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Executive function depletion in children and its impact on theory of mind

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ABSTRACT

The current studies provide an experimental, rather than correlational, method for testing hypotheses about the role of executive function (EF) in conceptual development. Previous research has established that adults' tendency to deploy EF can be temporarily diminished by use. Exercising self-control in one context decreases adults' performance on other EF demanding tasks immediately thereafter. Using two different depletion methods, Experiments 1 and 3 extend this finding to preschool-aged children. Experiments 2 and 4 make use of these EF depletion methods to elucidate the role of EF in children's theory of mind reasoning. Experiment 2 shows that EF depletion affects 5-year-olds' ability to predict another's behavior on the basis of that person's false belief, and Experiment 4 shows that this negative effect of depletion extends to 4- and 5-year-olds' ability to explain others' behavior on the basis of their false beliefs. These findings provide direct evidence that EF is required for the expression of an understanding of others' false beliefs across a variety of task demands, even in children who clearly have the capacity to construct such representations. We suggest ways in which depletion may be used as a tool for further investigating the role of executive function in cognitive development.

1. Introduction

The hypothesis of a 'central executive' or a set of executive functions (EF) was introduced by neuropsychologists as they sought to explain the damage done by lesions to the frontal lobe, which often result in subtle but devastating effects on the ability to plan and make everyday decisions (Shallice & Burgess, 1991). Research on healthy adults has helped psychologists to dissect EF into partially separable component processes, including inhibition, working memory, and task- or set-switching abilities. These processes often operate together to allow for the execution of complex cognitive processes and behavior (Miyake et al., 2000).

1.1. EF and cognitive development

Recently, developmental research has begun to show just how crucial EF resources are for learning. Measures of EF correlate with teachers' assessments of 'school readiness' and with students' academic performance (Blair & Razza, 2007). Moreover, EF skill correlates with children's performance on tests of understanding in both academic and non-academic domains, including theory of mind, math, biology, and physical reasoning (Baker, Gjersoe, Sibielska-Woch, Leslie, & Hood, 2011; Bull & Scerif, 2001; Carlson & Moses, 2001; Zaitchik, Iqbal, & Carey, 2013). These correlations persist even when age and verbal intelligence are controlled for, suggesting that EF may have a direct relationship with knowledge acquisition and use.

Such findings have spurred psychologists and educators to begin to design EF training programs for classrooms (e.g. Diamond, Barnett, Thomas, & Munro, 2007), but as they do so it would be useful to have a clearer picture of *how* EF relates to the acquisition and use of new knowledge. Though the correlational research referenced above is persuasive regarding the existence of a relationship, it cannot tell us what role EF plays in learning or even, in some cases, what the direction of causation is. Even under the assumption that the maturation of EF plays a role in driving conceptual development, a correlation between EF and performance in any particular domain is compatible with a role for EF in either the *construction* of a particular body of knowledge or the selective application and *expression* of that knowledge once it has been acquired, or both. Unfortunately, we currently lack experimental methods we can use to directly test the role of EF in children's learning and reasoning processes.

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The best test of an expression account of the correlations between measures of EF and measures of conceptual understanding would be to experimentally manipulate the EF of a group of participants who normally show evidence of having the knowledge in question. Evidence that participants randomly assigned to a low EF condition perform worse on relevant tasks than participants in a high EF condition would show that, even after the acquisition of the knowledge in question, EF capacity affects its use. It is likely that the reason this approach has not been taken in the past is that developmental researchers have viewed EF as a stable trait or skill that, while trainable over long periods of time, is not malleable within the scope of a single experimental session. This assumption turns out to be false. Recent research with adults has shown that EF can be temporarily depleted with use. Participants who complete a task involving heavy EF demands do worse on a subsequent EF-laden task than participants who begin with an easy task that places minimal demands on EF (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Schmeichel, 2007; for reviews see Hagger, Wood, Stiff, & Chatzisarantis, 2010; Hofmann, Schmeichel, & Baddeley, 2012). Here we adapt this experimental paradigm for use with children and then to use it to test whether EF is needed for preschoolers' expression of their theory of mind.

1.2. EF and theory of mind

Theory of mind refers to the lens through which human adults view one another, explaining behavior by appealing to mental states like thoughts, feelings, and goals. Many of the social cognitive capacities that comprise a full theory of mind begin to emerge in infancy, but one central component – an explicit understanding of beliefs – appears much later, around 3 or 4 years of age (Wellman, Cross, & Watson, 2001; Wimmer & Perner, 1983). This is a striking delay, and the fact that preschoolers are also undergoing substantial improvements in multiple areas of EF has not gone unnoticed. A number of studies have demonstrated a strong correlation between young children's ability to reason about beliefs and their EF skills (e.g. Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Hughes, 1998). This research has inspired both expression and construction accounts of how EF maturation may lead to more successful belief reasoning, as well as additional theories questioning whether causation may run in the opposite direction (e.g. Perner & Lang, 1999) or be related to a third, unmeasured variable such as hierarchical reasoning abilities (e.g., Frye, Zelazo, & Palfai, 1995) or the maturation of dopaminergic systems in the frontal lobes, which in turn contributes to the maturation of both EF and theory of mind, independently (Lackner, Bowman, & Sabbagh, 2010).

