Research Article

The Relationship Between Executive Functions and Language Abilities in Children: A Latent Variables Approach

Margarita Kaushanskaya,^a Ji Sook Park,^a Ishanti Gangopadhyay,^a
Meghan M. Davidson,^a and Susan Ellis Weismer^a

Purpose: We aimed to outline the latent variables approach for measuring nonverbal executive function (EF) skills in school-age children, and to examine the relationship between nonverbal EF skills and language performance in this age group.

Method: Seventy-one typically developing children, ages 8 through 11, participated in the study. Three EF components, inhibition, updating, and task-shifting, were each indexed using 2 nonverbal tasks. A latent variables approach was used to extract latent scores that represented each EF construct. Children were also administered common standardized language measures. Multiple regression analyses were conducted to examine the relationship between EF and language skills.

Results: Nonverbal updating was associated with the Receptive Language Index on the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4). When composites denoting lexical–semantic and syntactic abilities were derived, nonverbal inhibition (but not shifting or updating) was found to predict children’s syntactic abilities. These relationships held when the effects of age, IQ, and socioeconomic status were controlled.

Conclusions: The study makes a methodological contribution by explicating a method by which researchers can use the latent variables approach when measuring EF performance in school-age children. The study makes a theoretical and a clinical contribution by suggesting that language performance may be related to domain-general EFs.

Executive functions (EFs) are a set of top-down cognitive control processes used to manage thought and behavior (Diamond, 2013; Miyake et al., 2000). EFs are crucial to the ability to adapt efficiently to changes in the environment (Huizinga, Dolan, & van der Molen, 2006; Zelazo, Müller, Frye, & Marcovitch, 2003), and to the ability to manage basic daily tasks, such as planning, decision making, and problem solving (Friedman et al., 2006; Miyake et al., 2000). It is not surprising then that there is a wealth of literature linking EFs and broad quality-of-life outcomes, including academic achievement (e.g., Best, Miller, & Naglieri, 2011; Blair & Razza, 2007) and social–emotional development (Broidy et al., 2003; Ferrier, Bassett, & Denham, 2014). Most relevant to the field of communication sciences and disorders, EF difficulties have been documented in populations with

communication impairments, including individuals with specific language impairment (SLI; e.g., Henry, Messer, & Nash, 2012; Im-Bolter, Johnson, & Pascual-Leone, 2006), autism spectrum disorders (e.g., Joseph, McGrath, & Tager-Flusberg, 2005), reading disabilities (e.g., Sesma, Mahone, Levine, Eason, & Cutting, 2009), aphasia (Yeung & Law, 2010), and traumatic brain injury (e.g., Sainson, Barat, & Aguert, 2014).

There is a great deal of interest in accurately measuring EF skills in our field, both for the purposes of documenting EF deficits in impaired populations and for the purposes of possibly influencing language outcomes through targeting EF skills. In the present study, we examined EF performance in a sample of monolingual typically developing children, with the following three goals. The first goal was a methodological one: We aimed to document the use of a latent variables approach when measuring nonverbal EF performance in children. The second goal was a clinical one: We aimed to examine whether children’s performance on common standardized language measures is associated with EFs. The third goal was a theoretical one: We aimed to examine whether domain-general EF skills (as indexed by performance on nonverbal EF tasks) would contribute to

^aUniversity of Wisconsin–Madison

Correspondence to Margarita Kaushanskaya: kaushanskaya@wisc.edu

Editor: Rhea Paul

Associate Editor: Shelley Gray

Received September 3, 2015

Revision received February 24, 2016

Accepted August 9, 2016

https://doi.org/10.1044/2016_JSLHR-L-15-0310

Disclosure: The authors have declared that no competing interests existed at the time of publication.

variability in children's lexical-semantic and syntactic skills.

The Structure and the Measures of EFs

Classic conceptualizations envisioned EF as a unitary construct (e.g., Baddeley & Hitch, 1974; Norman & Shallice, 1986). In contrast, later work construed EFs as distinct components, but the exact components varied across theoretical frameworks and studies. Many conceptualizations of EF components exist (see Jurado & Rosselli, 2007, for review); however, recent, large-scale, data-driven studies have yielded fairly consistent findings regarding the structure of EFs. This work suggests that EFs consist of related, but separable subcomponents (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Vaughan & Giovanello, 2010), that include *inhibition* (the ability to suppress attention to irrelevant information), *updating* (the ability to incorporate new information in working memory), and *task-shifting* (the ability to flexibly switch between mental states, tasks, and operations). This fundamental three-component structure of EFs has also been documented in school-age children (e.g., ages 11–12 years, Duan, Wei, Wang, & Shi, 2010; ages 8–13 years, Lehto et al., 2003; ages 10–12 years, Rose, Feldman, & Jankowski, 2011; ages 7–12 years, Wu et al., 2011), and is the EF framework we adopted in the present study.

Although there is general agreement about the multi-component structure of EFs, there is a great deal of variability in how EFs are measured across various studies, and how performance levels on the various EF tasks are determined. For instance, inhibition has been measured using a number of different tasks, including the Stroop task (MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Stroop, 1935), the Simon task (Hommel, 2011), the Eriksen flanker task (Eriksen & Eriksen, 1974; Mullane, Corkum, Klein, & McLaughlin, 2009), the antisaccade task (Luna, 2009; Munoz & Everling, 2004), and the go/no-go task (Cragg & Nation, 2008). Updating has been measured by the Corsi blocks task (Lezak, 1983); *n*-back tasks (Owen, McMillan, Laird, & Bullmore, 2005); counting, reading, and operation span tasks (Barrouillet, Gavens, Vergauwe, Gaillard, & Camos, 2009; Case, 1995; Daneman & Carpenter, 1980; Turner & Engle, 1989); and symmetry span tasks (Kane et al., 2004).

The difficulties with interpreting EF data that ensue as the result of task variability are complemented by the well-known problems of task relatedness and task impurity associated with EF measures. Any one EF task is unlikely to measure a single EF component. For instance, the Wisconsin card sorting task requires individuals to sort bivalent cards by a single dimension (e.g., the color or the shape). Although purportedly a task-shifting measure, this task requires updating of working memory in order to keep the rules in an active state and inhibition to suppress prepotent responses (Diamond, 2013). Further, an EF task is likely to measure not only the EF construct it targets, but also non-EF-related abilities (e.g., performance on the

Stroop task reflects not only the ability to use inhibitory control, but also the ability to process color and read words; Miyake & Friedman, 2012).

The methodological goal of the present study was to explicitly document, in a step-by-step manner, a latent variables approach to capturing EF performance in school-aged children. We adapted the Miyake et al. (2000) conceptualization of EFs and administered two measures to index each of the three EF components of interest—inhibition, shifting, and updating. We used a latent variables approach to extract the latent variables representing the three EF components, inhibition, shifting, and updating. The latent variables approach extracts shared variance from multiple measures, while eliminating task-specific variance and measurement error (Tabachnick & Fidell, 2013). This approach has yielded relatively pure EF measures in prior work (Friedman et al., 2006; Lehto et al., 2003; Miyake et al., 2000), but has not yet been used in studies examining the relationship between EFs and language abilities.

