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K. A. Espy
University of Nebraska-Lincoln, kespy2@unl.edu

R. B. Bull

J Martin

W. Stroup
University of Nebraska-Lincoln, wstroup1@unl.edu

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Measuring the Development of Executive Control With the Shape School

Kimberly Andrews Espy
University of Nebraska—Lincoln

Rebecca Bull
University of Aberdeen

Jessica Martin
Southern Illinois University School of Medicine

Walter Stroup
University of Nebraska—Lincoln

Although several neurodevelopmental and psychiatric disorders can emerge during the preschool period, there are comparatively few instruments to assess executive control. Evidence for validity of the Shape School (K. A. Espy, 1997) was examined in a sample of 219 typically developing young children. There was good evidence for validity, as Shape School performance variables were interrelated and were associated to other criterion measures considered to measure aspects of executive control. Also suggesting validity, the Shape School variables varied as a function of whether the task demands (a) were executive, (b) required inhibition of a prepotent response or context-controlled selection among relevant stimulus–response sets, and (c) included unitary or concurrent processing. The Shape School may be an effective tool by which to measure executive control in young children who have atypical developmental patterns.

Keywords: executive function, cognitive assessment, preschoolers, hierarchical linear modeling

Despite widespread recognition that executive control develops significantly during the preschool years; plays a central role in cognition, academic learning, and social behavior (e.g., Bull, Johnston, & Roy, 1999; Desimone & Duncan, 1995; Espy, McDiarmid, Cwik, Senn, Hamby, & Stalets, 2004; Gathercole & Pickering, 2000; Hughes, 1998b; Hughes, White, Sharpen, & Dunn, 2000; Isquith, Gioia, & Espy, 2004); and is affected in those who have diverse clinical disorders (e.g., Anderson, Anderson, Grimwood, & Nolan, 2004; Espy, Kaufmann, & Glisky, 1999; Espy et al., 2002; Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004; Pennington & Ozonoff, 1996), there are few validated instruments available to measure these abilities. Young children have a more limited knowledge base, are less verbally proficient, are more impulsive, and have more difficulty attending, factors that constrain their performance on complex executive tasks. Thus, modern efforts have focused on careful design of developmentally appropriate tasks that engage young children in order to better capture their executive abilities.

Although there are many different models of executive control, the most prominent in pediatric clinical neuropsychology include a fractionated-ability structure of working memory, inhibitory control, and adaptive shifting/rule-governed behavior (e.g., Anderson, 1998; Levin et al., 1996; Welsh, Pennington, & Groisser, 1991). What the various accounts differ in is the relative weights ascribed to these executive constructs and when or how they are combined, whether they are differentially localized within the brain, and when or how they develop during childhood. In contrast, recent studies in developmental cognitive neuroscience have manipulated specific task demands (e.g., increasing working memory load, decreasing inhibitory demands) to characterize executive control organization (e.g., Diamond, Briand, Fossella, & Gehlbach, 2004; Espy, 1997; Zelazo, Mueller, Frye, & Marcovitch, 2003).

Regardless of the executive control model utilized, studies of normative executive control in preschool children use several paradigms: (a) rule-governed, attribute-based sorting tasks (e.g., Espy, Kaufmann, McDiarmid, & Glisky, 1999; Hughes, 1998a; Dimensional Change Card Sort [DCCS], as discussed in Zelazo, Frye, & Rapus, 1996); (b) manual selection or verbal naming of stimuli that conflict or interfere on the basis of natural associations (e.g., Carlson & Moses, 2001; Diamond, Kirkham, & Amso, 2002; Wright, Waterman, Prescott, & Murdoch-Eaton, 2003); and (c) manual search tasks that impose working memory demands (e.g., Diamond, Prevor, Callender, & Druin, 1997; Espy, Kaufmann, Glisky, & McDiarmid, 2001; Hughes, 1998a) or inhibiting prepotent or prohibited somatic motor responses (e.g., Carlson & Moses, 2001; Espy, Kaufmann, McDiarmid, & Glisky, 1999; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Reed, Pien, &

Kimberly Andrews Espy, Office of Research & Graduate Studies and the Department of Psychology, University of Nebraska—Lincoln; Rebecca Bull, School of Psychology, University of Aberdeen, Aberdeen, Scotland; Jessica Martin, Department of Family & Community Medicine, Southern Illinois University School of Medicine; Walter Stroup, Department of Statistics, University of Nebraska—Lincoln.

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Correspondence concerning this article should be addressed to Kimberly Andrews Espy, Associate Vice Chancellor for Research, 303 Canfield Administration Building, University of Nebraska—Lincoln, Lincoln, NE 68688-0433. E-mail: kespy2@unl.edu

Rothbart, 1984). Note that these tasks vary along several dimensions.

