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# Successful voluntary recruitment of cognitive control under acute stress

Franziska Plessow [a,b,c,*], Susann Schade [a], Clemens Kirschbaum [a], Rico Fischer [a,d]

[a] Department of Psychology, Technische Universität Dresden, Dresden, Germany
[b] Neuroendocrine Unit, Massachusetts General Hospital, Boston, MA, USA
[c] Department of Medicine, Harvard Medical School, Boston, MA, USA
[d] Department of Psychology, University of Greifswald, Greifswald, Germany

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ABSTRACT

In highly complex task situations (dual tasking) stressed individuals have been shown to adapt the most resource-efficient task processing strategy, accepting costs of performance. We argue that an interpretation of this behavior in terms of a stress-induced impairment of cognitive control might be too simplified. In the present study, we therefore tested whether stressed individuals are still capable to up-regulate cognitive control when instructed to adapt more resource-intensive strategies, enabling preservation of task performance. Fifty-six participants underwent either an established psychosocial stress induction protocol (Trier Social Stress Test) or a standardized control intervention. Afterwards, all participants performed a dual task in which task prioritization was systematically varied, calling for the adoption of different task processing strategies that require more or less voluntary top-down control. Although individuals of the stress group showed a pronounced stress response, as indicated by salivary cortisol, they were able to recruit more resources and to engage more voluntary top-down control when instructed to do so. This finding suggests an adaptive nature of control regulation under acute stress that reflects a compensatory capacity with the potential to account for some of the observed ostensible impairments of cognitive control. Our finding calls for careful empirical examination of whether stressed individuals *cannot* or *do not* recruit certain cognitive control functions in a given situation that will inform novel interventions to optimize performance in high-stress environments.



## 1. Introduction

In modern society, increasingly high-tech 24/7 lifestyles present two novel major challenges. Firstly, levels of stress increase, causing tremendous costs to occupational health and the economy. Secondly, the increasing complexity of technology has resulted in higher demands on voluntary top-down control to manage complex multitasking in technical environments, such as lifestyles requiring frequent human-machine interactions. The simultaneous impact of both developments creates an unprecedented challenge for the individual. Empowering individuals to effectively live up to those new standards will become a major research goal in maintaining health and productivity of societies over the next decades. The first step toward achieving this goal is to gain a profound understanding of the limitations and potential of the stressed human mind when it comes to implementing voluntary top-down control; the essential cognitive mechanisms underlying complex behavior and decision-making processes by adaptively regulating actions, thoughts, and emotions (Braver, 2012; Hofmann, Schmeichel, & Baddeley, 2012; Miller & Cohen, 2001; Shallice & Burgess, 1996).

Currently, the most common view on how stress affects cognitive control converges on the assumption that acute uncontrollable stress impairs prefrontal cortex (PFC)-dependent cognitive functions, including cognitive control (Arnsten, 2009; Shansky & Lipps, 2013; Shields, Sazma, & Yonelinas, 2016). As a consequence, control of behavior, thoughts, and emotions switches from top-down control to bottom-up regulated processing based on more primitive parts of the brain (Arnsten, 2009) and a stronger recourse to reflex-like "habit" memory (Schwabe, 2013; Schwabe, Wolf, & Oitzl, 2010). Recent research indeed indicates a detrimental impact of acute stress experience on cognitive control, which has been mostly related to resource depletion under acute stress (e.g., Alexander, Hillier, Smith, Tivarus, & Beversdorf, 2007; Alomari, Fernandez, Banks, Acosta, & Tartar, 2015; Bogdanov & Schwabe, 2016; Liston, McEwen, & Casey, 2009; Plessow, Kiesel, & Kirschbaum, 2012; Sanger, Bechtold, Schoofs, Blaszkewicz, & Wascher, 2014). This resource binding has been proposed on a

* Corresponding author at: Neuroendocrine Unit, Massachusetts General Hospital, 55 Fruit Street BUL457B, Boston, MA 02114, USA.
*E-mail address:* fplessow@mgh.harvard.edu (F. Plessow).

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cognitive level for stress-related information processing and coping mechanisms (Robert & Hockey, 1997) but has also received support from neuroimaging studies demonstrating reduced neural activity in the frontoparietal network underlying cognitive control when investigated under stress (e.g., Liston et al., 2009; Ossewaarde et al., 2011; Qin, Hermans, van Marle, Luo, & Fernandez, 2009).

However, a strict perspective of a loss of voluntary top-down control under acute stress extradites individuals to a mere reliance on established automatized action procedures to cope with novel and fast-changing characteristics of high-demanding environments. Stress would therefore inevitably increase the risk of maladaptive and inadequate cognitive control functioning. This, in turn, would impair complex goal-directed behavior and decision-making processes and increase the susceptibility to self-control failures and impulsive behavior. Reliable top-down control seems too essential to allow individuals to shift their action control from voluntary top-down control to reflexive bottom-up guidance, especially in challenging situations. It can be hypothesized that the idea of a stress-induced down-regulation of cognitive control is overly simplified and might not capture the full picture. Supporting this assumption, we have demonstrated that compared to controls, stressed individuals displayed increased shielding of the relevant task goal that was applied even in conditions in which goal shielding was not indicated (Plessow, Fischer, Kirschbaum, & Goschke, 2011). Rather than impairing action control, acute stress resulted in a strategic *increase* of control engagement, which can be interpreted as a compensatory mechanism in response to stress experience (Easterbrook, 1959). The tonic character of the increased goal shielding led to a decrease in cognitive flexibility, replacing the more error-prone task processing strategy of a conflict-induced trial-to-trial adaptation of goal shielding. This clearly represents a stress-related reallocation of cognitive resources (Chajut & Algom, 2003; Kofman, Meiran, Greenberg, Balas, & Cohen, 2006) and a shift *within* PFC-mediated cognitive control strategies rather than a shift *away from* cognitive control.

