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Review

The strength model of self-control revisited: Linking acute and chronic effects of exercise on executive functions

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Abstract

Since the 1960's, hundreds of articles have been published on the effects of exercise on cognition and more recently on executive functions. A large variety of effects have been observed: acute or long-lasting, facilitating or debilitating. Several theoretical frameworks have been proposed to explain these effects with plausible mechanisms. However, as yet none of these models has succeeded in unifying all the observations in a single framework that subsumes all effects. The aim of the present review is to revisit the strength model of self-control initiated by Baumeister and his colleagues in the 1990's in order to extend its assumptions to exercise psychology. This model provides a heuristic framework that can explain and predict the effects of acute and chronic exercise on effortful tasks tapping self-regulation or executive functions. A reconsideration of exercise as a self-control task results from this perspective. A new avenue for future research is delineated besides more traditional approaches.

Keywords: Adherence; Effort; Motivation; Pleasure; Positive mood; Resource; Self-regulation; Training; Transfer; Willpower

1. Introduction

Homo sapiens have always had to cope with stressful environmental and social events that require self-regulation and executive functions, two intricately linked mental functions. For instance, individuals regularly have to change or stop behaviors that would place them at risk for severe injury, health problems, death, group exclusion, or failure to reach a specific goal. Self-regulation refers to psychophysiological processes that enable an individual to guide his/her goal-directed activities over time and across changing circumstances.[1] Executive functions are high-level cognitive functions that subserve and are a prerequisite for self-regulation.[2,3] According to a well-known and frequently used taxonomy,[4] at least three main and elementary components of executive functions can be identified: (1) maintenance and updating of relevant information in working memory, (2) inhibition of prepotent impulses, unwanted and intrusive thoughts, embarrassing emotions, or automatized responses, and (3) mental set shifting also known as cognitive flexibility. Other high-level cognitive processes such as volition and planning[5] and sustained and selective attention[6] have also been considered to be intrinsically linked to executive functions. Self-regulation and executive functions bring into play energetic resources, commonly named effort, in order to meet the demands of a task.[7,8] Cognitive neurosciences have shown that functioning of self-regulation and executive functions are both strongly but not exclusively dependent on the integrity of prefrontal regions,[9–11] one of the most extended but vulnerable parts of the Homo sapiens' brain.[12,13] The well-functioning of executive functions is generally measured with neuropsychological or cognitive tasks. In order to clarify the terminology used in this article, we name "self-regulation task" an effortful task involving executive functions and prefrontal brain regions.

Considering the prevalence and the salience of executive control in human behavior, it seems important to study factors that impair or improve its functioning. Consistent findings have emerged from the scientific literature over the last 30

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years: chronic exercise improves executive functions in children,[14] young adults,[15] and older adults[16] and slows down the aging process in prefrontal brain regions,[17] whereas acute exercise impairs or improves performance in tasks tapping executive functions according to the conditions of execution of the cognitive task[18,19] (while exercising versus just after exercise). Most of these positive or negative effects of exercise have been explained by different theoretical models (e.g., neurotrophic factors hypothesis for chronic exercise,[20] hypofrontality hypothesis or catecholaminergic hypothesis for acute exercise[21]). However, none of these current theories unify all of the observations reported above in a single framework that subsumes all effects. The main purpose of this article is to present a theoretical model that establishes a link between acute and chronic effects of exercise on executive functions and proposes alternative but plausible mechanisms to explain the causal relationship between exercise and executive functions. Formalizing heuristic models characterized by a limited number of inter-related variables and a high predictive value is the Holy Grail of empirical science. The model of interest is a new application and extension of an already existing model rather than a completely new model. We will present an argument that Baumeister's strength model of self-control,[22–24] revisited from the perspective of exercise psychology, furnishes an adequate theoretical framework to explain and predict effects of acute as well as chronic exercise on self-regulation tasks.

This model, originating from social psychology, resembles classical resource models from cognitive psychology because the main assumption considers that individuals have a limited amount of energetic resources to cope with self-regulation problems. However, it differs from classical models because it is more focused on the delayed consequences of resource depletion on a subsequent self-regulation task than the immediate consequences of dividing resources to perform two tasks at once. We will see later in this article that this specificity of the strength model of self-control opens new perspectives in the comprehension of the exercise-cognition relationship.

The article is divided into six sections including this introductive first section. In Section 2, we present Baumeister's strength model of self-control and its extensions and make a short comparative analysis of this model with more classical cognitive-energetic models. In Section 3, we synthesize the main results concerning the effects of self-control depletion tasks on exercise. In Section 4, we consider some methodological issues related to the study of the exercise−self-regulation relationship, distinguish two types of exercises based upon requirements for self-control resources, summarize the existing data showing an effect of exercise on self-regulation task, and present briefly both the current explanatory mechanisms underlying these effects and the alternative explanations in the framework of the strength model of self-control. In Section 5, we consider the possibility to increase the capacity in self-control resources by exercising and cognitive training. Finally, in Section 6, we present some arguments for the interest to strengthen self-control resources in order to increase short-term and long-term adherence processes.

2. The strength model of self-control

Among existing models of self-regulation,[25–28] the most currently adapted to health and exercise psychology is Baumeister's strength model of self-control.[29] Self-control is viewed as a limited resource that is depleted when people engage in behaviors that require self-regulation.[22,29] Self-regulation refers to a psychological function and is defined as "*any efforts undertaken to alter one's behavior*",[30] whereas self-control, colloquially known as willpower, is related to a mental capacity (i.e., a cognitive resource) and defined as "*the exertion of control over the self by the self (…) when a person attempts to change the way he or she would otherwise think, feel, or behave*".[22] As suggested by Baumeister,[31] self-regulation is linked to executive functions but would be only solicited in tasks which require overriding or inhibiting competing behaviors, desires or emotions. Consequently, we can consider that self-regulation and executive functions share effort as a resource to consciously alter behavior (e.g., restraining impulses and resisting temptations) or to successfully perform stressful and/or attention-demanding tasks. In other words, we can consider that mental effort is to executive functions what self-control is to self-regulation. Indeed, the effort mechanism that is a part of Sanders' and Hockey's models presents high similitudes with Baumeister's self-control mechanism.

Baumeister's model conceives self-control as a limited and global resource and explains conditions in which it may fail. Depletion of self-control resources in one domain leads to self-regulatory failure in others. Indeed, the strength model of self-control considers different domains or spheres of self-regulation. A meta-analysis carried out by Hagger et al.[24] reported seven domains in which consequences of self-control depletion had been studied: control of thoughts, control of emotions, control of attention, control of impulses, cognitive performance, choice and volition, and social processing. A possible eighth sphere of self-regulation could be added to this list and studied in the field of exercise psychology: control of effort during exercise.

Baumeister and Vohs[32] identified four main requirements for effective self-regulation: (1) standards, (2) self-monitoring, (3) willpower, and (4) motivation. First, situations and tasks that require self-regulation must be determined by a clear and well-defined standard (i.e., goal, norm, or value). Second, self-monitoring involves comparing the relevant aspect of the self (e.g., desire to regularly practice physical activity although currently sedentary) to the standard (e.g., following the WHO recommendations concerning physical activity). This ability requires evaluating progress toward achieving the standard. Third, changing the self is difficult and requires a capacity-limited resource named self-control or willpower. Following the comparison with the standard, self-control capacity leads either to change the self in order to bring it up to the standard or confirming that it has now been brought into line. Finally,