EF and Language Abilities

The relationship between EFs and language has been of long-standing interest in the field of communication sciences and disorders (e.g., Bishop & Norbury, 2005; Ellis Weismer, Plante, Jones, & Tomblin, 2005; Henry et al., 2012; Im-Bolter et al., 2006; Vugs, Hendriks, Cuperus, & Verhoeven, 2014), and has often been examined through testing EF abilities in populations with language impairments. For instance, children with SLI have been shown to perform less well than their typically developing peers on inhibition (Bishop & Norbury, 2005; Im-Bolter et al., 2006), task-shifting (Marton, 2008), and updating of working memory measures (Ellis Weismer et al., 2005; Henry et al., 2012; Vugs et al., 2014). These findings have been interpreted to indicate that deficits associated with language may be domain-general rather than domain-specific, and have thus contributed to a wider inquiry regarding the cognitive mechanisms that may underlie language development (Bates & MacWhinney, 1987; Green, 1998; Tomasello, 2003).

There is evidence to suggest that language and EF abilities also interact in typical populations (e.g., Choi & Trueswell, 2010; Mazuka, Jincho, & Onishi, 2009; Moser, Fridriksson, & Healy, 2007; Slevc, 2011; Woodard, Pozzan, & Trueswell, 2016). For instance, inhibition skills have been implicated in the resolution of lexical and syntactic ambiguity in children (ages 7–10 years) and young adults (Khanna & Boland, 2010). Updating of working memory has similarly been revealed as the mechanism that may underlie auditory and written sentence comprehension in both children and adults (e.g., Daneman & Carpenter, 1980; Roberts, Marinins, Felser, & Clahsen, 2007) and sentence production in young adults (Slevc, 2011). Therefore, there is evidence for a relationship between EF and language skills, both in populations with typical language skills and in populations with language impairments. However, two aspects of prior work may challenge the conclusion that domain-general EF mechanisms underlie language ability.

First, many studies that have reported links between EF and language abilities used verbal tasks to measure EF. For instance, the reading span task requires individuals to read and comprehend complex sentences, and the dimensional change card sort (DCCS) task presents cues and instructions using verbal prompts. Although verbal EF measures are undoubtedly useful for indexing the ability to deploy EF skills in the verbal domain, they are less useful for examining whether language performance is associated with domain-general cognitive functioning. That is, a relationship between language abilities and verbal EF skills can be driven by the overlap in the language demands across the two domains, rather than the involvement of domain-general EF skills in language processing (see MacDonald and Christiansen, 2002, for a similar argument). Therefore, in the present study, we focused on nonverbal EF tasks and examined their contributions to language performance in children. Any associations between language and EFs observed in the present study would therefore be more likely to reflect the association between language ability and domain-general cognitive processing.

Second, although the associations between language and EFs have been examined in prior work, these explorations have targeted vastly different EF and language measures. For example, some studies have documented an association between lexical-semantic processing and inhibition (Bilenko, Grindrod, Myers, & Blumstein, 2009; Khanna & Boland, 2010). On the other hand, other studies have linked lexical-semantic processing with updating of working memory (Gathercole & Baddeley, 1990; Khanna & Boland, 2010; Weiland, Barata, & Yoshikawa, 2013), although it is notable that many of these studies used verbal measures of working memory (e.g., Gathercole & Baddeley, 1990; Weiland et al., 2013). Whereas some studies have also found that syntactic processing was associated with inhibition and/or shifting (Mazuka et al., 2009; Novick et al., 2005), others have linked syntactic processing with updating (Moser et al., 2007; Roberts et al., 2007). It is possible, and even likely, that different aspects of language processing (and/or different language-processing tasks) are associated with distinct EF skills. For instance, in the work on syntactic processing, the ability to recover from garden path sentences has been linked with inhibition/shifting (Mazuka et al., 2009; Novick et al., 2005; Woodard et al., 2016), while the ability to identify errors in sentences (Gangopadhyay, Davidson, Ellis Weismer, & Kaushanskaya, 2016) and the ability to integrate a word into the broader sentence structure (Roberts et al., 2007) have been linked with updating. However, because the vast majority of prior work focusing on language-EF relationships targeted a single EF task and a single language task, there remains the question regarding the specificity and the generality of the language-EF relationships. In the present study, we administered multiple measures of EF, as well as multiple measures of language ability, to the same group of children. This allowed us to examine which of the three EF components is associated with which specific language abilities.

The Current Study

The goals of the present work were: (a) to delineate a latent variables approach when measuring EFs in children, (b) to examine the relationship between nonverbal EFs and children's performance on standardized measures of language abilities, and (c) to examine specific relationships between nonverbal EFs and children's lexical-semantic versus syntactic abilities. To this end, we tested typically developing, school-age (ages 8–11 years), monolingual children on a battery of EF tasks and a battery of standardized language tests. The school-age period was targeted for two reasons. First, the three EF components that were the focus of the present study have been confirmed in school-age children (Duan et al., 2010; Rose et al., 2011; Wu et al., 2011). In younger children, there was a possibility of finding a more integrated EF system (e.g., Wiebe, Espy, & Charak, 2008). Second, there is evidence that EF tasks scaled to the cognitive capacity of preschool-age children may not capture the same EF processes as the tasks appropriate for adults (e.g., Blair, Zelazo, & Greenberg, 2005), and that preschoolers' performance on EF tasks is associated with limitations in non-EF-related domains such as understanding the task instructions (e.g., Luciana, 2003; Luciana & Nelson, 2002). Thus, school-aged children were the ideal population for the purposes of the present study as they were still developing their EFs (Best & Miller, 2010), but could complete adult-like EF tasks.

To accomplish our first methodological goal, we began by selecting the EF tasks that have been most frequently used in prior studies to measure inhibition, shifting, and updating. We administered two tasks for each of the EF sub-components, and utilized a latent variables approach to derive the EF constructs of interest. To accomplish our second and third goals, we focused on relating performance on nonverbal EF tasks to performance on language measures. Our hypothesis was that if there is a relationship between language and domain-general EF abilities, we would observe associations between nonverbal EF performance and language performance in children. With the view to inform clinical practice, we first examined the associations between children's performance on standardized language measures and EF skills. If children's standard language scores were found to be related to their EF performance, we would have evidence that measures used to document typicality of the language system also index nonlinguistic cognitive skills. With the view to inform the theoretical inquiry into domain-generality of language, we examined whether two aspects of language ability, lexical-semantic skills and syntactic skills, are differentially associated with inhibition, shifting, and updating.

Method

Participants

The University of Wisconsin–Madison Institutional Review Board approved this study. All parents consented to their child's participation, and all children gave oral

assent. Participants included 71 children with typical development (38 boys, 33 girls; 55 White, eight Black, one Asian, and seven reported as Other) between the ages of 8 and 11 enrolled in elementary schools in Madison, Wisconsin, and the surrounding area. The children were native speakers of English with no exposure to any language other than English, either at home or in school. All children had normal hearing and vision, and no history of language impairment or developmental disabilities, per parent report. All children passed a hearing screening using conventional pure-tone audiometry at 20 db HL at the frequencies 1000, 2000, and 4000 Hz, per ASHA guidelines.

