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On the structure and development of executive functions in middle and late childhood: Remodeling and Commentary on Brydges, Fox, Reid, and Anderson

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ABSTRACT

This is a commentary on the study presented by Brydges, Fox, Reid, and Anderson (2014) on the structure and development of executive functions in middle and late childhood. We argue that the modeling approach adopted by the authors was incomplete suggesting a differentiation of executive function from a unitary to a bi-factor structure from 8 to 10 years of age. The data presented in the target article were reanalyzed by a different structural equation modeling approach. A series of powerful models suggested that a differentiated structure defined by inhibition, shifting, and storage was always present, but the relations between these processes varied with development. Theoretical and methodological implications are discussed.

In a recent paper, Brydges, Fox, Reid, and Anderson (2014) presented a two-wave longitudinal study which explored the structure of executive function. To achieve their aim, these scholars examined primary school children twice. Children were first examined when they were 8 years and 3 months old and once again two years later. The children were examined (see details in the target article) with tasks addressed to three components of executive function: Inhibition (control of Stroop interference, success on go/no go tasks, and success in changing from a practiced to a less familiar response); working memory (Letter–Number Sequencing, Backward Digit Span, and sentence repetition); and shifting (Wisconsin Card Sorting, Verbal Fluency, and letter monitoring).

To examine the organization of these processes, Brydges et al. (2014) tested various Structural Equation Models capturing performance at each of the two testing waves. They concluded that their best solution was a combination of two models, a single factor model best fitting to the performance of the 8-year olds and a two-factor model best fitting to the performance of the 10-year olds. In this later model one of the factors stood for an integrated inhibition/shifting function and the other stood for working memory (see Fig. 2 of the target paper). They interpreted this pair of models to imply that executive function differentiates from a unitary executive control process to a differentiated function involving mental flexibility and working memory capacity. The relation between the unitary executive function at 8 years with each of the two functions at 10 years was declared as less than optimal because a model assuming perfect (i.e., equal to 1) relation between the first wave factor and the two second wave factors did not fit the data well. In this commentary we show that this interpretation is both theoretically and technically incomplete. In concern to theory, the authors contrasted two models. Based on Miyake,

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Friedman, Emerson, Witski, and Howerter (2000), the first model postulates a general domain free executive core and three independent abilities (prepotent response inhibition, updating of working memory, and task shifting), moderately related through the core. Based on developmental research, the second model assumes a unitary executive function in preschool years which differentiates in middle childhood into a function underlying mental control and another underlying working memory.

However, there is a third model summarized but not tested in the target article. According to this model, all three functions are always present and distinct from each other. Their relative importance and inter-relations vary as a function of developmental phase and task. For instance, inhibition tasks require more attention control and less working memory capacity. Working memory tasks require a minimum of attention control and more storage and recall capacity. Shifting tasks may require employing both according to a rule-bound plan. In development, command of the three processes expands in a recycling fashion. That is, at each next developmental phase they become increasingly refined and directed as part of mental plans that become explicit. As a result, their relations vary with developmental phase. Specifically, in the preschool years executive control culminates at 4–6 years in a "focus–choose–respond" program allowing toddlers to focus on 2–3 inter-related representations and alternate between them while both are in focus. When established, this program fully accounts for performance on inhibition, working memory, and rule-based sorting tasks (Demetriou, Spanoudis, & Shayer, 2014a; Demetriou, Spanoudis, Shayer, van der Ven, et al., 2014b; Demetriou et al., 2013). Latter, in middle childhood, this program expands into a "scan–select–search–shift(compare–reduce)" loop allowing children to inter-link conceptual spaces or action plans. This loop allows conceptual fluency that is expressed into increasingly automated and precise inhibition, efficient shifting between conceptual spaces or response options (e.g. various object categories), and enhanced working memory.

1. Results

This model allows several predictions, some concerned with task structure and some with developmental patterns, which may be tested against the predictions tested in the target article. In concern to task structure, we predict that all three sets of tasks used involve three layers of processes. First, all of them require selective attention directed by a represented goal. This requires a minimum of working memory (the goal) and command of a binary choice process (a stimulus or a response dictated by a goal versus another stimulus or response dictated by a dominant stimulus or a response set). Two of the three sets, the working memory and the shifting tasks, also require an executive plan for scanning representations and aligning them according to a rule. Finally, the working memory tasks require, in addition to the processes above, special storage and recall processes. In concern to development, we predict that the structure above would capture performance at both testing waves. The major developmental change occurring in the age phase involved in this study is concerned with shifting. As noted above, in the 8–10 years phase shifting comes increasingly under conceptual control. In modeling, this would come as two seemingly conflicting patterns of relations. On the one hand, the relative power of the factor standing for shifting should diminish to indicate that shifting comes increasingly under central conceptual control. At the same time, working memory rather than inhibition at first testing would have to be the best predictor of shifting at second testing to reflect its increasing submission to representational control. On the other hand, however, shifting at first testing must be the major predictor of inhibition and working memory at second testing to reflect its increasing dominance as the major tool of executive control.

We tested three types of models, using the data presented in Tables 1 and 2 of the target article. First we tested several models based on the two models accepted by Brydges et al. (2014) as the best description of the data (see Fig. 2 of the target article). The first model is a complete realization of the Brydges et al. model in that all nine measures at first testing were related to one factor and at second the three inhibition and the three shifting measures were related to one factor and the three working memory measures were related to another factor. The only difference between the model presented in the target article and the model presented here is that the present model was tested on both waves at the same time rather than separately. The fit of this model was not acceptable, $\chi^2(123) = 284.26$, $p = .000$, CFI = .70, RMSEA = .099 (CI = .084 − .114). When the relation between the first wave factor with each of the two second waves factors was fixed to unity, as done in the target article, the fit of the model improved significantly, $\chi^2(125) = 221.09$, $p = .000$, CFI = .82, RMSEA = .076 (CI = .059 − .091); $\Delta\ \chi^2(2) = 63.17$, $p < .001$. This finding suggests that the factors were related, albeit not optimally. Thus, these two relations were let free to be estimated. Under this condition, the model fit improved extensively, reaching acceptability standards, $\chi^2(123) = 173.12$, $p = .002$, CFI = .91, RMSEA = .055 (CI = .034 − .073), model AIC = −72.88; $\Delta\ \chi^2(2) = 47.97$, $p < .001$. In fact these relations were very high: .91 for the inhibition/flexibility factor and .78 for the working

Table 1
Nested factor model across tasks and testing waves.

Task	Attention control/inhibition	Shifting	WM
1st wave			
Stroop	.60*		
Go/no go	.16		
Compatibility RT	.35*		
WCST	.41*	.26[1]	
Verbal flexibility	.60[1]	.22	
Letter monitoring	.51*	.30*	
Let–Num. Sequen	.50*	.59*	.11
BDS	.44*	.17	.66*
Sentence Repetit.	.21*	.39*	.20*
2nd wave			
Stroop	.75*		
Go/no go	.33*		
Comp RT	.22*		
WCST 2	.28*	.11	
Verbal flexibility	.45*	−.04	
Letter monitoring	.34*	−.17	
Let–Num Sequen	.30*	.51*	.20*
BDS	.33*	–	.94[1]
Sentence Repetit.	.10	.42*	.22*

Note: Asterisks mark significant relations and superscripts mark fixed relations.