A similar argument can be made for a shift from a more serial to a more parallel task processing mode in dual tasking under stress, as reflected in higher between-task interference (crosstalk; Plessow, Schade, Kirschbaum, & Fischer, 2012). Serial task processing has been claimed to be more efficient in terms of overall dual-task performance (Logan & Gordon, 2001; Miller, Ulrich, & Rolke, 2009) and reduced between-task interference (Lehle & Hübner, 2009). Similarly, the continuous sequential queuing of task component processing and the reduction of between-task interference are associated with increased cognitive control (Logan & Gordon, 2001; Meyer & Kieras, 1997; Sigman & Dehaene, 2006), strong involvement of the frontoparietal network (Dux, Ivanoff, Asplund, & Marois, 2006; Marois & Ivanoff, 2005; Schubert & Szameitat, 2003; Stelzel, Brandt, & Schubert, 2009; Tombu et al., 2011), and high levels of mental effort (indexed by increased levels in peripheral physiological measures and subjective effort ratings; Lehle, Steinhauser, & Hübner, 2009). A more parallel integrative task processing mode, on the other hand, has been shown to lead to larger overall costs in dual-task performance and increased between-task interference (Lehle & Hübner, 2009; Miller et al., 2009; Tombu & Jolicoeur, 2003) but is associated with reduced mental effort (Lehle et al., 2009). Under acute stress, individuals seem to sacrifice task processing efficiency (serial processing) in favor of adopting the most resource-saving task processing mode (parallel processing; for a similar discussion, see Steinhauser, Maier, & Hübner, 2007). This behavior is observed despite the fact that instructions at the beginning of the experiment emphasized to prioritize Task 1, which is best achieved by delaying Task 2 processing.

The adaptive nature of control regulation as a compensatory capacity under acute stress (Plessow et al., 2011) offers a new perspective on findings interpreted as stress-related impairments of cognitive control. It is crucial to differentiate whether they reflect the fact that stressed individuals *cannot* or *do not* recruit certain control competencies. If the first explanation is true, a shift away from strong serial task component queuing to more integrative task processing simply reflects a stress-induced impairment of cognitive control that necessitates this shift in task processing strategies. However, if the second hypothesis is correct, a stressed cognitive system makes a choice (irrespective of deliberation) between different possible task processing strategies, most likely favoring the adoption of the most parsimonious and resource-efficient task processing strategy (Plessow et al., 2011; Robert & Hockey, 1997).

In order to differentiate between these two possible explanations, it is essential to demonstrate that participants are able to recruit cognitive control under acute stress when required to do so. The aim of the present study was therefore to test whether participants exposed to an acute psychosocial stressor can voluntarily up- and down-regulate cognitive control to adopt different dual-task processing modes. We used the same dual-task paradigm of Plessow, Schade, et al. (2012) but introduced an instruction manipulation that was consistently repeated throughout the experiment. In alternating blocks, subjects were instructed to either follow a resource-saving simultaneous dual-task processing strategy (allowing for more integrative processing with increased between-task interference) or a resource-demanding sequential dual-task processing strategy (requiring serial task processing and sequential task component scheduling; see also Lehle & Hübner, 2009). Using this approach, Lehle and Hübner (2009) demonstrated that non-stressed individuals can voluntarily up- and down-regulate cognitive control (i.e., increase the amount of task shielding to reduce between-task interference) in dual tasks according to the instructions that are provided.

In the present study, acute stress was induced using a well-established psychosocial stress induction protocol (Trier Social Stress Test [TSST]; Kirschbaum, Pirke, & Hellhammer, 1993), proven to reliably trigger a physiological stress response in a controlled laboratory setting (Dickerson & Kemeny, 2004). In addition to the stress group, we tested a second sample of individuals who underwent a standardized control intervention closely resembling the TSST except for its stress-inducing features (Het, Rohleder, Schoofs, Kirschbaum, & Wolf, 2009).

In a first step and comparable to Plessow, Schade, et al. (2012), we aimed at demonstrating a strong physiological stress response for individuals exposed to the TSST. Second, and in contrast to Plessow, Schade, et al. (2012), we tested whether stressed individuals can alternatingly adopt and recruit different dual-task processing strategies, e.g., up-regulate cognitive control to preserve task performance when asked to do so. Two contradicting hypotheses can be formulated with respect to cognitive performance in the stress group[1]: (1) If acute stress impairs cognitive control processes of task shielding, stressed individuals will not be able to up-regulate cognitive control and thus fail in the adoption of more resource-demanding control strategies in blocks with sequential task processing requirements. In this scenario, we would expect between-task interference under serial task processing instructions to mirror the extent of between-task interference under parallel task processing instructions. (2) If acute stress does not impair cognitive control functions required for task shielding, stressed participants will be able to voluntarily recruit and alternate between different control strategies, successfully adopting the resource-consuming serial task

[1] Please note that the primary hypotheses did not depend on comparison between stress and non-stress groups but were instead directed at the stress group alone, i.e., whether stressed individuals are able to voluntarily adopt serial versus parallel dual-task processing modes.