All testing took place in a child-friendly laboratory at the Waisman Center at the University of Wisconsin–Madison. Children were tested over the course of two sessions scheduled after school or during the weekends, with each session lasting approximately 1.5 to 2 hr. During the first session, children were administered standardized tests assessing nonverbal intelligence, broad language skills, and morphological comprehension. During the second session, children completed all the EF tasks (in randomized order), as well as the standardized receptive vocabulary measure. A team of six thoroughly trained examiners (undergraduate and graduate students in the department of Communication Sciences and Disorders) administered all the measures.

Standardized Tests

All children were administered a battery of standardized language and cognitive tests. The Perceptual Reasoning Index of the Wechsler Intelligence Scale for Children–Fourth Edition (Wechsler, 2003) was used to measure children’s nonverbal intelligence. Children’s overall receptive and expressive language abilities were measured using the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; reliability measured via Cronbach’s coefficient $\alpha = .89$ for Receptive Language Index, $.93$ for Expressive Language Index; Semel, Wiig, & Secord, 2003). Receptive vocabulary knowledge was measured using the Peabody Picture Vocabulary Test–Fourth Edition (PPVT-4; reliability = $.96$ – $.98$ for ages 8–12 years; Dunn & Dunn, 2007). Morphological comprehension was measured through the Morphological Comprehension subtest of the Test of Language Development–Intermediate: Fourth Edition (TOLD-I:4; reliability measured via coefficient $\alpha = .97$; Hammill & Newcomer, 2008). Table 1 presents children’s demographic information and performance on the standardized tests.

For clinical purposes, we used the standard scores from each language measure (CELF-4 Receptive and Expressive Indexes, PPVT-4, and TOLD-I:4 Morphological Comprehension) because these scores are used clinically to make decisions regarding a child’s language status. For theoretical purposes, we derived composite variables to separately index lexical–semantic abilities and syntactic abilities. In these calculations, we first transformed children’s standard scores into z scores. To obtain the lexical–semantic composite, we averaged children’s performance on the

PPVT-4 and on the Word Classes–Receptive subtest on the CELF-4. The PPVT-4 requires children to map an auditory word onto the target picture, while the Word Classes–Receptive subtest requires children to select two semantically related words among four auditory words. To obtain the syntactic composite, we averaged children’s performance on the Concepts and Following Directions subtest of the CELF-4 and the Morphological Comprehension subtest of TOLD-I:4. The Concepts and Following Directions subtest requires children to point to items corresponding to auditory instructions, and the Morphological Comprehension subtest requires children to identify whether auditory sentences are grammatically correct or incorrect.

Nonverbal EF Measures

Our primary selection criteria for the EF measures were (a) appropriateness for school-aged children; (b) ease of adaptability to nonverbal stimuli; and (c) levels of performance that are not at floor, demonstrated by school-age children in pilot studies. The exact structure of each task (e.g., number of stimuli, stimulus duration, and inter-stimulus intervals) was developed on the basis of pilot testing with children in the target age range. Task instructions were also refined during piloting to ensure their age appropriateness. All the EF tasks were computerized using E-Prime 2.0 software, which recorded children’s accuracy and reaction time (RT). For RT, outliers were identified as RTs below or above $2.5 SD$ from the mean, for each child for each task. The percentage of the total outliers eliminated across all the EF tasks was less than 3%. RTs for correct responses were averaged to index each child’s mean RT. Visual schematics and detailed descriptions of all the EF measures can be found in online Supplemental Material S1.

Inhibition

Child-appropriate versions of the flanker and go/no-go tasks were used to measure inhibition skills. The flanker task has been used extensively by prior studies to index inhibition skills (e.g., Mullane et al., 2009; Salthouse, 2010). The flanker task required the child to respond to the direction of the middle stimulus (i.e., the direction of the head of the middle fish) while ignoring surrounding stimuli. Both accuracy and RTs were collected. The go/no-go task is a common measure of inhibition (e.g., Brocki & Bohlin, 2004; Cragg & Nation, 2008; Jonkman, 2006) that required children to respond to a target stimulus, but not respond to a nontarget stimulus. Accuracy and RTs in the go condition and accuracy in the no-go condition were collected. It is important to note that the flanker and the go/no-go tasks are classically believed to measure different aspects of inhibition, with the flanker indexing resistance to interference, and the go/no-go indexing response inhibition. However, there is evidence to suggest that response inhibition and resistance to distractor interference are strongly correlated and fall into a single factor (Friedman & Miyake, 2004). Indeed, this was the pattern in our data.

Table 1. Participants' demographic information and performance on standardized tests.

Scale	Subscale	<i>M</i>	<i>SD</i>	Range
Age (years)		9.34	1.02	8.00–11.92
SES ^a		17.22	3.10	10–24
WISC-IV		111.47	12.67	84–141
CELF-4	Receptive Language Score	110.92	13.99	81–137
	Expressive Language Score	109.16	12.83	87–138
TOLD-I:4	Morphological Comprehension	11.38	2.55	6–16
PPVT-4		117.64	17.51	86–155
Composite	Syntax z score	0.03	0.83	–2.28–1.31
	Semantics z score	–0.01	0.92	–1.63–2.06

Note. Standard scores were used for the WISC-IV, CELF-4, and PPVT-4 scores; scaled scores were used for the TOLD-I:4. Z scores were used for the composite scores of Syntax (the Concepts and Following Directions subtest of the CELF-4 and the Morphological Comprehension Subtest of TOLD-I:4) and Semantics (Word Classes–Receptive Subtest of the CELF-4 and PPVT-4). SES = socioeconomic status; WISC-IV = Wechsler Intelligence Scale for Children, Fourth Edition; CELF-4 = Clinical Evaluation of Language Fundamentals, Fourth Edition; TOLD-I:4 = Test of Language Development–Intermediate: Fourth Edition; PPVT-4 = Peabody Picture Vocabulary Test, Fourth Edition.

^aSES: Total years of maternal education.

Updating of Working Memory

The *n*-back and Corsi blocks tasks were used to assess the child's ability to maintain and manipulate information over a brief period of time. The *n*-back task is a very common measure of updating (e.g., Owen et al., 2005; Vaughan & Giovanello, 2010; Wilhelm, Hildebrandt, & Oberauer, 2013). The *n*-back task required the child to decide whether each item (an abstract shape) in a running sequence matched the item that was presented *n* positions previously. Accuracy and RTs were collected. The Corsi blocks task required children to remember a sequence of spatial locations on the screen. Just like the *n*-back task, the Corsi blocks task is a commonly used measure of updating, especially in the nonverbal domain (e.g., Diamond, 2013; Pagulayan, Bush, Medina, Bartok, & Krikorian, 2006). Only accuracy was collected.

Task Shifting

The local/global task and the dimensional change card sort (DCCS) task were used to measure the child's ability to flexibly shift between mental states and rules. The local/global task is a very common measure of shifting (e.g., Hull, Martin, Beier, Lane, & Hamilton, 2008; Miyake et al., 2000; Vaughan & Giovanello, 2010) that required the child to shift between identifying shapes at the local and the global level. Both accuracy and RTs were collected. The DCCS task is a commonly used measure of shifting (e.g., Diamond & Kirkham, 2005; Morton, Bosma, & Ansari, 2009; Zelazo et al., 2003) that required the child to first sort bivalent cards on the basis of one dimension (e.g., color) and then a different dimension (e.g., shape). Both accuracy and RTs were collected.

