Developmental Psychology
2008, Vol. 44, No. 2, 575–587

0012-1649/08/$12.00 DOI: 10.1037/0012-1649.44.2.575

Using Confirmatory Factor Analysis to Understand Executive Control in Preschool Children: I. Latent Structure

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Although many tasks have been developed recently to study executive control in the preschool years, the constructs that underlie performance on these tasks are poorly understood. In particular, it is unclear whether executive control is composed of multiple, separable cognitive abilities (e.g., inhibition and working memory) or whether it is unitary in nature. A sample of 243 normally developing children between 2.3 and 6 years of age completed a battery of age-appropriate executive control tasks. Confirmatory factor analysis was used to compare multiple models of executive control empirically. A single-factor, general model was sufficient to account for the data. Furthermore, the fit of the unitary model was invariant across subgroups of children divided by socioeconomic status or sex. Girls displayed a higher level of latent executive control than boys, and children of higher and lower socioeconomic status did not differ in level. In typically developing preschool children, tasks conceptualized as indexes of working memory and inhibitory control in fact measured a single cognitive ability, despite surface differences between task characteristics.

Keywords: executive control, inhibition, working memory, preschool, confirmatory factor analysis

Supplemental materials: http://dx.doi.org/10.1037/0012-1649.44.2.575.supp

Executive control is a term used to refer broadly to those cognitive abilities that are associated with or subserved by the prefrontal cortex and interconnected subcortical system (Diamond, 2001; Stuss, 1992). Although research on executive control has been underway for several decades, it is remarkable that there remains no well-agreed-on definition as yet. One school of thought has conceptualized executive control as a group of relatively independent, or fractionated, cognitive abilities, typically including working memory, the ability to keep information in mind to guide ongoing or later behavior (Baddeley & Hitch, 1974); inhibitory control, the ability to keep irrelevant or misleading information from interfering with performance (Diamond, 1990; Harnishfeger & Bjorklund, 1993); and set shifting, or the ability to adapt strategies to changing situational demands (Zelazo, Frye, & Rapus, 1996). In contrast, others have argued that executive control is a unitary, domain-general construct that manifests in different ways depending on contextual demands (e.g., Duncan & Miller, 2002; Duncan & Owen, 2000).

Prefrontal systems undergo a protracted course of development (Benes, 2001). In comparison with posterior cortical areas, the phases of prefrontal cortical development, including neuronal generation, differentiation, and synaptic pruning, occur later and over a longer period of time (Giedd et al., 1999; Huttenlocher, 1990). Myelination of fibers within the prefrontal cortex is not complete until early adulthood (Paus et al., 2001). Executive control undergoes a similarly delayed developmental trajectory, whereby, for example, performance on "classic" executive tasks such as the Tower of Hanoi or Stroop tasks improves through late childhood and adolescence (Welsh, Pennington, & Groisser, 1991). The preschool years are a particularly important phase in the development of these skills (Espy, 2004). In this period, children make the transition from infancy to childhood and are increasingly expected to exhibit greater control of their behavior in everyday life and to modulate behavior appropriately in contexts outside the home to achieve a goal—for example, to learn new information in school. Children's developing ability to regulate their behavior depends not only on executive control but also on the related processes of emotion regulation and effortful control (Kochanska, Murray, & Harlan, 2000). However, the focus of the present investigation is limited to executive control of cognition, which guided our review of the literature and the selection of tasks included in this study.

Until recently, few measures of executive control were available for use in preschool children. Adult measures have strong verbal demands either in testing format or in instructions, so that preschoolers typically are unable to complete the tasks or exhibit floor

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This research was supported by National Institutes of Health Grants R01 MH065668, R01 DA014661, R01 HD050309, and 5P01 HD038051. Portions of these data were presented at the meeting of the International Neuropsychological Society, February 2005, St. Louis, Missouri, and the meeting of Cognitive Development Society, October 2005, San Diego, California. We thank Megan Banet, Mary Cwik, Heather Kaiser, Jessica Martin, and other members of the Developmental Cognitive Neuroscience Laboratory for assistance with data collection, and we are grateful to the children and families who participated in this study.

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levels of performance. There now are an established literature and a broad repertoire of executive tasks appropriate for preschool children (e.g., Carlson, 2005; Diamond, Prevor, Callender, & Druin, 1997; Espy, Kaufmann, McDiarmid, & Glisky, 1999; Hughes, 1998). Nevertheless, disagreement remains regarding what exactly executive control entails. In the adult literature, a useful approach to addressing this problem has been to better characterize the interrelations among measures of executive control and thereby identify the organization of the underlying cognitive constructs of interest (e.g., Miyake et al., 2000).

Factor Analysis and the Structure of Executive Control

Factor analysis can be used to identify the latent structure underlying observed cognitive task performance (Gorsuch, 1983). Factor analysis capitalizes on true score variance and allows one to address the question of whether performance on different tasks can be summarized or represented by one or several latent common factors. Furthermore, by examining patterns of factor loadings, the relations between the measured variables and the identified latent factors, it is possible to draw inferences regarding the interpretation of the identified factors and the shared cognitive abilities presumed to underlie relations among task performances. A table reviewing results from factor analytic studies on executive control is available as supplementary material to this article.

To date, many studies have used exploratory factor analysis (EFA) or principal-components analysis to examine the structure of executive control. Generally, these studies have identified more than one factor or component explaining variability in executive control task performance in samples of adults (Lamar, Zonderman, & Resnick, 2002; Robbins et al., 1998) and of children (Klenberg, Korkman, & Lahti-Nuuttila, 2001; Welsh et al., 1991). A fractionated executive structure also is supported by other findings. For example, the reported correlations between different measures of executive control tend to be low and often fail to reach significance (Robbins, 1998). Focal lesions to different parts of the frontal lobes result in differential, discrete performance deficits (e.g., Stuss & Levine, 2002).

However, because both principle-components analysis and EFA are exploratory techniques used to represent the observed data and do not include formal a priori hypothesis testing, the conclusions that can be drawn from these methods are limited. The degree of independence of the factors identified in some of these studies also is questionable. Many early exploratory studies used Varimax rotation, which solves for the best fitting orthogonal, or uncorrelated, solution. Gorsuch (1997) argued that this approach is biased to identify factors that are sample specific and difficult to replicate. He recommended the use of oblique rotations that allow for correlated factors but nevertheless yield independent factors if they better fit the data. In studies in which correlated factors have been allowed, substantial interfactor correlations (rs = .30–.70) have been observed (e.g., Boone et al., 1998; Brookshire, Levin, Song, & Zhang, 2004; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; but see Brocki & Bohlin, 2004, for an exception).

Furthermore, differences in the executive tasks administered influence the larger conclusions drawn from factor analytic studies. Because executive control entails the regulation of other cognitive skills to achieve a goal or end state, executive control tasks also require nonexecutive cognitive skills (Kane & Engle, 2002). It is not surprising, then, that executive control task performance can be influenced by nonexecutive task demands (Lamar, Zonderman, and Resnick, 2002), which may affect factor analysis results. In some studies, multiple dependent measures from a single task were included in the factor analysis (e.g., Boone et al., 1998; Espy et al., 1999; Pineda & Merchan, 2003). To the extent that these measures are correlated because of shared method variance, they will load together on the same factor. This potentially spurious common loading can skew relations from dependent measures from other tasks and make it difficult to interpret the best fitting solution. To prevent this problem, the inclusion of only one indicator variable per task is preferred (Gorsuch, 1983). In sum, the outcome of any EFA will be influenced by any source of common variability, including nonexecutive demands, not just the cognitive construct of interest.

