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Evidencing the developmental shift from reactive to proactive control in early childhood and its relationship to working memory

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ABSTRACT

As they age, children tend to get more effective at regulating their behavior in complex situations; this improvement in cognitive control is often interpreted as a shift from predominantly reactive control to proactive control. There are three issues with this interpretation. First, hard evidence is lacking that younger children actually rely on reactive control. Second, the precise age range when such a shift would occur is still unclear. Third, the reasons for this shift have not been explored. In the current study, we tested the hypothesis that children under 5 years of age do rely on reactive control, that they progressively shift to proactive control with age, and that this shift is related to increases in working memory capacity (which is necessary for proactive control). Children aged 4 to 7 years performed a cognitive control task, the AX-CPT (AX–Continuous Performance Task), as well as verbal and visuospatial working memory tasks. Using the paradigmatic AX-CPT in this age range allowed us to observe, for the first time, an actual reactive pattern in children under 5 years of age. There was a progressive shift from reactive control to proactive control, with an estimated turning point between 5 and 6 years of age. The effect of age on proactive control was essentially shared with working memory capacity, confirming that these two cognitive processes develop in tandem.

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Introduction

As children age, they get progressively more adept at organizing their actions, inhibiting inappropriate responses, and generally controlling their behavior. This progress is defined as improvement in cognitive control, or the ability to regulate one's behavior to achieve a particular goal (e.g., Miller & Cohen, 2001). Increases in cognitive control efficiency have been widely documented throughout childhood and until adolescence (see Diamond, 2013, for a review); most of the literature has focused on the executive functions through which cognitive control is exerted—such as inhibition, shifting, and updating—and on age-related increases in the efficacy of these executive functions (e.g., Diamond, 2013; Garon, Bryson, & Smith, 2008; Morra, Panesi, Traverso, & Usai, 2018). However, developmental improvements in cognitive control can be viewed not only as quantitative but also as qualitative (Chevalier, 2015).

A number of authors have proposed that age-related increases in cognitive control ability can be described as a shift between two cognitive control strategies: reactive control and proactive control (e.g., Brahmbhatt, White, & Barch, 2010; Chatham, Frank, & Munakata, 2009; Chevalier, Martis, Curran, & Munakata, 2015; Lorsbach & Reimer, 2008; Lucenet & Blaye, 2014; Munakata, Snyder, & Chatham, 2012). In this view, younger children would rely primarily on reactive control, which involves waiting for a control-demanding event to occur and then implementing cognitive control as a late correction mechanism (see Braver, 2012; Braver, Gray, & Burgess, 2007). Conversely, older children would tend to use proactive control, an anticipatory mechanism that involves actively maintaining goal-relevant information in working memory so as to optimally orient behavior when the event occurs. Proactive control places more demands on working memory, but it is generally more effective, which would explain the better cognitive control performance of older children. The developmental shift from one mechanism to the other would presumably occur at around 5 or 6 years of age (e.g., Blackwell & Munakata, 2014; Chevalier, 2015; Lucenet & Blaye, 2014).

This account of development, framed within the dual mechanisms of control account (Braver, 2012; Braver et al., 2007), offers a powerful framework to interpret age-related improvements in cognitive control in that it allows for more fine-grained hypotheses than purely quantitative differences in control performance. Critically, it also offers a straightforward way to test these hypotheses by using a specific experimental paradigm, the AX-CPT (AX–Continuous Performance Task; Servan-Schreiber, Cohen, & Steingard, 1996; see also Braver et al., 2007). The AX-CPT was designed specifically to assess whether participants are actively maintaining goal-relevant information in working memory to prepare a response in advance and has been used in the vast majority of studies on reactive and proactive control (Braver, 2012; Braver et al., 2007).

In the AX-CPT, participants are confronted with sequences of cue and probe letters; they are required to respond positively to the probe letter only if it is an X and if the preceding cue was an A (AX sequence). Due to the large proportion of AX trials, participants who use proactive control tend to prepare a target response when the cue is an A, which elicits high error rates and very slow response times when the probe letter happens to be something other than an X (AY trials). Conversely, these participants can answer quickly and accurately by preparing a nontarget response on trials where the cue is a letter other than A even if it is followed by an X (BX trials). The opposite pattern is observed for participants who use reactive control; not preparing a target response in advance elicits relatively fast response times and few errors on AY trials, but the X probe tends to lure them into incorrectly making a target response on BX trials. The AX-CPT has been used in many studies, repeatedly showing that young adults rely on proactive control (Braver et al., 2007), whereas healthy older adults demonstrate a typical reactive pattern with higher error rates on BX trials than on AY trials (Braver et al., 2001; Braver, Satpute, Rush, Racine, & Barch, 2005; Paxton, Barch, Storandt, & Braver, 2006; Paxton, Barch, Racine, & Braver, 2008).

Because it is usually considered that ‘‘young children rely exclusively on reactive control” (Chevalier, 2015, p. 240; see Barker & Munakata, 2015, Blackwell & Munakata, 2014, or Munakata et al., 2012, for similar statements), and because the AX-CPT paradigm allows for a clear dissociation between the two mechanisms—as demonstrated in the context of normal aging—it seems like the