The first of these dimensions is the type of inhibition required. In some tasks, the child must suppress somatic motor responses, for example, by remaining still while the examiner tries to distract him or her. In others, inhibition is more "cognitive"; that is, an internally represented rule or response set that had been previously active must be disengaged subsequently and controlled if the child is to engage and implement another response. Friedman and Miyake (2004) found evidence for this distinction using structural equation modeling to parse normative adult performance on those tasks that require inhibiting a prepotent response or resisting interference from distraction that is irrelevant to the current task from those involved in resistance to proactive interference from a previously active rule or response set. However, Diamond recently has argued that a common mechanism, "attentional inertia," underlies the classic dysexecutive behavior that young children display across tasks (Kirkham, Cruess, & Diamond, 2003). In an argument akin to the "task-set inertia" concept from the adult cognitive literature (e.g., Allport, Styles, & Hsieh, 1994), she states that performance is disrupted when the young child's attention gets pulled away from the response set at hand by conflicting stimulus properties, thereby leading to the classic dissociation between knowledge and action. Inhibition resolves the conflicts among stimulus properties, response mappings, and current context demands, allowing the child to select and activate one rule or response in one context, then cognitively disengage when the context changes, and in turn select another competing but now-relevant response or set (Miller & Cohen, 2001). In these studies, in which inhibition can be described as context-controlled selection, a manual response often is the response method (e.g., button press), but it is not itself a target of inhibition per se. It remains to be determined empirically how "attentional inertia" might operate in the intentional suppression of a somatic motor response, or whether in fact these two inhibitory processes are distinguishable in young children (Bishop, Aamodt-Leaper, Creswell, McGurk, & Skuse, 2001; Nigg, 2000).

Second, the nature of the conflict varies. In tasks requiring suppression of executive motor response, conflict often is with a prohibited action or previously rewarded response. In "Day–Night" (Gerstadt, Hong, & Diamond, 1994), Luria's Tapping task (Diamond & Taylor, 1996), and Dots (Diamond et al., 2004), the executive demands require a response that is counter to the "natural" stimulus–response mapping that is built from the everyday sensory, motor, and linguistic environment (e.g., saying "night" to a picture of the sun in the sky). In contrast, the DCCS utilizes conflict between the stimuli properties and the required response, but the conflict between the two dimensions is arbitrary (e.g., color is not inherently related to shape). Conflict demands appear critical to invoking executive control, as some postulate that it is the conflict between stimulus–response mappings and new reward contingencies that drives prefrontal activation (e.g., Miller, 2000; O'Reilly, Noelle, Braver, & Cohen, 2002). For example, 3-year-olds can sort the conflicting cards successfully when the second dimension is not present (Brooks, Hanauer, Padowska, & Rosman, 2003) or is irrelevant to sorting (Perner & Lang, 2002; Rennie, Bull, & Diamond, 2004), or when the response is not canonically related (Diamond et al., 2002).

The demands on working memory and short-term storage also vary, with tasks such as Six Boxes (Diamond et al., 1997) and Noisy Book (Hughes, 1998a) involving significant storage demands, whereas others, including various delay tasks (e.g., Carlson & Moses, 2001; Kochanska et al., 1996), appear to require little information to be retained online to guide subsequent performance.

Finally, most executive tasks for preschoolers developed to date are nonverbal—an advantage for assessing young preschool children with less mature verbal skills. However, given the rapid increase in verbal proficiency in this age range, and the importance of executive skills in the more verbally laden academic context in the transition to formal schooling, it would be useful to have tools to assess individual variances in executive abilities that utilize verbal material. Performance on such tasks may be more highly related to outcomes of interest that load heavily on verbal skills, such as reading and mathematics.

Because a central interest in the cognitive developmental literature has been to characterize at what age a child "passes" or "fails" a given task, the sensitivity of many experimental tasks is restricted to a narrow age range. Such tasks are not well suited to clinical use in evaluating children of varying ages. Furthermore, basic psychometric properties, such as reliability and validity, have not been studied, a process critical in the clinical context where "high stakes" judgments about individual children are made. Determining reliability for executive tasks is complicated, however, as novelty, salience, and difficulty play important roles in invoking executive control, both on cognitive (e.g., O'Reilly et al., 2002) and neural levels (e.g., Barch et al., 1997; Casey et al., 2001). The purpose of this study, then, was to investigate evidence for validity of a newly developed measure of executive control, the Shape School (Espy, 1997), in a large, diverse sample of young children, first by examining internal association and variable interrelations, then by investigating predictive associations with other commercially available, validated executive tasks, and finally by determining task sensitivity to differing executive demands and to individual background characteristics.

Method

Participants

The sample was composed of 219 typically developing children who ranged in age from 3 years 6 months to 6 years 1 month ($M = 4.82$ years, $SD = 0.50$ years). There were 119 girls (54%) and 100 boys. Consistent with the demographics of the local area, 85% ($n = 187$) of the sample was Caucasian. Of those of minority race/ethnicity, 22 children were African American, 8 were Asian, and 2 were of mixed race. None of these children were diagnosed with any neurological, psychiatric, or developmental disorders, determined on the basis of parental report. Children varied with respect to vocabulary skills (assessed by either the available Picture Vocabulary subtest from the Woodcock–Johnson Psycho-Educational Battery—Revised (WJ–R; Woodcock & Johnson, 1989; $n = 112$) or the Vocabulary subtest from the Wechsler Preschool and Primary Scale of Intelligence—Revised (WPPSI–R; Wechsler, 1990; $n = 113$). Both of these tasks assess vocabulary. In the WPPSI–R, items progress from picture identification to definition of word meaning. The WJ–R is composed entirely of picture identification items. The average standard score was 106.22 ($SD = 12.90$). As there was no difference in the standard scores derived from these two instruments, $F(1, 213) = 0.06$, $p > .80$, and the instruments utilize the same metric (expected mean and standard deviation), scores were pooled for the purposes of investigation of individual differences in performance.