Confirmatory factor analysis (CFA), a latent variable approach, addresses these limitations and provides a method by which to compare the utility of various structures. CFA includes multiple indexes of fit, which can be used to evaluate different models and thereby empirically test models previously developed through EFA conducted on data from other samples (e.g., Strauss, Thompson, Adams, Redline, & Burant, 2000). Furthermore, using CFA to model the cognitive constructs thought to underlie performance on different tasks allows one to extract a more "purified" latent variable (Miyake et al., 2000), because one can model different sources of performance variability on an a priori basis, utilizing what is known about task demands. In CFA, the tasks that are expected to share common executive demands, and thus to load on a common factor, are specified before the model is run. CFA also can be used to assess whether the same latent structure fits equally well to data for subsamples that differ on key characteristics, such as sex (Kim, Brody, & Murry, 2003). A series of studies by Miyake et al. (2000; Friedman & Miyake, 2004; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001) demonstrated successful application of this method in adults. Miyake et al. (2000) selected simple tasks to index inhibition, working memory updating, and set shifting. CFA results supported a three-factor model, although correlations between the three factors were substantial (rs > .40). Models with fewer factors fitted the obtained data significantly more poorly.

Unfortunately, there is a paucity of factor analytic studies addressing the organization of executive control in children in the preschool years. Several studies of executive control development have included samples of preschoolers, but because many tasks could not be administered to these young children, their data were used for cross-age comparison but excluded from factor analyses (Klenberg et al., 2001; Welsh et al., 1991). To our knowledge, only one study has explored the structure of executive control in preschool children (Espy et al., 1999), although Murray and Kochanska (2000) included PCA in their study of early self-regulation, a closely related construct that encompasses socioemotional dimensions in addition to executive control. Similar to reported findings in adults and older children, the best fitting model of executive control in the preschool period included multiple factors (Espy et al., 1999). CFA has been applied even less frequently in child samples. Two notable exceptions used CFA to compare models originally derived from EFA, with other models including fewer factors (Brookshire et al., 2004; Lehto et al., 2003). It is interesting that the model confirmed by Lehto et al. was structurally similar to the three-factor model favored by Miyake et al. (2000). Unfortunately, however, both the CFA and the EFA models were conducted with the same data set, which, unfortunately, compromises the obtained evidence of validation of the observed latent structure. No study to date has used CFA to assess the structure of executive control in children under the age of 6 years—the goal of the present investigation. Previous successes in using exploratory methods with this age group indicate that it should be possible to apply CFA to preschool data. To construct a series of testable models, we examined the literature on current theories of executive control and then used it to select multiple age-appropriate tasks to index each hypothetical latent variable. Our approach was modeled after that of Miyake and his colleagues (Friedman & Miyake, 2001; Miyake et al., 2000, 2001).

Models of Executive Control

The primary task of an adequate model of preschool executive control is to define the processes that enable successful, goal-directed behavior in young children. Working memory and inhibition are central to executive control (Miyake et al., 2000; Zacks & Hasher, 1994). Kirkham, Cruess, and Diamond (2003) argued that working memory and inhibition together play a critical role in the ability to overcome "attentional inertia"—that is, focusing on the same previously relevant aspects of a stimulus even when contextual demands change. The first model tested in the present study was a two-factor model including factors of Inhibition and Working Memory, with at least three tasks specified to load on each latent factor (see Figure 1). Another candidate executive control process is the ability to flexibly switch between modes of responding as environmental or task demands change (e.g., Miyake et al., 2000). Unfortunately, it was not possible to consider a separate shifting construct, because at the time of study design there were very few preschool tasks available in the literature. The foremost task, the dimensional change card sort (Zelazo et al., 1996), is not suitably scaled psychometrically for the purposes of CFA. Thus, the present investigation focused on the putative distinction between inhibition and working memory.

Some investigators have parsed the inhibition construct into unique subprocesses. For example, Nigg (2000) distinguished inhibitory control over cognitive processes from inhibitory control over motor responses. In contrast, Friedman and Miyake (2004) found differences between tasks in which interference resulted from conflicting information present in the environment within a given trial (i.e., distractor interference) and tasks in which interference built up over successive trials (i.e., proactive interference). The second and third models tested, then, grouped the inhibition tasks on the basis of inhibition type (motor vs. cognitive inhibition) and source of interference (distractor interference vs. proactive interference).

There is an ongoing debate as to whether activation-only models can explain findings that others have argued require both inhibition and activation (Miller & Cohen, 2001; Munakata, Morton, & Yerys, 2003). These ideas are consistent with Duncan and Owen's (2000) review of the neuroimaging literature, in which they identified a single network of frontal brain structures that were recruited consistently on tasks previously argued to differ in cognitive demands (working memory span, delay, response conflict, task novelty). Our fourth model included a single executive control factor, and all tasks in the battery loaded on a single factor.

Another, less interesting possibility is that variance in children's performance on the executive control task battery is attributable to factors unrelated to executive control. The final three comparison models grouped the tasks on the basis of other, nonexecutive task demands: Tasks that required children to learn and remember a verbal rule were contrasted with nonverbal tasks that required only reaching responses (e.g., delayed response), tasks that included visuospatial information were contrasted with tasks that did not, and tasks in which children's performance was timed were contrasted with tasks without such requirements.

After identifying the model of preschool executive control that best fitted the data, we evaluated model fit across subgroups of the sample through analysis of measurement invariance. Age differences in executive control are fundamental to the preschool period and thus were of central interest. Furthermore, some studies with children and with nonhuman primates have revealed sex differences in some aspects of executive control (Overman, Bachevalier, Schuhmann, & McDonough-Ryan, 1996), and a recent study by Noble, Norman, and Farah (2005) identified robust relations between socioeconomic status (SES) and executive control in children. Thus, possible organizational differences in executive control were examined as a function of background characteristics of the child, namely, age, sex, and SES.

