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The effects of gender and age on inhibition and working memory organization in 14- to 19-year-old adolescents and young adults

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ABSTRACT

This study aimed to investigate how two core dimensions of executive function (EF), inhibition and working memory (WM), were organized during adolescence. A sample of 240 14- to 19-year-old adolescents was assessed with a battery that comprised inhibition (go/no-go, antisaccade and stop signal tasks) and WM tasks (symmetry span, reading span and Mr. Cucumber tasks). A confirmatory factor analysis was used to examine the latent structure of EF. The following two models were considered: a one-factor model where WM and inhibitory tasks were clustered together and a two-factor model where all inhibitory tasks were clustered into a separate factor from WM tasks. The two-factor model, in which inhibition and WM emerged as being separate but associated, best fit the data. An invariance analysis across gender revealed different effects of age on male and female EF latent structure, which suggests the existence of gender differences in the maturation of inhibition and WM processes.

1. Introduction

Inhibition and working memory (WM) are two basic abilities of a complex construct that is called executive function (EF). This term is used to refer to a set of top-down processes that allow one to regulate one's own thoughts and behaviors (Miyake & Friedman, 2012). The abilities that constitute these processes are inhibition, cognitive flexibility and the ability to dynamically update WM. The importance of these processes in many aspects of everyday life has been documented (Mischel & Ayduk, 2002; Moffitt et al., 2011), as they are essential in every non-automatic action, new skill development and thought management. The literature shows that the latent organization of these components changes between preschool and adulthood, evolving from a unitary structure to a more differentiated one (e.g., Lee, Bull, & Ho, 2013; Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Miyake et al., 2000; Monette, Brigas, & Lafreniere, 2015; Usai, Viterbori, Traverso, & De Franchis, 2014; Wiebe et al., 2011).

Recently, a great deal of attention has been given to EF in early childhood (see, e.g., Best & Miller, 2010; Garon, Bryson, & Smith, 2008). By contrast, few studies on EF have taken into account the earlier years (Riggs, Black, & Ritt-Olson, 2015) or the very last years of adolescence (Friedman et al., 2016; Friedman, Miyake, Robinson, & Hewitt, 2011; Friedman et al., 2008); specifically, scarce research on EF has focused on the age range from 14 to 19 years (Huizinga, Dolan, & Van der Molen, 2006; McAuley & White, 2011). During this stage of development, EF abilities are still developing while many brain changes occur, and an increase in cognitive functions and social and emotional behavior has been recorded. In fact, cognitive processing speeds up, and EF shows impressive improvements that are also exhibited in abilities such as abstract thought, organization, decision making, planning, and response inhibition (Dahl, 2004).

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1.1. Response inhibition

Inhibition, as one of the core abilities of EF (Miyake & Friedman, 2012), has been widely studied in children from an early age. It is defined as "a deliberate overriding of a dominant or prepotent response" (Miyake & Friedman, 2012, p. 2), and it encompasses different behavioral and cognitive abilities, such as managing impulses and interferences (Diamond, 2013; Nigg, 2000) that start to be differentiated at a very early age (Gandolfi, Viterbori, Traverso, & Usai, 2014). These processes play a crucial role in cognitive activities and social interactions, and they allow one to manage interfering stimuli, maintain attention, and suppress prepotent responses or override automatic actions when needed.

Response inhibition, which is one of the earliest differentiated inhibitory components (Gandolfi et al., 2014), involves the ability to regulate one's behavior and to control one's emotions to support the regulation of a behavior. The experimental tasks that are used to assess response inhibition require participants to either withhold a response (i.e., stop signal and go/no-go paradigms) or execute a subdominant response in the face of a more dominant response (Stroop and antisaccade paradigms).