Materials

Shape School. The Shape School (Espy, 1997) is designed to assess different aspects of executive control in young children using colorful, affectively engaging stimuli presented in an age-appropriate and appealing format, a storybook. The story has four parts, which constitute Conditions A, B, C, and D. Each child participates in all four conditions and always in the same fixed order. The story begins by setting up the premise, showing stimulus figures (colored squares and circles with cartoon faces, arms, and legs) playing on a playground. After being introduced to one class of children, whose "names" are their colors, the child names each stimulus figure color, which allows the test conductor to assess whether the child can reliably recognize and name the colors. As the story continues, the child is told that the story figures are lining up to go into the play yard. In this control condition, Condition A, the child names the color of each of the figures, which are arranged in three lines of five across the page. This condition serves two purposes, to measure baseline naming speed and, more important, to establish the relation between stimulus properties (color) and response (naming stimulus color). The fact that conflicting shape information is present in each stimulus but is not yet identified as relevant enables direct condition comparisons.

In Condition B, the story line continues with it being lunchtime, where not all of the figures have finished their work. "Happy" and "sad/frustrated" expressions are added to the faces of the stimulus figures to depict those who have completed their work and those who have not, respectively. The child is instructed to call the names of the figures who have finished their work to proceed to lunch and not to call the names of those who are not ready. In the same configuration of three rows of five figures each, there are nine happy-faced stimuli requiring the color-naming response and six sad/frustrated-faced stimuli requiring response suppression.

A second classroom is introduced in Condition C, in which the stimulus figures wear hats. The child is instructed that the names of the hatted pupils are the figure shapes and that the names of the hatless pupils remain the stimulus figure colors. After practice with six stimulus figures, the child is told that the figures are in line to go to storytime; the child then names the shapes of the figures with hats and colors of the hatless figures in the three row by five figure configuration. There are eight figures without hats and seven with hats interspersed randomly, and the child must switch between naming hatted figure color and hatless figure shape as cued, respectively. Finally, in Condition D, the "happy" and "sad" expressions are reintroduced for both hatted and hatless figures, with the child instructed that not all figures are ready to participate in art. The child has to concurrently suppress naming the "sad/frustrated" figures (hatted and hatless), name the shapes of the hatted, happy-faced figures, and name the colors of the hatless, happy-faced figures. There are five hatless, happy-faced figures; three hatted, happy-faced figures; three hatted, sad-faced figures; and four hatless, sad-faced figures, again interspersed across the three row by five figure array. A summary description of the Shape School tasks and the hypothesized demands is in Table 1.

In all conditions, children are not allowed to proceed to the test page array unless they have named the characters successfully on the practice page, a step taken to ensure adequate rule knowledge prior to application. The experimenter records the number of stimuli correctly identified according to the pertinent rule (accuracy) and the time to complete naming the pertinent stimuli in the array (latency) for each of the conditions. A simple stopwatch is used to record latency for the child to name all relevant stimuli on the page.

Statue. Statue is an attention/executive function NEPSY subtest (Korkman, Kirk, & Kemp, 1998). The child stands in a set position (i.e., with eyes closed, without body movements or vocalizations) pretending to hold a flag for a 75-s period. At set intervals, the examiner coughs, knocks on the table, drops a pencil, or says "Ho Hum!" as a distraction to induce the child to break the still posture. For each 5-s epoch, the child is awarded 2 points if there is no inappropriate response (i.e., the eyes are kept shut and there is no body movement or vocalization), 1 point if there is one inappropriate response, and 0 points if there is more than one inappropriate response, with a maximum score of 30. The reported NEPSY Statue

Table 1
Summary of Shape School Conditions

Condition and task description	Hypothesized demands
A	
Name figure colors	Maintain S–R rules online Attend to relevant attributes Access semantic stores Expressive naming
B	
Name colors of happy-faced figures Inhibit naming of sad/frustrated-faced figures	Maintain S–R rules online Attend to relevant attributes Access semantic stores *Response suppression* Expressive naming
C	
Name colors of hatless figures Name shapes of hatted figures	Maintain S–R rules online Attend to relevant attributes Access semantic stores *Context-controlled selection* Expressive naming
D	
Name colors of happy-faced, hatless figures Inhibit naming of sad/frustrated-faced, hatless figures Name shapes of happy-faced, hatted figures Inhibit naming of sad/frustrated-faced, hatted figures	Maintain S–R rules online Attend to relevant attributes Access semantic stores *Concurrent context-controlled selection* Response suppression Expressive naming

Note. S–R = stimulus–response. Unique demands are noted in italics.

test–retest correlation is .50 in 3- to 4-year-olds and .75 in 5- and 6-year-olds.