Results

Step 1: Selecting EF Variables

IBM SPSS Version 22 was used for all the analyses. The full list of all the performance indexes yielded by each

task can be found in online Supplemental Material S1. We began by screening the various indexes of performance from each task for suitability using correlation matrices. The full correlation matrix is available upon request. Because variables that show correlations of above .30 can be meaningfully considered for a factor analysis (Hair, Black, Babin, & Anderson, 2010; Tabachnick & Fidell, 2013), we first identified measures that showed correlations of > .30 across the two tasks measuring the same construct (e.g., flanker and go/no-go). These overlapping variables were entered into the principal component analysis (PCA).

The initial screening yielded 14 variables (marked by asterisks in online Supplemental Material S2) that were suitable for further consideration. Because some variables were not normally distributed, we examined a number of different transformation options (logarithmic, square root, inverse, square, cubic value). The square-value transformation normalized the accuracy data best, and the log transformation normalized the reaction time data best in terms of accounting for skewness and kurtosis. The variables that were not normally distributed were transformed accordingly, and then entered into the PCA.

Six EF variables were selected on the basis of the PCA that showed the highest loading within each factor for each task and less robust loadings on the other factor (see online Supplemental Material S3). All six selected variables were accuracy variables and included: Corsi Blocks Total Capacity; *N*-back, 1-back Accuracy (target condition); Flanker Accuracy (incongruent condition); Go/No-go Accuracy (no-go condition); DCCS (mixed switch condition); and Local/Global Accuracy (incongruent condition). Table 2 presents children's performance on the selected EF variables.

Step 2: Latent Variables Analysis

The PCA is an appropriate analysis for data reduction and was therefore ideally suited for identifying the target EF performance measures from a large pool of

Table 2. Children's performance (accuracy rates) on the selected EF variables.

Variable	<i>M</i>	<i>SD</i>	Range
Corsi Blocks Capacity ^a	4.77	8.10	3.0–7.0
<i>n</i> -back Target Accuracy (1-back condition)	0.80	0.19	0.10–1.00
Flanker Accuracy (incongruent condition)	0.94	0.09	0.58–1.00
Go/No-go Accuracy (no-go condition)	0.81	0.14	0.35–1.00
DCCS Accuracy (mixed switch condition)	0.74	0.14	0.38–1.00
Local/Global Accuracy (incongruent condition)	0.86	0.16	0.25–1.00

Note. DCCS = Dimensional Change Card Sort task.

^aCorsi Blocks scores indicate the highest level at which the children responded to at least two out of three items correctly.

possible EF measures yielded by our six tasks. However, the PCA does not separate unique and shared variance between variables. Therefore, it is less suitable for identifying latent variables within a set of multiple measures. Principal axis factoring (PAF), on the other hand, analyzes the shared variance between tasks, thus alleviating the issues of task impurity caused by task-specific unique variance and error variance. It therefore enables identification of the latent variables that underlie performance on multiple tasks (see Costello & Osborne, 2005, for review). Therefore, as the next step of the present study, we used PAF to extract the latent EF variables.

The six selected variables indexing EF performance were entered into the PAF with oblique rotation. The factor analysis was acceptable by passing the minimum value of .50 on Kaiser-Meyer-Olkin measure of sampling adequacy (.58) and rejecting the null hypothesis ($p < .001$), on the Barrett's test of sphericity. Three factors whose eigenvalues were greater than 1 were identified. Because eigenvalues are known to yield overextracted factors (Costello & Osborne, 2005), we examined the scree plot (see online Supplemental Material S4), which confirmed that the three identified factors were above the cutoff point, and should thus be retained. We also conducted a Monte Carlo parallel analysis (Hayton, Allen, & Scarpello, 2004) to confirm the retained number of factors. The Monte Carlo parallel analysis can reveal factors while avoiding sampling errors (O'Connor, 2000; Hayton et al., 2004). Using this analysis, the eigenvalue of the fourth factor (0.06) exceeded the eigenvalue extracted by the factor analysis (−0.14). Thus, we confirmed that the actual eigenvalues corresponding to the three factors from the PAF were greater than the average random eigenvalues yielded by the parallel analysis. These findings strongly support the reliability of the three factors extracted through the PAF.

The three factors were extracted using the Anderson–Rubin approach. This approach is known to produce factor scores that are uncorrelated with each other (Tabachnick & Fidell, 2013). Loadings of variables on the three factors, communalities, and percent of variance are shown in Table 3. The three factors explained 72.30% of variance in the six EF variables, and the three latent variables were labeled Inhibition, Updating, and Shifting. Table 4 presents

correlations between the three factors and the selected EF variables.

Step 3: Linking EF and Performance on Standardized Language Measures

Multiple regression analyses were conducted in which the CELF-4 Receptive and Expressive, PPVT-4, and TOLD-I:4 scores were entered as the outcome variables, and the three latent EF variables were entered as predictors. Preliminary correlation analyses indicated that there were correlations among socioeconomic status (SES), IQ, EF, and language measures, and between age and EF measures (see online Supplemental Material S5). Thus, all regression analyses were conducted first without adjusting for age, SES, and IQ, and then controlling for the influences of age, SES, and IQ.

Regression Analyses Without the Control Variables

CELF-4 Receptive Language was predicted by updating ($\beta = .35$, $t = 3.14$, $p = .003$), but not by shifting ($\beta = .22$, $t = 1.96$, $p = .055$), or inhibition ($\beta = .06$, $t = 0.57$, $p = .572$), $F(3, 65) = 4.67$, $p = .005$. Once insignificant predictors were removed, updating predicted 12.5% of the variance in Receptive Language, $\Delta F(1, 67) = 9.55$, $p = .003$. Conversely, CELF-4 Expressive Language was predicted by shifting ($\beta = .27$, $t = 2.26$, $p = .027$), but not by updating ($\beta = .12$, $t = 0.97$, $p = .335$) or inhibition ($\beta = .01$, $t = 0.12$, $p = .909$), although the overall model was not significant, $F(3, 64) = 2.02$, $p = .120$. Once insignificant predictors were removed, shifting predicted 7.3% of the variance in Expressive Language, $\Delta F(1, 66) = 5.17$, $p = .026$.

TOLD-I:4 Morphological Comprehension performance was predicted by none of the EFs, $F(3, 62) = 1.33$, $p = .273$: shifting ($\beta = .19$, $t = 1.52$, $p = .133$), updating ($\beta = -.03$, $t = -0.27$, $p = .785$), or inhibition ($\beta = .16$, $t = 1.27$, $p = .211$). The PPVT-4 performance was similarly not predicted by any of the EF variables, $F(3, 64) = 1.11$, $p = .352$: shifting ($\beta = .17$, $t = 1.35$, $p = .181$), updating ($\beta = .13$, $t = 1.09$, $p = .280$), or inhibition ($\beta = -.07$, $t = -0.55$, $p = .582$).

Regression Analyses Controlling for Age, SES, and IQ

Above and beyond the control variables, CELF-4 Receptive Language was predicted only by updating ($\beta = .29$,

Table 3. Factor loadings, communalities (h^2), and percentage of variance for the principal factors extraction and oblique rotation on the nonverbal EF variables.

