Research Article

The Relationship Between Language and Planning in Children With Language Impairment

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Purpose: This study examined the relationship between language and planning, a higher order executive function skill, in children with specific language impairment (SLI) and typically developing (TD) children. We hypothesized differences between groups in planning performance and in the role of verbal mediation during planning.

Method: Thirty-one children with SLI and 50 TD age-matched peers (8–12 years) participated in the study. We assessed language ability via a standardized language measure and planning via a dual-task Tower of London paradigm with 3 conditions: no secondary task (baseline), articulatory suppression secondary task (disrupted verbal mediation), and motor suppression secondary task (control for secondary task demand).

Results: We found similar overall accuracy between children with SLI and TD peers on the Tower of London. Children with SLI executed trials more slowly at baseline

than TD peers but not under articulatory suppression, and children with SLI spent less time planning than TD children at baseline and under articulatory suppression. There was a significant interaction among group, language ability, and planning time under articulatory suppression. Children with SLI who had relatively better language ability spent less time planning than children with SLI who had poorer language ability when verbal mediation was disrupted. This pattern was reversed for TD children.

Conclusions: This study provides evidence for a relationship between language and planning, yet this relationship differed between children with SLI compared to TD peers. Findings suggest that children with SLI use nonlinguistic perceptual strategies to a greater degree than verbal strategies on visuospatial planning tasks and that intervention might address strategy use for planning.

Specific language impairment (SLI) has a prevalence rate of approximately 7% and is associated with academic and other lifelong challenges (Conti-Ramsden, Durkin, Simkin, & Knox, 2009; Tomblin et al., 1997; Whitehouse, Watt, Line, & Bishop, 2009; also see Norbury et al.'s [2016] finding of a similar prevalence rate for “language disorder of unknown origin” when the non-verbal IQ (NVIQ) criterion is extended from within normal limits to low average). In children with SLI (also referred to as developmental language disorder; Bishop, Snowling, Thompson, Greenhalgh, & CATALISE-2 Consortium, 2017), executive function (EF) ability—a construct of

cognitive processes involved in goal-directed behavior—tends to be poorer than in typically developing (TD) peers (Pauls & Archibald, 2016; Vissers, Koolen, Hermans, Sheper, & Knoors, 2015) and correlated with a child's individual language level (Kapa, Plante, & Doubleday, 2017; Wittke, Spaulding, & Schectman, 2013). EF is related to academic performance and outcomes (Best, Miller, & Naglieri, 2011; Moffitt et al., 2011; also see Lan, Legare, Ponitz, Li, & Morrison, 2011, for a cross-cultural comparison). Furthermore, teacher ratings of EF ability, rather than language impairment severity, predict which preschool-age children with SLI receive treatment (Wittke & Spaulding, 2018).

Working memory (WM), inhibitory control, and cognitive flexibility (shifting) have been proposed to comprise core cognitive components of EF, with a central attentional system that impacts all EF components; these processes are recruited in self-regulating, goal-directed behavior (Marcovitch & Zelazo, 2009). Research on EF in children with SLI has found poorer WM (Lukács, Ladányi, Fazekas,

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& Kemény, 2016; Reichenbach, Bastian, Rohrbach, Gross, & Sarrar, 2016), inhibition (Marton, Campanelli, Eichorn, Scheuer, & Yoon, 2014; Spaulding, 2010), cognitive flexibility (Kapa et al., 2017), planning (Henry, Messer, & Nash, 2012; Marton, 2008), and verbal and visual attentional control (Kapa et al., 2017) relative to TD peers (but see Lukács et al., 2016, with no nonverbal EF deficits, and Pauls & Archibald, 2016, for further discussion). According to an integrative framework of EF, these cognitive processes form a hierarchy: Lower level components subserve higher level integrated abilities (Garon, Bryson, & Smith, 2008; Kapa et al., 2017; Miyake et al., 2000; also see Diamond, 2013, for an alternative yet related conceptualization). Planning and problem solving superordinate EF behaviors rely on the coordination of lower level EF abilities. As viewed by the integrative framework, complex skills, such as planning, are constructed from lower level skills, such as WM and inhibition. Although this framework suggests that lower level EF components underlie higher level goal-directed behavior, language ability in the form of verbal mediation has also been implicated in planning performance (Alderson-Day & Fernyhough, 2015; Kapa et al., 2017; Vissers et al., 2015). *Verbal mediation* (also referred to as inner speech or language-based reflection) is the use of language to reflect on and guide behavior, such as the following inner monologue during puzzle completion: “This piece has a straight side, so it must be an edge piece, but that piece has no straight side, so it must go more toward the middle.” It remains unclear how verbal mediation is used in integrated EF processes, as well as how differences in language ability affect its use in higher level cognitive processes such as planning. Despite evidence of EF deficits in SLI, the use of verbal mediation in EF performance is not well understood in children with SLI.

Theoretical Explanation of the Relationship Between Language and EF

Marcovitch and Zelazo (2009) propose a hierarchical competing systems model (HCSM) of executive functioning that implicates language-based self-reflection (verbal mediation) as foundational for engaging in goal-directed behavior. It provides a framework for the development of verbally based conscious control of behavior and emphasizes the critical role of language in higher level EF tasks. In this model, a representational system overrides a habit system, often visuospatial or perceptual in nature, when language-based reflection occurs prior to a learner responding to a task. While the habit system responds according to prior experiences, the higher level representational system weighs multiple response options and can select alternative responses. The lower quality representations of the habit system are incrementally replaced by the higher quality representations of the representational system as the learner becomes proficient at using language to isolate the object of consciousness from context. The learner is then able to explicitly weigh options rather than implicitly process perceptual information. This process is influenced by attention and

labeling, as well as by task demands and ability level of the learner (Marcovitch & Zelazo, 2009). For instance, children will require few trials to develop a habitual response on a simple task (e.g., a lower level WM task, such as digit span), and their memory trace will be strong, whereas children will require more trials to develop a habitual response on a complex task (e.g., a higher level WM task, such as backward digit span interleaved with a grammatical judgment task), and their memory trace will be poorer. If provided cues to reflect, the children are more likely to override their habitual response and their behavior should be more optimal.

