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The effects of acute stress on core executive functions: A meta-analysis and comparison with cortisol☆

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ABSTRACT

Core executive functions such as working memory, inhibition, and cognitive flexibility are integral to daily life. A growing body of research has suggested that acute stress may impair core executive functions. However, there are a number of inconsistencies in the literature, leading to uncertainty about how or even if acute stress influences core executive functions. We addressed this by conducting a meta-analysis of acute stress effects on working memory, inhibition, and cognitive flexibility. We found that stress impaired working memory and cognitive flexibility, whereas it had nuanced effects on inhibition. Many of these effects were moderated by other variables, such as sex. In addition, we compared effects of acute stress on core executive functions to effects of cortisol administration and found some striking differences. Our findings indicate that stress works through mechanisms aside from or in addition to cortisol to produce a state characterized by more reactive processing of salient stimuli but greater control over actions. We conclude by highlighting some important future directions for stress and executive function research.

Contents

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1. Introduction

Intuitively, most of us believe that stress usually impairs our cognitive abilities. Intuition often fails us, though. As such, developing a scientific understanding of exactly how stress influences cognitive processes is of paramount importance given the ubiquity of stress in most peoples' daily lives (Cohen and Janicki-Deverts, 2012) and the importance of cognition in quality of life (Diamond, 2013). Moreover, what work has been done examining stress effects on cognition has often yielded counterintuitive results. That is, although there are clear cases in which stress disrupts some aspects of cognition there are others in which it clearly benefits cognitive processes. For example, stress generally impairs long term memory retrieval (Gagnon and Wagner, 2016), whereas it can enhance memory encoding (Wiemers et al., 2013), memory retention (Cahill et al., 2003), and decision-making (Shields et al., 2016a). Moreover, although there are many reports of stress impairing executive functions (Alexander et al., 2007; Schoofs et al., 2009), there are other cases in which stress has no effect on executive functions (Quinn and Joormann, 2015), and yet others show that stress can even improve them (Schwabe et al., 2013). Thus, there is a current need for taking a systematic and fine-grained approach to studying stress effects on individual cognitive processes in order to best understand how exactly stress influences cognition.

1.1. Executive function

One particularly important set of cognitive processes that may be influenced by stress is subsumed under the umbrella term *executive function*, which refers to the higher cognitive processes that enable planning, forethought, and goal-directed action (Diamond, 2013; Suchy, 2009; Williams et al., 2009). According to an influential theory, performance on complex executive tasks is underpinned by three core executive functions (Diamond, 2013; Miyake et al., 2000). The first of these, *working memory*, refers to the ability to keep information in mind and update/integrate current contents with new information (*e.g.*, in the verbal *n*-back task, participants must continually report if the letter/number they are hearing is the same letter/number they heard *n* letters/numbers ago). The second of these component processes, *inhibition*, refers to the ability to inhibit thoughts or prepotent responses in order to selectively attend to task-relevant information and engage in goal-directed rather than habitual actions (*e.g.*, in the stop-signal task, participants learn to respond in a particular way to stimuli but on a small proportion of trials they are signaled to withhold that response). The third component process underpinning executive function task performance is *cognitive flexibility*, which refers to the ability to flexibly shift between cognitive rules or modes of thought (*e.g.*, in the Wisconsin card sorting test, participants categorize cards according to rules that switch throughout the task, requiring participants to switch to a new rule rather than perseverating on an old and incorrect rule).

Although there is some disagreement about the specific tasks that best represent different executive functions, strong evidence that these executive functions are distinct comes from factor analyses (Friedman and Miyake, 2004; Miyake et al., 2001, 2000), brain lesions (Tsuchida and Fellows, 2013), and neuroimaging studies (Smolker et al., 2015). For example, factor analyses indicate that although the latent factors of inhibition, working memory, and cognitive flexibility are related, they are clearly separable as model fit suffers dramatically if one or more of these latent factors are excluded from the model (Miyake et al., 2000). Similarly, although the prefrontal cortex supports each executive function (Yuan and Raz, 2014), performance on executive function tasks can be distinguished at a more fine-grained level of analysis. For example, damage to the left ventrolateral prefrontal cortex is associated with impairments in inhibition and cognitive flexibility, whereas working memory impairments are associated with damage to various areas of the prefrontal cortex but notably not the ventrolateral prefrontal cortex (Tsuchida and Fellows, 2013). Likewise, in healthy young adults, working memory is associated with dorsolateral prefrontal cortex gray matter volume, whereas cognitive flexibility is associated with ventrolateral prefrontal cortex gray matter volume (Smolker et al., 2015). Similarly, functional activation in the left posterior superior parietal cortex and bilateral extrastriate cortex is greater when utilizing cognitive flexibility than when utilizing inhibition, whereas functional activation in the right superior parietal cortex, premotor cortex, and frontopolar cortex is greater when utilizing inhibition than when utilizing cognitive flexibility (Sylvester et al., 2003). Thus, at a neural level, both inhibition and cognitive flexibility appear to rely on the ventrolateral prefrontal cortex but differ in their recruitment of additional regions such as the parietal cortex; by contrast, working memory appears to rely on brain regions other than the ventrolateral prefrontal cortex, such as the dorsolateral prefrontal cortex. In sum, given that each executive function is at least somewhat separable from the other, any attempt to understand how stress might influence executive function should elucidate how stress influences the component cognitive processes underpinning complex executive function task performance.