Research Article

Applying an Integrative Framework of Executive Function to Preschoolers With Specific Language Impairment

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Purpose: The first goal of this research was to compare verbal and nonverbal executive function abilities between preschoolers with and without specific language impairment (SLI). The second goal was to assess the group differences on 4 executive function components in order to determine if the components may be hierarchically related as suggested within a developmental integrative framework of executive function.

Method: This study included 26 4- and 5-year-olds diagnosed with SLI and 26 typically developing age- and sex-matched peers. Participants were tested on verbal and nonverbal measures of sustained selective attention, working memory, inhibition, and shifting.

Results: The SLI group performed worse compared with typically developing children on both verbal and nonverbal

measures of sustained selective attention and working memory, the verbal inhibition task, and the nonverbal shifting task. Comparisons of standardized group differences between executive function measures revealed a linear increase with the following order: working memory, inhibition, shifting, and sustained selective attention.

Conclusion: The pattern of results suggests that preschoolers with SLI have deficits in executive functioning compared with typical peers, and deficits are not limited to verbal tasks. A significant linear relationship between group differences across executive function components supports the possibility of a hierarchical relationship between executive function skills.

Executive function refers to cognitive processes involved in the control of thought, attention, and behavior (Zelazo & Müller, 2010). Examples of cognitive skills that are typically categorized within executive function include focusing and sustaining attention, holding and manipulating information in memory (i.e., working memory), inhibiting distractors, shifting attention between tasks or stimuli, flexible thinking, planning, and problem solving. In recent years, researchers have become increasingly interested in children's executive function abilities because executive function abilities in childhood are related to social-emotional understanding (Rhoades, Greenberg, & Domitrovich, 2009) and academic success (Blair & Razza, 2007) suggesting far-reaching impact.

Developmental Integrative Framework of Executive Function

Integrative frameworks describe executive function as a set of related but separable cognitive abilities or components (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Integrative frameworks are supported by large sample studies of typically developing children tested with multiple executive function measures. Factor analysis techniques have found multiple semi-independent factors, which supports the idea of interrelated skills central to integrative frameworks (Huizinga, Dolan, & van der Molen, 2006 [7-, 11-, and 15-year-olds]; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003 [8- to 13-year-olds]; Rose, Feldman, & Jankowski, 2011 [11-year-olds]). Many such investigations have revealed that young children's executive function is best represented by two underlying factors—often represented by a separate factor for inhibition and a combined working memory and shifting component (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012 [3- to 5-year-olds]; Usai, Viterbori, Traverso, & De Franchis, 2014 [5- and 6-year-olds]). A recent investigation by Lee, Bull, and Ho (2013) of the development of executive function from early childhood through adolescence revealed that among younger children, executive function

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was best modeled as a two-factor system, but the more adult-like three-factor model began to emerge around age 11 and best fit the data by the time participants were 15 years of age. However, in contrast to the possibility of multiple executive function factors, other evidence on the basis of data from 2- to 6-year-old children (Wiebe, Espy, & Charak, 2008) and 7- to 9-year-olds (Brydges, Reid, Fox, & Anderson, 2012) supports a single executive function factor. This discrepancy may be due to the degree of interrelatedness of the particular tasks used across studies or on age-dependent changes in executive function skills during child development.

Garon, Bryson, and Smith (2008) described the emergence and development of executive function in early childhood and formalized their description as a developmental integrative framework model. Their model is an integrative framework in which components are interrelated but separable and, like integrative models of adult executive function (e.g., Miyake et al., 2000), the model includes three executive function components—working memory, inhibition, and shifting—along with an underlying attention component. Furthermore, Garon et al. describe a hierarchical relationship between executive function components in which more basic and earlier-developing skills, such as attention, underlie more complex components such as shifting, which involves the coordination of multiple executive functions (see Figure 1).

Following the Garon et al. (2008) model, attention underlies all executive function abilities. The next skill to develop within the hierarchy is working memory, followed by inhibition. These skills come online from infancy to the early preschool period, and as children mature, they gain the ability to coordinate different executive function components. Coordination of lower-level skills allows children to achieve more complex executive function abilities such as attention shifting, planning, and problem solving. Garon et al.'s model is based on typically developing children, but it has interesting implications for children with disordered development. Due to the hierarchical association between executive function components, this model would lead to

the prediction that a child with deficits in lower-level components would demonstrate difficulty in subsequent higher-level components due to the possibility of cascading effects of lower-level deficits.

Applying an integrative model of executive function to the investigation of executive function in young children with specific language impairment (SLI) presents advantages over considering executive function components in isolation among this population. One key advantage is the ability to compare across multiple executive function components between participants with and without SLI in order to determine within the same sample which components are areas of deficit for children with SLI and which are intact. Such comparisons are especially important given the conflicting findings in this literature regarding which aspects of executive function are areas of deficit for children with SLI. Furthermore, using an integrative model and testing multiple executive function components allows us to consider how executive function components are related within the participants with SLI in order to identify areas of overlap versus separation. Last, following a proposed model of executive function allows us to make testable predictions about the nature of the differences in executive function components between children with SLI and peers with typical language development.

SLI and Executive Function

In order to receive an SLI diagnosis, a child must have language abilities significantly below expectations for his or her age level, and these poor language skills must occur in the absence of hearing loss, cognitive impairment, diagnoses of other developmental disorders, or frank neurological damage. Although a diagnostic criterion for SLI is normal cognitive development, researchers have reported that many children who are diagnosed with this disorder also demonstrate subclinical deficits in nonlinguistic domains, including executive function (for review, see Kapa & Plante, 2015). Specific executive function components that have been assessed in children with SLI and compared with typically developing peers include sustained selective attention, working memory, inhibition, and shifting.

Sustained Selective Attention

Sustained selective attention is one's ability to maintain attention to a specific task, stimulus, or goal stimulus across time, which corresponds to the selective and focused attention described by Garon et al. (2008). Research on sustained selective attention in young children with SLI suggests that these children are worse at maintaining focused attention compared with age-matched peers with typical language abilities. Four- to 6-year-old children with SLI made more false alarm errors (i.e., impulsivity) and had fewer hits (i.e., inattention) than typically developing children on a visual continuous performance task (Finneran, Francis, & Leonard, 2009). These findings are consistent with other studies that also report a visual attention deficit in children with SLI on the basis of performance on a rapid

Figure 1. Developmental hierarchy of executive function components on the basis of a developmental integrative framework (Garon et al., 2008).

visual information processing task in which participants responded to a visual target stimulus in a continuous stream of stimuli (Marton, Campanelli, Scheuer, Yoon, & Eichorn, 2012 [10- to 14-year-olds]).

Spaulding, Plante, and Vance (2008) reported that 4- and 5-year-old children with SLI responded less accurately than typically developing preschoolers to auditory stimuli (both linguistic and nonlinguistic, environmental sound stimuli) during a continuous performance task that required a button-press response to a target stimulus and withholding responding to nontargets but that the groups did not differ in their performance on a visual task. Auditory attention deficits among preschoolers with SLI (Spaulding et al., 2008) converge with the findings that 6- to 10-year-old children with SLI have weak attention abilities as measured by an auditory continuous performance task (Montgomery, 2008; Montgomery, Evans, & Gillam, 2009). Likewise, 9- to 12-year-olds with SLI had significantly slower reaction speed compared with typical language peers on an auditory selective attention task that required attention to words presented in one ear while ignoring words simultaneously presented in the other ear (Victorino & Schwartz, 2015). In a meta-analysis, Ebert and Kohnert (2011) reported that, on the basis of evidence from 17 studies, children with SLI performed significantly worse on sustained selective attention tasks, including both visual and auditory stimuli, but the largest effects occurred on tests of auditory attention with linguistic stimuli, and the smallest effects were found when children were tested using visual stimuli.