The expression hypothesis is partly motivated by an analysis of the task demands associated with preschool measures of theory of mind. Clear evidence of belief understanding often involves reasoning about beliefs that conflict with reality, because it is in these cases that belief-based and reality-based predictions diverge (Dennett, 1978). For example, false belief tasks feature a protagonist who is mistaken about some fact, such as the location of a toy, and require the participant to predict the protagonist's thoughts or actions on the basis of this false belief. This methodological constraint means that passing tests of belief understanding requires more than just a functioning concept of beliefs (Bloom & German, 2000). Even assuming they represent the protagonist's belief, children must maintain both this representation and that of the actual location of the toy to follow the story and may have to inhibit the latter representation in order to base a judgment on the former. Moreover, both superficial aspects of the task, such as the need to point to an empty location when a salient object is nearby, and intrinsic aspects, such as the need to select between candidate representations of another's beliefs, may place further demands on inhibitory control (Carlson, Moses, & Hix, 1998; Leslie & Polizzi, 1998). Given such demands, it seems likely that canonical theory of mind tasks draw directly on main components of EF, including working memory and inhibitory control, and young preschoolers may simply lack the relevant EF to succeed. Indeed, when EF demands are increased, older children and even adults become more likely to fail tests of belief understanding (German & Hehman, 2006; Leslie, German, & Polizzi, 2005).

In fact, some researchers argue that the EF demands of preschool theory of mind tasks are the *only* thing masking an understanding of beliefs, even false beliefs, that is present from infancy (e.g. Leslie, 1994). Many recent studies show that even infants implicitly predict the actions of other agents on the basis of the information available to those agents, rather than on the basis of current reality (e.g. Onishi & Baillargeon, 2005; Song, Onishi, Baillargeon, & Fisher, 2008; Surian, Caldi, & Sperber, 2007; for a review see Baillargeon, Scott, & He, 2010). To the extent that these findings reflect a rich understanding of beliefs present from the second year of life on, there is no need for preschoolers to construct a new understanding of beliefs and thus no construction process for EF to play a role in. Researchers holding this point of view conclude that the correlations between EF and preschool theory of mind tasks reflect the EF demands of those tasks alone (the "expression alone" hypothesis; Kovács, 2009; Southgate, Senju, & Csibra, 2007). It is important to note, however, that not all expression accounts are mutually exclusive with construction accounts of theory of mind development or of the EF-Theory of Mind relationship. They merely argue that whenever the relevant understanding of beliefs does arise, it may fail to be expressed if EF skills are insufficient to meet the specific task demands of the probe for understanding.

Here we seek evidence in support of the basic hypothesis that the preschool measures of false belief understanding necessarily draw on executive function. We return in the general discussion to the stronger hypothesis that the developmental changes on theory of mind tasks observed in the preschool years may reflect improvements in EF *alone*.

Although the *prima facie* argument for a necessary role of EF in the expression of an understanding of false beliefs is compelling, there is no unequivocal evidence that EF is required to perform well on tests of false belief understanding. The observed developmental correlation between EF and belief understanding is obviously compatible with this hypothesis, but it is also compatible with other explanations, (e.g. Benson, Sabbagh, Carlson, & Zelazo, 2013; Frye et al., 1995; Lackner et al., 2010; Moses, 2001; Perner & Lang, 1999). Studies that attempt to reduce the EF skills required to pass tests of belief understanding by making reality less salient or by eliciting fewer prepotent responses often find better performance amongst 3-year-old children (e.g. Carlson et al., 1998; Wellman & Bartsch, 1988), but task changes intended to lessen EF demands may introduce other differences as well. Training studies aimed at improving children's EF skills also benefit belief understanding (Kloo & Perner, 2003), but such studies often take place over the course of several weeks or months, allowing for the possibility that improved EF skills contribute to the development of belief understanding in ways that go beyond greater capacity for expression.

Other findings challenge the view that an existing understanding of beliefs is simply unmasked as soon as preschoolers develop the requisite level of EF ability. For example, cross-cultural research has found that while Chinese preschoolers outperform American preschoolers on measures of EF they do no better on tests of belief understanding, and microgenetic research has shown that improvements in EF do not immediately extend to improvements in belief understanding (Sabbagh, Xu, Carlson, Moses, &