Variables	F1: Shifting	F2: Updating	F3: Inhibition	h^2
<i>n</i> -back Target Accuracy (1-back condition)		.49		.58
Corsi Blocks Capacity		.77		.25
Flanker Accuracy (incongruent condition)			.70	.54
Go/No-go Accuracy (no-go condition)			.62	.37
DCCS Accuracy (mixed switch condition)	.80			.62
Local/Global Accuracy (incongruent condition)	.60			.41
Eigenvalue	2.02	1.26	1.06	
Percent of variance	33.72	20.95	17.63	
Percent of cumulative variance	33.72	54.67	72.30	

$t = 2.40$, $p = .019$), and not by shifting ($\beta = .09$, $t = 0.75$, $p = .455$) or inhibition ($\beta = .17$, $t = 1.58$, $p = .119$). The overall model approached significance, $\Delta F(3, 60) = 2.73$, $p = .052$, $r^2 = .084$. Once insignificant predictors were removed, updating predicted 5.2% of the variance in Receptive Language, $\Delta F(1, 62) = 4.98$, $p = .029$. None of the EFs predicted CELF-4 Expressive Language, $\Delta F(3, 60) = 0.46$, $p = .71$: shifting ($\beta = .09$, $t = 0.71$, $p = .48$), updating ($\beta = .00$, $t = 0.02$, $p = .99$), or inhibition ($\beta = .10$, $t = 0.90$, $p = .374$).

Above and beyond the control variables, TOLD-I:4 performance was predicted by inhibition ($\beta = .26$, $t = 2.21$, $p = .031$), but not by shifting ($\beta = .10$, $t = 0.77$, $p = .445$), or updating ($\beta = -.07$, $t = -0.49$, $p = .623$), $\Delta F(3, 59) = 2.04$, $p = .12$. Once insignificant predictors were removed, inhibition predicted 6.3% of the variance in TOLD-I:4 scores, $\Delta F(1, 61) = 5.11$, $p = .027$. For the PPVT-4, none of the EF variables was a significant predictor, $\Delta F(3, 61) = 0.12$, $p = .767$: shifting ($\beta = .03$, $t = 0.23$, $p = .819$), updating ($\beta = .10$, $t = 0.86$, $p = .395$), or inhibition ($\beta = .07$, $t = 0.65$, $p = .518$).

Step 4: Linking EF to Lexical–Semantic and Syntactic Performance

Without controlling for age, SES, and IQ, for the Syntactic composite, updating was a significant predictor ($\beta = .26$, $t = 2.20$, $p = .031$), while shifting and inhibition were not significant predictors ($\beta = .22$, $t = 1.90$, $p = .06$ and $\beta = .23$, $t = 1.94$, $p = .057$, respectively), although they

both trended toward significance, $F(3, 62) = 4.08$, $p = .010$, $r^2 = .16$. Once insignificant predictors were removed, updating predicted 6.5% of the variance in the Syntactic composite, $\Delta F(1, 64) = 4.47$, $p = .038$. For the Lexical–Semantic composite, none of the EFs was a significant predictor, $F(3, 64) = 1.50$, $p = .223$: shifting ($\beta = .17$, $t = 1.36$, $p = .178$), updating ($\beta = .18$, $t = 1.45$, $p = .153$), or inhibition ($\beta = -.09$, $t = -0.75$, $p = .459$).

After controlling for age, SES, and IQ, for the Syntactic composite, only inhibition was a significant predictor ($\beta = .33$, $t = 3.12$, $p = .003$). Updating was approaching significance ($\beta = .24$, $t = 1.995$, $p = .051$), but shifting was not a significant predictor ($\beta = .15$, $t = 1.21$, $p = .232$), $\Delta F(3, 59) = 4.75$, $p = .005$, $r^2 = .15$. Once insignificant predictors were removed, inhibition predicted 10.2% of the variance in the Syntactic composite, $\Delta F(1, 61) = 9.34$, $p = .003$. However, after removing inhibition and shifting, updating no longer accounted for significant variance in the Syntactic composite scores, $\Delta F(1, 61) = 2.45$, $p = .123$. For the Lexical–Semantic composite, above and beyond the control variables, none of the EF variables was a significant predictor, $\Delta F(3, 58) = 0.02$, $p = .995$: shifting ($\beta = .01$, $t = 0.07$, $p = .947$), updating ($\beta = .03$, $t = 0.24$, $p = .808$), or inhibition ($\beta = -.01$, $t = -0.11$, $p = .914$).

Discussion

In the present study, we delineated a latent variables approach to measuring EF skills in school-age children with typical language skills. We suggest that this approach

Table 4. Correlations between the latent variables and the selected EF variables.

	Inhibition	Updating	Shifting
<i>n</i> -back Target Accuracy (1-back condition)	.05	.95**	.10
Corsi Blocks Capacity	.05	.61**	.11
Flanker Accuracy (incongruent condition)	.88**	.01	.25*
Go/No-go Accuracy (no-go condition)	.77**	.07	.02
DCCS Accuracy (mixed switch condition)	.12	-.02	.94**
Local/Global Accuracy (incongruent condition)	.05	.20	.70**

Note. DCCS = Dimensional Change Card Sort task.

* $p < .05$. ** $p < .001$.

may be helpful in navigating some methodological issues that surround the measurement of EFs. We also examined the relationship between EFs and language skills using nonverbal EF tasks and widely used standardized language measures. Our findings indicate that scores obtained by children with typical language skills on standardized language measures are only weakly associated with performance on EF tasks. However, inhibition (but not updating or shifting) was found to be associated with syntactic (but not lexical-semantic) performance, indicating specific, mechanistic links between domain-general inhibitory control and syntactic ability.

One widely accepted conceptualization of EFs envisions the EF as consisting of three components: inhibition, updating, and task-shifting (Miyake et al., 2000). In the present study, we relied on this definition of EFs and used a latent variables approach to demonstrate a method by which researchers can extract latent variables that index inhibition, updating, and shifting in a sample of monolingual school-age children with typical language skills. These components of EFs have been confirmed in school-age children (e.g., Lehto et al., 2003), although it is important to note that a few studies using similar latent variable-type approaches have at times yielded a two-factor rather than a three-factor structure (e.g., Huizinga et al., 2006; van der Sluis, de Jong, & van der Leij, 2007). The differences in EF components identified across studies may be related to particular populations targeted, sample sizes, measures administered, and performance indexes selected (e.g., Huizinga et al. [2006] vs. Miyake et al. [2000] vs. van der Sluis et al. [2007]). Variability in EF tasks and measures across studies is unavoidable, especially when different age groups are considered, and when populations with different levels of EF abilities are of interest. That is, some EF tasks are not appropriate for use with younger children (e.g., Best, Miller, & Jones, 2009; Davidson, Amso, Cruess-Anderson, & Diamond, 2006), and with populations with cognitive deficits (Anderson, Jacobs, & Anderson, 2010). Furthermore, some measures (e.g., accuracy) may be better able to capture the variability in task performance on some tasks versus others (e.g., updating vs. inhibition), and in some populations (e.g., children) versus others (e.g., adults).