Working Memory

Working memory, also referred to as updating, is one's ability to hold information in memory and to perform mental operations on this information (Diamond, 2013). Several studies have assessed the working memory abilities of children with SLI. The majority of these studies find evidence that children with SLI demonstrate poorer working memory when compared with typically developing, age-matched children on working memory tasks that require the storage and processing of auditory information. Both school-age and preschool-age children with SLI have been shown to have deficits on tasks such as listening recall and counting recall that require holding auditory information in memory (words or numbers) while completing other operations, such as judging the accuracy of a sentence or counting aloud (Archibald & Gathercole, 2006 [7- to 11-year-olds]; Henry, Messer, & Nash, 2012 [8- to 13-year-olds]; Vugs, Hendricks, Cuperus, & Verhoeven, 2014 [4- to 5-year-olds]). Poorer auditory working memory in children with SLI has also been documented in backward digit span tasks in which participants remember lists of digits and repeat them in the reverse order of presentation (Archibald & Gathercole, 2006; Duinmeijer, de Jong, & Scheper, 2012 [6- to 9-year-olds]; Vugs et al., 2014).

In contrast, evidence is somewhat mixed with regard to if working memory deficits in SLI extend to visual memory measures. Many studies suggest that children with SLI are worse at visual working memory when compared

with peers with typical language development. For example, 7- to 8-year-olds with SLI perform more poorly on a visual fast mapping task than children without SLI (Alt, 2013). Likewise, working memory deficits have been reported for children with SLI on the basis of their performance on visual tasks in which participants must recall spatial information, such as the odd-one-out task that requires participants to identify which item in a set of visual stimuli arranged in a grid does not match the other stimuli and then recall the location of the mismatch stimulus in a blank grid (Henry et al., 2012 [8- to 13-year-olds]; Vugs et al., 2014 [4- to 5-year-olds]). Deficits in visual working memory for children with SLI also have been reported on the basis of their performance on visual span tasks in which participants recalled and reproduced the order of a sequence of visual targets (Hoffman & Gillam, 2004 [8- to 10-year-olds]; Marton et al., 2012 [10- to 14-year-olds]) and on a visual N-back task in which participants compared target visual stimuli with previously presented images (Im-Bolter, Johnson, & Pascual-Leone, 2006 [7- to 10-year-olds]).

In contrast, others report that children with SLI perform equivalently to typical language peers on measures requiring recall of visual information, such as block or picture location (Hutchinson, Bavin, Efron, & Sciberras, 2012 [6- to 9-year-olds]; Lum, Conti-Ramsden, Page, & Ullman, 2012 [8- to 11-year-olds]; Petruccielli, Bavin, & Bretherton, 2012 [5-year-olds]). However, Vugs, Cuperus, Hendriks, and Verhoeven (2013) conducted a meta-analysis of studies testing visuospatial working memory in children with language impairment and concluded that children with language impairment perform significantly worse than peers with typical language development on visual tasks that require both short-term memory and working memory. Thus, children with SLI appear to demonstrate working memory deficits across both visual and auditory modalities.

Inhibition

Inhibition, also referred to as inhibitory control, is the ability to avoid external distraction or to prevent oneself from making a prepotent, but incorrect, response (Diamond, 2013). The limited evidence that exists regarding inhibition abilities of children with SLI suggests that they perform worse than age-matched controls. For example, 7- to 12-year-olds with SLI made more errors than peers with typical language abilities in an antisaccade task, which is a simple visual response inhibition task that required participants to inhibit looking toward a cue presented before a target (Im-Bolter et al., 2006). Other research has also reported visual inhibition deficits among SLI participants compared with participants with typical language development when they were required to produce opposite hand shapes in response to an experimenter (Henry et al., 2012 [8- to 13-year-olds]) and when withholding a response during a visual stop signal task (Marton et al., 2012 [10- to 14-year-olds]).

There are also reports of auditory inhibition deficits associated with SLI. Roello, Ferretti, Colonnello, and Levi (2015) compared inhibition abilities between 4- and

5-year-old children with and without SLI using a sun–moon task that requires children to say *day* in response to the moon and *night* in response to the sun and found that the children with SLI were less accurate on this task than children with typically developing language. Spaulding (2010) reported that 4- to 5-year-olds with SLI performed more poorly than typically developing preschoolers on both an auditory stop signal task with verbal stimuli and a verbal distractor task in which children had to ignore distracting words to focus on the target word. In contrast, 8- to 13-year-olds with SLI performed equally to children with typical language in a task that required participants to provide an opposite verbal response instead of copying the experimenter (Henry et al., 2012). The majority of this research suggests that children with SLI demonstrate poor inhibition, and this appears to affect both visual and auditory/verbal measures. However, these conclusions are somewhat tentative because they are based on the few studies that have tested inhibition in SLI.

Shifting

Shifting, also referred to as cognitive flexibility, is the ability to flexibly adjust to changing rules or task demands, such as switching attention between tasks, stimuli, or stimulus properties (Diamond, 2013). In contrast to the research on other executive function components, the majority of studies that have assessed attention shifting indicate that this skill is unaffected in SLI. For example, 6- to 12-year-olds with and without SLI performed equally on the Wisconsin Card Sorting Test (Weyandt & Willis, 1994), which can be interpreted as a shifting measure (Miyake et al., 2000). Other studies have used visual tasks in which children are cued to switch attention between two stimulus dimensions, such as digit versus number of digits (Im-Bolter et al., 2006 [7- to 12-year-olds]) or two types of stimuli as is the case in a trail-making task in which focus shifts between letters and numbers (Henry et al., 2012 [8- to 13-year-olds]; Im-Bolter et al., 2006). When completing such tasks, children with SLI responded more slowly and made more errors than typically developing children, but there were no group differences in local switch costs or the difference in response time/accuracy between switch and nonswitch trials (Dibbets, Bakker, & Jolles, 2006 [6-year-olds]; Im-Bolter et al., 2006), which led researchers to conclude that children with SLI have comparable shifting abilities to those of typically developing children.

In contrast to these studies reporting intact shifting abilities in children with SLI, both Roello et al. (2015) and Farrant, Mayberry, and Fletcher (2012) found evidence of shifting deficits among children with SLI. Roello et al. reported that 4- and 5-year-old children with SLI performed worse than typically developing children on a task in which participants categorized objects in two different ways, which required shifting attention between the categorization properties. Farrant et al. found a shifting deficit associated with SLI as evidenced by poorer performance in 4- to 6-year-old children with SLI on a card-sorting task in which children

shifted attention between two stimulus properties. One possible explanation for the discrepancy in reports of the shifting abilities of children with SLI is that the deficits reported in younger children may resolve and no longer be evident when tested in older children.

Current Study

As summarized here, extant research has considered the executive function abilities of children with SLI, and areas of deficit have been reported; however, there is some conflicting information regarding which executive function components may be affected in children with SLI. Furthermore, the existing literature provides mixed evidence regarding whether executive function deficits in children with SLI are limited to verbal measures or if they also extend to nonverbal executive function tasks. If SLI deficits are restricted to verbal executive function measures, this may reflect the impaired language system of children with SLI whereas poor performance on nonverbal executive function measures would suggest a domain-general executive function deficit. Last, many of the existing studies compared children with SLI and children with typical language on a single executive function component, which obscures the possible relationships between executive function components in this population. The few studies that have tested multiple executive function components have included older, school-age children (Henry et al., 2012; Im-Bolter et al., 2006; Marton et al., 2012), so it remains unclear how these components are related during the preschool period when these skills are emerging (Carlson, 2005).

The first goal of the current study was to compare performance of preschoolers with and without SLI on a battery of executive function tasks that provide measures of verbal and nonverbal abilities on four executive function components. These comparisons were designed to identify executive function components that may be affected in preschoolers with SLI and to test whether SLI executive function deficits are domain-specific (i.e., limited to verbal tasks) or domain-general. We hypothesized that preschoolers with SLI would perform worse than typically developing peers on all measures but that group differences would be larger on verbal measures than nonverbal measures.