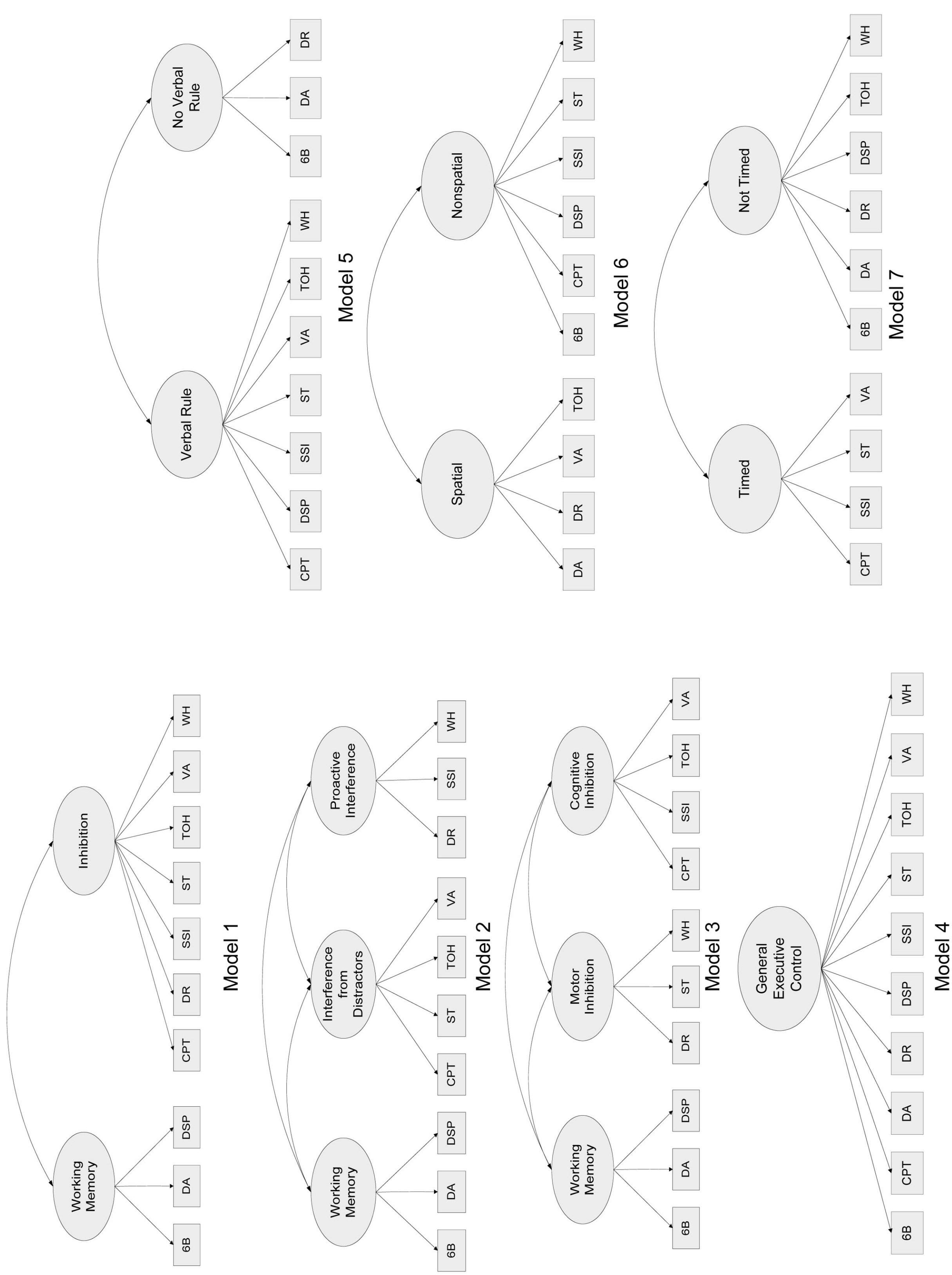
Method

Participants

The sample included 243 preschool children (135 girls, 108 boys) who were recruited through birth announcements, from local preschools, through the local health department, and by word of mouth. Children ranged in age from 2 years 4 months to 6 years (M = 3 years 11 months, SD = 12 months). The sample was composed of 171 Caucasian, 43 African American, 9 Asian American, 1 Native American, 4 Hispanic, and 14 multiracial children; 1 child's race was not reported. The average maternal education of the sample was 14 years 1 month (SD = 2 years 3 months; range = 8 years to 20 years). A subsample of the children were recruited as full-term preschool controls in a longitudinal study of preterm infants (n = 14); these children were assessed longitudinally, although only data from the first assessment were included in the present analysis. Each child was tested individually in a laboratory setting by trained child clinical psychology graduate students. In total, nine examiners conducted testing for this study, and adherence to experimental protocols was maintained by regular team meetings with Kimberly Andrews Espy. Children received a small toy, and parents received a gift card as compensation for their time and travel expenses.

Executive Control Tasks

Participants completed a battery of preschool executive control measures that varied in format and demands, including three tasks considered a priori to demand working memory and seven tasks that required inhibitory processes. The inhibition tasks were chosen so that they could be parsed further on the basis of types of interference (distractor vs. proactive interference) or of inhibition


Working Memory
Inhibition
6B
DA
DSP
CPT
DR
SSI
ST
TOH
VA
WH
Model 1
Working Memory
Interference from Distractors
Proactive Interference
6B
DA
DSP
CPT
ST
TOH
VA
DR
SSI
WH
Model 2
Working Memory
Motor Inhibition
Cognitive Inhibition
6B
DA
DSP
DR
ST
WH
CPT
SSI
TOH
VA
Model 3
General Executive Control
6B
CPT
DA
DR
DSP
SSI
ST
TOH
VA
WH
Model 4
Verbal Rule
No Verbal Rule
CPT
DSP
SSI
ST
VA
TOH
WH
6B
DA
DR
Model 5
Spatial
Nonspatial
DA
DR
VA
TOH
6B
CPT
DSP
SSI
ST
WH
Model 6
Timed
Not Timed
CPT
SSI
ST
VA
6B
DA
DR
DSP
TOH
WH
Model 7

(motor vs. cognitive). A schematic depicting these comparative models is contained in Figure 1. Children's task performance was scored online by the examiner, except for the Child Continuous Performance Test (CPT), which required a computer button press. Any scoring discrepancies were reviewed with Kimberly Andrews Espy for resolution and consistent implementation across examiners. For each task, only one dependent measure was selected for inclusion in the analyses, listed in Table 1.

Working memory. In the Delayed Alternation task, a treat was hidden out of the child's sight in one of two locations. After a pretrial, the correct location alternated whenever the child correctly retrieved the reward, so the child had to remember the previous location across a 10-s delay (Espy et al., 1999; Goldman, Rosvold, Vest, & Galkin, 1971). In the Six Boxes task (Diamond et al., 1997), six boxes that differed in shape and color were initially baited, and the child was allowed to open one box on each trial. Box locations were scrambled between trials, so children had to remember which boxes had already been opened. Children also completed the Digit Span subtest of the Differential Abilities Scale (Elliott, 1990).

Inhibitory control. In the Delayed Response task (Goldman, Rosvold, & Mishkin, 1970), treats were hidden in a pseudorandom order in two locations in the child's view. After a 10-s delay with active distraction, the child was allowed to search at one of the locations. Diamond (e.g., Diamond & Doar, 1989) has argued that this task requires inhibition, in that the child must inhibit a prepotent tendency to reach to the location that was rewarded on the previous trial (but may be incorrect on the present trial) but also must remember the treat's present hiding location. This task was included primarily as a measure of motor inhibition, as we reasoned that in preschool children difficulties emanate more from response conflict than from memory of the treat's current location (as it is hidden in plain sight of the child). It was included among the tasks that required resistance to proactive interference, as interference with a current reach depends on reaches on previous trials. The Whisper task (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996) required children to whisper the names of a series of pictures of familiar and unfamiliar characters. Children are presumed to have a prepotent tendency to speak or shout the names rather than whispering them, particularly for characters familiar to the children. This task was conceptualized as requiring motor inhibition and resistance to proactive interference. Two subtests of the NEPSY, a commercially available, norm-referenced developmental neuropsychological battery, were administered (Korkman, Kirk, & Kemp, 1998). In NEPSY Statue, children stood in a statue pose for 75 s while the examiner attempted to distract them by coughing, dropping her pencil, and so on. Each 5-s epoch was scored for eye and body movement and for talking. Statue was selected as an index of motor inhibition and resistance to interference from distractors. In NEPSY Visual Attention, children were asked to circle the target cats distributed on a page amidst a variety of distractors. This task was chosen because of its apparent cognitive inhibition demands and resistance to interference from distractors.

In the inhibit condition of the Shape School task (Espy, 1997; Espy, Bull, Martin, & Stroup, 2006), children name the colors of different shape characters when cued with a happy face but must suppress the naming response when characters have sad faces. Successful performance on the Shape School task was conceptualized as requiring cognitive inhibition, because of the internalized verbal response, and proactive interference, because children have to suppress a naming response that was established on previously named stimuli. In the Tower of Hanoi task (Simon, 1975; Welsh et al., 1991), children must move a set of rings into a goal configuration by moving one ring at a time and following rules about relative placement of the rings. The number of illegal moves divided by the total number of moves was used as an index of failure to inhibit tempting but "illegal" steps in problem solution (Bull, Espy, & Senn, 2004). Because interference from task performance was expected to result from the perceptual salience of the target configuration (present at all times), this task was categorized as requiring resistance to distractor interference and motor inhibition. Finally, in the CPT (Kerns & Rondeau, 1998), children pressed a button when pictures of infrequent target animals were displayed on a computer screen but did not respond to frequent distractor pictures. All animal pictures were accompanied by animal sounds that conflicted with the picture identities and were thus an additional source of interference. This task was grouped with tasks that required cognitive inhibition and resistance to distractor interference.

