



Editorial

Modes of executive function and their coordination: Introduction to the special section



The papers in this special section explore the variety of different modes of executive function that can be implemented, and the different possible manners in which these modes may be coordinated. While it is clear that prefrontal regions exert top-down control to modulate the processing and activation of posterior brain regions, they must do so in a multiplicity of situations that have varying demands and characteristics. As such, it is highly unlikely that such control is implemented in a uniform manner across such a variety of different situations. Moreover, while there are many well-recognized benefits of executive functioning for controlling thoughts, actions, and emotions, the variety of executive demands and complexities of executive functions raise the possibility of trade-offs, or unique benefits and costs, associated with different modes of executive function (Cohen, McClure, & Yu, 2007; Goschke, 2000). In this special issue, the contributors examine, both from theoretical and empirical viewpoints, some of the diverse modes of executive function and factors that influence when and how these modes are invoked. In addition, they consider what advantages, as well as disadvantages, are afforded by these different modes, and how they may be coordinated.

The special issue is divided into three main parts. The first three papers provide thought-provoking ideas on different modes of executive function and the conditions under which each will occur. Dixon et al. turn on its head the idea that brain regions involved in cognitive control and those traditionally referred to as the “default” network are mutually antagonistic. Rather, they argue that regions involved in cognitive control, most notably lateral prefrontal regions, are engaged whenever there is a high level of intentionality, meaning that processing is being guided or controlled. They argue that such intentionality may occur either for externally-directed or for internally-directed cognition. Externally-directed cognition involves processes such as selecting information in the environment relevant to the current task and tends to engage posterior sensory and attention regions. In contrast, internally-directed cognition, involving memory and self-related thought, tends to activate regions typically associated with the default network. They argue that these two systems are only antagonistic when both must share the resources of lateral prefrontal cortex because processing is intentional. In contrast, if either externally- or internally-directed cognition is occurring with low levels of intentionality, then externally and internally-directed cognition need not be mutually exclusive. In fact, they often co-occur in situations such as creative thinking. This framework helps to illustrate the interplay between executive and non-executive processes.

A similar point regarding this interplay between executive and non-executive processes is made by De Baene et al., who focus on

aspects of preparatory control that allow one to switch from one task to another. They argue that activation of goals by a strategy-dependent process is an executive operation supported by the lateral prefrontal cortex and the inferior parietal lobe, and can be indexed by an ERP signature of an early positive potential recorded over parietal and frontal regions. In contrast, they suggest that the activation of task rules is strategy-independent and relies on pre-supplementary motor area and superior parietal regions, and is indexed by later parietal and late frontal ERP components.

A third theoretical perspective on when cognitive control needs to be invoked and when it actually interferes with processing comes from Chrysikou et al., whose perspective relies heavily on work from developmental cognitive neuroscience. They propose in their matched filter hypothesis that the level of cognitive control employed needs to be suited to task characteristics. They argue that high levels of cognitive control are best suited for tasks that are explicit, rule-based, verbal and abstract, whereas high levels of cognitive control can actually be detrimental for tasks that are implicit, reward-based, non-verbal or intuitive. As such, certain abilities that are acquired during childhood, such as language, are actually harder to learn during adulthood because high levels of cognitive control are detrimental to, for example, learning implicit aspects of language acquisition. Such language acquisition is possible in childhood because frontal regions are not yet fully developed. What is common to all three of these perspectives is that while certain aspects of processing are better performed when cognitive control is invoked, under other conditions, processing need not invoke the resources required for control, and control is not helpful or may even be counterproductive.

The next section, consisting of two papers, those by Blackwell et al. and by Peters et al., discuss the developmental trajectory of acquisition of cognitive control abilities. Both rightfully point out that executive abilities are not only affected by chronological age, but also individual differences in strategy or implementation even within individuals of the same age.