The second goal of this study was to examine the executive function differences between preschoolers with and without SLI within the developmental integrative framework described by Garon et al. (2008). On the basis of the relationship between executive function components, we hypothesized that group differences in executive function would increase from lower- to higher-level components with the largest difference between children with SLI and typical language occurring on our measure of shifting. This prediction is based on the possibility that deficits in the lower-level components would result in cascading effects with the largest negative impact on higher-level skills. Although this hypothesized pattern of results is in line with the predicted relationship between executive function components described by Garon et al., it should be noted that it is not necessarily supported by previous

research on executive function abilities in children with SLI. To be specific, although previous work has provided evidence of attention, working memory, and inhibition deficits in children with SLI relative to typical peers, it conflicts with the majority of previous studies that report intact shifting abilities among children with SLI (e.g., Dibbets et al., 2006; Henry et al., 2012; Im-Bolter et al., 2006; Weyandt & Willis, 1994).

Method

Participants

Fifty-two 4- and 5-year-olds participated in the study. These participants were native English speakers, who passed a hearing screening at 1000, 2000, and 4000 Hz in both ears at 25 dB; received a standard score of 75 or above on a nonverbal intelligence measure, the Kaufman Assessment Battery for Children, Second Edition (Kaufman & Kaufman, 2004); and had no diagnosis of motor, behavioral, cognitive, or neurological disorders. Half of participants ($n = 26$, 13 girls, 13 boys) were classified as having typical language development, and the other half ($n = 26$, 13 girls, 13 boys) were classified as having SLI. Children in the typical language group scored 87 or higher (Greenslade, Plante, & Vance, 2009) on the Structured Photographic Expressive Language Test–Preschool, Second Edition (SPELT-P 2; Dawson et al., 2005) standardized language measure. These children also scored within normal limits on the Goldman-Fristoe Test of Articulation–Second Edition (Goldman & Fristoe, 2000) and had no history of speech or language therapy, and a certified speech-language pathologist judged their language to be within age expectations during informal conversations across approximately 10 testing sessions over the course of the study. Children assigned to the SLI group had standard scores below 87 on the SPELT-P 2, and a speech-language pathologist judged their conversational language abilities to be atypical during informal conversational interactions across approximately 10 testing sessions over the course of the study. Each child included in the typically developing group was matched to a child in the SLI group on sex and age (± 4 months). The Peabody Picture Vocabulary Test–Fourth Edition (Dunn & Dunn, 2007) was administered to all children to describe current receptive vocabulary knowledge.

Test results for both groups are reported in Table 1. The two language groups were compared with one another on age and maternal education (proxy for socioeconomic status [SES]), two demographic variables known to influence executive function abilities (Carlson, 2005; Hackman & Farah, 2009). These group comparisons revealed that the groups did not differ significantly on age, $t(50) = 0.28$, $p = .78$, or maternal education, $t(40) = 1.03$, $p = .31$. In addition, the groups' scores on standardized language and nonverbal intelligence tests were compared. Consistent with our expectations, the SLI group scored significantly lower than the typical language group on the SPELT-P 2, $t(50) = 11.34$, $p < .001$, Cohen's $d = 3.14$; the Peabody

Table 1. Group means (standard deviations) and ranges of demographic and standardized measures.

Parameter	SLI		TD	
	<i>M</i> (<i>SD</i>)	Range	<i>M</i> (<i>SD</i>)	Range
Age (months)	59.1 (5.9)	49–70	59.5 (4.8)	50–69
Maternal education	14.3 (1.5)	12–17	14.9 (2.6)	8–17
KABC-II*	102.6 (12.7)	81–132	110.4 (12.5)	87–135
SPELT-P 2*	71.0 (12.4)	34–85	106.7 (10.1)	89–125
PPVT-4*	95.8 (12.4)	73–129	111.8 (16.1)	75–144
GFTA-2*	82.2 (19.8)	45–111	105.2 (8.7)	90–119

Note. Maternal education is the number of years of education completed with scores ranging from 8 to 17 (graduate degree). KABC-II, SPELT-P 2, PPVT-4, and GFTA-2 are standard scores. Each standardized measure has an $M = 100$ and $SD = 15$. SLI = specific language impairment; TD = typically developing; KABC-II = Kaufman Assessment Battery for Children, Second Edition; SPELT-P 2 = Structured Photographic Expressive Language Test–Preschool, Second Edition; PPVT-4 = Peabody Picture Vocabulary Test–Fourth Edition; GFTA-2 = Goldman-Fristoe Test of Articulation–Second Edition.

* $p < .05$.

Picture Vocabulary Test–Fourth Edition, $t(50) = 3.98$, $p < .001$, Cohen's $d = 1.10$; and the Goldman-Fristoe Test of Articulation–Second Edition, $t(35) = 5.38$, $p < .001$, Cohen's $d = 1.50$. The SLI group's nonverbal intelligence score was also significantly below that of the typical language group, $t(50) = 2.22$, $p = .03$, Cohen's $d = 0.62$.

Materials and Procedures

Research participants were recruited from area pre-schools and day cares with an effort to sample a representative SES range. Before testing began, we received written parental consent and verbal child assent. Children were tested individually by trained research assistants and participated for approximately 20 min each day over the course of 10 testing sessions. In addition, parents and teachers completed questionnaires indicating if they had concerns about each child's language, speech, hearing, or cognitive abilities. All tasks were presented in a quasi-random order, and administration of the verbal and nonverbal measures of a single executive function component in the same day were avoided.

Executive Function Tasks

Each participant completed a total of eight executive function measures designed to assess verbal and nonverbal performance on each of the four executive function components of interest: sustained selective attention, working memory, inhibition, and shifting (see Figure 1). Each task used here, with the exception of our attention measure and verbal shifting, was described and categorized by Garon et al. (2008). Reverse span tasks are categorized as complex working memory tasks, day–night is categorized as a complex response inhibition task, and card sorting is

described as an attention-shifting measure. For the purposes of this research, tasks were broadly categorized as verbal if they included verbal stimuli and/or required children to produce a verbal response. Tasks were classified as nonverbal if they included primarily visual stimuli and did not require a verbal response from participants. However, it should be noted that none of the measures can be described entirely as nonverbal because all included verbal task instructions and feedback, and participants may have been engaging in self-directed speech (covert or overt) to complete both verbal and nonverbal tasks. Thus, although we have dichotomized the tasks for descriptive purposes, it may be most accurate to consider the tasks on a continuum of verbal demands with the verbal tasks placing high overt demands on participants' verbal abilities (either comprehension, production, or both) and the nonverbal tasks placing relatively less demand on verbal abilities.

Sustained Selective Attention

Verbal and visual sustained selective attention were assessed using two similar computerized continuous performance tasks presented via DirectRT (Jarvis, 2008). In both tasks, participants were required to press a button in response to a target and to withhold responding to nontargets. Each task began with a series of 15 training items followed by 60 test items. During both the test and training items, the program provided positive feedback for hits (i.e., a button press in response to a target) and negative feedback in the form of a red X on a black screen following false alarms (i.e., a button press in response to a nontarget). In addition, during training, the experimenter provided positive and negative verbal feedback in response to correct rejection and misses, respectively, but no feedback was provided for misses or correct rejections during the test phase. The test items comprised 20 target trials and 40 nontarget trials for a total of 60 test trials. In the verbal sustained selective attention task, the target was a phrase, "It's a fly," and nontarget phrases differed in the final word (e.g., "It's a rock," "It's a star"). Stimuli were degraded by adding a 14 dB Gaussian noise mask to half of the verbal target items and half of the nontarget items in order to increase the attentional demand for the masked items (Spaulding et al., 2008).