Visual Attention (VA). In this second attention/executive function NEPSY subtest, the child is instructed to find the items that match the target stimuli among a page of targets and distractors. In the standard NEPSY administration, VA includes different arrays for children ages 3 and 4 years versus those ages 5 years and above. Only the random cat array is common to both age groups. Therefore, for the purposes of this study, the number of targets (maximum 20 cats) correctly identified and completion time (maximum 180 s) from the random cat array only were scored to enable comparison across the full age spectrum. The reported test–retest reliability for VA was .69 in 3- and 4-year-olds and .71 in 5- and 6-year-olds.

Digit Span. After an initial practice session, a standard sequence of digits is presented auditorily, starting from a span length of two. Each child is required to recall the digit strings in the order of presentation, with a maximum of two trials at each string length. Maximum digit span length is recorded. The reported reliability coefficients for all ages exceeded 0.85 (Elliott, 1990).

Procedure

A trained child-clinical graduate student blind to the experimental hypotheses administered the Shape School and the criterion tests to preschool children in a single session. The children were assessed individually in a quiet room, with the parent or guardian present (completing study forms). Short breaks were used when necessary to maintain cooperation and interest. Parents were compensated for study participation, and the children received a bag of developmentally appropriate toys, stickers, and other small items.

Design

Evidence for validity was examined first by considering internal association (Cronbach's alpha) and the pattern of intra- and intercondition correlations among the Shape School variables. Predictive validity was considered by comparing the relations between performance on the Shape School and performance on standardized tests specifically considered to measure executive abilities in this age range, namely NEPSY Attention/Executive Function Domain subtests and Digit Span. These standardized tasks were chosen as a "first pass" to establish evidence for predictive validity of the Shape School because (a) they have known psychometric properties and (b) they are commercially available to clinicians and researchers, thereby providing a shared, widespread basis for evaluation and comparison (e.g., Friedman & Miyake, 2004). Furthermore, all criterion measures provide a distributed range of scores that better captures the range of executive skills among young children, unlike the nonstandardized, experimental DCCS, which is scored on a pass–fail basis.

Finally, evidence for validity was investigated by determining whether Shape School performance differed by executive task demands and individual differences in child characteristics. In Condition A, basic psychomotor naming speed of simple stimulus–response mappings can be disambiguated from the additional executive abilities utilized in Conditions B, C, and D. Therefore, evidence for validity was supported if performance differed between the control condition, A, and the executive conditions, B, C, and D. In Condition B, a cue is provided to indicate when the child should suppress the color-naming response. Then in Condition C, the child must utilize the second conflicting dimension (shape) to name the relevant cued stimuli, which are intermixed with stimuli that are named by the first dimension (color). Because both conditions include (a) a relatively constant working memory load of maintaining two rules in mind with overt cues present that signal the correct stimulus–response mapping and (b) proactive interference from the same previously active response set, we believed condition-related performance differences would shed light on the nature of inhibitory processes. Evidence for validity was provided if performance differed between Condition B (response suppression) and Condition C (context-controlled selection). Finally, complexity, whether at the level of the stimulus (Brooks et al., 2003; Perner & Lang, 2002), response (Rennie et al., 2004), or stimulus–response mapping rule (Zelazo et al., 2003), affects executive task performance. At the most basic level, complexity can be operationalized as performing a task with uniquely specific demands in a single block, versus performing the task demands concurrently, where specific task demands are interleaved. In the Dots task, for example, children homozygous for the Met/Met allele for the catechol-O-methyltransferase genotype made more errors only in the mixed condition, relative to children homozygous for the Val/Val allele, suggesting that concurrent execution required more executive engagement (Diamond et al., 2004). Evidence for validity was supported if Condition D performance, where children must both suppress responses and select response sets in the relevant context, differed from that of the average of the single-block conditions, B and C.

Because executive control develops rapidly in preschoolers, these three theoretically derived, a priori condition comparisons were evaluated simultaneously beyond any background individual differences due to child age or sex, using hierarchical linear modeling (SAS Proc Mixed, v8, maximum likelihood estimation). This approach offers several advantages over traditional analysis of variance, the most relevant of which is allowing the examination of the relative contribution of within- and between-subject sources of variation in task performance. In these analyses, age was centered at 4.5 years (the sample mean age), and the Bonferroni correction was applied to maintain familywise alpha, in which $\alpha_{\text{critical}} = (.05/3) = .0125$ for each planned comparison. Consistent with previous investigations, strong age-related performance differences in latency were expected on the Shape School indexes, given the young age range sampled. Because the Shape School is hypothesized to measure executive skills comparably across the age range studied, condition-related performance differences (Age × Condition interactions) were not expected to vary with child age. Although young girls often demonstrate more advanced language skills than young boys do, most studies have not found sex-related executive performance differences in preschoolers (e.g., Espy et al., 2001). Hence, such differences were not expected to be evident on the Shape School indexes, nor was Shape School condition performance expected to vary by sex.

Finally, the role of child vocabulary skills in Shape School performance was explored. Given the verbally laden, material-specific format of the Shape School, overall performance might vary by child vocabulary; furthermore, these differences in proficiency might be more evident in the executive conditions, related to facilitated automaticity and retrieval. In contrast to age and sex, which are static demographic covariates endemic to the child, vocabulary skills develop dynamically across age and are effects of interest. Therefore, these exploratory analyses were conducted by sequentially adding the effect of vocabulary to the existing models, which also included the age and sex covariates.