For our purposes, the particular EF components yielded by the present study and the particular indexes of EF performance chosen to represent each EF measure are less important than the feasibility of the approach we used to derive them. That is, our goals were *not* to confirm a particular EF structure, to endorse a particular battery of EF tasks, or to specify a particular performance measure for each EF task. Rather, our goal was to delineate an approach to measuring multiple components of EFs in a manner that would sidestep the issues of task impurity associated with measuring EF abilities. The take-away message is that researchers interested in measuring EF skills and linking them with performance in other domains (e.g., language) can follow a latent variables approach to capture the EF constructs in their data.

Prior examinations of the EF-language relationships have yielded a complex picture. There is a significant volume of group-based, comparative studies documenting EF deficits in individuals with language impairments compared to individuals with typical language skills (e.g., Henry et al., 2012), and a large number of psycholinguistic, individual difference-type studies documenting involvement of EF skills in various aspects of language processing (e.g., Khanna & Boland, 2010). This body of research is frequently interpreted to suggest that EF skills are related to language development and processing. However, there remains a general lack of clarity with regard to which particular aspects of EF are relevant to which particular aspects of language ability. This rich body of research is further complicated by the use of verbal tasks to measure EF skills.

In the present study, we used nonverbal tasks to measure EFs, and this allowed us to examine whether domain-general EF mechanisms are related to language. For clinical purposes, we were interested in examining whether EFs are related to standard scores on common, standardized language measures often used in our field to document language impairment in children. If such links were found, they would indicate that the standardized measures that purportedly measure language ability also capture variability in nonlinguistic skills. Our main finding was that there were only weak relationships between EF components and standard language scores, especially once age, SES, and IQ were taken into account. The only reliable link observed in our data was between updating of working memory and the Receptive Language Score on the CELF-4. The Receptive Language Score on the CELF-4 subsumes performance on Concepts and Following Directions and Word Classes, Receptive (for 9–12-year-olds) as well as Sentence Structure (for 8-year-olds). All of these rely on children's ability to encode auditory information and then use this information in the service of the task. Our findings suggest that a weaker Receptive Language Score on the CELF-4 may signal not only a weakness in the language system, but also possibly a weakness in the general ability to update information in working memory. It is important to point out, however, that our finding of only a weak relationship between EFs and standard language scores is specific to the standardized measures targeted by the present study and to children with typical language skills in this particular age range. Future studies will need to examine the relationship between EFs and other common language measures in children with language impairment at different ages in order to speak to the generalizability and the clinical utility of our findings.

Theoretically, the question of interest in the present study was whether domain-general inhibition, updating, and shifting skills would contribute differentially to children's syntactic versus lexical-semantic performance. We found that inhibition (but not shifting or updating) was a reliable predictor of syntactic performance, even after accounting for age, SES, and IQ. Our finding with respect to the inhibition-syntax relationship is consistent with previous studies that showed an association between inhibition and syntactic

comprehension abilities (Choi & Trueswell, 2010; Mazuka et al., 2009; Novick et al., 2005; Woodard et al., 2016). It is notable that prior studies have also identified relationships between syntactic performance and updating (Moser et al., 2007; Roberts et al., 2007), whereas we did not. This may be due to the fact that in prior studies, updating was tested using a different set of measures than the ones used here. It may also be the case that in prior studies updating was considered in isolation, whereas in the present study, it was considered in tandem with inhibition. Because inhibition and updating are related constructs (e.g., Diamond, 2013; Miyake et al., 2000), our finding that inhibition but not updating was related to syntactic performance may have been conditioned by the fact that we considered *both* EFs in relation to syntactic ability.

Our finding a link between inhibition and syntactic abilities is remarkable considering that our measure of syntax was a composite of two off-line syntactic comprehension tasks that did not involve any conflict. Previous studies that have documented a connection between inhibition and syntactic abilities have typically targeted a specific syntactic process such as the ability to recover from garden path sentences (e.g., Mazuka et al., 2009; Novick et al., 2005; Woodard et al., 2016). This process requires one to resolve syntactic ambiguity and thus shares task demands with inhibitory control tasks that also require one to resolve ambiguity in the input. Furthermore, prior studies have typically targeted timed tasks that required speedy encoding and processing of complex syntactic structures (e.g., grammaticality-judgment task). Such syntactic measures share time-based parameters with inhibition tasks (in which instructions emphasize both speed and accuracy). In our study, the syntax measures indexed children's ability to follow syntactically complex instructions and to detect syntactic errors. These tasks did not impose time demands on the children and did not require children to resolve conflicting information. Nevertheless, children's ability to perform syntactic operations was significantly associated with their ability to inhibit non-linguistic information. We thus have strong evidence that domain-general inhibitory control skills contribute broadly to children's syntactic ability.

It is important to note that none of the EFs were associated with lexical-semantic performance in the present study. This is in contrast to a number of prior studies that have documented connections between various EFs and lexical-semantic skills in both children (Gathercole & Baddeley, 1990; Khanna & Boland, 2010; Weiland et al., 2013) and in adults (Bilenko et al., 2009). The biggest difference between the prior studies and our study is the prior studies' use of verbal measures to index updating of working memory (e.g., Gathercole & Baddeley, 1990; Khanna & Boland, 2010; Weiland et al., 2013). The findings in the present study therefore suggest that when language demands of the EF tasks are minimized, their association with lexical-semantic abilities also becomes limited. This highlights the importance of using nonverbal EF tasks when attempting to delineate the involvement of domain-general EFs in language performance. In addition, our use of off-line lexical-semantic

measures may have contributed to the lack of the relationship between lexical-semantic and EF measures in the present study. Studies in which significant relationships between EFs and lexical-semantic skills have been documented have typically targeted processing-type tasks (such as lexical priming or lexical decision), in which one's ability to quickly access a word (often from a pool of related candidates) was probed (e.g., Haebig, Kaushanskaya, & Ellis Weismer, 2015; Khanna & Boland, 2010). In the present study, lexical-semantic abilities were measured through the use of off-line comprehension tasks that did not impose time demands on the children. It is therefore possible that the use of online measures of lexical processing that involve competition and that prioritize speedy responses would yield stronger relationships between lexical-semantic abilities and nonverbal EFs.

The present work has a number of limitations that should be carefully considered by future studies. The first of these is our relatively small sample size. Although the number of participants in the present study exceeds the minimum requirements for a factor analysis (Hair et al., 2010), a larger sample size would render the findings more reliable. Administration of only two tasks to index each EF component is a related limitation; although it is an improvement over a large number of existing studies in which a single task is typically used to index EFs, it does reduce the reliability of the latent variables approach. Future studies should administer at least three tasks for the EF component of interest to a larger pool of participants in order to confirm our findings. Second, our findings are specific to children who perform within the normal range on the language measures. In fact, the children in the present study were characterized by higher levels of SES, IQ, and language abilities than those observed in the general population. Therefore, the applicability of the findings to populations outside of this performance range remains to be determined. Third, the findings here may accurately capture the dynamics of language-EF relationships in this particular age range, but by no means can be taken to represent such relationships in younger children. Fourth, we make no claims as to the directionality of the relationship between language and EFs observed in the present study. It may very well be the case that children rely on domain-general inhibition skills when engaging in syntactic processing; conversely, it may be that children rely on strategic language use when engaging in complex tasks that involve nonverbal stimuli (e.g., visual shapes). Cross-sectional work of the kind implemented here, while a necessary first step, must be followed up by longitudinal examinations of the relationships among EF and language measures in order to delineate the directionality of these relationships.