The visual sustained selective attention task included an image of a pig as the target and images of other animals (e.g., horse, snake) as nontargets. Half of the visual target items and half of the nontarget items included a visual mask that obscured approximately 30% of the image. Again, this was designed to increase attentional demand for the visual stimuli. In both the verbal and visual sustained selective attention tasks, the available response window was 6,000 ms following the onset of a target trial, and response windows were 3,000 ms (20 trials), 4,000 ms (10 trials), or 5,000 ms (10 trials) following the onset of nontarget trials. Responses made during this window were scored as hits or false alarms, and failure to respond during this window was scored as either a miss or correct rejection. Visual stimuli remained on the screen until the participant responded or

until the response window time had elapsed. Due to the dynamic nature of the verbal stimuli versus the static nature of the visual stimuli, these response windows led to longer exposure to the visual stimuli compared with the verbal stimuli.

Working Memory

Verbal working memory was assessed using a backward word-span task, which required children to repeat lists of common one-syllable words (e.g., dog, foot, train) after the experimenter in reverse order. The task began with six training items that included picture cards to help establish the concept of repetition in reverse. These picture cards were not used during administration of test trials. During the training phase, participants received feedback from the experimenter. Following practice, test trials were administered of increasing length from two to six words with two trials of each span length until the child made errors on both lists of a given length. The total number of lists correctly repeated served as the verbal working memory score.

The nonverbal working memory measure was a backward block-tapping task. This task required children to tap a set of six identical blocks in the reverse order as the experimenter. The block-tapping span task began with six training items that included experimenter feedback and then proceeded with two tapping spans of each length from one to six blocks until the child made errors on two spans of the same length. The nonverbal working memory score was total number of spans correctly repeated.

Inhibition

Two computerized measures that are based on Diamond, Kirkham, and Amso's (2002) day-night task were used to assess children's inhibition. Each task required the child to respond to day or night stimuli by pressing either a button labeled with an illustrated sun image or a button labeled with an illustrated moon image. Participants were required to inhibit prepotent responding of sun for day and moon for night and instead provide the opposite response pairings. In the verbal day-night task, children pressed the buttons in response to auditory stimuli of a woman saying *day* or *night*. In the nonverbal task, children pressed a button in response to visual stimuli: a photograph of the daytime sky or a photograph of the nighttime sky. The tasks began with instructions, which included the need to respond as quickly as possible, followed by four practice trials during which the child was given feedback from the experimenter. Following the practice trials, children completed 30 test trials.

Shifting

Two tasks that required switching attention between different stimulus dimensions were used to measure children's verbal and nonverbal shifting abilities. The verbal shifting task used a computerized format that required children to switch between labeling different properties of stimulus images. The stimuli were illustrated images of a

girl with a cat and a boy with a dog. Children began the task with the preswitch phase, or “pet game,” during which each stimulus picture was preceded by a visual and auditory cue (collar image and bell sound), and the correct response to each image was labeling the animal (e.g., cat or dog). After completing two practice trials that included experimenter feedback and six test trials, the task switched to the postswitch phase, or “kid game,” in which the correct response was to label the child (e.g., boy or girl). Postswitch stimuli were preceded by a different visual and auditory cue (t-shirt and gong sound), and the postswitch phase included six test trials.

The advanced task phase required children to switch randomly between the pet game and the kid game using the two cue types to guide their responding. This phase began with instructions followed by four practice items and 12 test items. Experimenters recorded children’s first response to each item, and overall accuracy for each task phase—preswitch, postswitch, and advanced—was calculated. All children completed the three phases of the task, but to make scores more parallel to those from the nonverbal shifting task, those children who did not correctly sort at least 83% of the postswitch cards correctly were assigned a score of zero for the advanced sorting portion. The total number of points was then divided by the maximum possible in order to derive a percentage of correct responses for each participant.

Eighteen of the children in the SLI group completed an earlier version of the verbal shifting task that included more trials. This task comprised 10 preswitch trials, 10 postswitch trials, and 20 advanced trials. The task was revised to mirror the nonverbal shifting task. Comparisons between children who completed the earlier and revised versions of the task revealed equivalent performance across the two task versions.

Nonverbal shifting was tested using the dimensional change card sort (DCCS; Zelazo, Frye, & Rapus, 1996). Children first completed the standard version of the DCCS in which they received a set of 12 test cards with images that varied on the dimensions of color and shape (e.g., red rabbits and blue cars). Two sorting bins were placed in front of the participant, each labeled with a target card (e.g., blue rabbit and red car). In the preswitch phase of the task, children sorted the test cards on the basis of one dimension (color or shape). After children sorted six cards, the experimenter informed them that the game changed, and in this postswitch phase, children sorted the remaining six cards on the basis of the opposite dimension (shape or color).

Those children who passed postswitch sorting, which was defined as correctly sorting five out of six postswitch cards in the standard DCCS, completed the advanced version of the DCCS (Carlson, 2005; Zelazo, 2006). The advanced version of the task maintains the same target cards used in the standard task, but half of the 12 test cards have a black rectangular border surrounding the image. Children were instructed to sort the cards with a border by one dimension (e.g., color) and to sort the cards without

borders using the other dimension (e.g., shape). The border cards were randomly intermixed within the deck of test cards, so children were unaware of when a sorting dimension switch would occur. Sorting accuracy was recorded and summed for the preswitch, postswitch, and advanced DCCS phases for a maximum of 24 points. Each child’s total was divided by 24 in order to provide the percentage of correct responses.

Results

Comparing Group Executive Function Scores

Group means and standard deviations in each executive function task are reported in Table 2. Executive function scores were transformed into standardized z scores on the basis of the total sample collapsed across groups. This permitted comparisons across different metrics and tests. A mixed effects Group (SLI and typically developing) $\times$ Domain (verbal and nonverbal) $\times$ Component (sustained selective attention, working memory, inhibition, shifting) omnibus analysis of variance was conducted in order to compare the SLI and typically developing groups across the verbal and nonverbal executive function measures. This analysis revealed a significant main effect of Group, $F(1, 50) = 12.74, p = .001, \eta_p^2 = .203$, and a significant Group $\times$ Domain $\times$ Component three-way interaction, $F(3, 150) = 3.53, p = .02, \eta_p^2 = .066$. The same analysis was conducted with the Kaufman Assessment Battery for Children, Second Edition, scores entered as a covariate in order to rule out the possibility that executive function differences were driven by the discrepancy in nonverbal IQ between the groups. This analysis of covariance also resulted in a significant main effect of Group, $F(1, 49) = 6.97, p = .01, \eta_p^2 = .125$, and a significant Group $\times$ Domain $\times$ Component three-way interaction, $F(3, 147) = 4.14, p = .007, \eta_p^2 = .078$. Because the group differences in executive function remained after controlling for nonverbal IQ, this covariate was excluded from subsequent analyses.

Additional analyses of variance were used to decompose the three-way interaction by testing Group $\times$ Domain for each of the four components separately. Because these analyses were within executive function components, which were measured using the same metric, raw scores were used instead of z scores. The results of these analyses are reported in Table 3. In summary, there was a significant main effect of Group with no main effect of Domain or Group $\times$ Domain interaction for both sustained selective attention and working memory, suggesting that children with SLI performed more poorly than children with typical language development on both verbal and nonverbal measures of these executive function components. In contrast, there were significant main effects of Group, Domain, and Group $\times$ Domain interactions for both inhibition and shifting analyses. In the case of inhibition, the SLI group was only significantly worse on the verbal day–night task compared with the typical language group. With regard to the shifting measures, the groups only significantly differed on the DCCS,

Table 2. Group means (standard deviations) and ranges of executive function measures.

