intensities (light, moderate, and high), as well as the cardiorespiratory fitness level and sex of the participants, affect PA-related shifts in functional brain haemodynamics [46].

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