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A role for executive functions in explanatory understanding of the physical world

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ABSTRACT

Are executive functions needed *only* for the *expression* of an already present understanding of the physical world or they are needed for the *construction* of that understanding? We addressed this question in the context of Hood's (1995) tubes task. When asked to find a ball dropped down an opaque curved tube, 2- and 3-year-olds search *directly* below the place where they have seen the ball dropped, rather than at the bottom of the *tube* into which the ball was dropped. Instructions about the role of the tubes, but not visual feedback about the correct location of the ball, help children improve on this task. We found that children who scored higher on specific EF measures and on performance IQ showed greater improvement on the tubes task after receiving instructions about the role of the tubes than did children with lower EFs and performance IQ. These results suggest that EFs are needed for the *construction* of new explanatory understanding of the physical world.

1. Introduction

Our conceptual understanding of the world undergoes profound changes in early childhood, due to both the addition of new factual knowledge to our existing theories about the world and, more rarely, overall structural changes in those theories. The timing and nature of concept addition and change vary substantially from one domain to the next. Therefore, conceptual development must first be examined within the domain of a particular theory. However, a full understanding of conceptual development also requires investigating the role of *general* cognitive capacities in learning *across* different domains. Here we investigate the contribution of executive functions (EFs) to preschool children's ability to change their understanding of the physical world.

EFs are a suite of abilities that include holding and flexibly manipulating thoughts in mind, maintaining a particular goal while inhibiting various types of endogenous and exogenous interference, and selecting appropriate responses. Three core EFs have been identified in the literature: (a) inhibition, (b) working memory, and (c) set shifting (Diamond, 2013; Miyake et al., 2000). These core EFs are in turn thought to underlie more complex cognitive reasoning skills, such as comprehension and consistency monitoring, the formation of abstract representations, and the construction and maintenance of the hierarchical rules that guide behavior (Diamond, 2013; Kharitonova & Munakata, 2011; Snyder & Munakata, 2010; Zelazo & Frye, 1997), and they are part of the construct of fluid IQ (Duncan, Burgess, & Emslie, 1995).

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EFs are certainly linked to learning in childhood, as they correlate with and predict academic achievement. EFs are more strongly associated with school readiness than is IQ, entry-level reading skills, or entry-level math skills (Blair & Razza, 2007; Diamond, Barnett, Thomas, & Munro, 2007; Morrison, Ponitz, & McClelland, 2010). Moreover, EFs maintain their importance throughout the school years; indeed, working memory and inhibition independently predict math and reading scores in every grade from preschool through high school (e.g., Blair & Razza, 2007; Gathercole, Tiffany, Briscoe, Thorn, & ALSPAC Team, 2005). There are many reasons this relationship might hold, including, possibly, that EFs are crucial for the acquisition of conceptual knowledge. The present paper begins to explore this possibility in the context of developing an understanding of the physical world, building on parallels with the much more fully explored case study of the relations between EFs and developing theory of mind (ToM).

1.1. Case study of relations between EFs and developing ToM

A large literature on early developing ToM supports five generalizations. First, young infants have rich abstract representations of intentional agents. Infants distinguish self-moving objects from dispositionally inert ones, and reason about actions of self-moving objects in terms of those objects' goals and perceptual states (Gergely & Csibra, 2003; Luo & Baillargeon, 2007; Luo & Johnson, 2009; Woodward, 1998). By the second year of life at the latest, infants predict these agents' future actions in terms of the information those other agents have had access to, as if tracking their epistemic states (Kovács, Téglás, & Endress, 2010; Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007; see Carey, 2009 for review). A second generalization is that despite such representations being attested in infancy, when preschool children are asked to explicitly access these representations they robustly fail to manifest knowledge with the same content. The striking failures of children under age 4 on explicit false belief tasks are well known (Wellman, Cross, & Watson, 2001), and are interrelated with failures at articulating sources of knowledge (Gopnik & Graff, 1988; O'Neill & Gopnik, 1991), the appearance/reality distinction (Flavell, Green, & Flavell, 1986; Gopnik & Astington, 1988), and Level II perspective taking (Flavell, Everett, Croft, & Flavell, 1981; Flavell, Green, & Flavell, 1989; Moll & Meltzoff, 2011).

There are two broad, possible accounts of preschoolers' failures in the face of infants' success. One posits *continuity* from infancy throughout development in representational content, and explains preschoolers' failure in terms of performance demands in the preschool tests that are lacking in the infant tests. In particular, it has been suggested that the preschool tasks make executive function (EF) demands that the infant tasks do not, frequently because the preschool tasks are designed to pit correct answers against incorrect ones that align with good heuristic guides (e.g., people usually look for objects where they are because they usually have true beliefs about the objects' locations). Suppressing answers with this intuitive appeal plausibly draws upon children's inhibitory control. On this account, the developmental changes observed in the preschool years reflect known developmental advances in executive function, rather than changes in the representations that underlie reasoning about agents and their mental states. The third generalization from the ToM literature is that, indeed, measures of EF predict performance on explicit ToM tasks in the preschool years. A recent meta-analysis of data from one hundred studies conducted over the last 20 years in 15 different countries included almost 10,000 3–6-year-old participants and confirmed a significant relationship between performance on preschool false belief tasks and EFs, especially measures of conflict inhibition, even after controlling for age and verbal ability (Devine & Hughes, 2014). Finally, as continuity theory would predict, temporary depletion of EFs leads to decreased performance on false-belief tasks in 4- and 5-year-olds (Powell & Carey, 2016).

While not denying that EFs are likely critical to performance on tests of ToM, and that EF development may thus account for some of the improvements on tests of ToM understanding with age (Moses, 2001), the *fourth* generalization from the ToM literature is that there is *also* learning-driven change within the domain-specific representations and computations children bring to the tasks. That is, ToM development requires *learning/construction* of new representational resources during the preschool years. Performance on a variety of preschool ToM tasks is influenced by exposure to input illustrating the link between thoughts and behaviors, including input from explicit training (Appleton & Reddy, 1996; Slaughter & Gopnik, 1996), amount of mental state language in parental input (Ruffman, Slade, & Crowe, 2002), and environmental factors such as having older siblings (Perner, Ruffman, & Leekam, 1994). Finally, Sabbagh, Xu, Carlson, Moses, and Lee (2006) compared over 100Chinese with over 100 American 3.5–4.5-year-olds on large batteries of EF measures and ToM measures. In this sample, the Chinese children were a full 6 months ahead of the American children on all of the EF measures, but the two populations were identical in their performance on the ToM tasks. Thus, superior EFs are not sufficient for superior performance on ToM tasks. This result undermines the claim that the maturation of EFs can completely explain the developmental changes on performance on ToM tasks, contrary to the continuity hypothesis. Some learning or construction specific to ToM is also implicated in the observed developmental changes in the preschool years.

EFs may be implicated, as suggested above, in the *expression* of conceptual understanding in the context of a particular task. Researchers who accept the continuity assumption hold that the development of the capacity to *express* the innate knowledge is the *full* explanation of the developmental changes observed in the preschool years on the explicit tasks, and also the *full* explanation of the correlations between measures of young children's EF and their performance on the explicit tasks. We call this the *expression alone* hypothesis. Contrary to the *expression alone* hypothesis, the *fifth* generalization from the ToM literature is that EFs are drawn upon by the learning/construction mechanisms that underlie change in ToM in the preschool years. One source of evidence for this generalization derives from longitudinal data, which show that variation in early measurements of EFs predict later performance on ToM tasks rather (or more) than the reverse (Carlson, Mandell, &