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Review

Physical activity and the brain: A review of this dynamic, bi-directional relationship

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ABSTRACT

The brain plays a major role in regulating physical activity behavior and exercise performance. Regular physical activity may also play a key role in the prevention and treatment of various neurological conditions, such as Parkinson's disease, Alzheimer's disease, depression, and cognitive function. This implies that not only does the brain (or the nervous system) regulate aspects of physical activity, but also that physical activity may potentially influence brain-related function and outcomes. This review details this bi-directional relationship and addresses its implications for improving physical activity, exercise performance, and brain-related function and outcomes.

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1. Introduction

Human movement is facilitated from efferent pathways originating in the brain's motor and association cortices (Kandel et al., 2000), with different types of movement behaviors (e.g., spontaneous, voluntary, vigorous, or urgent motor behavior) likely being regulated by different central nervous system structures and through the release of different neurotransmitters and peptides (Rauch et al., 2013). In addition to movement behavior such as general physical activity, there is recent evidence suggesting that the brain plays a major role in regulating exercise performance. In this narrative review, the crucial role the brain plays in regulating activity behavior and exercise performance is showcased, as is the emerging work delineating the neuroprotective, neurorestorative, and morphological effects of physical activity on the brain, particularly with regard to cognitive and executive functioning, depression, Parkinson's disease and Alzheimer's disease. This implies that not only does the brain (or the nervous system) regulate aspects of physical activity, but also that physical activity may potentially influence brain-related function and outcomes, suggesting a bi-directional relationship.

2. Is exercise performance neurobiologically 'regulated'?

Research in sports medicine lends strong support for a major role of the brain in regulating exercise performance. The Central Governor Model (CGM) (Noakes et al., 2004; Noakes, 2011; Noakes, 2012) posits that the brain regulates exercise performance by regulating motor unit recruitment to ensure homeostasis is maintained, and thus, helps to prevent potential damage from occurring (e.g., ischemia in various organs). In support of the CGM, research suggests that athletes subconsciously alter their pacing strategy to ensure that homeostasis, and most obviously, thermoregulation, is maintained (Marino et al., 2003). Additionally, proper regulation of arousal, calmness, and focus may play an important role in the regulation of pacing, all of which may be influenced by correct balance of neurotransmitters and/or other peptides, including dopamine, serotonin, norepinephrine, acetylcholine, and endorphins (Rauch et al., 2013). Further, researchers have shown that task familiarity and training status influence the ability to learn a pacing strategy (Williams et al., 2012), with experienced athletes adopting an optimum pacing strategy (Hettinga et al., 2011). This may occur through the involvement of such brain regions as the dorsal posterior insula, which collects afferent sensory input regarding homeostasis, and the anterior insula which produces a sensation based on that collected information regarding the homeostatic state of the body (Noakes, 2012). Additional emerging research shows that non-invasive brain stimulation over the temporal cortex induces electrical activity in the insular cortex, modulates autonomic nervous system activity and ratings of perceived exertion (RPE) during submaximal exercise, and improves maximal exercise performance (Okano et al., 2013). Overall, these findings suggest that the brain plays a crucial role in the regulation of effort perception, pacing and exercise performance.

3. Is physically activity neurobiologically 'influenced'?

The above narrative demonstrates that the brain plays a crucial role in regulating exercise performance. Because of this, an important question to ask is whether physical activity, which may influence exercise performance, is neurobiologically regulated. Garland et al. (2011) defines 'neurobiological control' as, "…in a given environment, two individuals will exhibit an innately different behavioral or physiological state, or will respond differently to a change in that environment." Others have used the term 'activity stat' to describe the potential neurobiological basis of physical activity, which relates to the idea of regulating energy homeostasis (Rowland, 1998), and can be considered similar to the CGM which postulates that the brain plays a crucial role in regulating exercise performance (Noakes, 1998). As will be discussed below, there is evidence suggesting that an individual's physical activity, and perhaps even sedentary behavior, may be neurobiologically 'influenced' (Dishman, 1981).

To examine the potential neurobiological influence on physical activity, studies have investigated the day-to-day variability of physical activity with relatively stable daily energy expenditure suggesting some intrinsic neurobiological, as opposed to environmental, influence on physical activity. Comprehensive discussion of the influence of neurobiology on individual physical activity behavior can be found elsewhere (Rowland, 1998; Bouchard and Rankinen, 2006; Eisenmann and Wickel, 2009; Garland et al., 2011), but several important works are worth discussion. In a meta-analysis of 21 studies, Black and Cole (2000) reported that the mean within-individual coefficient of variation for daily expenditure was 12% (range 6.5–22.6%), suggesting relatively stable between-day activity behavior; similar findings have been reported elsewhere (Wickel and Eisenmann, 2006). Such minimal variation of physical activity in different environments suggests a neurobiological influence. Unpublished data by Sullivan, Loprinzi, Rockcastle, McCormick, Sinko, and Cameron measured the influence of the size and type of housing environment on physical activity by Actical accelerometry in adult female rhesus monkeys. Results showed no difference in mean activity between groups of monkeys living in single cages (270,020 $\pm$ 44,281 counts/day; $n = 17$) and monkeys living in group housing (281,203 $\pm$ 28,952 counts/day; $n = 12$). Similarly, there was no difference in the measured level of physical activity when monkeys moved between individual cages and larger social pens. Though there were large differences in activity among individuals, the size and