During adolescence, biologically based changes in emotions and motivation seem to co-occur with a tendency toward impulsiveness, risk taking and sensation seeking (Dahl, 2004); however, much less is known about the role that is played by response inhibition and in general the ability to manage impulses. Miyake and Friedman (2012) investigated EF abilities in adolescence and highlighted the role that inhibition may play in supporting the other control processes. Response inhibition seems to emerge quite early in development, with a distinct timing between simple inhibition (withholding and/or delaying a prepotent or automatic response) from 4 months to 3 years of age and up and complex inhibition (holding a rule in one's mind, responding according to this rule and inhibiting a prepotent response) from 22 months to 3 years of age and up depending on the task (e.g. Clark et al., 2013; for reviews see Best & Miller, 2010; Garon et al., 2008), and it continuously develops from age 5–8 (Carlson, 2005). Anderson, Anderson, Northam, Jacobs, and Catroppa (2001) found that this ability evolves through adolescence. The ability to manage responses peaks at approximately 15 years of age; however, there is a general lack of studies that investigates what may occur next between age 15 and the early 20s. Brain imaging studies have shown that changes in performance during adolescence are also associated with brain development. Cognitive maturation is associated with progressive increases in the activation of task-relevant prefrontal brain regions and their connections to the striatal and parieto-temporal regions that mediate top-down control in the context of inhibition, attention, motivation control and timing functions (Rubia et al., 2013). Using the antisaccade paradigm, Ordaz, Foran, Velanova, and Luna (2013) confirmed that the motor response control regions matured earlier than the inhibition and error-processing regions.

In consideration of the studies on behavioral development and brain maturation, it is not yet certain whether response inhibition reaches maturity in early adolescence or if it continues to develop until young adulthood. Moreover, an important challenge in the assessment of EFs and consequently of response inhibition is the impurity problem. Task impurity refers to the fact that most measures of EF involve non-executive processes that can influence task performance (Miyake et al., 2000). The impurity problem can be addressed by assessing inhibition with multiple tasks and then extracting their shared variance with confirmatory factor analysis (CFA). To the best of our knowledge, very few studies have used CFA to assess the inhibitory latent component with a focus on response inhibition in adolescents and young adults (e.g., Brydges, Fox, Reid, & Anderson, 2014; Friedman et al., 2016; Huizinga et al., 2006; McAuley & White, 2011), and the age ranges that have been considered are either too early or late in development.

1.2. Working memory

WM is the ability to store useful information while completing a task when the information is no longer present, and it is fundamental to remembering information and constructing a sense of continuity in temporal order, taking into account the number of operations that are needed to complete an action (Diamond, 2013).

This ability might be distinct in verbal WM and visual-spatial WM because of the nature of the stimuli to be processed (Baddeley, 1986; see Engle, Kane, & Tuholski, 1999). Moreover, it is composed of a static dimension, the WM capacity, and a more dynamic dimension that is called updating, which differ in cognitive load and the skills that are needed. Together, these dimensions allow information to be dynamically updated, which is a process that may also involve inhibition to address interferences and non-useful information (Miyake & Friedman, 2012).

Behavioral and brain functioning studies have established that WM develops during childhood through adolescence. Different tasks that assess WM have shown linear increases in performance from 4 years of age through adolescence (Gathercole, Pickering, Ambridge, & Wearing, 2004). Moreover, better performance in WM tasks reflects a more mature pattern of brain activation of a WM-specific network of brain regions that include the dorsolateral prefrontal cortex (Satterthwaite et al., 2013). An increase in individuals' executive function throughout adolescence should reflect progress along this same maturation process. A systematic review and meta-analyses that considered studies with healthy adolescents (10–17 years old) and young adults (18–30 years old) confirmed that brain activation during adolescence increased with age principally in the higher order cortices, which are part of the core WM network (Andre, Picchioni, Zhang, & Toulopoulou, 2015).

1.3. The relationship between inhibition and WM

Recent studies have shown that inhibition and WM are already distinct dimensions in childhood (Lee et al., 2013). However, the debate concerning their independence is still ongoing (e.g., Wright & Diamond, 2014), and several studies have shown that these dimensions are related (Diamond, 2013). Many open-ended questions still require answers. Best and Miller (2010) reported that many tasks that assess inhibition also require WM (Garon et al., 2008; Simpson & Riggs, 2005), and the combined demand for these