Results

First, Cronbach's alpha coefficients computed with the responses to each of the stimuli within each condition revealed adequate association in the executive conditions, Conditions B ($\alpha = .71$), C ($\alpha = .80$), and D ($\alpha = .74$). In Condition A ($\alpha = .56$), the coefficient likely was attenuated due to the high level of naming accuracy in this very simple condition. Then, correlations among Shape School condition-respective accuracies and latencies were calculated, with Table 2 showing the correlations within each dependent variable for each Shape School condition. Note the interrelations among the respective accuracies from the executive conditions, B, C, and D. Condition A accuracy was not related to that of B, C, and D, although again, this correlation likely was attenuated due to low variability. In contrast, respective latencies were interrelated among all Shape School conditions. In Condition A, there was no relation between accuracy and latency ($r_A = -.04$, $p_A > .52$), suggesting that deploying the simple stimulus–response rule did not require any trade-off in accuracy to achieve speeded naming. In contrast, there was evidence for such a trade-off in Conditions B and D, in which the number of correctly identified stimuli and completion time were associated ($r_B = -.18$, $p_B < .01$; $r_D = -.20$, $p_D < .01$). It was interesting to note that there was a marginal relation between Condition C accuracy and latency ($r_C = .12$, $p_C < .09$), with children who named more stimuli correctly taking longer to complete the condition.

The relationships between Shape School performance and the criterion measures are depicted in Table 3. Only Condition A performance was related to the Statue raw score, with children who were able to maintain the fixed "statue" position for longer durations taking less time to complete Shape School Condition A. VA random cat array performance was related to the respective Shape School Conditions B, C, and D latencies; those children who correctly identified more cats took less time to complete these conditions. After the experimenters controlled for Condition A baseline naming speed, the number of VA cats the children identified was still related to latency for Shape School Conditions B, C, and D ($r_B = -0.22$, $p < .01$; $r_C = -.21$, $p < .01$; and $r_D = -.26$, $p < .01$). It is interesting that the number of cats correctly identified was also associated with Condition C accuracy. Not surprisingly, completion time of the VA random cat array was correlated with all the Shape School condition latencies. When baseline naming speed in Condition A was controlled, only the relation between the latency to complete the random VA cat array and Shape School Condition C persisted ($r_C = .19$, $p < .02$). The magnitude of the associations between the respective Condition A, B, and C latencies and the criterion measures did not differ by criterion measure, $F_A(3, 141) = 0.15$, $p > .93$; $F_B(3, 141) = 1.24$, $p > .30$; $F_C(3, 141) = 1.16$, $p > .33$; nor by condition, $F_{\text{Digit Span}}(3, 181) = 1.22$, $p > .30$; $F_{\text{Statue}}(3, 162) = 1.07$, $p > .36$; $F_{\text{VA targets}}(3, 151) = 1.36$, $p > .25$; and $F_{\text{VA time}}(3, 151) = 0.14$, $p > .93$. For Condition D latency, the correlation magnitudes differed marginally by criterion measure, $F_D(3, 141) = 2.54$, $p < .06$, where the correlation between Condition D latency and the number of VA cats correctly identified was larger than the respective correlation with Statue, $F_D(1, 149) = 7.49$, $p < .007$.

Table 2
Correlations Among Shape School Variables by Condition

Condition	A	B	C	D
		Stimuli correctly identified		
A	—			
B	−.03	—		
C	.02	.30****	—	
D	.01	.40****	.55****	—
		Completion time		
A	—			
B	.41****	—		
C	.39****	.33****	—	
D	.41****	.44****	.53****	—

Note. $N = 219$.
$^{****}p < .0001$.

Table 3
Shape School Bivariate Correlations With Criterion Measures

Condition and Shape School index	Digit Span[a]	Statue[b]	VA cat targets[c]	VA cat time[d]
A				
Accuracy	−.01	−.11	−.04	.05
Latency	.06	.18*	.12	.15
B				
Accuracy	.08	.00	.05	.01
Latency	.19**	.06	.25**	.20**
C				
Accuracy	.26****	.07	.19*	.06
Latency	.15*	.08	.24**	.19*
D				
Accuracy	.12	.07	.08	.04
Latency[e]	.10	.03	.29***	.17*

Note. For magnitude comparisons, all variables were transformed to *z* scores to render standard deviations on the same metric. All time variables were multiplied by −1. VA = Visual Attention.
[a] $N = 185$, $M = 3.81$, $SD = 0.89$. [b] $N = 166$, $M = 22.38$, $SD = 7.59$. [c] $N = 155$, $M = 17.74$, $SD = 2.77$. [d] $N = 155$, $M = 83.88$, $SD = 32.67$. [e] Correlation magnitude varied by criterion measure, where correlation with the number of targets correctly identified on the Visual Attention cat array was significantly greater ($p < .05$) than that with Statue.
$^{*}p < .05$. $^{**}p = < .01$. $^{***}p = < .001$. $^{****}p < .0001$.

