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Development of hot and cool executive function during the transition to adolescence

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ABSTRACT

This study examined the development of executive function (EF) in a typically developing sample from middle childhood to adolescence using a range of tasks varying in affective significance. A total of 102 participants between 8 and 15 years of age completed the Iowa Gambling Task, the Color Word Stroop, a Delay Discounting task, and a Digit Span task. Age-related improvements were found on all tasks, but improvements on relatively cool tasks (Color Word Stroop and Backward Digit Span) occurred earlier in this age range, whereas improvements on relatively hot tasks (Iowa Gambling Task and Delay Discounting) were more gradual and occurred later. Exploratory factor analysis indicated that performance on all tasks could be accounted for by a single-factor model. Together, these findings indicate that although similar abilities may underlie both hot and cool EF, hot EF develops relatively slowly, which may have implications for the risky behavior often observed during adolescence. Future work should include additional measures to characterize more intensively the development of both hot and cool EF during the transition to adolescence.

Introduction

Adolescence is a period of increasing autonomy and self-regulatory demands that is often accompanied by risky behavior and poor decisions that can have lifelong negative consequences (e.g., Dahl,

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2004; Ernst & Hardin, 2010; Steinberg, 2005; Steinberg et al., 2009; Van Leijenhorst & Crone, 2009). Common risks taken by teens include reckless or intoxicated driving, experimenting with drugs and alcohol, and unprotected sex. One factor contributing to the high incidence of such behaviors may be the continued immaturity of executive function (EF), a neuropsychological term that refers to the higher order cognitive control of thought, action, and emotion (e.g., Zelazo, Carlson, & Kesek, 2008).

Impairments in EF are associated with a wide variety of psychiatric disorders with childhood onset, including attention deficit/hyperactivity disorder, conduct disorder, and autism (e.g., Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), as well as with specific problem behaviors such as physical aggression and substance abuse (e.g., Séguin & Zelazo, 2005). Even in healthy children, however, individual differences in EF are associated with important developmental outcomes, including school readiness during early childhood (Blair & Razza, 2007; Diamond, Barnett, Thomas, & Munro, 2007), and social and cognitive function during young adulthood (e.g., Duckworth & Seligman, 2005; Eigsti et al., 2006).

An important aspect of EF is the ability to respond flexibly and adaptively in situations that prime maladaptive and/or prepotent responses, leading to impulsive acts and errors in judgment. In these cases, highly salient information often introduces an element of emotion that can cloud otherwise good judgment (but see also Damasio, 1999, for a discussion of the contribution of emotion to adaptive decision making). Adolescence may mark a period of particular vulnerability to such errors in part because the development of EF continues throughout this period, lagging behind the development of other cognitive skills (e.g., Diamond, 2002; Luciana & Nelson, 1998, 2002; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Welsh, Pennington, & Groisser, 1991). Moreover, the transition to adolescence is often accompanied by a new set of challenging emotional experiences that may further undermine emerging cognitive control. Research on adolescents' EF under more and less emotion-laden circumstances may help us to understand discrepancies between adolescents' theoretical understanding of the potential negative consequences of their behavior and their real-life choices in emotion-laden situations (e.g., in the face of peer pressure), and it may also inform us more generally about the role of emotion in EF across development.

EF is increasingly believed to involve a number of related but distinct subfunctions, including working memory, inhibitory control, and cognitive flexibility (Miyake et al., 2000), that together allow conscious, goal-directed thought and behavior; that is, they allow the deliberate use of one's knowledge in the service of one's goals. Research on the development of EF suggests that it emerges early (around the end of infancy) and shows marked changes during the preschool years, but also that it continues to develop at least through adolescence, in parallel with the protracted development of prefrontal cortex (Zelazo et al., 2008). Traditionally, EF has been examined using relatively abstract decontextualized tasks that lack a significant affective or motivational component. More recent characterizations of EF have suggested that EF tasks vary in motivational significance, with motivationally and emotionally significant tasks described as "hot" and more abstract tasks described as "cool" (Zelazo & Cunningham, 2007; Zelazo & Müller, 2002). Hot tasks are thought to involve stimuli, decisions, and outcomes that are motivationally salient. Considering the development of EF in more affectively relevant hot situations extends the construct of EF to everyday decision making, which is rarely conducted in the absence of motivational and emotional influences.

Rather than considering EF in hot and cool situations in a dichotomous fashion, this characterization recognizes the interplay between relatively hot aspects of EF and relatively cool aspects of EF (Cunningham & Zelazo, 2007). According to this model, information is processed hierarchically, with relatively quick evaluative reactions followed by the generation of approach–avoidance-oriented responses. These relatively simple responses may suffice, or, if necessary, further processing and reprocessing of information may ensue that allows reflection on context and future consequences, and that supports the top-down control of behavior. The extent to which a reflective response is likely to be generated depends on a number of factors, including time, motivation, and neural and cognitive maturity. Given that neural development also proceeds in a generally hierarchical fashion, with areas of the brain associated with more complex processing developing later than areas of the brain associated with more automatic processing (e.g., Bunge & Zelazo, 2006), children and adolescents may be expected to be less reflective than adults. Moreover, difficulty in generating reflective responses is likely