Blackwell et al. examine two groups of six-year-old children, those who show a developmentally more immature pattern of perseverating when they must switch task goals, and those who have already acquired the ability to flexibly switch between tasks. The children who have the more developmentally mature ability to switch are also better able to exert cognitive control when ignoring salient but irrelevant task information (in a Simon task). However, they are less able to inhibit responding on a stop-signal task compared to children who perseverate in invoking an old task rule. These findings suggest that as children develop, their ability to proactively maintain goals improves, leading to the benefits of

filtering out extraneous information and switching goals when instructed. However, such developments may also have associated costs if children are not yet able to maintain two goals simultaneously. This inability impedes processing on the Stop-Signal task, in which the task rules change, requiring them to respond on some trials and to refrain from responding on others.

Peters et al. look at the executive processes involved in learning from feedback. They find with their task that four different strategies are invoked, which vary from low to high in how optimal each is for efficiently zeroing in on a solution. Interestingly, across each of their age groups from age 8 to young adulthood there is at least one individual who invokes each of the four different strategies. What increases with age is the proportion of individuals in the high optimal group. When examining neural activity, an optimal strategy was associated with activation in cognitive control regions such as the dorsolateral prefrontal cortex, and this variance was above and beyond effects of age on activation in cognitive control regions. Once again, there is evidence that the way cognitive control is invoked may show a general developmental pattern, but individual differences within that pattern are significant. Moreover, this study illustrates that the neural substrates involved in patterns of developmental change can be separable from those involved in individual variation.

The next set of papers discusses links between dopaminergic function and modes of executive function. In their computational modeling of task-switching abilities, Herd et al. provide evidence that both the computations and likely underlying neural systems that support the on-line maintenance of goals may be at odds with those that enable the ability to switch between tasks. They argue that recurrent activity in the prefrontal cortex, supported by tonic levels of dopamine, enables the stable representation of task goals, while dopaminergic function of the basal ganglia works to gate the information held in working memory by the prefrontal cortex. If dopamine levels are high, goals are maintained too strongly, and task-switching abilities are compromised.

The next two papers examine the role of dopamine in executive function through experimental manipulations. Aarts et al. examine task-switching ability in individuals with Parkinson's disease, which is characterized by decreased levels of dopamine in the basal ganglia. They show that when dopaminergic function is increased in individuals with Parkinson's disease through medication, increases in brain activation, as measured by the BOLD response of fMRI, in the dorsal striatum predict better task-switching ability. These benefits are distinct from costs observed in reward-related processing that affect the ventral striatum. Colzato et al. discuss work in which they augmented baseline dopamine levels in neurologically-normal individuals through the administration of tyrosine. Compared to placebo, individuals who have had tyrosine supplementation showed an increased ability to exert inhibitory control in a stop-signal task, but no change in basic response execution abilities, illustrating a specific effect on cognitive control. These three papers provide both a strong theoretical framework as well as empirical findings that are

consistent with other work suggesting an important role of dopaminergic function in executive processes.

To wrap up the issue, Goschke and Bolt provide an overview of how executive function and emotional and motivational processing may interact, considering at the same time the role of dopamine in executive function. They focus on the trade-off or control dilemma between goal maintenance (stability) and task switching (flexibility), similar to that modeled by Herd et al. Goschke and Bolt argue that positive affect is associated with more open and adaptable changes in behavior (i.e. flexibility). However, this mode has a potential cost of decreased stability of goal maintenance that can result in distractibility. In contrast, when there is motivation towards rewarding stimuli or situations, which is supported by dopaminergic function, goal maintenance increases as to focus on the possibility of receiving a reward. This mode has a potential cost of overly rigid goal maintenance that can result in perseveration. Thus, they propose that positive affect and reward processing interact with executive function in somewhat distinct manners.

In sum, the papers in this special issue highlight the complexity of when and how executive functions are invoked, and the interplay between executive and non-executive processes, which sometimes are supported by overlapping but in other cases by distinct brain regions. It is this rich interplay that allows for the complexity of human thought and action. These papers also point toward important directions for future work, in considering distinct modes of executive function, how these modes and non-executive processes are coordinated given their unique costs and benefits, and how taking these processes into account can advance an understanding of developing and mature behaviors and associated neural systems.

References

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