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A cross-sectional examination of response inhibition and working memory on the Stroop task

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ABSTRACT

The authors examined the association between working memory and response inhibition on the Stroop task using a cross-sectional, international sample of 5099 individuals (49.3% male) ages 10–30 (M = 17.04 years; SD = 5.9). Response inhibition was measured using a Stroop task that included "equal" and "unequal" blocks, during which the relative frequency of neutral and incongruent trials was manipulated. Competing stimuli in incongruent trials evinced inhibitory functioning, and having a lower proportion of incongruent trials (as in unequal blocks) placed higher demands on working memory. Results for accuracy indicated that age and working memory were independently associated with response inhibition. Age differences in response inhibition followed a curvilinear trajectory, with performance improving into early adulthood. Response inhibition was greatest among individuals with high working memory. For response time, age uniquely predicted response inhibition in unequal blocks. In equal blocks, age differences in response inhibition varied as a function of working memory, with age differences being least pronounced among individuals with high working memory. The implications of considering

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the association between response inhibition and working memory in the context of development are discussed.

1. Introduction

Adolescence is a period during which individuals must learn to navigate the increasing academic, social, and personal challenges they face. The ability to regulate behavior in favor of short- and long-term goals is one skill critical to mastering these challenges. Response inhibition and working memory are two executive processes that facilitate the ability to engage in such goal-directed behavior (DeLuca et al., 2003; Miller & Cohen, 2001). Research on adults indicates that response inhibition and working memory are psychologically distinct (e.g., Friedman & Miyake, 2004), yet functionally concomitant processes (Davidson, Amso, Anderson, & Diamond, 2006; Engle & Kane, 2004). Further, findings from some studies suggest that working memory facilitates response inhibition, such that individuals with high working memory demonstrate better performance on measures of response inhibition compared to individuals with low working memory (e.g., Egner & Hirsch, 2005; Long & Prat, 2002; Miller & Cohen, 2001; Weldon, Mushlin, Kim, & Sohn, 2013). However, such findings have not been replicated in samples that include adolescents. Understanding the relation between these two processes at a time during which they are still developing (e.g., Huizinga, Dolan, & van der Molen, 2006) affords a more comprehensive picture of adolescent executive functioning. In the present study, we explored whether interindividual variation in working memory contributed to variation in response inhibition across different periods of development, using a cross-sectional sample of individuals between the ages of 10 and 30 years.

Response inhibition − the ability to deliberately inhibit automatic or prepotent responses (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) – is part of a family of functionally similar inhibitory processes responsible for regulating thoughts and actions (Andrews-Hanna et al., 2011; Braver, 2012; Nigg, 2000). Cross-sectional studies of response inhibition indicate that inhibitory skills continue maturing into the early twenties (Davidson et al., 2006; Luna et al., 2001; Velanova, Wheeler, & Luna, 2009), with evidence to suggest that these age patterns are relatively consistent among individuals from various countries across the world (Steinberg et al., 2017). Thus, adolescence is a time when individuals are still developing self-regulatory abilities. Understanding how to facilitate inhibitory functioning during this sensitive period is important given the observed link between inhibitory function and academic achievement, occupational success, law-abiding behaviors, and psychological well-being (Moffitt, Poulton, & Caspi, 2013).

Working memory, which also continues maturing into the early twenties (DeLuca et al., 2003; Huizinga et al., 2006; Luciana, Conklin, Hooper, & Yarger, 2005), entails a set of cognitive processes responsible for the maintenance and manipulation of mentally represented information, as well as attentional control (Cowan et al., 2005; Kane, Bleckley, Conway, & Engle, 2001). In many conceptions of working memory, one of the crucial functions subserved by this system is the ability to hold current task goals in an active, quickly retrievable state (Engle, 2002) and it is this domain-general facet of working memory that has been linked to inhibitory functioning (Kane & Engle, 2003). Researchers who advocate this view postulate that successful response inhibition requires active maintenance of task goals in memory, which is achieved via efficient attentional control (Conway et al., 2005; Diamond, 2013; Engle & Kane, 2004; Kuo, Stokes, & Nobre, 2012; Miyake et al., 2000). From this vantage point, working memory *capacity* refers to the extent of an individual's ability to control attention and actively maintain goals in mind (Engle, 2002).

One task well-suited for examining response inhibition in relation to goal maintenance in working memory is the Stroop task (Kane & Engle, 2003; Long & Prat, 2002). On this standard measure of response inhibition (Friedman & Miyake, 2004; Huizinga et al., 2006; MacLeod, 1991; Nee, Wager, & Jonides, 2007; Veroude, Jolles, Croiset, & Krabbendamn, 2013), participants are asked to quickly and accurately indicate the color in which a word is displayed while ignoring its semantic meaning. On incongruent trials, a color word is displayed in an incongruent color (e.g., the word 'blue' displayed in green font), requiring that participants inhibit the prepotent response to read the word and instead respond on the basis of the word's physical color. Response inhibition and the resolution of cognitive conflict on incongruent trials not only requires efficient self-regulatory abilities, but also relies on attentional resources and the active maintenance, in working memory, of the task goal (Kane & Engle, 2002; Marsh et al., 2006).

Response inhibition on the Stroop task is typically operationalized as the *Stroop interference effect* (Stroop effect) (Adleman et al., 2002; Andrews-Hanna et al., 2011; Long & Prat, 2002; MacLeod, 1991; Morey et al., 2012) wherein performance on incongruent trials is compared to performance on some variation of a baseline trial (e.g., Huizinga et al., 2006) such as congruent trials, in which the color of the word matches its meaning (e.g., the word 'blue' displayed in the color blue) or neutral trials, where the presented word is a non-color word (e.g., 'math' displayed in any color). Lower accuracy scores and slower response times on incongruent trials relative to baseline trials reflect a larger Stroop effect. The Stroop effect is thought to result from cognitive conflict induced by incongruent trials (Kane & Engle, 2003), which is exacerbated by a deficient ability to resist interfering stimuli (Andrews-Hanna et al., 2011; Marsh et al., 2006). Additionally, researchers assert that the Stroop effect results from a failure to maintain the task goal in active memory (Kane & Engle, 2003). In effect, individuals with stronger inhibitory control and greater working memory capacity typically evince smaller Stroop effects compared to individuals with weak inhibitory control and low working memory (cf., Engle & Kane, 2004). Thus, performance on the Stroop task captures information about both inhibitory function and working memory capacity.

Considering that executive functions such as response inhibition and working memory are not fully developed during the adolescent years, one might expect that, compared to adults, adolescents evince a larger Stroop effect. However, cross-sectional examinations of Stroop performance yield inconsistent results, with findings from some studies indicating that adolescents evince a larger Stroop effect with respect to response time (Huizinga et al., 2006) and accuracy (Marsh et al., 2006) compared to adults, other