An unconditional means model revealed significant within-person variation in Shape School performance in both accuracy ($\sigma_\varepsilon^2 = 0.51$, $SE = 0.19$, $z = 2.71$, $p < .01$) and latency ($\sigma_\varepsilon^2 = 73.55$, $SE = 16.17$, $z = 4.55$, $p < .0001$). Between-person effects in accuracy ($M = 13.38$, $SE = 0.09$), $t(218) = 146.73$, $p < .0001$, and latency ($M = 35.84$, $SE = 0.86$), $t(218) = 41.79$, $p < .0001$, also were nonzero. In the conditional models that included the effects of the child's age and sex covariates and those of the pertinent within-subject effect of condition, there was substantial within-person variation in accuracy ($\sigma_0^2 = 1.01$, $SE = 0.18$, $z = 5.72$, $p < .0001$). Although neither covariate was related to performance (both $ps > .05$), Shape School accuracy differed as a function of condition, $F(3, 645) = 60.61$, $p < .0001$. Condition-related differences in accuracy, however, did not differ by child age, $F(3, 645) = 1.89$, $p > .13$; sex, $F(3, 645) = 1.23$, $p > .29$; or the interaction of age and sex, $F(4, 645) = 0.14$, $p > .96$. Condition-related performance accounted for 41.87% of the individual variation in Shape School accuracy, on average, beyond that related to the covariates.[1] In like fashion, the inclusion of the within-subject condition term in addition to the child age and sex covariates resulted in significant within-person variation in latency ($\sigma_0^2 = 105.90$, $SE = 14.90$, $z = 7.11$, $p < .0001$). As with accu-

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[1] Pseudo-R^2 is the proportion reduction in residual variance as predictors are added to a model; that is, it is the variation difference between a full and a more restricted model. As such, these pseudo-R^2 values do not sum, as the pool of available variance depends on the two models selected for comparison. For additional information, see Singer and Willett (2003).

racy, Shape School latency differed by condition, $F(3, 645) = 196.63$, $p < .0001$; although these condition-related latency differences did not vary by child age, $F(3, 645) = 1.63$, $p > .18$; sex, $F(3, 645) = 0.41$, $p > .74$; or the interaction of age and sex, $F(4, 645) = 0.52$, $p > .71$. Condition-related latency accounted for 47.15% (see Footnote 1) of individual performance variation above that of the covariates. Furthermore, as hypothesized, the child's age was related to Shape School latency ($\gamma = -7.32$, $SE = 2.85$), $t(645) = -2.57$, $p < .01$, whereas sex was not ($\gamma = -0.11$, $SE = 2.78$), $t(645) = -0.04$, $p > .97$. In both of these models, the significant main effect of the condition provides the basis to further pursue evidence for validity by examining the a priori condition contrasts.

In the first a priori contrast examining sensitivity to executive demands, both accuracy, $t(645) = 9.78$, $p < .0001$, and latency, $t(645) = 11.58$, $p < .0001$, differed between the executive (average of Conditions B, C, and D) and control (Condition A) conditions, consistent with our hypothesis. Young children named nearly all of the control Condition A stimuli correctly, on average ($M = 14.93$ stimuli, $SE = 0.14$), $t(645) = 109.64$, $p < .0001$. The "cost" on naming accuracy of the added executive demands across Conditions B, C, and D was −2.10 stimuli ($SE = 0.21$), $t(645) = -9.78$, $p < .0001$, resulting in an expected value of 12.82 stimuli correctly named across executive conditions. A similar pattern was evident for latency, where the expected completion time was 22.78 s ($SE = 1.15$), $t(645) = 19.76$, $p < .0001$, with a cost of an additional 19.37 s ($SE = 1.67$) across the executive conditions, $t(645) = 11.58$, $p < .0001$.

Consistent with prediction, a similar pattern was evident for both accuracy and latency in the second contrast comparing Shape School performance by inhibitory processing demands, namely, comparing response suppression in Condition B and context-controlled selection in Condition C. Young children, on average, named 14.34 stimuli ($SE = 0.14$) correctly in Condition B, $t(1, 645) = 105.34$, $p < .0001$. The difference in naming accuracy as a function of inhibitory demands was −2.25 stimuli ($SE = 0.26$), $t(1, 645) = -8.55$, $p < .0001$. Accuracy on Condition C stimuli was estimated to be 11.98 stimuli correctly named ($SE = 0.14$), $t(1, 645) = 88.01$, $p < .0001$. A comparable pattern was observed for latency, where the estimated completion time was 26.76 s in Condition B ($SE = 1.15$), $t(1, 645) = 23.21$, $p < .0001$. The difference in latency between the two inhibitory conditions, on average, was 20.93 s ($SE = 2.05$), $t(1, 645) = 10.22$, $p < .0001$. The expected Condition C latency was 47.41 s for Condition C ($SE = 1.15$), $t(1, 645) = 41.12$, $p < .0001$.

Finally, in the a priori comparison examining the cost of performing concurrent executive processing in Condition D versus the single, blocked executive demands in Conditions B and C, the same pattern was evident for both accuracy and latency, as we hypothesized. The difference in accuracy on average across Conditions B and C was 0.83 ($SE = 0.23$), $t(1, 645) = 3.63$, $p < .0003$, lower than on Condition D, in which young children were estimated to name an average of 12.26 stimuli correctly ($SE = .14$), $t(1, 645) = 90.08$, $p < .0001$. Similarly, for latency, the expected value for the single-block conditions was 20.93 s more ($SE = 2.05$), $t(1, 645) = 10.22$, $p < .0001$, than for the concurrent condition, Condition D, in which children took an estimated 46.42 s ($SE = 1.15$) to complete the concurrent condition, $t(1, 645) = 40.27$, $p < .0001$.