Function	SLI		TD	
	<i>M (SD)</i>	Range	<i>M (SD)</i>	Range
Verbal sustained attention	0.93 (0.12)	0.57–1.00	0.98 (0.03)	0.88–1.00
Nonverbal sustained attention	0.94 (0.09)	0.60–1.00	0.98 (0.04)	0.85–1.00
Verbal working memory	1.20 (1.30)	0.00–3.00	1.90 (1.50)	0.00–4.00
Nonverbal working memory	0.92 (0.84)	0.00–2.00	1.70 (1.50)	0.00–4.00
Verbal inhibition	0.51 (0.28)	0.03–1.00	0.81 (0.23)	0.13–1.00
Nonverbal inhibition	0.72 (0.27)	0.00–1.00	0.82 (0.21)	0.30–1.00
Verbal shifting	0.71 (0.26)	0.21–1.00	0.77 (0.22)	0.29–1.00
Nonverbal shifting	0.48 (0.26)	0.25–0.92	0.73 (0.13)	0.25–1.00

Note. The verbal working memory and nonverbal working memory tasks each have a minimum score of zero and a maximum score of 10. All other scores are represented as the proportion of correct responses with a minimum value of zero and maximum value of 1.0. SLI = specific language impairment; TD = typically developing.

which was the nonverbal measure, with the typical group significantly outperforming the SLI group.

Comparing Group Differences Across Components

We combined the verbal and nonverbal measures for each executive function task and then standardized the SLI

group scores using the mean and standard deviation of the TD group. The following formula was used for this procedure:

$$z_{\text{SLI}} = \frac{x_{\text{SLI}} - \bar{x}_{\text{TD}}}{s_{\text{TD}}}$$

where z_{SLI} is the standardized score for a member of the SLI group, x_{SLI} is the raw score for a member of the SLI group, $\bar{x}_{\text{TD}}$ is the mean score for the TD group, and s_{TD} is the standard deviation for the TD group. The mean standardized score for each end point (attention, inhibition, memory, and shifting) was calculated. The sustained selective attention measures were the most difficult for the SLI participants relative to the TD participants ($z = -1.33$), followed by shifting ($z = -1.21$), inhibition ($z = -0.97$), and working memory ($z = -0.56$).

These mean scores were arranged in increasing order of absolute value to assess the trend in difficulty by using a simple linear regression. The slope of the resulting regression line was significant, $\alpha = 1.66$, $\beta = -.25$, $p = .03$, indicating that the group differences significantly increased in a linear fashion such that the smallest group difference was found for the working memory measures and the largest group difference was found for the sustained selective attention measures (Figure 2).

Discussion

The goals of this study were to compare verbal and nonverbal executive function abilities between preschool-age children with SLI and age-matched children with typical language development and to examine the size of group differences across executive function components. We predicted that children with SLI would perform worse than typically developing children on all executive function components but that the group differences would be largest on the verbal measures. We also hypothesized that, on the basis of the hierarchical development of executive function skills described by Garon et al. (2008), the

Table 3. Summary of between-groups analysis of variance comparisons of executive function components.

Function	<i>df</i>	<i>F</i>	<i>p</i>	η_p^2
Sustained selective attention				
Group	50	5.178	.027	.094
Domain	50	0.336	.565	.007
Group $\times$ Domain	50	0.272	.604	.005
Nonverbal sustained selective attention				
Group	50	2.875	.096	.054
Verbal sustained selective attention				
Group	50	3.993	.051	.074
Working memory				
Group	50	5.893	.019	.105
Domain	50	1.343	.252	.026
Group $\times$ Domain	50	0.011	.917	.000
Nonverbal working memory				
Group	50	5.241	.026	.095
Verbal working memory				
Group	50	3.691	.060	.069
Inhibition				
Group	50	11.618	.001	.189
Domain	50	9.601	.003	.161
Group $\times$ Domain	50	8.224	.006	.141
Nonverbal inhibition				
Group	50	2.130	.151	.041
Verbal inhibition				
Group	50	18.256	.000	.267
Shifting				
Group	50	10.712	.002	.176
Domain	50	13.178	.001	.209
Group $\times$ Domain	50	5.753	.020	.103
Nonverbal shifting				
Group	50	19.803	.000	.284
Verbal shifting				
Group	50	1.069	.306	.021

Figure 2. Linear regression representing the intercept and slope of the absolute value of group z score differences on measures of each executive function component. The smallest group difference was found on the working memory component, and the largest difference was in sustained selective attention.

magnitude of group differences would increase from lower- to higher-level skills within the hierarchy (see Figure 1).

Our first hypothesis, that children with SLI would have poorer executive function abilities than typical language peers, was supported by the data. On each executive function component—sustained selective attention, working memory, inhibition, and shifting—the typical language group outperformed the SLI group in either or both verbal and nonverbal domains. These findings are in line with previous research comparing children with SLI with typically developing peers. Many prior studies have demonstrated that children with SLI have deficits in attention (e.g., Marton et al., 2012; Spaulding et al., 2008), working memory (e.g., Henry et al., 2012; Marton et al., 2012; Vugs et al., 2014), and inhibition (e.g., Henry et al., 2012; Marton et al., 2012; Roello et al., 2015; Spaulding, 2010). Fewer studies have assessed shifting abilities in children with SLI, but our current findings mirror two previous investigations that reported nonverbal shifting deficits in SLI (Farrant et al., 2012; Roello et al., 2015).

Our second prediction that group differences would be larger on verbal measures was largely unsupported by our data. No significant main effect or interaction involving domain was found for measures of sustained selective attention or working memory, indicating that group differences on these measures were statistically similar for both the verbal and nonverbal tasks. In contrast, a significant main effect and interaction with domain for the inhibition component revealed that both groups were less accurate

on the verbal task compared to the nonverbal task, and the groups significantly differed only in their performance on the verbal task. On the shifting measures, again both a main effect and interaction for domain were found due to the fact that both groups had lower scores on the nonverbal task compared with the verbal task, and the groups only significantly differed on the nonverbal measure. Taken together, this pattern of results suggests that children with SLI have domain-general executive function deficits because they are not limited to verbal tasks. This is consistent with previous research including meta-analyses (Ebert & Kohnert, 2011; Vugs et al., 2013) that have found evidence of SLI deficits on verbal and nonverbal executive function measures.

Our final prediction was that children with SLI would show larger executive function deficits on higher-level components and smaller deficits on lower-level components. On the basis of Garon et al.'s (2008) developmental integrative framework model of executive function, we expected the difference between children with SLI and typically developing children to increase within the hierarchy. This prediction was rooted in the assumption put forth by Garon et al. that higher-level components require the coordination of lower-level skills. Therefore, we posited that if children with SLI have deficits in lower-level components, these deficits would lead to cascading effects in higher-level executive function components. This led to our hypothesis that group differences would increase from lower- to higher-level components within the model. The linear relationship between standardized group differences actually revealed that the largest group difference was found for our measure of sustained selective attention, which was in fact the lowest-level executive function component in our model. The other three components followed the expected pattern with the smallest group difference between our working memory measure and the largest difference on the shifting measure (see Figure 2).

With the exception of the attention component, it appears that the executive function deficits associated with SLI exist at every level of the hierarchy, and these deficits increase as components become more complex and require coordination of lower-level skills. Thus, our findings partially support the Garon et al. (2008) model as applied to children with SLI. Group differences between working memory, inhibition, and shifting followed the expected increase on the basis of this model. In contrast, we hypothesized that group differences would be smallest on our measures of sustained selective attention, but this was in fact the largest difference between the groups. It is likely that poor attention had upstream effects on the three other executive function skills. However, the magnitude of the measured effect for attention was disproportionate relative to the predictions of the Garon et al. model.