Statistical Methods

Descriptive analyses were conducted with SAS Version 8.02. CFAs were conducted with Mplus Version 4.21 (Muthén & Muthén, 2006). First, a set of models derived from previous research were compared empirically, and the best fitting model was selected via the appropriate fit statistics. The chi-square test indexes overall fit of a model; nonsignificant values indicate acceptable fit. The root-mean-square error of approximation (Browne & Cudeck, 1993) is an adjusted fit index, with values less than .08 indicating acceptable fit to the data. The comparative fit index is a relative fit index used to compare each model to a baseline independence model (a model in which all the correlations or covariances are zero), with values between .95 and 1.00 indicating good model fit (Hu & Bentler, 1999). All model comparisons were nested and thus could be conducted via the difference in each model's chi-square value. When two models did not differ significantly, the simpler model was favored because of greater parsimony (Bollen, 1989). The Bayesian information criterion also was examined; a 10-point difference is evidence of a model difference in goodness of fit, favoring the model with the smaller Bayesian information criterion (Raftery, 1993).

To assess factorial invariance, we divided the total sample into subgroups on the basis of sex (boys vs. girls), SES (indexed by maternal education: children whose mother had a high school

Figure 1 (opposite). Path diagrams for planned confirmatory factor analysis Models 1 through 7. Single-headed arrows represent paths of factor loadings; double-headed arrows represent factor correlations. 6B = Six Boxes task; DA = Delayed Alternation task; DSP = Differential Abilities Scale Digit Span subscale; CPT = Child Continuous Performance Test; DR = Delayed Response task; SSI = Shape School inhibit condition; ST = NEPSY Statue subscale; TOH = Tower of Hanoi; VA = NEPSY Visual Attention subscale (cats only); WH = Whisper task.

Table 1
Descriptive Statistics for Executive Control Task Performance and Age, for the Complete Sample and by Sex

Task	All children (*N* = 135–239)			Girls (*n* = 83–135)		Boys (*n* = 52–109)		Sex differences		
	Range	*M*	*SD*	*M*	*SD*	*M*	*SD*	*t*	*df*	*p*
Delayed Alternation: correct searches	1–16	9.06	2.39	9.17	2.42	8.93	2.36	0.74	222	.46
DAS Digit Span: maximum span	1–6	3.38	1.31	3.53	1.29	3.18	1.33	1.86	194	.06
Six Boxes: efficiency (correct searches/total searches)	0.33–1.00	0.68	0.18	0.71	0.19	0.65	0.17	2.54	235	<.05
Delayed Response: correct searches	2–17	13.43	2.84	13.69	3.12	13.12	2.70	1.52	237	.13
NEPSY Statue: 5-second epochs without movement	0–30	14.49	10.45	15.81	10.86	12.62	9.55	2.15	193	<.05
Whisper: correct trials	0–20	16.55	5.05	17.13	4.46	15.87	5.62	1.81	188	.07
Continuous Performance Test: efficiency (hits/total responses)	0–1	0.49	0.33	0.55	0.34	0.41	0.29	2.71	145	<.01
Shape School (Inhibit condition): latency (seconds)[a*]	10–125	30.19	19.74	27.83	18.27	33.94	21.53	−1.76	133	.08
Visual Attention: efficiency (correct responses - errors/latency)	−0.35–0.62	0.13	0.16	0.16	0.17	0.10	0.14	3.17	230	<.01
Tower of Hanoi: "inefficiency" (illegal moves/total moves)[a]	0–1	0.31	0.24	0.30	0.22	0.33	0.25	−0.85	186	.40
Age (years)	2.25–6.00	3.95	0.98	4.03	1.04	3.87	0.89	1.27	242	.21

Note. DAS = Differential Abilities Scale.
[a] A higher score indicates poorer performance.

diploma or less vs. children whose mother had at least some college-level education), and age (divided approximately at the sample mean: younger vs. older than 4 years). For each characteristic of interest in turn, levels of factorial invariance were tested through a series of models. Models were nested, so they could be compared via chi-square difference tests. Nonsignificant chi-square differences between models represented acceptable fit of the more restrictive model, whereas a significant chi-square difference value favored the less restrictive model. For the first, least restrictive invariance model, no equality constraints were imposed; only the factor patterns were held constant across groups (i.e., the same factors were specified, reflecting the same tasks, but loadings, means, and residuals were allowed to vary freely; Meredith, 1993). The second model was a test of weak measurement invariance, so that the loadings of all tasks on their latent factors were held to be equal across groups. The third model tested strong measurement invariance; that is, the intercepts of the measured variables were held constant across group. When strong invariance holds, group differences in means and variances of the latent variables are a function of group differences in means and variances of the measured variables, indicating that the same latent factors are identified in each group (Widaman & Reise, 1997). Fourth, as a test of strict measurement invariance, in the next model the residual variances of the measured variables were constrained to be equal across groups. It is important to note that with strict invariance, group differences in means and variances of the measured variables reflect group differences in measurement that are solely attributable to their common factors. The fifth and sixth models constrained factor variances–covariances and factor means, respectively, to be equal across groups; as such, they were not tests of metric invariance per se.

Results

Mean scores and standard deviations for performance on each executive control task are presented in Table 1, for the total sample and for boys and girls separately, in addition to statistical tests for sex-related performance differences. In general, girls outperformed boys, and on many tasks this difference reached or approached conventional levels of statistical significance. Zero-order correlations between executive control tasks and relations with age are shown in Table 2. With few exceptions, there were significant low to moderate correlations between tasks that were expected to require similar cognitive abilities. Correlations between putative working memory and inhibition tasks also were significant and of similar magnitude. All tasks were correlated with age. As expected, older children exhibited better performance.

For all tasks, we examined distributions of responses to check for ceiling or floor effects and deviations from normality. For the Whisper task, there was a strong ceiling effect, in that 52% of children achieved the maximum score. Consequently, this task was not included in factor analysis. Shape School latencies were log-transformed to normalize the distribution, and outliers more than three standard deviations away from the mean were trimmed. Then, for all tasks, performance scores were converted to z scores to minimize the impact of different variable scaling on fitting model invariance. For two tasks for which higher scores indicated poorer performance, the scores were reflected to simplify factor loading interpretations.

The proportion of available data for each task ranged from 56% to 98%. The two tasks with the most missing data were Shape School (44%) and the CPT (39%), with the remaining tasks having less than 23% missingness. The CPT was computer administered, and the primary reason for data loss was intermittent computer failure. Less frequently, data were missing because a child could

Table 2
Correlations Between Executive Control Task Performance Scores, Age, and Maternal Education

Task	1	2	3	4	5	6	7	8	9	10
1. Delayed Alternation	-									
2. DAS Digit Span	.23**	-								
3. Six Boxes	.21**	.27**	-							
4. Delayed Response	.22**	.26**	.22**	-						
5. NEPSY Statue	.29**	.46**	.37**	.31**	-					
6. Whisper	.14†	.32**	.17*	.20**	.35**	-				
7. Child Continuous Performance Test	.30**	.46**	.31**	.27**	.57**	.16†	-			
8. Shape School (inhibit condition)	.15†	.26**	.22*	−.01	.32**	.08	.30**	-		
9. NEPSY Visual Attention	.38*	.42**	.24**	.23**	.57**	.30**	.50**	.34**	-	
10. Tower of Hanoi	.17*	.37**	.14+	.26**	.30**	.28**	.30**	−.01	.29**	-
Age (years)	.38**	.64**	.43**	.27**	.59**	.31**	.58**	.48**	.58**	.38**
Maternal education (years)	.11†	.14†	.11	.16*	.21**	.17*	.22**	.10	.16*	.03

Note. DAS = Differential Abilities Scale.
† $p < .10$. * $p < .05$. ** $p < .01$.

not be engaged in one of the tasks or because of examiner error in task administration. Logistic regression analyses were conducted to assess relations between missingness and age, sex, and maternal education for each task. For the Differential Abilities Scale Digit Span subscale only, missingness was related to maternal education ($p < .05$); sex was related to missingness for NEPSY Visual Attention ($p < .05$). No other tasks showed relations between missingness and sex or maternal education (ps $> .10$). Missing data were thus considered to be consistent with a missing at random pattern with respect to sex and maternal education (Little & Rubin, 2002). However, it was no surprise that younger children were more likely to have missing data than were older children. Age was related to missingness for all tasks except Delayed Response, for which a marginal trend was observed ($p < .06$). Because age-related differences in the structure of executive control were of central interest, invariance analyses grouping children by age were conducted nonetheless. However, these results must be interpreted with caution because the pattern of data missingness was related to age. Missing data were estimated with the expectation maximization algorithm in Mplus on the basis of all available data points (Muthén & Muthén, 2006).