Additionally, high-ability learners will be more likely to attain a habitual response in fewer trials and more likely to have a higher quality representation than low-ability learners. High-ability learners are able to engage in explicit language-based reflection and override prepotent responses more efficiently and effectively. The role of language in goal-directed behavior increases over development and with increased task complexity, and weaknesses on lower level EF skills are compounded in higher level EF skills (Fatzer & Roebers, 2012; Kapa et al., 2017; Marcovitch & Zelazo, 2009). According to the integrative framework of EF, planning involves interactive coordination of lower level EF skills—a process likely to draw on verbal mediation and therefore to be particularly challenging for lower ability learners, such as children with language impairment (Garon et al., 2008; Kapa et al., 2017; Marton et al., 2014). The HCSM does not posit specific relationships between particular components of language (e.g., morphosyntax) and EF performance (Marcovitch & Zelazo, 2009), yet children with SLI have language impairments across language domains that likely affect how verbal mediation develops and how it is used to guide behavior (Abdul Aziz, Fletcher, & Bayliss, 2017; Alderson-Day & Fernyhough, 2015; Lidstone, Meins, & Fernyhough, 2012). Few studies, however, have used experimental paradigms that reveal the role of verbal mediation in planning performance in children with SLI.

Examining the Relationship Between Language and EF

Dual-task paradigms are used to examine the role of verbal mediation during EF task performance by adding a secondary verbal task and comparing this performance to a no-secondary task condition and a motor secondary task control condition (Alderson-Day & Fernyhough, 2015; Fatzer & Roebers, 2012; Lidstone, Meins, & Fernyhough, 2010; Lidstone et al., 2012). In a secondary verbal task, the person engages in articulatory suppression, such as producing the word *Monday* upon hearing a *beep*, while completing the primary EF task. In a secondary motor task, the person engages in motor suppression, such as tapping their foot upon hearing a *beep*, while completing the primary EF task. Articulatory suppression is presumed to disrupt language-based reflection, or verbal mediation, while motor suppression is presumed to control for the

added cognitive demands of the secondary verbal task. Comparing EF performance between these conditions can reveal the influence of language on EF performance as distinct from a general increase in cognitive demand due to the secondary task (Gangopadhyay, MacDonald, Ellis Weismer, & Kaushanskaya, 2018; Holland & Low, 2010; Lidstone et al., 2010; Williams, Peng, & Wallace, 2016).

As would be expected, articulatory suppression has been shown to affect EF performance (Gangopadhyay et al., 2018; Taylor, Maybery, & Whitehouse, 2012; Williams et al., 2016). Fatzer and Roebbers (2012), for instance, found a significant detrimental effect of articulatory suppression on a WM task relative to the motor suppression and no secondary tasks in 9-year-olds and a marginal effect in 6-year-olds. This effect was smaller on a cognitive flexibility task, and there was no effect of articulatory suppression on an inhibition task. On an arithmetic switching task, Emerson and Miyake (2003) found greater switch cost and slower task completion time under articulatory suppression relative to motor suppression in adults. In fact, there was no difference in switch costs between motor suppression and baseline (no secondary task) on this switching task, while the effect of articulatory suppression was large.

The effect of articulatory suppression on EF performance has also been compared to EF behavioral ratings in TD adults. Wallace, Peng, and Williams (2017) found that individual differences in the change in planning performance between dual-task conditions predicted self-ratings on the Behavioral Rating Inventory of Executive Function (BRIEF). For participants who performed worse on the planning task under articulatory suppression relative to motor suppression, performance was positively correlated with self-monitoring scores on the BRIEF. For participants with equal performance between conditions or poorer performance under motor suppression, performance was not significantly correlated with the BRIEF. This finding suggests that differential effects of articulatory suppression may be related to individual differences in the relationship between verbal mediation and EF (Wallace et al., 2017).

Planning and SLI

Studies that examine language use in higher level EF performance in children with SLI have primarily focused on inner speech (verbal mediation) during planning, although they also included measures of planning performance (Abdul Aziz et al., 2017; Lidstone et al., 2012). On the Tower of London (ToL), a commonly used planning task, prior studies varied the number of minimum moves required to complete each trial, which causes trials to be more or less difficult. This approach is problematic because the relationship between verbal mediation and task difficulty is nonlinear. That is, performance on less difficult tasks does not require verbal mediation, performance on more difficult tasks is not benefited by verbal mediation, and performance on moderately difficulty tasks is likely to engage verbal mediation as a facilitative strategy (Alderson-Day & Fernyhough,

2015; Fernyhough & Fradley, 2005; Vygotsky, 1987). Thus, consistent task difficulty controls for these task demand differences. The focus on inner speech rather than planning per se in Abdul Aziz et al. (2017) and Lidstone et al. (2012) also influenced their scoring systems and dependent variables. Abdul Aziz et al. used a discrete scoring system (correct = 3 points, completed on the first trial = 2 points, completed on the second trial = 1 point, incomplete = 0 points). Lidstone et al. (2012) used a global measure of percentage of accurately solved trials rather than directly measuring number of moves. On the other hand, studies that focus on planning performance often use consistent task difficulty (e.g., four-move problems); additional, more sensitive measures (e.g., number of moves and planning and execution time); and standard ToL administration (Gangopadhyay et al., 2018; Marton, 2008).

Not surprisingly, evidence on how planning performance in children with SLI compares to planning in typical peers is mixed. Marton (2008) showed that school-age children with SLI have significantly faster initiation times and more frequent rule violations than age-matched peers yet have similar accuracy, execution time, and total time to complete ToL trials. Abdul Aziz et al. (2017), however, found that for children with below-average language ability, discrete scores on the ToL were significantly lower than for children with average to above-average language ability; groups were not significantly different on age, and NVIQ was statistically controlled. In the only study to employ a dual-task paradigm with children with SLI, children with SLI correctly solved a significantly lower percentage of ToL problems than TD peers who were individually matched for age and NVIQ (Lidstone et al., 2012). Nonetheless, children with SLI demonstrated similar mean response times, secondary task error rates, and change in performance due to articulatory suppression as TD peers across measures. Beyond the mixed evidence on group differences in planning performance measures, children with SLI demonstrate developmental delays relative to TD peers on measures of inner speech (verbal mediation) as their inner speech has been shown to be less internalized (Abdul Aziz et al., 2017; Lidstone et al., 2012). These findings suggest that children with SLI use language differently to engage in planning relative to TD peers—differences that have not yet been captured in planning performance measures.