Although the large group difference in attention may reflect a unique aspect of the executive function profile of SLI, other explanations are also possible. This difference may be due to the complexity of the attention measures we used here. To be specific, the continuous performance

tasks used in the present study index two aspects of attention: both selective attention to a specific stimulus and sustained attention across a period of time. Such complex tasks may require use of what we considered to be higher-level executive function components, such as working memory and inhibition (Fisher & Kloos, 2016), and therefore, the continuous performance tasks required the executive function components tapped by our other measures. For example, holding the target stimulus in mind would require working memory, withholding responses to nontargets would require inhibition, and moving between target and nontarget trials would require shifting. In our own data, we find significant correlations between measures of sustained selective attention, working memory, and shifting (see Appendix). Allan, Allan, Lerner, Farrington, and Lonigan (2015) recently reported that among preschool-age children, omission and commission errors on a continuous performance task were correlated with measures of inhibition and working memory, but confirmatory factor analyses revealed that the executive function measures and continuous performance task errors were separate factors. In other words, these skills are related but distinct. Additional evidence and more sophisticated statistical modeling will be necessary to disentangle the directionality of the relationship between attention and other executive function components.

Although we found evidence of increasing deficits among the executive function hierarchy, it should be noted that the increasing deficits were not uniformly represented across components and domains as the SLI group performed equally as well as the typical group on our nonverbal inhibition measure and verbal shifting measure. These findings are in contrast with our expectations of both verbal and nonverbal deficits for the SLI group across all executive function components tested. Future investigation will be necessary to establish if these discrepancies were due to the specific inhibition and shifting measures used here or if nonverbal inhibition and verbal shifting are truly intact abilities among children with SLI. It would be ideal for future work in this area to include multiple verbal and nonverbal measures of each component in order to provide clarity. However, taken together, the findings from the current study support the notion that children with SLI have executive function deficits when compared with children with typical language abilities, these deficits are found across all executive function components we assessed here, and the magnitude of these group differences varies across components.

The partial support of the predicted hierarchy in a population with decreased executive function skills indicates that the Garon et al. (2008) framework has utility for understanding executive function outside of typical development, but more research is needed for establishing and confirming the underlying structure and development of executive function in young children with SLI and how this population compares with typically developing peers. As previously mentioned, there is debate regarding unitary versus integrative structures of executive function in young

children with typical development. Some factor analyses indicate that executive function abilities are best represented by a single factor whereas others find that young children's executive function is best represented by two factors. In contrast, the Garon et al. model assumes a three-factor structure of executive function that has yet to be confirmed for preschool-age typically developing children. Although the structure of executive function in typically developing children is debated, it has received little attention for children with SLI. Future work identifying the number and nature of factors underlying executive function abilities in young children with SLI is necessary for fully understanding executive function in this population.

Strengths and Limitations

A notable strength of this study relative to previous research on executive function abilities in SLI is that our SLI and typically developing groups were matched on key demographic variables. Because executive function abilities continue to mature into early adulthood, it is crucial to consider age as a potential confounding variable. In the current study, we used a small age range of children who were 4 and 5 years old at the time of testing, and we matched each typical language subject within 4 months of age to a subject in the SLI group. This practice helped to ensure that group differences were not an effect of maturational differences. Likewise, SES has been shown to be positively related to children's executive function abilities (Hackman & Farah, 2009), and therefore, it was imperative that our two groups did not differ on this variable. Another strength of this study was the inclusion of measures of multiple executive function components within the same sample, which provides us with a more complete picture of the executive function abilities in children with SLI.

Although this study has strengths, there are also limitations. One limitation is the possibility that the verbal shifting measure that we created for this study was not successful in tapping children's shifting abilities. Indeed, both groups had higher average scores on the verbal shifting task than on the DCCS, which was our nonverbal shifting measure, but this difference was only significant in the SLI group. Several differences between the two tasks may have contributed to the divergence in performance. First, in the DCCS, children are given verbal reminders of the sorting rule (e.g., "Red ones go here, and blue ones go here") before each trial whereas the verbal task included visual sorting rule reminders (e.g., an image of a collar). Perhaps children found the visual cues more useful than the verbal cues, leading to better shifting performance.

Another possibility is that the child's verbal response in the verbal shifting task may have been, in essence, a form of self-directed speech that improved performance. Indeed, previous researchers have found that when children verbally label the relevant dimension of DCCS cards, their sorting performance improves (Kirkham, Cruess, & Diamond, 2003). Last, during the advanced phase of the DCCS, the cue to each sorting dimension is abstract in the form of a

black rectangle signaling the color dimension or the absence of a black rectangle indicating the shape dimension. In contrast to this, semantically related cues were used to indicate which dimension to use in the verbal shifting task. A collar signaled that participants should focus on the animal dimension, and a shirt signaled focus on the child dimension. Thus, random shifting between the two dimensions, as was required in the advanced versions of both the DCCS and verbal shifting tasks, may have been easier in the case of less abstract cues used in verbal shifting.

Both of these potential differences between the DCCS and verbal shifting tasks highlight an underlying problem in the attempt to compare across executive function components, which is that, although tasks are designed to assess specific executive function components, it is challenging to equate task difficulty across tasks both within and between components. The current study is based on the notion that higher-level executive function components would prove more difficult for children with SLI compared with lower-level components. However, there are certainly cases in which lower-level executive function tasks could be more difficult than those meant to measure higher-level tasks, for example, if stimuli were made more complex or if tasks included dual demands.

A second potential limitation of this study is the possibility that children were using language to mediate responding on nonverbal tasks as well as verbal tasks. As mentioned, we classified tasks with verbal stimuli or verbal responses as verbal tasks and those without verbal stimuli or responses as nonverbal. However, the nonverbal tasks included verbal instructions, and children may have been using verbal strategies to complete them. For example, we witnessed some participants labeling the animal stimuli aloud in the nonverbal sustained attention task. Therefore, although language was not required to successfully complete the nonverbal tasks, group differences on these measures may reflect, to some extent, group differences in successfully using language as a response strategy. It is possible that typically developing children used language to improve their performance even on nonverbal measures whereas this may not have occurred in the SLI group.

Future Directions

Given the evidence of executive function deficits associated with SLI, there are now several open questions left to address. The first set of questions concerns the nature of the relationship between executive function and language abilities in this population. There is evidence from typically developing children that language and executive function may have a bidirectional association with executive function skills improving language abilities, such as vocabulary learning (Kapa & Colombo, 2014; Majerus & Boukebza, 2013) and language skills mediating executive function (Fitzer & Roebbers, 2012; Miyake, Emerson, Padilla, & Ahn, 2004; Müller, Zelazo, Hood, Leone, & Rohrer, 2004). However, this relationship has been less explored in the SLI population in which both language

and executive function are affected. Lidstone, Meins, and Fernyhough (2012) reported that articulatory suppression during a planning task affected children with and without SLI equally, suggesting that children with SLI also use language to mediate their executive function behavior. In contrast, other research has reported that explicitly instructing children with SLI to use language during task performance impedes their performance (Eichorn, Marton, Campanelli, & Scheuer, 2014). Our own data can speak to this relationship as there are significant positive correlations between some of the executive function tasks and SPELT-P 2 and Peabody Picture Vocabulary Test–Fourth Edition standard scores in both the typically developing and SLI groups (see Appendix). However, these correlational data cannot identify the directionality of the relationship between language and executive function.

Additional research is necessary in order to understand how language and executive function are related in children with SLI. It may be the case that impaired language is leading to deficits in executive function. For example, children with SLI may be less efficient in using language to mediate their responding on executive function tasks (Eichorn et al., 2014). As an alternative, children's language impairment may be caused, or at least exacerbated, by their underlying executive function difficulties. For example, poorer attention skills may make it more difficult for children with SLI to recognize underlying grammatical rules in language input, or working memory deficits may disrupt word learning. Last, it may be the case that, as with typical populations, language and executive function are bidirectionally related in SLI with deficits in one area potentially compounding problems in the other. This relationship may be further clarified by comparing executive function and language abilities in children with SLI with these abilities in children with other developmental disorders that have been shown to affect executive function (e.g., attention-deficit/hyperactivity disorder, autism spectrum disorder) in order to better define the effects of executive function deficits versus language deficits.