Factor Solutions

CFA under maximum likelihood estimation was used to evaluate a model series illustrated in Figure 1. All multiple-factor models included correlations between factors, and error variances of the measured variables both within and across factors were uncorrelated. Table 3 lists the models and their fit statistics, and Table 4 summarizes the model fit comparisons. Although, in general, the two-factor and three-factor models displayed acceptable fit to the data, their fit was not significantly better than that of the simplest, one-factor model (Model 4). The three-factor model including working memory, proactive interference, and interference from distractors (Model 2) approached a significant improvement in fit over the working memory/inhibition model (Model 1; $p = .07$) but did not differ from the one-factor model. Thus, for reasons of parsimony, the unitary executive control model was preferred. As illustrated in Figure 2, the standardized factor loadings for Model 4 were significant and exceeded a cutoff value of .40 (Stevens, 2001). The proportion of variance in individual task scores explained by latent executive control varied considerably across tasks. Over half of the variability in NEPSY Visual Attention and CPT performance was related to latent executive control, whereas squared multiple correlation values were closer to .20 for the Six Boxes, Delayed Response, NEPSY Statue, and Delayed Alternation tasks. This pattern is consistent with the definition of executive control as only one construct that contributes to performance on any individual task (Miyake et al., 2000).

Table 3
Goodness of Fit Indexes for Alternative Confirmatory Factor Analysis Models

Model (no. factors)	χ^2	*df*	*p*	RMSEA	CFI	BIC
1. Working Memory and Inhibition (2)[a]	31.07	26	.23	.03	.987	4,859.00
2. Working Memory, Interference From Distractors, and Proactive Interference (3)[a]	25.87	24	.36	.02	.995	4,864.79
3. Working Memory, Motor Inhibition, and Cognitive Inhibition (3)[a]	30.33	24	.17	.03	.983	4,869.25
4. General Executive Control (1)	31.14	27	.27	.03	.989	4,853.58
5. Verbal and Nonverbal Rule (2)	29.55	26	.29	.02	.991	4,857.48
6. Spatial and Nonspatial Tasks (2)	30.69	26	.24	.03	.988	4,858.63
7. Timed and Untimed Tasks (2)	28.58	26	.33	.02	.993	4,856.52

Note. RMSEA = root-mean-square error of approximation; CFI = comparative fit index; BIC = Bayesian information criterion.
[a] Not positive definite residual covariance matrix.

Table 4
Comparative Fit of Confirmatory Factor Analysis Models

Model comparison	$\Delta\chi^2$	Δdf	p	BIC difference
Model 1 vs. Model 2	5.20	2	.07	5.79
Model 1 vs. Model 3	0.74	2	.69	10.25
Model 1 vs. Model 4	0.07	1	.79	5.42
Model 4 vs. Model 5	1.59	1	.21	3.90
Model 4 vs. Model 6	0.45	1	.50	5.05
Model 4 vs. Model 7	2.56	1	.11	2.94
Model 4 vs. Model 2	5.27	3	.15	11.21

Note. The favored model is underlined. When two models did not differ statistically, the more parsimonious model was chosen (Bollen, 1989). BIC = Bayesian information criterion.

Tests of Invariance

After the best fitting model was established for the entire sample, relative model fits between groups of interest were evaluated. As detailed in the *Statistical Methods* section, up to six increasingly restrictive models were tested, with each successive model retaining the equality constraints of the preceding model. Tests of invariance for children grouped by sex, maternal education, and age are provided in Table 5. Strict measurement invariance was supported in analyses of sex, although boys and girls differed in latent variable means. Because girls were set as the referent group, their mean factor score was zero (SD = .89), whereas boys' mean factor score was −.35 (SD = .66; Cohen's d = 0.64, a medium effect size). When children were grouped by their mother's educational attainment, strict measurement invariance was again supported, even when latent means and variances–covariances could be constrained to equality. In these models, there was no difference in mean latent executive control, and the latent executive control factor accounted for the same proportion of variance in tasks across groups defined by the level of maternal educational attainment.

Models that grouped children by age demonstrated an overall poorer fit to the data, with CFI values below the preferred value of .95. There was not a statistically significant worsening of fit until residuals were constrained to be equal across younger and older preschool children (see the Model 4 comparison in Table 5, the *Tests of invariance by age* section). Of the models tested, a strong invariance model was preferred, in which equal unstandardized factor loadings were specified across age groups (see Figure 2). Although tasks loaded similarly on the latent executive control factor, the factor explained different amounts of variance in individual tasks at the two ages. Executive control, then, likely drives task performance somewhat differently with development. Most notably, the latent factor explained 43% and 53% of for the variance in younger preschool children's performance on the CPT and NEPSY Statue respectively, but only 31% and 32% for older children.

Discussion

The goal of this investigation was to better understand the structure of executive control in preschool children. A diverse battery of executive control tasks was administered to a sample of 243 children between 2.25 and 6 years of age. A series of models was tested via CFA to assess the utility of differing conceptualizations of executive control organization in explaining variability in children's task performance. The simplest model, a single Executive Control factor, was supported over other, multifactor models, in which tasks were parsed in terms of working memory and inhibitory control demands as well as alternative explanations regarding differences in nonexecutive skills. Simply put, no explanatory power was gained when multiple distinct factors were retained in the model.

The findings of a unitary model of executive control contrast with extant findings. Studies of older children and adults utilizing both EFA and CFA methods typically have supported the existence of multiple dimensions of executive control, the fractionation view, although these dimensions are by no means independent (e.g., Brookshire et al., 2004; Miyake et al., 2000). Because of the more limited behavioral repertoire of preschool children, the tasks used were simpler by necessity and therefore might be more homogeneous in executive demands than those used with adults. However, a cursory review of the tasks included in the present study contradicts this view. The responses required of children varied considerably, from simply standing still (NEPSY Statue) to searching for hidden rewards (Delayed Response), pressing a button (CPT), and providing a verbal response (Shape School). Furthermore, the models in which tasks were grouped on the basis of nonexecutive task demands did not result in a significant improvement in fit to the data.

Given that different components of executive control seem to be identifiable in school-age children, the single-factor executive control model may be specific to the preschool years. For example, for young children, inhibitory processes may be actively developing during this period and may not be fully mature until later in development. The design of the present study and the observed relation between age and missingness limit the conclusions that can be drawn regarding age invariance. However, the results of exploratory analyses indicate that the overall unitary executive control model could be fitted for both younger and older preschoolers, with relatively subtle differences in model specification

Figure 2 (opposite). Best fitting model for the full sample and for the sample split at age 4 years. Standardized factor loadings (λ) are given within each indicator box along with observed variable squared multiple correlations. Standardized residual variances (ε) are listed below each error term box. Note that for the panels depicting model differences across age, unstandardized factor loadings are constrained to equality, but standardized loadings differ because of differences in standard errors between age groups. 6B = Six Boxes task; CPT = Child Continuous Performance Test; DA = Delayed Alternation task; DR = Delayed Response task; DSP = Differential Abilities Scale Digit Span subscale; SSI = Shape School inhibit condition; ST = NEPSY Statue subscale; TOH = Tower of Hanoi; VA = NEPSY Visual Attention subscale (cats only).