The Current Study

The aim of the current study was to elucidate the relationship between language and planning, a higher level EF skill, in children with SLI using the HCSM as our conceptual framework. The only prior study that examined the relationship between language and planning in children with SLI using a dual-task paradigm focused on measuring inner speech (verbal mediation; Lidstone et al., 2012); thus, their procedures were not optimally suited for revealing group differences in planning performance or for revealing group differences in the relationship between language and planning performance. Evidence regarding planning deficits,

as well as other EF deficits, in children with SLI is mixed, possibly due to differences in construct measurement, task difficulty, and group matching (e.g., Abdul Aziz et al., 2017; Lidstone et al., 2012; Marton, 2008; Pauls & Archibald, 2016). The causative role of verbal mediation in EF deficits in children with SLI has also been called into question. When language impairment severity was used to represent individual differences in verbal mediation ability, it was found to be unrelated to the degree of EF deficits in children with SLI relative to TD peers (Pauls & Archibald, 2016).

We therefore examined the relationship between language and planning in children with SLI as compared to typically developing peers via performance on four-move ToL trials using a dual-task paradigm. Our experiment was composed of a no-secondary task baseline condition, an articulatory suppression secondary task condition, and a condition controlling for the additional cognitive load of the secondary task (i.e., motor suppression secondary task condition). We measured accuracy (number of moves), planning time, and execution time and directly compared the relationship between language and planning in children with SLI to that of TD peers. This approach characterizes planning performance with greater nuance—measuring accuracy directly and as a continuous variable and measuring time spent planning—to resolve discrepancies in the literature regarding planning performance and the way children with SLI use language to plan. Our research questions were as follows: (a) Does planning performance differ between school-age children with SLI and TD peers (1) at baseline or (2) when verbal mediation is disrupted? (b) Do children with SLI exhibit a different relationship between language and planning performance relative to TD peers (1) at baseline or (2) when verbal mediation is disrupted?

Method

Participants

This study was approved by the education and social behavioral institutional review board at the University of Wisconsin–Madison. Informed written consent was received from parents, and children gave verbal assent. Participants were recruited from the Madison metropolitan area and surrounding school districts as a part of a larger study on EF in different child populations. Thirty-one children with SLI and 50 typically developing (TD) peers aged 8–12 years (SLI: $M = 9.6$, $SD = 1.2$; TD: $M = 9.5$, $SD = 1.0$) participated in the current study. All participants were monolingual; passed a 1000-, 2000-, and 4000-Hz hearing screening at 20 dB; had normal or corrected-to-normal vision; and had no known history of autism, psychiatric, or neurological disorders. The TD group had NVIQ within age expectations (standard scores ≥ 85) on the Wechsler Intelligence Scale for Children–Fourth Edition (Wechsler, 2003). They also had expressive and receptive language scores on the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003)

within age expectations (standard scores ≥ 85) and no history of language delay or intervention, based on parental report.

Inclusionary criteria for the SLI group were as follows: NVIQ standard score ≥ 85 on the Wechsler Intelligence Scale for Children–Fourth Edition per traditional SLI criteria (rather than ≥ 70 per developmental language disorder criteria; Bishop et al., 2017) and CELF-4 Expressive or Receptive standard scores at least 1.25 SD s below the mean, as well as overall Core Language scores a minimum of 1 SD below the mean. We used total years of maternal education as a proxy for socioeconomic status (SES; 1 = first grade, 12 = high school, > 12 = postsecondary). The SLI and TD groups were matched for age ($p = .65$), but there were significant group differences for SES ($p < .01$) and NVIQ ($p < .001$). Groups were similar on gender (SLI: 52% male; TD: 58% male; $p = .58$); participant race demographics were 67% White, 21% African American, 0% Native American, 1% Asian, and 11% other, and 7% of participants were of Hispanic/Latino ethnicity per parental report. See Table 1 for demographic information and performance on standardized tests broken down by group.

Procedure

Children participated in two to three 2-hr sessions in child-friendly assessment rooms at the Waisman Center. During these assessment sessions, they were administered standardized cognitive tests, language measures, and experimental EF tasks. An experienced, certified speech-language pathologist evaluated children in the SLI group. Trained research assistants administered the experimental tasks, as well as the standardized assessments for children in the TD group.

Experimental Task

To measure planning, we computerized the Shallice (1982) ToL task using ToL software (Sanzen Neuropsychological, 2012). Each participant was directed to make one configuration of beads and pegs look the same as another configuration by moving one bead at a time with the computer mouse. We instructed the children to think about how they would match the pictures before they moved the first bead, and we presented a 2-s interstimulus fixation point between trials.

We selected trials for which the problem may be solved using exactly four moves with three differently colored beads and three pegs. This level of difficulty is age appropriate for our participants (Gangopadhyay et al., 2018; Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008; Lidstone et al., 2012), and consistent difficulty level is associated with more optimal performance measurement (Fernyhough & Fradley, 2005). We normed 22 unique four-move problems on adults to ensure consistent difficulty level across trials. To obtain our final stimulus set, we eliminated seven of the 22 problems for which adults took

Table 1. Participants' demographic information and performance on standardized tests, for the typically developing (TD) group and the group with specific language impairment (SLI).