In conclusion, we believe that the latent variables approach may be useful to researchers who are engaged in attempting to measure EF abilities in children. Of course, each research team will be motivated by their specific questions and populations when selecting specific EF tasks and EF performance measures. Therefore, there will never be uniformity in EF tasks and measures across studies,

nor should there be. We only propose that researchers may want to use multiple measures of EFs, identify the best indexes of EF performance empirically, and derive latent variables for the EF components of interest that are relatively free from task-specific influences. Clinically, it is crucial that our standardized measures of language ability actually measure language. Our results indicate that the CELF-4 Receptive Index may also capture children's domain-general updating ability. Theoretically, the domain specificity of language has been at the crux of scientific inquiry, and arguably the nature of syntax has been the most contentious aspect of this inquiry. Our results indicate that children's ability to analyze syntactic information may be associated with domain-general inhibition skills. Considering that these were school-age children with superb language skills, these results may have important implications for children with language impairments who have been shown to have difficulties with both updating and with inhibition. The next step, therefore, is to examine the degree to which these findings apply to populations with language impairments.

Acknowledgments

This research was supported by National Institute on Deafness and Other Communication Disorders Grant R01 DC011750 (awarded to Susan Ellis Weismer and Margarita Kaushanskaya) and National Institute on Child Health and Human Development Grant P30 HD03352 (awarded to Waisman Center, Marsha Mailick, PI). We are grateful to all of the families who participated in this study, as well as to the school administrators and teachers who generously helped us to recruit participants. We also would like to thank Milijana Buac, Megan Gross, Eileen Haebig, and Margarethe McDonald for their assistance with task design and their comments on the previous versions of this manuscript. Finally, we are grateful to Elizabeth Ales, Natalie Bowman, Nicole Compt, Kimberly Crespo, Kathryn Ficho, Sarah Jordan, Hailey Kuettner, Eva Lopez, Jessica Martalock, Elizabeth Mormer, Emily Murphy, Sarah Naumann, Stephanie Palm, Halice Patel, Rachel Roman, Tina Shieh, and Lauren Utech for their assistance with data collection and coding.

References

- Anderson, V., Jacobs, R., & Anderson, P. J. (2010). *Executive functions and the frontal lobes: A lifespan perspective*. Philadelphia, PA: Taylor & Francis.
- Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47–90). New York, NY: Academic Press.
- Barrouillet, P., Gavens, N., Vergauwe, E., Gaillard, V., & Camos, V. (2009). Working memory span development: A time-based resource-sharing model account. *Developmental Psychology*, 45, 477–490.
- Bates, E., & MacWhinney, B. (1987). Competition, variation, and language learning. In B. MacWhinney (Ed.), *Mechanisms of language acquisition*. Hillsdale, NJ: Erlbaum.
- Best, J., & Miller, P. (2010). A developmental perspective on executive function. *Child Development*, 81, 1641–1660.
- Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review*, 29, 180–200.
- Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, 21, 327–336.
- Bilenko, N. Y., Grindrod, C. M., Myers, E. B., & Blumstein, S. E. (2009). Neural correlates of semantic competition during processing of ambiguous words. *Journal of Cognitive Neuroscience*, 21, 960–975.
- Bishop, D. V. M., & Norbury, C. F. (2005). Executive functions in children with communication impairments, in relation to autistic symptomatology 2: Response inhibition. *Autism*, 9, 29–43.
- Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, 78, 647–663.
- Blair, C., Zelazo, P. D., & Greenberg, M. T. (2005). The measurement of executive function in early childhood. *Developmental Neuropsychology*, 28, 561–571.
- Brocki, K. C., & Bohlin, G. (2004). Executive function in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology*, 26, 571–593.
- Broidy, L. M., Nagin, D. S., Tremblay, R. E., Brame, B., Dodge, K. A., & Fergusson, D. E. (2003). Developmental trajectories of childhood disruptive behaviors and adolescent delinquency: A six-site cross-national study. *Developmental Psychology*, 30, 222–245.
- Case, R. (1995). Capacity-based explanations of working memory growth: A brief history and reevaluation. In F. E. Weinert & W. Schneider (Eds.), *Memory performance and competencies: Issues in growth and development* (pp. 23–44). Mahwah, NJ: Erlbaum.
- Choi, Y., & Trueswell, J. C. (2010). Children's (in)ability to recover from garden paths in a verb-final language: Evidence for developing control in sentence processing. *Journal of Experimental Child Psychology*, 106, 41–61.
- Costello, A. B., & Osborne, J. W. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical Assessment, Research & Evaluation*, 10, 1–9.
- Cragg, L., & Nation, K. (2008). Go or no-go? Developmental improvements in the efficiency of response inhibition in mid-childhood. *Developmental Science*, 11, 819–827.
- Daneman, M., & Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 19, 450–466.
- Davidson, M. C., Amso, D., Cruess-Anderson, L., & Diamond, A. (2006). Development of cognitive control and executive functions from 4–13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, 44, 2037–2078.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168.
- Diamond, A., & Kirkham, N. (2005). Not quite as grown-up as we like to think: Parallels between cognition in childhood and adulthood. *Psychological Science*, 16, 291–297.
- Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12-year-old children. *Psychological Test and Assessment Modeling*, 52, 419–431.
- Dunn, L., & Dunn, D. (2007). *Peabody Picture Vocabulary Test* (4th ed.). Minneapolis, MN: Pearson.
- Ellis Weismer, S., Plante, E., Jones, M., & Tomblin, J. B. (2005). A functional magnetic resonance imaging investigation of verbal working memory in adolescents with specific language