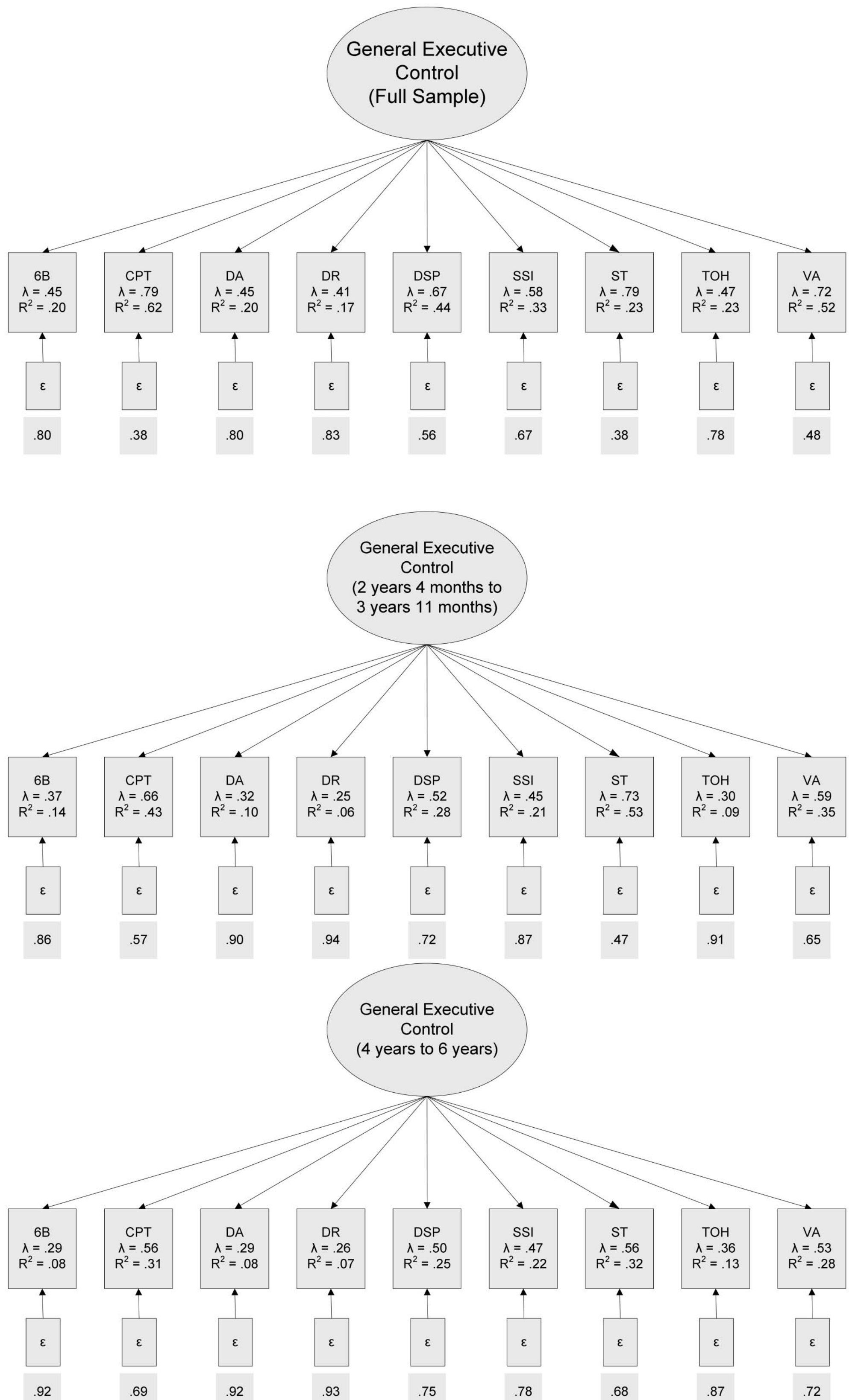

General Executive Control (Full Sample)
6B λ = .45 R2 = .20
CPT λ = .79 R2 = .62
DA λ = .45 R2 = .20
DR λ = .41 R2 = .17
DSP λ = .67 R2 = .44
SSI λ = .58 R2 = .33
ST λ = .79 R2 = .23
TOH λ = .47 R2 = .23
VA λ = .72 R2 = .52
ε
.80 .38 .80 .83 .56 .67 .38 .78 .48
General Executive Control (2 years 4 months to 3 years 11 months)
6B λ = .37 R2 = .14
CPT λ = .66 R2 = .43
DA λ = .32 R2 = .10
DR λ = .25 R2 = .06
DSP λ = .52 R2 = .28
SSI λ = .45 R2 = .21
ST λ = .73 R2 = .53
TOH λ = .30 R2 = .09
VA λ = .59 R2 = .35
ε
.86 .57 .90 .94 .72 .87 .47 .91 .65
General Executive Control (4 years to 6 years)
6B λ = .29 R2 = .08
CPT λ = .56 R2 = .31
DA λ = .29 R2 = .08
DR λ = .26 R2 = .07
DSP λ = .50 R2 = .25
SSI λ = .47 R2 = .22
ST λ = .56 R2 = .32
TOH λ = .36 R2 = .13
VA λ = .53 R2 = .28
ε
.92 .69 .92 .93 .75 .78 .68 .87 .72

Table 5
Tests of Invariance for the Best Fitting Confirmatory Factor Analysis Model

Model	χ^2	*df*	*p*	RMSEA	CFI	BIC	$\Delta\chi^2$	Δdf	Δp
Baseline	31.14	27	.27	.03	.989	4767.99			
Tests of invariance by sex									
M1	66.62	54	.12	.04	.965	4,969.07			
M2	71.35	62	.20	.04	.974	4,929.85	4.73	8	.79
M3	75.13	70	.32	.03	.986	4,889.68	3.78	8	.88
M4	83.09	79	.35	.02	.989	4,848.20	7.96	9	.54
M5	89.18	80	.23	.03	.974	4,848.81	6.09	1	.01
M6	99.45	81	.08	.04	.948	4,853.58	10.27	1	.001
Tests of invariance by maternal education									
M1	67.44	54	.10	.05	.965	4,975.90			
M2	74.38	62	.13	.04	.967	4,938.89	6.94	8	.54
M3	81.82	70	.16	.04	.969	4,902.39	7.44	8	.49
M4	89.46	79	.20	.03	.972	4,860.59	7.64	9	.57
M5	90.28	80	.20	.03	.973	4,855.92	0.82	1	.37
M6	93.43	81	.16	.04	.967	4,853.58	3.15	1	.08
Tests of invariance by age									
M1	69.69	54	.07	.05	.905	4,802.52			
M2	82.07	62	.04	.05	.879	4,770.96	12.38	8	.14
M3	89.71	70	.06	.05	.881	4,734.65	7.64	8	.47
M4	112.15	79	.008	.06	.800	4,707.65	22.44	9	.008

Note. RMSEA = root-mean-square error of approximation; CFI = comparative fit index; BIC = Bayesian information criterion; Baseline = no invariance constraints; M = Model; M1 = configural invariance; M2 = weak measurement invariance; M3 = strong measurement invariance; M4 = strict measurement invariance; M5 = equivalent latent variable variance–covariance matrices; M6 = equivalent latent variable means.

between the age groups, in that the portion of variability explained by the latent executive control factor differed for several tasks. If there were developmental differences in the underlying cognitive subprocesses that drive performance on executive control tasks early in life, substantial differences in model fit with advancing age would be expected. Testing for replication is needed in other preschool samples to further confirm this intriguing preliminary finding.

