Intelligence 47 (2014) 34–43

Contents lists available at ScienceDirect

Intelligence

The differentiation of executive functions in middle and late childhood: A longitudinal latent-variable analysis

Christopher R. Brydges [a,b,*], Allison M. Fox [b], Corinne L. Reid [a], Mike Anderson [a,b]

[a] School of Psychology and Exercise Science, Murdoch University, Murdoch WA 6150, Australia
[b] Neurocognitive Development Unit, School of Psychology, University of Western Australia, Crawley WA 6009, Australia

ARTICLE INFO

Article history:
Received 9 June 2014
Received in revised form 28 August 2014
Accepted 29 August 2014
Available online 26 September 2014

Keywords:
Children
Executive function
Shifting
Working memory
Inhibition

ABSTRACT

Executive functions are cognitive processes that are associated with goal-directed behaviour. Although these functions are commonly thought to be related yet separable in young adults, attempts to replicate this finding in children have been mixed, as executive functions are indistinguishable in children up to 9 years of age but are related yet separable by 10–11 years. We aimed to provide longitudinal evidence of the differentiation of executive functions in this age range. The present study tested 135 children on a range of inhibition, working memory, and shifting measures twice over a two year period (mean age = 8 years 3 months and 10 years 3 months) to determine if any changes in the structure of executive function occur in this age range. Longitudinal factor analyses showed that the structure of executive functions significantly differed between testing periods, and that the factor structure of executive functions changed from a one-factor (i.e. unitary) model to a two-factor model where working memory was separable yet related to an inhibition/shifting factor. Further structural equation models showed that the unitary factor from testing period 1 was highly, but not entirely, predictive of the two factors yielded from testing period 2. The results provide evidence for the development and differentiation of executive functions, and the distinction between general and specific executive abilities.

Executive functions are higher-order cognitive processes that allow for and control goal-directed behaviours (Miller & Cohen, 2001). The development of these functions is of critical importance, as they are commonly associated with performance on complex tasks (Miyake et al., 2000) and academic outcomes (St Clair-Thompson & Gathercole, 2006). One commonly accepted model of executive functions is the 'unity and diversity' model proposed by Miyake et al. (2000). Miyake et al. tested 137 young adults on multiple measures of three commonly theorised executive functions (prepotent response inhibition, updating of working memory, and task shifting), and extracted latent variables for each of these three constructs by using confirmatory factor analysis (CFA). The resultant model provided evidence of these constructs being related yet distinct from each other, as evidenced by moderately strong inter-factor correlations (range $r = .42$ to $r = .63$). This model proposes that there is a general, domain-free ability underlying all executive processes, as well as several independent abilities specific to each single executive function (Miyake & Friedman, 2012). The general, common ability causes each single executive function to correlate with each other, whereas the specific abilities cause each function to be separable from each other.

Although the Miyake et al. (2000) model is generally considered the seminal model of executive functions, attempts to replicate it in children have been mixed. Specifically, the structure of executive functions though early to mid-childhood, up to around the age of 9 years, appears to be unitary (i.e. a one-factor model of executive functioning is the best fit of the data). Wiebe, Espy, and Charak (2008) administered a range of

* Corresponding author at: Murdoch University, 90 South St, Murdoch, WA 6150, Australia. Tel.: +61 8 9360 6741; fax: +61 8 9360 6492.
E-mail address: c.brydges@murdoch.edu.au (C.R. Brydges).

http://dx.doi.org/10.1016/j.intell.2014.08.010
0160-2896/

inhibition and working memory tasks to 243 typically developing children aged between 2.3 and 6 years. The unitary model of executive functioning was found to be the best and most parsimonious fit of the data. Furthermore, invariance testing between the younger (2 years 4 months – 3 years 11 months) and older (4 years 0 months – 6 years 0 months) children found no structural differences in executive functioning between these two groups. That is, the unitary model was as good a fit in the younger children as it was in the older children. More recently, Lynn (1992) tested 228 young children (mean age 3.01 years) on a battery of working memory and inhibition tasks, and found that the best and most parsimonious fit for the data was also a one factor model of executive functioning. Willoughby, Wirth, Blair, and Greenberg (2012) found the same pattern of results when testing a sample of 5 year olds ($N = 1036$) on a range of executive function measures. Once more, a unitary executive function factor was found to be the best and most parsimonious fit. A two factor model, where working memory was a separate factor to inhibition/shifting, was also tested; however, given that the model fit statistics were no better for this model than the unitary model, and that the correlation between the two factors was extremely high ($r = .89$), it was concluded that executive functions are unitary in this age group. Finally, Brydges, Reid, Fox, and Anderson (2012) tested 215 typically developing children aged 7 and 9 years on a range of inhibition, working memory, and shifting measures. Although behavioural performance significantly improved between the two age groups, relations between measures was reported to be invariant (i.e. there were no differences in the underlying structure of executive functions between the ages of 7 and 9 years). Furthermore, when the Miyake et al. model of executive functions was tested in this sample, it was found that a single factor model of executive functions was the best fit for the data. That is, executive functions were reported to be unitary in typical children up to the age of 9 years.