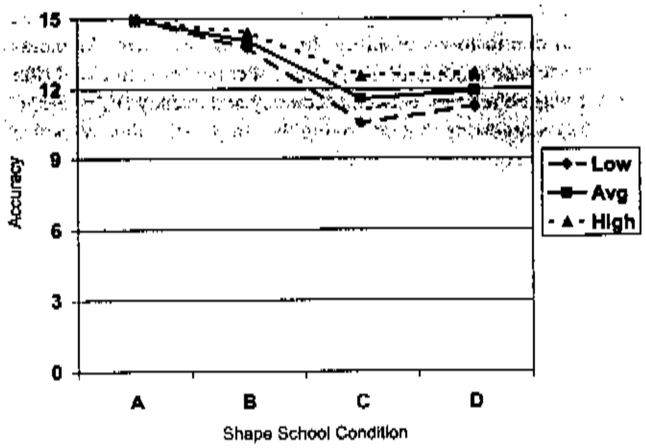

Figure 1. Shape School accuracy as a function of condition type and vocabulary level (Low = 85; Average (Avg) = 100; High = 115).

To explore the role of child vocabulary, we reran the same models, including a main effect of child vocabulary and an interaction of vocabulary with condition type for both accuracy and latency-dependent variables. Only for Shape School accuracy did the effect of condition type vary by vocabulary, $F(1, 630) = 9.86$, $p < .0001$, in addition to a significant main effect of vocabulary level ($\gamma = .72$, $SE = .16$), $t(1, 630) = 4.48$, $p < .0001$. These results are depicted in Figure 1. There was little difference in Condition A accuracy between children of higher (standard score = 115), middle (standard score = 100), and lower (standard score = 85) vocabulary levels. There was a moderate difference in accuracy in Condition B among children of varying levels of vocabulary. There was a substantial difference in accuracy on Condition C among children of varying vocabulary levels. It is interesting that accuracy on Condition D related to vocabulary level was attenuated relative to Condition C but was more substantial than Condition B. Although the vocabulary-related effects were significant, they accounted for only 3.47% (see Footnote 1) of the variance in Shape School accuracy beyond the effects of the covariates and condition type. In contrast to accuracy, only the main effect of vocabulary was significant, $t(1, 630) = -2.88$, $p < .0041$, with children who had higher vocabulary scores completing the conditions faster by an average of −3.97 s ($SE = 1.38$) independent of condition type, $F(3, 630) = 0.69$, $p > .55$.

Discussion

Our purpose for this article was to investigate the evidence for validity for the Shape School (Espy, 1997), a novel test of executive control recently developed for preschool children. First, the Shape School items were associated adequately, demonstrated by acceptable Cronbach's alpha values for each condition and the consistent interrelations among condition accuracies and latencies. Note, however, that a substantive relation among latencies across conditions is expected, even in very young preschool children, consistent with a common contribution of general processing speed. Furthermore, Shape School performance was related to performance on other commercially available tests that purport to measure executive control. Generally, nonzero relations to criterion measures were most evident for Shape School latencies, although the magnitude of the criterion associations did not differ by condition. Not surprisingly, latency measures better reflected intersubject variability, given the high degree of naming accuracy under these simple stimulus–response mappings. Also, Shape School condition latency relations with Digit Span and both VA indexes were nonzero in contrast to those with Statue, although the magnitude of the correlations did not differ statistically by criterion measure. These findings provide good evidence for validity, although future investigations should include a wide range of criterion measures, including experimental executive tasks and tasks that are not expected to be related to Shape School performance, in order to assess discriminant validity.

These findings also shed some light on the processes that might subserve Shape School performance. VA is considered to be a selective–sustained attention task, whereas Digit Span is typically viewed as assessing short-term memory span. Faster identification of the relevant features that distinguish figures, as evidenced on VA, would also facilitate Shape School performance. The ability to hold more information in mind, measured by maximal digit span, would enable more proficient Shape School performance, perhaps by more efficient maintenance of relevant stimulus–response mappings. These findings fit within the rubric of the interplay between working memory and attention deployment (e.g., Cowan, 1995; Kane, Bleckley, Conway, & Engle, 2001) and the overlap with executive control, more broadly (e.g., Kastner & Ungerleider, 2000; Posner & Peterson, 1990). These interrelations likely are developmentally dynamic and will require longitudinal, multimethod investigations for a more full characterization.