Some have argued that even in mature adults, a single cognitive process underlies performance on executive or frontally supported tasks (Duncan & Owen, 2000; Miller & Cohen, 2001). Duncan and Miller (2002) have proposed an adaptive coding model, in which prefrontal activation serves to bias neural processing in other regions of cortex, depending on the specific context. In this model, prefrontal neurons may boost the activation of subdominant information or responses, allowing them to "win out" over prepotent response tendencies and thereby be expressed in overt behavior. When behavior is dominated by prepotent responding, this response pattern may not necessarily be due to failure of inhibition but rather may result from failure to enhance the activation of the correct stimulus–response relation (Munakata, 1998; Miller & Cohen, 2001). In the preschool years, the connections between the correct stimuli and responses likely are weaker than in older children. At this age, then, the default prepotent response may be expressed across different contexts and degrees of conflict because the signal strength of the connection to the correct response is small in magnitude, and the immature nervous system of the preschool child may be less able to enhance the activation of the correct stimulus–response relation. In this framework, the common thread that characterizes executive control across tasks is the enhancement of relevant stimulus–response relations to achieve goal-oriented executive control of thought and action, whether the information to be sustained is "stand still" in the NEPSY Statue task, "look under the left cup on this trial" in the Delayed Response task, or "name only the characters with happy faces" in the Shape School task. This model may hold particular appeal in its potential to explain dysexecutive behavior in preschool children, who, across a variety of circumstances and tasks, typically provide the most obvious response.

The single-factor executive control model showed strict measurement invariance for boys and girls, although girls displayed higher absolute levels of latent executive control than did boys. Strict measurement invariance also was observed between children whose mother had only a high school education and those whose mother had college-level educational attainment. In contrast to sex-related differences in latent executive control, children whose mothers differed in educational attainment did not differ in the latent level of executive control. These findings contrast with those of Noble et al. (2005), which might be related to sampling or to our use of maternal education as a proxy for SES. It is important to note that the meaning of the executive control construct did not differ by this demographic characteristic.

Improved understanding of executive control will shed light on children's ability to achieve well-regulated, goal-directed thought and action more broadly. Effortful control is an important regulatory aspect of child temperament that underlies behavior in the everyday context (Rothbart, Ahadi, & Evans, 2000). Beyond executive control of cognition, development of the ability to regulate both positive and negative emotions is important for socialization and functioning in the broader societal context (Kochanska et al., 2000). The approach to executive control development taken in the present study is informed primarily by neuropsychological models of prefrontal function, although, clearly, executive control is but one aspect of the broader concept of self-regulation. Future efforts need to examine potential convergences with related self-regulatory behaviors in the socioemotional domains—for example, by linking children's executive control observed in the laboratory with self-regulatory abilities observed in the everyday context. Using the CFA approach applied here will help to reveal interrelations among self-regulatory processes across different contexts and methods.

Because executive control processes appear to be central in the etiology of externalizing behavior disorders (Nigg & Casey, 2005), the current findings have substantive clinical implications. For example, the observed sex difference in latent executive control, a more pure measure of the executive construct, may have clinical relevance given substantially higher risk for attention-deficit/hyperactivity disorder and disruptive behavior disorders in boys (Scahill & Schwab-Stone, 2000). The literature has been equivocal as to the nature of sex differences in executive control, with differences found for some types of tasks but not others (Overman et al., 1996; Seidman et al., 2005), despite the fact that the neural substrates of executive control, the prefrontal cortex, reach maturity more quickly in girls than in boys (Giedd et al., 1999). The noted differences in executive control likely better reflect true sex differences in the executive process common across all tasks, as the latent variable approach parses executive control from nonexecutive task demands, such as language, that may show sex-related differences.

There also are methodological implications for future studies of executive control in preschool children. Subtle differences in relations between individual tasks and the latent executive control process imply that different tasks are better indexes of executive control at different ages in the preschool age range. Carlson (2005) drew similar conclusions analyzing equated task performances by age group. To adequately measure developmental change or to detect performance impairments in clinical populations, selected tasks must be equally valid and comparably discriminative across groups. However, the age-related findings must be taken with caution because missing data were related to age, and the decision to split the sample at 4 years old was arbitrary, as children were recruited to cover the entire preschool age span. To address age effects with a cross-sectional design, researchers should explicitly select groups of children in narrow age bands. More critical, the fundamental question at issue is how executive control dynamically unfolds across development and how it supports key childhood competencies or marks problematic behaviors. As a first step to addressing these questions, children who vary in pertinent background characteristics need to be evaluated repeatedly with age with concurrent assessment of everyday behavior and functioning.

References

Baddeley, A., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.

Benes, F. M. (2001). The development of prefrontal cortex: The maturation of neurotransmitter systems and their interactions. In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 79–105). Cambridge, MA: MIT Press.

Bollen, K. A. (1989). *Structural equations with latent variables.* New York: Wiley.

Boone, K. B., Pontón, M. O., Gorsuch, R. L., González, J. J., & Miller, B. L. (1998). Factor analysis of four measures of prefrontal lobe functioning. *Archives of Clinical Neuropsychology, 13,* 585–595.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26,* 571–593.

Brookshire, B., Levin, H. S., Song, J. X., & Zhang, L. (2004). Components of executive function in typically developing and head-injured children. *Developmental Neuropsychology, 25,* 61–83.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 136–162). Newbury Park, CA: Sage.

Bull, R., Espy, K. A., & Senn, T. E. (2004). The Towers of London and Hanoi: Contributions of inhibition, switching and memory span in preschool children. *Journal of Child Psychology and Psychiatry, 45,* 743–754.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28,* 595–616.

Diamond, A. (1990). Developmental time course in human infants and infant monkeys, and the neural bases of inhibitory control of reaching. In A. Diamond (Ed.), *The development and neural bases of higher cognitive functions* (pp. 637–676). New York: New York Academy of Sciences.

Diamond, A. (2001). A model system for studying the role of dopamine in the prefrontal cortex during early development in humans: Early and continuously treated phenylketonuria. In C. A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 433–472). Cambridge, MA: MIT Press.

Diamond, A., & Doar, B. (1989). The performance of human infants on a measure of frontal cortex function, the delayed response task. *Developmental Psychobiology, 22,* 271–294.

Diamond, A., Prevor, M. B., Callender, G., & Druin, D. P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs of the Society for Research in Child Development, 62*(Serial No. 252).

Duncan, J., & Miller, E. K. (2002). Cognitive focusing through adaptive neural coding in the primate prefrontal cortex. In D. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 278–291). Oxford, England: Oxford University Press.

Duncan, J., & Owen, A. M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in Neuroscience, 23,* 475–483.

Elliott, C. D. (1990). *Differential Abilities Scale.* San Antonio, TX: Psychological Corporation.

Espy, K. A. (1997). The Shape School: Assessing executive function in preschool children. *Developmental Neuropsychology, 13,* 495–499.

Espy, K. A. (2004). Introduction: Executive control in preschool children. *Developmental Neuropsychology, 26,* 379–384.

Espy, K. A., Bull, R. B., Martin, J., & Stroup, W. (2006). Measuring the development of executive control with the Shape School. *Psychological Assessment, 18,* 373–381.

Espy, K. A., Kaufmann, P. M., McDiarmid, M. D., & Glisky, M. L. (1999). Executive functioning in preschool children: Performance on A-not-B and other delayed response format tasks. *Brain and Cognition, 41,* 178–199.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 133,* 101–135.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., et al. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience, 2,* 861–863.