Participant characteristics	TD (<i>n</i> = 50)	SLI (<i>n</i> = 31)	<i>p</i> value
Age in years			
<i>M</i> (<i>SD</i>)	9.5 (1.0)	9.6 (1.2)	<i>ns</i>
Range	8.0–11.9	8.0–12.0	(<i>p</i> = .65)
Maternal education in years (SES)			
<i>M</i> (<i>SD</i>)	17.1 (3.1)	15.0 (3.8)	TD > SLI**
Range	10.0–22.0	11.0–26.0	
Nonverbal Cognition (WISC-IV)			
<i>M</i> (<i>SD</i>)	110.0 (12.6)	96.3 (10.8)	TD > SLI***
Range	84.0–141.0	71.0–121.0	
Core Language (CELF-4)			
<i>M</i> (<i>SD</i>)	108.5 (12.4)	79.5 (6.6)	TD > SLI***
Range	87.0–134.0	60.0–91.0	
Expressive Language (CELF-4)			
<i>M</i> (<i>SD</i>)	108.4 (13.3)	78.6 (8.5)	TD > SLI***
Range	89.0–138.0	59.0–93.0	
Receptive Language (CELF-4)			
<i>M</i> (<i>SD</i>)	110.1 (14.3)	85.4 (10.2)	TD > SLI***
Range	81.0–137.0	61.0–103.0	

Note. Standard scores were used for the WISC-IV and CELF-4. *ns* = not statistically significant; SES = socioeconomic status; WISC-IV = Wechsler Intelligence Scale for Children–Fourth Edition; CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition.

Group difference at $p < .01$. *Group difference at $p < .001$.

the greatest number of moves to solve and most time to complete. The final stimulus set involved 15 trials in which number of moves ranged from 4 to 4.76 and total time to complete ranged from 7.79 to 13.17 s.

The 15 ToL trials were randomly allocated to three conditions: no secondary task, articulatory suppression secondary task (articulatory suppression), and motor suppression secondary task (motor suppression). We administered conditions in random order and pseudorandomized the order of trials within each condition. The no-secondary task condition involved the administration procedure outlined above. For articulatory suppression, we instructed the participants to verbally produce “maybe” upon hearing a *beep* during each ToL trial. For motor suppression, we instructed the participants to tap their foot on a pedal upon hearing a *beep* during each ToL trial. The *beep* was a simple tone generated by E-Prime Studio 2.0 at 750-ms intervals. We recorded verbal responses via a digital audiorecorder and foot presses via E-Prime. Participants were redirected to engage in the secondary task if they appeared to forget to do so during the trial. We administered five untimed no-secondary task practice trials prior to initiating the experimental trials, and we provided verbal feedback on performance for practice trials, but not test trials.

Outcome measures included number of moves per trial (number of moves to complete a trial), planning time (time to first move), and execution time (time to complete a trial beginning at the first move). We also measured secondary task performance: Motor suppression secondary task accuracy was the proportion of total foot presses to total number of *beeps* presented; articulatory suppression secondary task accuracy was the proportion of “maybe” productions to total number of *beeps* presented.

Analyses

We ran separate mixed-effects models (lme4; Bates, Mächler, Bolker, & Walker, 2015) in R Studio (R Core Team, 2018) for three outcome variables—number of moves, planning time, execution time—regressing performance for each outcome measure on group, condition, and core language. We used core language because verbal mediation is thought to draw on overall language ability rather than a specific domain of language (e.g., composite language abilities rather than morphosyntax; Abdul Aziz et al., 2017; Lidstone et al., 2012; Marcovitch & Zelazo, 2009). Given that groups did not reach the suggested matching threshold ($p \geq .50$; Kover & Atwood, 2013) on SES ($p < .01$), we entered SES as a covariate in our statistical models to control for potential group differences in environmental factors. We chose to avoid diminishing true group differences by equating or controlling NVIQ as it may be a key differentiating feature of SLI and TD groups (Kover & Atwood, 2013). We did, however, rerun all analyses to covary NVIQ, and we report both sets of findings in the Results section. We included interaction terms for group and condition, group and core language, and condition and core language as well as a three-way interaction between group, condition, and core language. Random effects were included for by-subject intercept and by-subject slope for condition to account for potential order effects. We coded the TD group versus SLI group as -0.5 and 0.5 , respectively. We dummy coded condition first with no secondary task as the reference group (no secondary task vs. articulatory suppression; no secondary task vs. motor suppression), and then models were rerun with motor suppression as the reference group (motor suppression vs. no secondary task; motor suppression vs. articulatory suppression) in order to obtain

comparisons between each condition. Per linear model diagnostics, we log transformed each outcome measure and eliminated participants from the original sample (TD: $n = 70$, SLI: $n = 36$) for whom multiple observations exceeded acceptable levels of leverage, regression model fit, and model influence and whose exclusion improved group matching (TD: $n = 13$, SLI: $n = 5$; Judd, McClelland, & Ryan, 2009). Finally, we eliminated trials exceeding 20 moves or 75 s (0.02% of the total trials) for a total of 989 trials included in our analyses.

Results

The Relationship Between Group, Language, and Planning Performance

Number of Moves

Table 2 provides a summary of all descriptive data for the ToL task. For total number of moves, there was a significant main effect of SES ($b = 0.74$, $F = 5.11$, $p < .05$) and no other significant main effects. When no secondary task was the reference variable, there was a significant effect of SES ($b = -0.01$, $SE = 0.00$, $t = -2.62$, $p < .05$); relatively higher SES was associated with fewer moves (better performance) than somewhat lower SES. There was a significant interaction between articulatory suppression and Core Language ($b = -0.26$, $SE = 0.12$, $t = -2.24$, $p < .05$). Follow-up analyses revealed that better language ability was associated with fewer moves in the articulatory suppression

($b = -0.02$, $SE = 0.00$, $t = -7.14$, $p < .01$) and no secondary task ($b = -0.00$, $SE = 0.00$, $t = -3.10$, $p < .01$) conditions than poorer language ability. When motor suppression was the reference variable, the significant effect of SES remained ($b = -0.01$, $SE = 0.00$, $t = -2.26$, $p < .05$) and there were no other significant effects ($ps > .05$).

When including NVIQ as a covariate in the analysis of total number of moves, NVIQ was not significantly related to performance ($p > .05$), the main effect of SES remained significant ($p < .05$), and the main effect of condition became significant ($b = 1.11$, $F = 3.83$, $p < .05$), indicating the presence of a significant difference between conditions. When no secondary task was the reference variable, both the significant effect of SES and significant interaction between articulatory suppression and Core Language remained ($ps < .05$). There was an additional significant effect of articulatory suppression ($b = 1.53$, $SE = 0.06$, $t = 2.76$, $p < .01$). When motor suppression was the reference variable, there was no change in results relative to when NVIQ was not included in the statistical model.