The second set of questions pertains to possible interventions to improve executive function abilities in children with SLI. Among children with typically developing language, a number of methods have been designed to improve executive functioning (Diamond & Lee, 2011; Dowsett & Livesey, 2000; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). It remains to be seen if similar approaches could effectively improve executive function in this population. Furthermore, it would be interesting to test the effects of executive function training on language outcomes in children with SLI. If executive function deficits are contributing to language impairment in this population, then it follows that improving executive function may in turn benefit children's language abilities. Previous research suggests that training nonlinguistic cognitive skills in children with SLI leads to improvements in children's expressive language abilities. The efficacy of cognitive skill training for improving SLI has been established in a small-scale study (two participants) of monolingual children

(Ebert & Kohnert, 2009) and in two studies including bilingual children with SLI (Ebert, Kohnert, Pham, Disher, & Payesteh, 2014; Ebert, Rentmeester-Disher, & Kohnert, 2012). Future studies are necessary for identifying which types of cognitive training are most effective for improving language abilities in children with SLI.

Last, future research addressing similar questions regarding the underlying nature of executive function components both within samples of children with SLI and between children with SLI and typical language development will benefit from advanced modeling techniques. A necessary first step will be using exploratory or confirmatory factor analysis techniques to identify the underlying structure of executive function among young children with SLI to determine whether executive function in this population is best represented as a unitary factor or if it fits within multifactor integrative frameworks of executive function. Future comparisons of executive function abilities between children with and without SLI would be strengthened by using structural equation modeling in order to determine the nature of the relationship between executive function components both within and between groups. This method also has the advantage of reducing measurement error by relying on comparisons of latent instead of manifest variables for comparison. However, for such modeling to be conducted, substantially higher sample sizes would be necessary and multiple measures of each executive function component would be needed in order to create stable latent variables.

Summary

In the current study, preschool children with and without SLI were tested on a battery of executive function tests to assess their sustained selective attention, working memory, inhibition, and shifting in both the verbal and nonverbal domains. Comparisons between the two groups revealed that children with SLI performed worse than age-matched peers with typical language on measures of all four executive function components. Furthermore, these deficits were not limited to verbal tasks. Children with SLI had poorer outcomes on tests of both verbal and nonverbal sustained attention and working memory measures. Their performance was also significantly worse than children with typical language development on a measure of nonverbal shifting. Taken together, these results suggest that children with SLI demonstrate a domain-general executive function deficit. Furthermore, we considered the linear relationship between standardized group differences on each of the tested executive function components and found increases in effect sizes that partially correspond to the developmental hierarchy of executive function described by Garon et al. (2008) with increasing group differences from working memory to inhibition to shifting. In contrast to our predictions, the largest group difference was found on our measures of sustained selective attention. Overall, this pattern of findings supports the possibility that deficits in lower-level executive function components among children

with SLI may potentially lead to increasing problems with higher-level executive function components. However, more research is necessary in this area in order to clearly establish the structure of executive function components in young children with SLI and to model the relationship between these components.

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References

- Allan, D. M., Allan, N. P., Lerner, M. D., Farrington, A. L., & Lonigan, C. J. (2015). Identifying unique components of preschool children's self-regulatory skills using executive function tasks and continuous performance tests. *Early Childhood Research Quarterly, 32*, 40–50.
- Alt, M. (2013). Visual fast mapping in school-age children with specific language impairment. *Topics in Language Disorders, 33*, 328–346.
- Archibald, L. M. D., & Gathercole, S. E. (2006). Short-term and working memory in specific language impairment. *International Journal of Language & Communication Disorders, 41*, 675–693.
- 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.
- Brydges, C. R., Reid, C. L., Fox, A. M., & Anderson, M. (2012). A unitary executive function predicts intelligence in children. *Intelligence, 40*, 458–469.
- Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology, 28*, 595–616.
- Dawson, J., Stout, C., Eyer, J., Tattersall, P., Fonkalsrud, J., & Croley, K. (2005). *Structured Photographic Expressive Language Test—Preschool, Second Edition*. DeKalb, IL: Janelle Publications.
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168.
- Diamond, A., Kirkham, N., & Amso, D. (2002). Conditions under which young children can hold two rules in mind and inhibit a prepotent response. *Developmental Psychology, 38*, 352–362.
- Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*, 959–964.
- Dibbets, P., Bakker, K., & Jolles, J. (2006). Functional MRI of task switching in children with specific language impairment (SLI). *Neurocase, 12*, 71–79.
- Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in preschool children: Effects of “executive skills” training. *Developmental Psychobiology, 36*, 161–174.
- Duinmeijer, I., de Jong, J., & Schepers, A. (2012). Narrative abilities, memory and attention in children with specific language impairment. *International Journal of Language & Communication Disorders, 47*, 542–555.
- Dunn, L. M., & Dunn, D. M. (2007). *Peabody Picture Vocabulary Test—Fourth Edition*. Bloomington, MN: Pearson.