At some point after the age of 9 years, the individual executive functions differentiate themselves from each other, so that by the age of 10–11 years, the Miyake et al. (2000) model of executive functions is observed (i.e. children display 'unity and diversity'). Wu et al. (2011) tested 185 children (mean age of 10.08 years) on measures of working memory, inhibition, and shifting, and reported that a full three factor model (i.e. a model with three factors that all significantly correlate with each other) was the best fit for the data in this sample. Lehto, Juujärvi, Kooistra, and Pulkkinen (2003) tested 108 8–13 year old children (with a mean age of 10.5 years) on several measures of inhibition, working memory, and shifting, and reported that the full three factor model was also the best fit of the data. Duan, Wei, Wang, and Shi (2010) also tested the structure of executive functions in 11 and 12 year old children (mean age of 11.88 years), and found similar results. Specifically, the three executive function factors were separate, but moderately correlated with each other. Lastly, Shing, Lindenberger, Diamond, Li, and Davidson (2010) tested the differentiation of inhibitory control and memory maintenance (similar to updating of working memory) in 263 children aged 4–14 years. Latent variable analyses found that the two youngest age groups (4–7 and 7–9.5 years) did not produce separate factors for the two constructs, but the oldest children (9.5–14 years) did show two distinct factors, again providing further support for the differentiation of executive functions during childhood. In short, the previous studies described provide consistent support for unity (i.e. a general executive ability) and diversity (abilities specific to each executive function) being evident in children around the age of 10 years and above.

This pattern of development could be due to contrasting developmental trajectories of the general executive ability and the specific abilities described by Miyake and Friedman (2012), and appears to be analogous to the differentiation hypothesis of intelligence (Garrett, 1946). Specifically, Garrett administered a range of intelligence subtests to children and adolescents, and reported stronger correlations between tasks in children. From this, he postulated that the structure of intelligence changes from a unified, general ability to more specific abilities through childhood development. More recent research (Deary et al., 1996; Detterman & Daniel, 1989; Legree, Pifer, & Grafton, 1996) have found stronger correlations between measures of cognitive abilities in lower IQ groups than in higher IQ groups, providing support for Garrett's differentiation hypothesis (Anderson & Nelson, 2005).

Considering the close associations between intelligence and executive functions from both behavioural (Ackerman, Beier, & Boyle, 2005; Friedman et al., 2006; Obonsawin et al., 2002) and neuroimaging perspectives (Duncan & Owen, 2000; Tsujimoto, 2008), it is possible that the differentiation hypothesis may also apply to the childhood development of executive functions. Although executive functions are known to develop rapidly throughout childhood (Best, Miller, & Jones, 2009), the unitary structure of executive functions observed repeatedly and the measurement invariance reported by Wiebe et al. (2008) and Brydges et al. (2012) in children aged up to 9 years suggests that the general ability ("unity") develops rapidly through early childhood in typical children, whereas the specific abilities ("diversity") appear to have not developed to an observable degree at this age. From around the age of 10 years, however, this shift from a unitary structure of executive functioning to distinguishable yet related constructs may be due to the differential development of abilities specific to each single executive function, possibly because the prefrontal cortex (a region of the brain that is commonly implicated in executive functioning, Niendam et al., 2012) has become functionally organised into fractionated systems by this age (Tsujimoto). Although this trend has been observed in the previous research described above, it has not been tested directly by using a longitudinal sample of children over this age range.

The aim of this study was to examine the longitudinal development of executive functions across this critical period when the structure of executive functions changes from unitary (up to about the age of 9 years) to displaying unity and diversity (from around the age of 10 years). Thus, it was hypothesised that executive functions develop with age (Best et al., 2009). It was predicted that performance would improve on all measures between testing periods. Furthermore, it was hypothesised that children in mid-childhood would display a unitary executive function (Brydges et al., 2012), whereas children in late childhood would display increased diversity of executive functions (Lehto et al., 2003). This was tested using factorial invariance testing, which is a statistical procedure that examines the relative contributions of each indicator onto a latent variable across time points. That is, if the loadings of each indicator do not change with time, it can be assumed that the