Planning Time

For planning time, there was a significant main effect of condition ($b = 5.81$, $F = 8.69$, $p < .01$). When no secondary task was the reference variable, there were significant effects of articulatory suppression ($b = -0.55$, $SE = 0.18$, $t = -3.10$, $p < .01$) and Core Language ($b = 0.38$, $SE = 0.17$, $t = 2.28$, $p < .05$). Planning time was faster in the

Table 2. Participants' descriptive data for the Tower of London (ToL) measure, subdivided according to outcome measure, condition, and group.

Condition	ToL measure	TD ($n = 50$)	SLI ($n = 31$)
No secondary task (n trials = 330)	Number of moves		
	M (SD)	4.3 (0.4)	4.4 (0.6)
	Range	4.0–6.2	4.0–6.7
	Planning time		
	M (SD)	4.6 (1.8)	4.2 (1.3)
	Range	2.3–10.0	2.7–7.9
Articulatory suppression secondary task (n trials = 328)	Execution time		
	M (SD)	7.6 (2.3)	8.1 (4.2)
	Range	4.3–14.2	4.2–25.0
	Number of moves		
	M (SD)	5.2 (1.7)	5.5 (1.4)
	Range	4.0–12.6	4.0–8.6
Motor suppression secondary task (n trials = 331)	Planning time		
	M (SD)	4.4 (1.6)	4.1 (1.6)
	Range	2.1–9.8	2.1–7.7
	Execution time		
	M (SD)	10.6 (4.5)	11.0 (5.3)
	Range	4.5–28.3	5.1–26.4
	Number of moves		
	M (SD)	4.9 (1.0)	4.9 (0.9)
	Range	4.0–8.0	4.0–7.8
	Planning time		
	M (SD)	5.2 (1.9)	5.0 (2.5)
	Range	2.8–10.7	2.6–12.3
	Execution time		
	M (SD)	11.8 (3.5)	11.7 (4.7)
	Range	4.7–20.3	5.9–23.93

Note. TD = typically developing; SLI = specific language impairment.

articulatory suppression condition ($M = 4.26$, $SD = 1.56$) than in the no-secondary task condition ($M = 4.50$, $SD = 1.69$), and better language ability was associated with slower planning time than poorer language ability. There were significant interactions between group and articulatory suppression ($b = -1.00$, $SE = 0.35$, $t = -2.86$, $p < .01$) and between articulatory suppression and Core Language ($b = -0.46$, $SE = 0.16$, $t = -2.98$, $p < .01$). The SLI group had faster planning time ($M = 4.05$, $SD = 1.58$) in the articulatory suppression condition than the TD group ($M = 4.37$, $SD = 1.54$; $b = -0.32$, $SE = 0.11$, $t = -2.97$, $p < .01$), and the SLI group had faster planning time ($M = 4.23$, $SD = 1.34$) in the no-secondary task condition than the TD group ($M = 4.64$, $SD = 1.84$; $b = -0.41$, $SE = 0.11$, $t = -3.58$, $p < .01$). Better language ability was associated with faster planning time in the articulatory suppression ($b = 0.02$, $SE = 0.00$, $t = 6.17$, $p < .01$) and no-secondary task ($b = 0.03$, $SE = 0.00$, $t = 10.02$, $p < .01$) conditions than poorer language ability. There was a significant three-way interaction between group, articulatory suppression, and Core Language ($b = -0.80$, $SE = 0.31$, $t = -2.59$, $p < .05$). For the SLI group, better language ability was associated with faster planning time in the articulatory suppression condition ($b = -0.07$, $SE = 0.02$, $t = -4.74$, $p < .01$), but slower planning time in the no-secondary task condition ($b = 0.08$, $SE = 0.01$, $t = 6.63$, $p < .01$), than poorer language ability. For the TD group, better language ability was associated with slower planning time in the articulatory suppression ($b = 0.04$, $SE = 0.01$, $t = 8.72$, $p < .01$) and no-secondary task ($b = 0.06$, $SE = 0.01$, $t = 10.28$, $p < .01$) conditions than poorer language ability (see Figure 1).

When motor suppression was the reference variable, there was a significant effect of articulatory suppression ($b = -0.55$, $SE = 0.15$, $t = -3.71$, $p < .01$). Planning time was faster in the articulatory suppression condition ($M = 4.26$, $SD = 1.56$) than the motor suppression condition ($M = 5.16$, $SD = 2.14$). There was a significant three-way interaction between group, articulatory suppression, and Core Language ($b = -0.62$, $SE = 0.26$, $t = -2.33$, $p < .05$). For the SLI group, better language ability was associated with faster planning time in the articulatory suppression condition ($p < .01$), but slower planning time in the motor suppression condition ($b = 0.06$, $SE = 0.02$, $t = 2.30$, $p < .05$), than poorer language ability. For the TD group, better language ability was associated with slower planning time in the articulatory suppression ($p < .01$) and motor suppression ($b = 0.02$, $SE = 0.00$, $t = 3.52$, $p < .01$) conditions than poorer language ability (see Figure 1).

When including NVIQ as a covariate in the analysis of planning time, NVIQ was not significantly related to performance ($p > .05$) and the significant main effect of condition remained ($p < .05$). When no secondary task was the reference variable, the significant effect of articulatory suppression and Core Language, the interaction between group and articulatory suppression, the interaction between Core Language and articulatory suppression, and the three-way interaction between group, articulatory suppression,

and Core Language remained significant ($ps < .05$). When motor suppression was the reference variable, the significant effect of articulatory suppression was no longer significant ($b = -1.42$, $SE = 0.79$, $t = -1.79$, $p = .08$) and the interaction between group and articulatory suppression became significant ($b = 3.04$, $SE = 1.29$, $t = 2.35$, $p < .05$). The three-way interaction between group, articulatory suppression, and Core Language remained significant ($p < .05$).