Goldman, P. S., Rosvold, H. E., & Mishkin, M. (1970). Evidence for behavioral impairment following prefrontal lobectomy in the infant monkey. *Journal of Comparative and Physiological Psychology, 70,* 454–463.

Goldman, P. S., Rosvold, H. E., Vest, B., & Galkin, T. W. (1971). Analysis of the delayed-alternation deficit produced by dorsolateral prefrontal lesions in the rhesus monkey. *Journal of Comparative and Physiological Psychology, 77,* 212–220.

Gorsuch, R. L. (1983). *Factor analysis* (2nd ed.). Hillsdale, NJ: Erlbaum.

Gorsuch, R. L. (1997). Exploratory factor analysis: Its role in item analysis. *Journal of Personality Assessment, 68,* 532–560.

Harnishfeger, K. K., & Bjorklund, D. F. (1993). The ontogeny of inhibition mechanisms: A renewed approach to cognitive development. In M. L. Howe & R. Pasnak (Eds.), *Emerging themes in cognitive development: Vol. 1. Foundations* (pp. 28–49). New York: Springer-Verlag.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling, 6,* 1–55.

Hughes, C. (1998). Finding your marbles: Does preschoolers' strategic behavior predict later understanding of mind? *Developmental Psychology, 34,* 1326–1339.

Huttenlocher, P. R. (1990). Morphometric study of human cerebral cortex development. *Neuropsychologia, 28,* 517–527.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. *Psychonomic Bulletin & Review, 9,* 637–671.

Kerns, K. A., & Rondeau, L. A. (1998). Development of a continuous performance test for preschool children. *Journal of Attention Disorders, 2,* 229–238.

Kim, S., Brody, G. H., & Murry, V. M. (2003). Factor structure of the Early Adolescent Temperament Questionnaire and measurement invariance across gender. *Journal of Early Adolescence, 23,* 268–294.

Kirkham, N. Z., Cruess, L. M., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science, 6,* 449–467.

Klenberg, L., Korkman, M., & Lahti-Nuuttila, P. (2001). Differential development of attention and executive functions in 3- to 12-year-old Finnish children. *Developmental Neuropsychology, 20,* 407–428.

Kochanska, G., Murray, K., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology, 36,* 220–232.

Kochanska, G., Murray, K., Jacques, T. Y., Koenig, A. L., & Vandegeest, K. A. (1996). Inhibitory control in young children and its role in emerging internalization. *Child Development, 67,* 490–507.

Korkman, M., Kirk, U., & Kemp, S., (1998). *NEPSY: A developmental neuropsychological assessment.* San Antonio, TX: Psychological Corporation.

Lamar, M., Zonderman, A. B., & Resnick, S. (2002). Contributions of specific cognitive processes to executive functioning in an aging population. *Neuropsychology, 16,* 156–162.

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology, 21,* 59–80.

Little, R. J., & Rubin, D. B. (2002). *Statistical analysis with missing data* (2nd ed.). New York: Wiley.

Meredith, W. (1993). Measurement invariance, factor analysis and factorial invariance. *Psychometrika, 58,* 525–543.

Miller, E., & Cohen, J. (2001). An integrative theory of prefrontal cortex function. *Annual Reviews of Neuroscience, 24,* 167–202.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49–100.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, M. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology: General, 130,* 621–640.

Munakata, Y. (1998). Infant perseveration and implications for object permanence theories: A PDP model of the A-not-B task. *Developmental Science, 1,* 161–184.

Munakata, Y., Morton, J. B., & Yerys, B. E. (2003). Children's perseveration: Attentional inertia and alternative accounts. *Developmental Science, 6,* 471–473.

Murray, K. T., & Kochanska, K. (2002). Effortful control: Factor structure and relation to externalizing and internalizing behaviors. *Journal of Abnormal Child Psychology, 30,* 503–514.

Muthén, L. K., & Muthén, B. O. (2006). *Mplus user's guide* (4th ed.). Los Angeles: Muthén & Muthén.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126,* 220–246.

Nigg, J. T., & Casey, B. J. (2005). An integrative theory of attention-deficit/hyperactivity disorder based on the cognitive and affective neurosciences. *Development and Psychopathology, 17,* 785–806.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8,* 74–87.

Overman, W. H., Bachevalier, J., Schuhmann, E., & McDonough-Ryan, P. (1996). Cognitive gender differences in very young children parallel biologically based cognitive gender differences in monkeys. *Behavioral Neuroscience, 110,* 673–684.

Paus, T., Collins, D. L., Evans, A. C., Leonard, G., Pike, B., & Zijdenbos, A. (2001). Maturation of white matter in the human brain: A review of magnetic resonance studies. *Brain Research Bulletin, 54,* 255–266.

Pineda, D. A., & Merchan, V. (2003). Executive function in young Colombian adults. *International Journal of Neuroscience, 113,* 397–410.

Raftery, A. E. (1993). Bayesian model selection in structural equation models. In K. A. Bollen & J. S. Long (Eds.), *Testing structural equation models* (pp. 163–180). Newbury Park, CA: Sage.

Robbins, T. W. (1998). Dissociating executive functions of the prefrontal cortex. In A. C. Roberts, T. W. Robbins, & L. Weiskranz (Eds.), *The prefrontal cortex: Executive and cognitive functions* (pp. 117–130). Oxford, England: Oxford University Press.

Robbins, T. W., James, M., Owen, A. M., Sahakian, B. J., Lawrence, A. D., McInnes, L., & Rabbitt, P. M. A. (1998). A study of performance on tests from the CANTAB battery sensitive to frontal lobe dysfunction in a large sample of normal volunteers: Implications for theories of executive functioning and cognitive aging. *Journal of the International Neuropsychological Society, 4,* 474–490.

Rothbart, M. K., Ahadi, S. A., & Evans, D. E. (2000). Temperament and personality: Origins and outcomes. *Journal of Personality and Social Psychology, 78,* 122–135.

Scahill, L., & Schwab-Stone, M. (2000). Epidemiology of ADHD in school-age children. *Child and Adolescent Psychiatric Clinics of North America, 9,* 541–555.

Seidman, L. J., Biederman, J., Monuteaux, M. C., Valera, E., Doyle, A. E., & Faraone, S. V. (2005). Impact of gender and age on executive functioning: Do girls and boys with and without attention deficit hyperactivity disorder differ neuropsychologically in preteen and teenage years? *Developmental Neuropsychology, 27,* 79–105.

Simon, H. A. (1975). The functional equivalence of problem solving skills. *Cognitive Psychology, 7,* 268–288.

Stevens, J. P. (2001). *Applied multivariate statistics for the social sciences* (4th ed.). Mahwah, NJ: Erlbaum.

Strauss, M. E., Thompson, P., Adams, N. L., Redline, S., & Burant, C. (2000). Evaluation of a model of attention with confirmatory factor analysis. *Neuropsychology, 14,* 201–208.

Stuss, D. T. (1992). Biological and psychological development of executive functions. *Brain and Cognition, 20,* 8–23.

Stuss, D. T., & Levine, B. (2002). Lessons from studies of the frontal lobes. *Annual Review of Psychology, 53,* 401–433.

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology, 7,* 131–149.

Widaman, K. F., & Reise, S. P. (1997). Exploring the measurement invariance of psychological instruments: Applications in the substance abuse domain. In K. J. Bryant, M. Windle, & S. G. West (Eds.), *The science of prevention: Methodological advances from alcohol and substance abuse research* (pp. 281–324). Washington, DC: American Psychological Association.

Zacks, R. T., & Hasher, L. (1994). Directed ignoring: Inhibitory regulation of working memory. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 241–264). San Diego, CA: Academic Press.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11,* 37–63.

Received November 3, 2006
Revision received August 31, 2007
Accepted September 11, 2007 ■