It is significant that Shape School performance varied among conditions contrasted to reflect executive demand differences, a fact that provides cogent evidence for task validity. First, the basic distinction between the baseline control and executive conditions was supported. This distinction is important, providing a sound basis for future use of developmental cognitive neuroscience methods that isolate relative cognitive "costs," whereby baseline cognitive processes, in this case naming speed, are removed either statistically or through simple subtraction. Moreover, there was a clear distinction between performance on Conditions B and C, hypothesized to reflect differing inhibitory processes, response suppression, and context-controlled selection among competing stimulus–response rules. Likely contributing to the observed sensitivity in these contrasts is the general comparability between these two Shape School conditions in other demands, including comparable proactive interference (where the target of the "inhibition" is previously relevant information). The working memory load was considered comparable to those in Conditions B and C, although retaining a stimulus–response mapping for a suppressed response might not require the same memory resources as retaining a mapping with an elicited response. In light of Friedman and Miyake's (2004) distinction between inhibitory processes that control proactive interference from competing rules and distraction from irrelevant information, both Conditions B and C also are comparable in proactive interference and in the level of distraction provided by the surrounding stimuli in the storybook array. Note, however, that response suppression in the Shape School is not achieved through prohibition of somatic motor actions and that Condition B performance and Statue were not related. Inhibition of somatic motor actions might reflect a precursor to the types of inhibition considered here (Carlson & Moses, 2001). In future studies, further support for separable inhibitory skills could be established through unique relations to other cognitive or behavior outcomes (e.g., Bull & Scerif, 2001) or through distinct patterns of relative impairments in young children who have specific clinical disorders.

Evidence for validity was also provided through the demonstrated sensitivity to complexity level. There was a clear cost in performance, both in accuracy and latency, presumably through the additional cognitive resources necessary in the concurrent Condition D, relative to the single-block conditions, B and C. This effect is even more dramatic considering that in Condition D, the child has to name only eight stimuli—fewer than in either Condition B or C. Halford, Andrews, and Jensen (2002) have theorized that executive control is engaged precisely in response to complexity, although it remains less than clear how to operationalize complexity, whether at the level of the stimulus, response, or rule, and/or at processing levels. Concurrent processing demands inevitably make greater demands on memory; therefore, the increased time may reflect time to access long-term retrieval and memory stores (Munakata, Morton, & Yerys, 2003). In Condition D, children might need to reflect more upon the relevant stimulus–response mapping rule as they select and implement, given that the different relevant stimulus features are interspersed in the concurrent condition (Zelazo et al., 2003). Finally, there are more proactive stimulus features than were previously relevant, providing greater attentional pull; therefore, more inhibitory resources are demanded to resist this attentional inertia (Kirkham et al., 2003).

Of note was the lack of condition-related differences that varied with age or sex. These findings indicate that condition-related Shape School performance is not variable among older or younger preschoolers, girls or boys, and they support comparable sensitivity across the full preschool age range in both sexes. Not surprisingly, there were age-related main effect differences in naming speed in the latter two comparisons, presumably reflecting the same age-dependent increases in processing speed that underlie the intercorrelations among the condition latencies. Finally, Shape School performance differed somewhat among children who had varying vocabularies. First, independent of condition type, latencies generally were shorter in children who had higher vocabularies, suggesting facilitated retrieval of verbal information that resulted in more efficient speeded naming. Second, naming accuracy in the different Shape School conditions varied with the child's vocabulary level, as was particularly evident on Condition C relative to Condition B or D. Keeping in mind the caveat that two differing vocabulary measures were administered here, because the Shape School is a verbal naming task and vocabulary is the most reliable and stable index of general intelligence (Sattler, 1992), greater verbal proficiency appears to differentially facilitate accuracy in those conditions that require context-controlled selection. It is interesting that this relationship somewhat parallels the important role of fluid intelligence in executive control in adults (Duncan et al., 2000; Gray, Chabris, & Braver, 2003; Kane & Engle, 2002). Administering a more comprehensive intelligence measure to preschool children would properly address this issue.

The utility of the Shape School as a measure of executive control in preschool children was supported, with good evidence for validity demonstrated by multiple methods. A next step is to determine whether the Shape School is sensitive in children who have clinical disorders and whether unique profiles are evident in children who have different disorders. Another possibility is to further explore discriminative relations to tasks that measure other cognitive domains, such as intelligence and memory. Although there are many different experimental tasks to measure executive control in this age range, there are comparatively few tasks for which the psychometric properties have been explored (e.g., Espy & Cwik, 2004), a critical endeavor prior to application in the clinical context. Also, longitudinal investigations are sorely needed to (a) better map the dynamic process of the development of executive control and later executive abilities at school age and (b) determine the utility of the Shape School as an index of this unfolding process.

Certainly, there is more work to be done to improve the task parameters. First, minor changes, such as increasing the number of items in Condition D, might improve the detection of the cost of complexity. In addition, given the distinction between proactive interference and distraction noted by Friedman and Miyake (2004), the impact of the type of distraction could be manipulated by varying the presentation format to include single stimulus presentation, in addition to the storybook stimulus array. Although the proactive interference of the specific stimulus–response mappings is developed by the story line, the greater natural context available for the child to draw upon to execute the relevant response when the facial expression cues suppression and the hat cues another naming dimension might have influenced performance; this possibility could be manipulated fruitfully. Finally, it would be useful to constrain stimulus order to allow researchers to manipulate inhibitory load by systematically varying the number of stimuli that precede the inhibitory stimulus target. Such a change to both Conditions B and C might lend further support to the distinction between the demands for response suppression and context-controlled selection, for example, if the manipulation differentially affected performance. These issues notwithstanding, the Shape School offers potential as a tool to measure executive control in this challenging age range.

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