Execution Time

For execution time, there were no significant main effects. When no secondary task was the reference variable, there was a significant interaction between group and articulatory suppression ($b = -0.83$, $SE = 0.38$, $t = -2.19$, $p < .05$) and between Core Language and articulatory suppression ($b = -0.37$, $SE = 0.17$, $t = -2.21$, $p < .05$). Groups were similar on execution time in the articulatory suppression condition (SLI: $M = 10.68$, $SD = 5.59$; TD: $M = 10.60$, $SD = 4.50$; $p = .80$), yet the SLI group had slower execution time in the no-secondary task condition ($M = 8.11$, $SD = 4.19$) than the TD group ($M = 7.60$, $SD = 2.25$; $b = 0.51$, $SE = 0.21$, $t = 2.48$, $p < .05$). Language ability did not significantly predict execution time in the no-secondary task condition ($p = .18$), but better language ability was associated with slower execution time in the articulatory suppression condition than poorer language ability ($b = -0.04$, $SE = 0.01$, $t = -4.12$, $p < .01$). When motor suppression was the reference variable, there were no significant effects ($ps > .05$).

When including NVIQ as a covariate in the analysis of execution time, NVIQ was not significantly related to performance ($p > .05$) and the main effect of condition became significant ($b = 3.67$, $F = 4.64$, $p < .05$). When no secondary task was the reference variable, the interaction between Core Language and articulatory suppression remained significant ($p < .05$), and the effect of articulatory suppression and motor suppression became significant ($b = 2.16$, $SE = 0.81$, $t = 2.66$, $p < .05$, and $b = 1.80$, $SE = 0.79$, $t = 2.29$, $p < .05$, respectively). When motor suppression was the reference variable, the effect of no secondary task became significant ($b = -1.80$, $SE = 0.79$, $t = -2.29$, $p < .05$) and there were no other significant effects ($ps > .05$).

Secondary Task Accuracy

Secondary task accuracy (total correct “maybe” productions or foot taps over total *beeps*) was not significantly different between groups for the articulatory suppression (TD: $M = 0.90$, $SD = 0.12$; SLI: $M = 0.92$, $SD = 0.08$; $t = -0.63$, $p = .53$) or motor suppression (TD: $M = 0.71$, $SD = 0.16$; SLI: $M = 0.62$, $SD = 0.25$; $t = 1.75$, $p = .09$) conditions, and effect sizes were small (articulatory suppression $dR-sqr = 0.01$; motor suppression $dR-sqr = .05$); thus, group adherence to secondary task demands was not significantly different.

Discussion

Using the HCSM as our conceptual framework, we examined the relationship between language and planning,

Figure 1. Planning time: significant three-way interaction between group, condition, and Core Language. Planning time is measured in seconds, and Core Language is measured in the Clinical Evaluation of Language Fundamentals–Fourth Edition standard scores. Gray envelopes represent confidence intervals at the 95% level. SLI = specific language impairment; TD = typically developing.

as measured by the ToL, in children with SLI and typical development. We employed a dual-task paradigm that assessed planning under the following conditions: baseline performance, when disrupting verbal mediation (articulatory suppression), and when controlling for added cognitive demands of the secondary verbal task (motor suppression). We asked whether planning performance differs between school-age children with SLI and age-matched TD children at baseline or when verbal mediation is disrupted and whether children with SLI exhibit a different relationship between language and planning performance relative to TD peers under these conditions. According to the HCSM, children with relatively poorer language ability would be expected to perform more poorly than children with better language ability as they should be less able to use verbal mediation to plan. Thus, we expected the SLI group's performance to be worse than the TD group's performance at baseline, and we expected the SLI group's performance to be less disrupted by articulatory suppression under the assumption that they do not routinely use verbal mediation during planning. Prior work on inner speech (verbal mediation) suggests that children with SLI have a different relationship between language and planning performance than TD peers (Abdul Aziz et al., 2017; Lidstone et al., 2012).

Group Differences in Planning

Regarding the first research question, we found that children with SLI and age-matched TD peers displayed similar accuracy (number of moves) across conditions on the ToL. The SLI group had significantly faster planning time than the TD group at baseline and when verbal mediation was disrupted, but they were significantly slower than the TD group to execute the ToL trials at baseline. These findings imply that children with SLI were less affected by articulatory suppression than TD peers as the group difference in execution time observed at baseline disappeared when verbal mediation was disrupted. When considering both the planning and execution time patterns, children with SLI appeared to rely on verbal mediation in planning less than TD peers.

Findings related to our first research question are consistent with prior work showing that overall planning accuracy was not significantly different between SLI and TD groups at baseline (Marton, 2008). Marton (2008) examined ToL performance at baseline and found that children with SLI did not have deficits in accuracy (number of moves) on the ToL relative to age-matched TD peers. In contrast with our findings and those of Marton on baseline accuracy, Abdul Aziz et al. (2017) found poorer scores

(per their discrete scoring system) on the ToL at baseline for children with below-average relative to above-average language ability. Similarly, Lidstone et al. (2012) found a lower percentage of ToL problems solved accurately in children with SLI relative to TD children when aggregating baseline, articulatory suppression, and motor suppression performance together. Our results, however, align with Lidstone et al.'s (2012) finding that susceptibility to articulatory versus motor suppression secondary tasks did not differ between groups on their measure of planning accuracy.

The SLI group in the current study had faster planning time than the TD group at baseline, consistent with Marton's (2008) finding of faster initiation times for their SLI group. However, our SLI group had slower execution time than the TD group at baseline, in contrast with Marton's finding of similar execution times between groups. This discrepancy may be due to our use of four-move problems rather than problems of varied difficulty or our computerized version of the ToL rather than a tower board and beads. Differences in findings may also be related to language ability criteria for SLI group membership (e.g., CELF-4 standard scores vs. 1.5–2 years of below-average performance on Hungarian language measures; Marton, 2008). We are unable to make comparisons between our findings for planning and execution time and those of Lidstone et al. (2012) as they coupled planning time with execution time for a measure of mean response time. The Abdul Aziz et al. (2017) study did not measure planning or execution time.