- Ebert, K. D., & Kohnert, K. (2009). Non-linguistic cognitive treatment for primary language impairment. *Clinical Linguistics & Phonetics*, 23, 647–664.
- Ebert, K. D., & Kohnert, K. (2011). Sustained attention in children with primary language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research*, 54, 1372–1384.
- Ebert, K. D., Kohnert, K., Pham, G., Disher, J. R., & Payesteh, B. (2014). Three treatments for bilingual children with primary language impairment: Examining cross-linguistic and cross-domain effects. *Journal of Speech, Language, and Hearing Research*, 57, 172–186.
- Ebert, K. D., Rentmeester-Disher, J., & Kohnert, K. (2012). Non-linguistic cognitive treatment for bilingual children with primary language impairment. *Clinical Linguistics & Phonetics*, 26, 485–501.
- Eichorn, N., Marton, K., Campanelli, L., & Scheuer, J. (2014). Verbal strategies and non-verbal cues in school-age children with and without specific language impairment (SLI). *International Journal of Language & Communication Disorders*, 49, 618–630.
- Farrant, B. M., Mayberry, M. T., & Fletcher, J. (2012). Language, cognitive flexibility, and explicit false belief understanding: Longitudinal analysis in typical development and specific language impairment. *Child Development*, 83, 223–235.
- Fatzer, S. T., & Roebers, C. M. (2012). Language and executive functions: The effect of articulatory suppression on executive functioning in children. *Journal of Cognition and Development*, 13, 454–472.
- Finneran, D. A., Francis, A. L., & Leonard, L. B. (2009). Sustained attention in children with specific language impairment (SLI). *Journal of Speech, Language, and Hearing Research*, 52, 915–929.
- Fisher, A., & Kloos, H. (2016). Development of selective sustained attention: The role of executive functions. In J. A. Griffin, P. McCardle, & L. S. Freund (Eds.), *Executive function in pre-school-age children* (pp. 215–237). Washington, DC: American Psychological Association.
- Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, 134, 31–60.
- Goldman, R., & Fristoe, M. (2000). *Goldman-Fristoe Test of Articulation—Second Edition*. Minneapolis, MN: Pearson.
- Greenslade, K. J., Plante, E., & Vance, R. (2009). The diagnostic accuracy and construct validity of the Structured Photographic Expressive Language Test—Preschool: Second Edition. *Language, Speech, and Hearing Services in Schools*, 40, 150–160.
- Hackman, D. A., & Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends in Cognitive Sciences*, 13, 65–73.
- Henry, L. A., Messer, D. J., & Nash, G. (2012). Executive functioning in children with specific language impairment. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 53, 37–45.
- Hoffman, L. M., & Gillam, R. B. (2004). Verbal and spatial information processing constraints in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, 47, 114–125.
- 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.
- Hutchinson, E., Bavin, E., Efron, D., & Sciberras, E. (2012). A comparison of working memory profiles in school-age children with specific language impairment, attention deficit/hyperactivity disorder, comorbid SLI and ADHD and their typically developing peers. *Child Neuropsychology*, 18, 190–207.
- 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.
- Jarvis, W. B. G. (2008). DirectRT (Version 2008) [Computer software]. New York, NY: Empirisoft Corporation.
- Kapa, L. L., & Colombo, J. (2014). Attentional control in early and later bilingual children. *Cognitive Development*, 28, 233–246.
- Kapa, L. L., & Plante, E. (2015). Executive function in SLI: Recent advances and future directions. *Current Developmental Disorders Reports*, 2, 245–252.
- Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Assessment Battery for Children, Second Edition*. Circle Pines, MN: AGS.
- Kirkham, N. Z., Cruess, L., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science*, 6, 449–467.
- Lee, K., Bull, R., & Ho, R. M. H. (2013). Developmental changes in executive functioning. *Child Development*, 84, 1933–1953.
- 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.
- Lidstone, J. S. M., Meins, E., & Fernyhough, C. (2012). Verbal mediation of cognition in children with specific language impairment. *Development and Psychopathology*, 24, 651–660.
- Lum, J. A. G., Conti-Ramsden, G., Page, D., & Ullman, M. T. (2012). Working, declarative and procedural memory in specific language impairment. *Cortex*, 48, 1138–1154.
- Majerus, S., & Boukebza, C. (2013). Short-term memory for serial order supports vocabulary development: New evidence from a novel word learning paradigm. *Journal of Experimental Psychology*, 116, 811–828.
- Marton, K., Campanelli, L., Scheuer, J., Yoon, J., & Eichorn, N. (2012). Executive function profiles in children with and without specific language impairment. *Rivista Di Psicolinguista Applicata*, 12, 57–73.
- Miller, M. R., Giesbrecht, G. F., Müller, U., McInerney, R. J., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. *Journal of Cognition and Development*, 13, 395–423.
- Miyake, A., Emerson, M. J., Padilla, F., & Ahn, J. (2004). Inner speech as a retrieval aid for task goals: The effects of cue type and articulatory suppression in the random task cuing paradigm. *Acta Psychologica*, 115, 123–142.
- Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (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.
- Montgomery, J. W. (2008). Role of auditory attention in the real-time processing of simple grammar by children with specific language impairment: A preliminary investigation. *International Journal of Language & Communication Disorders*, 43, 499–527.
- Montgomery, J. W., Evans, J. L., & Gillam, R. B. (2009). Relation of auditory attention and complex sentence comprehension in children with specific language impairment: A preliminary study. *Applied Psycholinguistics*, 30, 123–151.
- Müller, U., Zelazo, P. D., Hood, S., Leone, T., & Rohrer, L. (2004). Interference control in a new rule use task: Age-related changes, labeling, and attention. *Child Development*, 75, 1594–1609.
- Petrucelli, N., Bavin, E. L., & Bretherton, L. (2012). Children with specific language impairment and resolved late talkers: Working memory profiles at 5 years. *Journal of Speech, Language, and Hearing Research*, 55, 1690–1703.

- Rhoades, B. L., Greenberg, M. T., & Domitrovich, C. E.** (2009). The contribution of inhibitory control to preschoolers' social-emotional competence. *Journal of Applied Developmental Psychology, 30*, 310–320.
- Roello, M., Ferretti, M. L., Colonnello, V., & Levi, G.** (2015). When words lead to solutions: Executive function deficits in preschool children with specific language impairment. *Research in Developmental Disabilities, 37*, 216–222.
- 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.
- Spaulding, T. J.** (2010). Investigating mechanisms of suppression in preschool children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 53*, 725–738.
- Spaulding, T. J., Plante, E., & Vance, R.** (2008). Sustained selective attention skills of preschool children with specific language impairment: Evidence for separate attentional capacities. *Journal of Speech, Language, and Hearing Research, 51*, 16–34.
- Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T.** (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science, 12*, 106–113.
- Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V.** (2014). Latent structure of executive function in five- and six-year-old children: A longitudinal study. *European Journal of Developmental Psychology, 11*, 447–462.
- Victorino, K. R., & Schwartz, R. G.** (2015). Control of auditory attention in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 58*, 1245–1257.
- Vugs, B., Cuperus, J., Hendriks, M., & Verhoeven, L.** (2013). Visuo-spatial working memory in specific language impairment: A meta-analysis. *Research in Developmental Disabilities, 34*, 2586–2597.
- 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*, 63–74.
- Weyandt, L. L., & Willis, W. G.** (1994). Executive functions in school-age children: Potential efficacy of tasks in discriminating clinical groups. *Developmental Neuropsychology, 10*, 27–38.
- 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*, 575–587.
- Zelazo, P. D.** (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols, 1*, 297–301.
- Zelazo, P. D., Frye, D., & Rapus, T.** (1996). An age-related dissociation between knowing the rules and using them. *Cognitive Development, 11*, 37–63.
- Zelazo, P. D., & Müller, U.** (2010). Executive function in typical and atypical development. In U. Goswami (Ed.), *The Wiley-Blackwell handbook of child cognitive development* (2nd ed.) (pp. 574–603). Oxford, UK: Wiley-Blackwell.

Appendix

Within Group Correlations

Table A1. SLI group correlations between measures of executive function, language, and nonverbal IQ.

Function	1	2	3	4	5	6	7	8	9
1. Verbal attention	—								
2. Nonverbal attention	.32	—							
3. Verbal WM	.41**	.21	—						
4. Nonverbal WM	.34*	.13	.28	—					
5. Verbal inhibition	.24	.32	.42**	.31	—				
6. Nonverbal inhibition	.55***	.12	.55***	.42**	.26	—			
7. Verbal shifting	.52***	.52***	.53***	.13	.40**	.42**	—		
8. Nonverbal shifting	.42**	.34*	.54***	.35*	.50***	.37*	.36*	—	
9. PPVT-4	.44**	.32	.32	.46**	.37*	.22	.70***	.38*	—
10. SPELT-P 2	.27	.39*	.20	.28	.68***	.15	.49**	.44**	.48**
11. KABC-II	.43**	.42**	.43**	.28	.24	.40**	.50***	.41**	.53***

Note. SLI = specific language impairment; WM = working memory; PPVT-4 = Peabody Picture Vocabulary Test–Fourth Edition; SPELT-P 2 = Structured Photographic Expressive Language Test–Preschool, Second Edition; KABC-II = Kaufman Assessment Battery for Children, Second Edition.

* $p < .10$. ** $p < .05$. *** $p < .01$.

Table A2. Typical language group correlations between measures of executive function, language, and nonverbal IQ.

Function	1	2	3	4	5	6	7	8	9	10
1. Verbal attention	—									
2. Nonverbal attention	.52***	—								
3. Verbal WM	.37*	.61**	—							
4. Nonverbal WM	.26	.50**	.60***	—						
5. Verbal inhibition	.52***	.77***	.49**	.36	—					
6. Nonverbal inhibition	.43**	.62***	.46**	.39**	.76***	—				
7. Verbal shifting	-.09	-.01	.24	.31	.05	.31	—			
8. Nonverbal shifting	.26	.22	.06	.06	.14	.27	.05	—		
9. PPVT-4	.43**	.54***	.63**	.33*	.50***	.51***	.12	.21	—	
10. SPELT-P 2	.27	.12	.64***	.53***	.16	.14	.06	.05	.45**	—
11. KABC-II	.47**	.52***	.71***	.52***	.55***	.41**	.45**	.15	.53***	.30

Note. WM = working memory; PPVT-4 = Peabody Picture Vocabulary Test–Fourth Edition; SPELT-P 2 = Structured Photographic Expressive Language Test–Preschool, Second Edition; KABC-II = Kaufman Assessment Battery for Children, Second Edition.

* $p < .10$. ** $p < .05$. *** $p < .01$. **** $p < .001$.