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Structure of executive functions in typically developing kindergarteners

Sébastien Monette [a,*], Marc Bigras [b], Marc-André Lafrenière [c]

[a] Centre Jeunesse de Montréal–Institut Universitaire (CJM–IU), Montréal, Québec H2L 4R5, Canada
[b] Université du Québec à Montréal (UQAM), Montréal, Québec H2L 2C4, Canada
[c] McGill University, Montréal, Québec H3A 0G4, Canada

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ABSTRACT

Whereas studies of the past 10 years have shown the executive functions (EFs) in adults to be differentiated into at least three principal components (working memory, inhibition, and flexibility), EF structure in children is far less well understood despite a large body of research on the subject. A study was undertaken to test different structural models of EFs through confirmatory factor analysis (CFA) on a large sample of typically developing kindergarteners ($N = 272$). The method employed sought to remedy the shortcomings of past research in this field such as absence of CFA, insufficient number of EF components tested, insufficient number of indicators per latent variable, and absence of control on processing speed. Children were assessed using a battery of EF tasks developed by the researchers to measure working memory (WM), flexibility, and inhibition (backward word span, backward block span, fruit Stroop, day–night test, hand Stroop, Trails-P, card sort, face sort, and verbal fluency shift). CFA results show the best-fitting model to comprise two factors, namely, an inhibition factor and a WM–flexibility factor. Invariance analyses suggest that this structure is the same for girls and boys and that latent variable means do not differ by sex. These results support the hypothesis of EF differentiation during development. The researchers formulate other hypotheses regarding neurophysiological development.

* Corresponding author.
E-mail address: sebastien_monette@hotmail.com (S. Monette).

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Introduction

Executive functions (EFs), also known as executive control and cognitive control, can be defined as a set of hypothetical mental processes that allow consciously controlling thought and action in order to orient behavior toward a future goal (Jurado & Rosselli, 2007). Numerous researchers consider working memory (WM), flexibility, and inhibition to be the principal components of EFs (Miyake et al., 2000), although other components are also mentioned at times (e.g., planning, fluency, task initiation, divided attention). Inhibition is the ability to suppress a dominant response in favor of another or no response. Flexibility or shifting is the ability to switch between mental sets or rules such as alternating between sorting objects by color and shape. WM, finally, is the ability to actively store, update, and manipulate relevant information during an ongoing task. It has been hypothesized that these core executive functions are relatively distinct but interrelated. Recent neuroimaging studies have tended to support this model; the three components have been shown to be associated with relatively distinct brain areas but also to share areas of activation (Collette et al., 2005; McNab et al., 2008). The term *executive functioning* has often been used synonymously with the term *frontal lobe functioning* (Stuss & Knight, 2002) given that EF tasks share the common characteristic of soliciting frontal areas of the brain (Alvarez & Emory, 2006), although the same tasks solicit other areas as well.

EF in children has been a topic of interest to researchers for more than two decades because this component of cognition has been shown to be associated with behaviors of daily life in typically developing children and to be impaired in children with developmental disorders (see Hughes, 2011, for a detailed update on the matter). In typically developing children, EF has shown a robust association with various abilities, including mental state awareness (also known as "theory of mind"), as well as with academic achievement and socio-affective functioning in general. Moreover, EF deficits have been regularly reported in children with cerebral damage consecutive to medical conditions such as phenylketonuria and sickle cell disease (Azadi, Seddigh, Tehrani-Doost, Alaghband-Rad, & Ashrafi, 2009; Kral, Brown, & Hynd, 2001), traumatic brain injury (Levin & Hanten, 2005), and prenatal exposure to teratogenic agents (Rasmussen, 2005). EF weaknesses have also been reported in children subjected to severe adverse environmental conditions such as early care deprivation (Stevens et al., 2008). Finally, EF deficits have been documented in some neurodevelopmental disorders (Kenworthy, Yerys, Anthony, & Wallace, 2008; Pennington & Ozonoff, 1996), including autism spectrum disorders, Tourette syndrome, and attention deficit/hyperactivity disorder (ADHD).

The question of how EFs are organized or structured in children, thus, remains of great interest from both fundamental and practical points of view. At the fundamental level, studying the structure of EFs contributes to mapping the different human cognitive functions and their development. At the practical level, better knowledge of this structure would allow developing assessment tests better adapted to children in different age brackets, which in turn would allow better screening and diagnosis of different disorders, not to mention better measurement of the impact of different rehabilitative or remedial interventions. This knowledge could also serve to better target interventions aimed directly at EFs such as computer-assisted cognitive remediation (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009) and neurofeedback (Riccio & Gomes, 2013).

Factor analysis studies with adults

The study by Miyake et al. (2000) has been by far the most cited in the field of research on the structure of EFs. These researchers used a battery of nine simple EF tests—three inhibition tests, three flexibility tests, and three WM tests—on a sample of young adults. They then tested various structural models of EF latent variables: a unitary model, three two-factor models, and two three-factor models. The three-factor model in which factors were intercorrelated proved to be the best fitting. Miyake and colleagues also showed that different complex EF tests used in clinical neuropsychology (Wisconsin Card Sorting Test, random number generation, Tower of Hanoi, and operation span) were associated in different ways to the EF latent variables revealed by confirmatory factor analysis (CFA). The innovative aspect of their research lay essentially in two elements: (a) the use of a confirmatory approach to test different EF models determined beforehand and (b) the use of a sufficient number of tests to