With respect to the second research question—whether the relationship between language and planning performance differed between SLI and TD groups—this relationship differed when verbal mediation was disrupted but was similar at baseline and in the motor suppression condition. Children with SLI with relatively better language ability were faster planners under articulatory suppression than children with SLI with poorer language ability. The inverse was true for the TD group—TD children with relatively better language ability were slower planners under articulatory suppression than TD children with poorer language ability. Thus, TD children showed a pattern consistent with HCSM predictions, whereas findings for the children with SLI were less clear. The relationship between language and planning time in children with SLI may represent evidence of nonlinguistic strategy use as they appear to rely less on verbal mediation to plan than TD peers. Furthermore, it is possible that children with SLI with relatively better language ability had better metalinguistic awareness of their own limitations in verbal mediation compared to children with SLI with poorer language ability; therefore, the children with SLI with better language ability tended to rely on perceptual strategies during planning. It may be possible to better account for this pattern of results within the framework of the HCSM by additionally considering the roles of attention and task demands in the relationship between verbal mediation and EF performance for children with language impairment in future studies. Including a measure of attention in analyses of EF performance may reveal further insights as attentional control is thought to manage

EF processes (Garon et al., 2008; Marcovitch & Zelazo, 2009), attention is specifically linked to EF performance in children with SLI (Abdul Aziz et al., 2017; Kapa et al., 2017; Marton, 2008), and deficits in attention are disproportionately high in children with SLI (Mueller & Tomblin, 2014). Systematically varying task demands may also clarify patterns found in the current study. For example, verbal mediation may be more or less beneficial to performance for TD children or children with SLI depending on task difficulty, affecting how language and EF performance are related (Alderson-Day & Fernyhough, 2015; Fernyhough & Fradley, 2005; Vygotsky, 1987).

Findings related to group differences in the relationship between language and planning performance align with prior work showing differences between children with SLI and TD children in the relationship between language and EF performance, even when overall accuracy between groups is not significantly different on EF tasks (Ellis Weismer et al., 2017; Marton, 2008). Prior research on planning focused on measures of inner speech (verbal mediation) and showed that inner speech in children with SLI was less internalized relative to TD peers, which suggests delayed verbal mediation development (Abdul Aziz et al., 2017; Lidstone et al., 2012). Similar to Lidstone et al. (2012), the current study used a dual-task paradigm to selectively disrupt verbal mediation but focused on how disrupted verbal mediation was related to ToL performance between groups. We also analyzed the relationship between language ability and planning performance and found an inverse relationship between language ability and planning time in children with SLI relative to TD peers when verbal mediation was disrupted. This finding adds nuance to the discrepancies between studies on ToL performance measures—discrepancies may relate to SLI group language ability. This possibility is difficult to resolve though because the relationship between language ability and planning performance was not directly analyzed in the prior studies. Not only has our study shown that group membership was related to planning and execution time, it has also shown that language ability was related differently to time spent planning in children with SLI compared to TD peers. Furthermore, language ability was related to accuracy at baseline and when verbal mediation was disrupted—over and above NVIQ. The relationship between language and accuracy coupled with group differences in planning and execution time suggests that children with relatively poorer language ability may have greater difficulty planning than children with better language ability.

On the surface, our results appear to conflict with the conclusions from the meta-analysis by Pauls and Archibald (2016); they concluded that severity of language impairment was unrelated to EF performance in children with SLI. Pauls and Archibald used effect size differences between SLI and TD groups as their measure of language impairment severity and interpreted this measure as being a proxy for potential verbal mediation. Thus, they concluded that differences between SLI and TD groups in verbal mediation may not underlie SLI group deficits in EF performance.

However, their study involved two core EF component skills, namely, inhibition and cognitive flexibility, while our study involved a higher level EF skill—planning. One possible explanation for the discrepancy between our studies, therefore, is that verbal mediation is less important to performance on lower level EF component tasks and more important to performance on higher level integrated EF tasks. Prior work, however, shows disrupted performance under articulatory suppression on core EF component skills, such as updating WM and cognitive flexibility in TD children (Emerson & Miyake, 2003; Fatzer & Roebbers, 2012) and in children with autism spectrum disorder (Russell-Smith, Comerford, Mayberry, & Whitehouse, 2014; Whitehouse, Mayberry, & Durkin, 2006; see Alderson-Day & Fernyhough, 2015, for further discussion). Contrasting findings may also be related to differences in language ability measures and experimental design rather than the lack of verbal mediation involvement in lower level EF component skills. In fact, Pauls and Archibald note that their measure of language impairment severity was a limitation of their study due to it representing varied measures of language ability, which may be more or less sensitive to language deficits (e.g., the sensitivity of an expressive vocabulary assessment vs. a morphosyntax assessment).

Theoretical and Clinical Implications

Our findings provide support for the HCSM (Marcovitch & Zelazo, 2009) for typical development, but the evidence is less straightforward for children with SLI. The HCSM posits that lower ability learners will have less optimal goal-directed behavior than high-ability learners as they are less able to use language-based reflection to override prepotent perceptual strategies (Marcovitch & Zelazo, 2009). It makes clear predictions about performance differences between children with better and poorer motor coordination and motor memory but less clear predictions about children with language impairment. Children with SLI are presumed to be less able to use verbal mediation to enhance performance because their overall language deficits (including phonological, semantic, and syntactic skills) are likely to interfere with the development and use of language-based reflection. In our study, children with SLI had similar accuracy as TD peers across conditions, but they took less time to plan than TD peers at baseline and under articulatory suppression and more time to execute trials than TD peers at baseline. The baseline group difference in ToL execution time disappeared when verbal mediation was disrupted. This finding suggests that SLI group performance was less disrupted by articulatory suppression than TD group performance as the gap between the time each group used to execute ToL trials at baseline closed under articulatory suppression. When considering the planning and execution time patterns together, the SLI group appeared to rely on verbal mediation to a lesser degree than the TD group. Furthermore, despite similar overall accuracy between groups, we found that language ability was related to accuracy for both groups at baseline and when verbal mediation was

disrupted. Thus, the HCSM characterization of a low-ability learner may not be entirely captured by language ability or by the relationship between language ability and accuracy on the ToL.