- impairment. *Journal of Speech, Language, and Hearing Research*, 48, 405–425.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, 16, 143–149.
- Ferrier, D. E., Bassett, H. H., & Denham, S. A. (2014). Relations between executive function and emotionality in preschoolers: Exploring a transitive cognition–emotion linkage. *Frontiers in Psychology*, 5, 1–12.
- Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology*, 133, 101–135.
- Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science*, 17, 172–179.
- Gangopadhyay, I., Davidson, M. M., Ellis Weismer, S., & Kaushanskaya, M. (2016). The role of nonverbal working memory in morphosyntactic processing by school-aged monolingual and bilingual children. *Journal of Experimental Child Psychology*, 142, 171–194.
- Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language*, 30, 336–360.
- Green, D. W. (1998). Mental control of the bilingual lexico–semantic system. *Bilingualism: Language and Cognition*, 1, 67–81.
- Haebig, E., Kaushanskaya, M., & Ellis Weismer, S. (2015). Lexical processing in school-age children with autism spectrum disorder and children with specific language impairment: The role of semantics. *Journal of Autism and Developmental Disorders*, 45, 4109–4123.
- Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis* (7th ed.). Upper Saddle River, NJ: Pearson Education.
- Hammill, D., & Newcomer, P. (2008). *Test of Language Development–Intermediate* (4th ed.). Austin, TX: Pro-Ed.
- Hayton, J. C., Allen, D. G., & Scarpello, V. (2004). Factor retention decisions in exploratory factor analysis: A tutorial on parallel analysis. *Organizational Research Methods*, 7, 191–205.
- Henry, L. A., Messer, D. J., & Nash, G. (2012). Executive functioning in children with specific language impairment. *Journal of Child Psychology and Psychiatry*, 53, 37–45.
- Hommel, B. (2011). The Simon effect as tool and heuristic. *Acta Psychologica*, 136, 189–202.
- Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, 44, 2017–2036.
- Hull, R., Martin, R. C., Beier, M. E., Lane, D., & Hamilton, A. C. (2008). Executive function in older adults: A structural equation modeling approach. *Neuropsychology*, 22, 508–522.
- Im-Bolter, N., Johnson, J., & Pascual-Leone, J. (2006). Processing limitations in children with specific language impairment: The role of executive function. *Child Development*, 77, 1822–1841.
- Jonkman, L. M. (2006). The development of preparation, conflict monitoring and inhibition from early childhood to young adulthood: A Go/No-go ERP study. *Brain Research*, 1097, 181–193.
- Joseph, R. M., McGrath, L. M., & Tager-Flusberg, H. (2005). Executive dysfunction and its relation to language ability in verbal school-age children with autism. *Developmental Neuropsychology*, 27, 361–378.
- Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review. *Neuropsychology Review*, 17, 213–233.
- Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working-memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology*, 133, 189–217.
- Khanna, M. M., & Boland, J. E. (2010). Children’s use of language context in lexical ambiguity resolution. *The Quarterly Journal of Experimental Psychology*, 63, 160–193.
- 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.
- Lezak, M. (1983). *Neuropsychological assessment*. New York, NY: Oxford University Press.
- Luciana, M. (2003). Practitioner review: Computerized assessment of neuropsychological function in children: Clinical and research applications of the Cambridge Neuropsychological Testing Automated Battery (CANTAB). *Journal of Child Psychology and Psychiatry*, 44, 649–663.
- Luciana, M., & Nelson, C. A. (2002). Assessment of neuropsychological function through use of the Cambridge neuropsychological testing automated battery: Performance in 4- to 12-year-old children. *Developmental Neuropsychology*, 22, 595–624.
- Luna, B. (2009). Developmental changes in cognitive control through adolescence. *Advances in Child Development and Behavior*, 37, 233–278.
- MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). *Psychological Review*, 109, 35–54.
- MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. *Psychology of Learning and Motivation*, 43, 163–214.
- Marton, K. (2008). Visuo-spatial processing and executive functions in children with specific language impairment. *International Journal of Language and Communication Disorders*, 43, 181–200.
- Mazuka, R., Jincho, N., & Onishi, H. (2009). Development of executive control and language processing. *Language and Linguistics Compass*, 3, 59–89.
- Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, 21, 8–14.
- 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.
- Morton, J. B., Bosma, R., & Ansari, D. (2009). Age-related changes in brain activation associated with dimensional shifts of attention: An fMRI study. *NeuroImage*, 46, 249–256.
- Moser, D. C., Fridriksson, J., & Healy, E. W. (2007). Sentence comprehension and general working memory. *Clinical Linguistics & Phonetics*, 21, 147–156.
- Mullane, J. C., Corkum, P. V., Klein, R. M., & McLaughlin, E. (2009). Interference control in children with and without ADHD: A systematic review of Flanker and Simon task performance. *Child Neuropsychology*, 15, 321–342.
- Munoz, D. P., & Everling, S. (2004). Look away: The anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience*, 5, 218–228.
- Norman, D., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. Davidson, R. G. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances*

- in research and theory (pp. 1–18). New York, NY: Plenum Press.
- Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective, & Behavioral Neuroscience*, 5(3), 263–281.
- O'Connor, B. P. (2000). SPSS and SAS programs for determining the number of components using parallel analysis and Velicer's MAP test. *Behavior Research Methods, Instrumentation, and Computers*, 32, 396–402.
- Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping*, 25, 46–59.
- Pagulayan, K. F., Bush, R. M., Medina, K. L., Bartok, J. A., & Krikorian, R. (2006). Developmental normative data for the Corsi Block-tapping task. *Journal of Clinical and Experimental Neuropsychology*, 28, 1043–1052.
- Roberts, L., Marinis, T., Felser, C., & Clahsen, H. (2007). Antecedent priming at trace positions in children's sentence processing. *Journal of Psycholinguistic Research*, 36, 175–188.
- Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental Science*, 14, 1161–1175.
- Sainson, C., Barat, M., & Aguert, M. (2014). Communication disorders and executive function impairment after severe traumatic brain injury: An exploratory study using the GALI (a grid for linguistic analysis of free conversational interchange). *Annals of Physical and Rehabilitation Medicine*, 57, 664–683.
- Salthouse, T. A. (2010). Is Flanker-based inhibition related to age? Identifying specific influences of individual differences on neurocognitive variables. *Brain and Cognition*, 73, 51–61.
- Semel, E., Wiig, E. H., & Secord, W. A. (2003). *Clinical evaluation of language fundamentals* (4th ed.). San Antonio, TX: Psychological Corporation.
- Sesma, H. W., Mahone, E. M., Levine, T., Eason, S. H., & Cutting, L. E. (2009). The contribution of executive skills to reading comprehension. *Child Neuropsychology*, 15, 232–246.
- Slevc, L. R. (2011). Saying what's on your mind: Working memory effects on sentence production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 37, 1503–1514.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 47, 499–504.
- Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Boston, MA: Pearson.
- Tomasello, M. (2003). *Constructing language: A usage-based theory of language acquisition*. Cambridge, MA: Harvard University Press.
- Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory & Language*, 28, 127–154.
- van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, 35, 427–449.
- Vaughan, L., & Giovanello, K. (2010). Executive function in daily life: Age-related influences of executive processes on instrumental activities of daily living. *Psychology and Aging*, 25, 343–355.
- Vugs, B., Hendriks, M., Cuperus, J., & Verhoeven, L. (2014). Working memory performance and executive function behaviors in young children with SLI. *Research in Developmental Disabilities*, 35, 62–74.
- Wechsler, D. (2003). *Wechsler Intelligence Scale for Children* (4th ed.) [Measurement instrument]. San Antonio, TX: Psychological Corporation.
- Weiland, C., Barata, M. C., & Yoshikawa, H. (2013). The co-occurring development of executive function skills and receptive vocabulary in preschool-aged children: A look at the direction of the developmental pathways. *Infant and Child Development*, 23, 4–21.
- Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, 44, 573–587.
- Wilhelm, O., Hildebrandt, A., & Oberauer, K. (2013). What is working memory capacity, and how can we measure it? *Frontiers in Psychology*, 4, 1–22.
- Woodard, K., Pozzan, L., & Trueswell, J. C. (2016). Taking your own path: Individual differences in executive function and language processing skills in child learners. *Journal of Experimental Child Psychology*, 141, 187–209.
- Wu, K. K., Chan, S. K., Leung, P. W. L., Liu, W. S., Leung, F. L., & Ng, R. (2011). Components and developmental differences of executive functioning for school-aged children. *Developmental Neuropsychology*, 36, 319–337.
- Yeung, O., & Law, S. P. (2010). Executive functions and aphasia treatment outcomes: Data from an ortho-phonological cueing therapy for anomia in Chinese. *International Journal of Speech-Language Pathology*, 12, 529–544.
- Zelazo, P. D., Müller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood [Monograph]. *Monographs of the Society for Research in Child Development*, 68(Serial No. 2), vii–137.