Further consideration of our finding relating to the group difference in the relationship between language ability and planning time when verbal mediation was disrupted may provide insight into the overall findings. The TD group pattern aligns with HCSM predictions, whereas the SLI group pattern appears to contradict HCSM predictions. This apparent contradiction might be at least partially explained on the basis of attentional control or task demands. Attention has been linked to EF performance in children with language impairment (Abdul Aziz et al., 2017; Marton, 2008), and the central executive attentional system manages inhibition of irrelevant representations, such as those derived from secondary tasks (Garon et al., 2008; Marcovitch & Zelazo, 2009). Language impairment severity may even dictate the degree to which distractions are resisted (Kapa et al., 2017; Wittke et al., 2013). In our study, children with SLI with relatively better language ability spent less time planning—likely drawing on perceptual abilities of planning tasks rather than verbal abilities during planning time prior to execution of planning tasks (Kaller et al., 2008). Prior work links nonlinguistic strategies with performance on visuospatial planning tasks, which may explain the level of accuracy achieved by these children (Eichorn, Marton, Campanelli, & Scheurer, 2014; Gangopadhyay et al., 2018; Holland & Low, 2010). Conversely, children with SLI with relatively poorer language ability spent more time planning—possibly perseverating on using verbal strategies. Indeed, the HCSM links perseverative behavior with dual-task constraints and with lower ability learners (Marcovitch & Zelazo, 2009). Language-based reflection is thought to override perseverative behavior, but perhaps to a lesser degree for children who are more severely affected by their language impairment (e.g., children with SLI make more perseverative errors than TD peers; Marton, 2008; Pauls & Archibald, 2016). Thus, whether children successfully use language-based reflection to override habitual responses may depend on attentional control and task demands to a greater degree in children with language impairment than in children with typical language development.

The clinical implications of these findings are that improving verbal mediation may bootstrap planning performance in children with SLI, particularly for children with more severe language impairment. Verbal mediation in planning may be important when alternative strategies are less useful than they are in a visuospatial-dominant task such as our planning task. In educational settings, for instance, verbal demands are high and many complex tasks require verbal planning, problem solving, and reasoning. Nonlinguistic strategy use may result in poorer performance for children with SLI relative to TD peers in these contexts. On the other hand, capitalizing on the ability to alternate between strategies may support performance on tasks that recruit the visuospatial domain more so than the verbal

domain, and prior work suggests that verbal cues may be detrimental to performance for children with SLI under certain task demands (Eichorn et al., 2014; Marton et al., 2014). According to the HCSM, language-based self-reflection provides the opportunity to weigh alternative responses against the habitual response to a task. It may be beneficial, therefore, to make explicit the choice of strategy given the task demands to improve attentional allocation and inhibition of the less optimal strategy as part of an intervention program for children with SLI.

Study Limitations

This study had several limitations. For instance, results may have been influenced by the difficulty level we chose for the ToL problems. It could be that our ToL problems were too simple to provide the variance in performance necessary to detect additional patterns. Mean accuracy was within 1.5 moves of perfect performance (i.e., number of moves = 4) across groups and conditions and within 0.4 moves at baseline (see Table 2). Increasing the difficulty of the problems, however, may have made the task too challenging under secondary task conditions. We found a much larger range in accuracy in the secondary task conditions (see Table 2). Lidstone et al. (2012) found low accuracy in secondary task conditions for two- to five-move problems (articulatory suppression = 43%, motor suppression = 52% for their SLI group). It may have been optimal to match secondary task difficulty—the motor suppression task was more challenging than the articulatory suppression task in the current study. Yet, prior work suggests that matching for secondary task difficulty may not be possible in the dual-task paradigm (Gangopadhyay et al., 2018; Lidstone et al., 2012).

The lack of equivalence between the groups in SES is a limitation of this study. We included SES as a covariate in our statistical models and found a significant effect of SES on accuracy at baseline and under the secondary task conditions. There were no significant effects of SES on other dependent measures of planning or any significant Group $\times$ SES interactions, so the group difference in SES appeared to have a limited effect on overall results. It might also be argued that the significant group difference in NVIQ is a limitation of the study; however, this pattern is common in studies comparing children with SLI and TD peers (Kuusisto, Nieminen, Helminen, & Kleemola, 2017; Marton, 2008; Pauls & Archibald, 2016; Spaulding, 2010), and statistically controlling for NVIQ did not meaningfully affect outcomes. The relatively small sample size is another limitation of the current study. Our SLI sample size is larger than many prior studies on this population (e.g., SLI: $n = 26$, Kapa et al., 2017; SLI: $n = 21$, Lidstone et al., 2012; SLI: $n = 22$, Spaulding, 2010) but smaller than others (e.g., SLI: $n = 41$, Henry et al., 2012; SLI: $n = 40$, Marton, 2008). Thus, results should be interpreted with caution.

Finally, our outcome measures are inherently related; thus, nonindependence in our outcome measures is an additional limitation. For the SLI group, there does not

appear to be a speed–accuracy trade-off in the articulatory suppression condition as faster planning was not coupled with poorer accuracy. Similarly, research has indicated that SLI group deficits in lexical decision tasks are not attributable to a speed–accuracy trade-off (Jones & Brandt, 2018). On the other hand, we found relatively better language ability was associated with slower planning time and greater accuracy for the TD group in the articulatory suppression condition. This was also the case for both groups at baseline and in the motor suppression condition. Although further investigation is required, this pattern may be an evidence of a speed–accuracy trade-off.

Conclusions and Future Directions

This study provides evidence for a link between language and planning, as posited by the HCSM (Marcovitch & Zelazo, 2009), in children with SLI and their TD peers. It also reveals differences between children with SLI and their TD peers in the relationship between language ability and planning performance. Future work should examine how these relationships change under different task demands (e.g., primarily verbal planning) and levels of difficulty (e.g., six-move ToL problems), as well as with different higher order EF skills (e.g., problem solving). Clarifying the directionality of the relationship between language and EF in typically developing children and in children with language impairment may also inform outstanding theoretical and clinical questions. We did not directly examine attentional control for which the HCSM posits an important role. Prior literature suggests that attention, especially in children with language impairment, may impact planning performance (Abdul Aziz et al., 2017; Marton, 2008). Finally, future work should consider the role of nonlinguistic strategies in the goal-directed behavior of children with SLI to further characterize the mechanisms underlying planning performance.

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