# Executive Functions and the Contribution of Short-Term Memory Span in Children With Specific Language Impairment

**Article** *in* Neuropsychology · August 2015

DOI: 10.1037/neu0000232 · Source: PubMed



**4 authors:**

Agnes Lukács
Budapest University of Technology and Econ…


Eniko Ladanyi
Paris Descartes, CPSC


Kata Fazekas
Budapest University of Technology and Econ…


Ferenc Kemeny
Karl-Franzens-Universität Graz

Neuropsychology

# Executive Functions and the Contribution of Short-Term Memory Span in Children With Specific Language Impairment

Ágnes Lukács, Enikő Ladányi, Kata Fazekas, and Ferenc Kemény

Online First Publication, August 17, 2015. http://dx.doi.org/10.1037/neu0000232

Neuropsychology


0894-4105/15/$12.00 http://dx.doi.org/10.1037/neu0000232

# Executive Functions and the Contribution of Short-Term Memory Span in Children With Specific Language Impairment

Ágnes Lukács
Budapest University of Technology and Economics

Enikő Ladányi
Budapest University of Technology and Economics and Hungarian Academy of Sciences

Kata Fazekas and Ferenc Kemény
Budapest University of Technology and Economics

***Objective:*** An increasing number of results show that specific language impairment (SLI) is often associated with impairments in executive functions (EF), but the nature, extent, and generality of these deficits is yet unclear. The aim of the paper is to present results from verbal and nonverbal tasks examining EF in children with SLI and their age-matched typically developing (TD) peers. ***Method:*** 31 children with SLI were tested on verbal and nonverbal versions of simple and complex span, fluency, N-back, and Stroop tasks. Their performance was compared with 31 TD children matched on age and nonverbal IQ. The design allows us to examine whether executive functions are similarly affected in SLI in verbal and nonverbal tasks. ***Results:*** The SLI group showed difficulties in verbal versions of complex span (listening span task) and fluency but not in inhibition (Stroop tasks) relative to TD age-matched children. Including simple verbal span (digit span) as a covariate eliminated group differences on both verbal tasks. ***Conclusions:*** Children with SLI were found to be impaired on several verbal measures of EF, but these differences were largely due to more fundamental deficits in verbal short-term span.

*Keywords:* specific language impairment, executive functions, short-term memory



Specific language impairment (SLI) is defined as a developmental disorder where language abilities are impaired in the absence of any hearing deficits, neurological disorders, intellectual disability, or other obvious nonlinguistic impairments that would explain the language problems. An increasing number of results, though, show that SLI is often associated with impairments in executive functions (EF), whereas the nature, extent, and generality of these deficits is yet unclear (see also the recent debate about terminology and diagnosis and comments: Bishop, 2014; Reilly et al., 2014). Language, as any complex goal-directed human behavior, relies heavily on nonlinguistic higher order executive functions responsible for the efficient coordination, selection, strategic use, and sustainment of relevant information in time. The role of working memory in language acquisition, production, and processing is now well-established (e.g., Engel de Abreu, Gathercole, & Martin, 2011; Lewis, Vasishth, & Van Dyke, 2006; Montgomery, Magimairaj, & Finney, 2010), and there is a growing body of research demonstrating that executive functions play an important role in production and comprehension at both the word and the sentence level where representations compete (e.g., Novick, Trueswell, & Thompson-Schill, 2005, 2010). These findings point to the importance of examining executive functions in SLI together with their relationship with language abilities and potential contribution to language symptoms.

## Executive Functions in SLI

Executive functions are a set of cognitive processes associated with the coordination, control, and regulation of other cognitive functions and adaptive and efficient goal-directed behavior, especially in complex and new tasks and situations that require sustained conscious attention, or in dual- and multiple-task situations involving divided attention (e.g., Anderson, 2002; Burgess, 2000; D′Esposito et al., 1995; Friedman et al., 2006; Huizinga, Dolan, & van der Molen, 2006; Miller & Cohen, 2001; Miyake et al., 2000). EF include generation of new responses (fluency); planning; switching between different tasks, mental sets, or actions; inhibition of irrelevant stimuli and inappropriate responses; generation of new responses and concurrent storage; updating; and manipulation of working memory representations of context-relevant information (Miyake et al., 2000). The concept and specific compo-

Ágnes Lukács, Department of Cognitive Science, Budapest University of Technology and Economics; Enikő Ladányi, Department of Cognitive Science, Budapest University of Technology and Economics, and Research Institute for Linguistics, Hungarian Academy of Sciences; Kata Fazekas and Ferenc Kemény, Department of Cognitive Science, Budapest University of Technology and Economics.

We are grateful to Lucy Henry for providing us with the odd-one-out task. The paper benefited a lot from discussions with members of the Language Impairment in a Multilingual Society: Linguistic Patterns and the Road to Assessment group (COST Action IS0804). This research was supported by Research Grant OTKA K 83619 “Nonlinguistic Abilities in Specific Language Impairment” from the Hungarian National Science Foundation to Ágnes Lukács.

Correspondence concerning this article should be addressed to Ágnes Lukács, BME Department of Cognitive Science, Egry J. u, 1, H-1111 Budapest, Hungary. E-mail: alukacs@cogsci.bme.hu

nents of executive functions are still subjects of considerable debate in the literature (e.g., Anderson, 2002; Baddeley, 1996; Engle & Kane, 2004; Miyake et al., 2000; Norman & Shallice, 1986; Smith & Jonides, 1999).

Evidence for EF impairments in SLI is controversial but present in several areas. Parental and self-ratings assessing everyday activities involving executive functions (on the Behavior Rating Inventory of Executive Function, Self-Report and Preschool Versions; Gioia, Espy, & Isquith, 2003; Guy, Isquith, & Gioia, 2004) in SLI suggest that deficits in executive function are severe enough to affect academic and everyday lives of both adolescents (Hughes, Turkstra, & Wulfeck, 2009) and preschool children with SLI (Wittke, Spaulding, & Schechtman, 2013). The studies summarized below give us a more detailed, though far from unequivocal, picture of how specific EF subfunctions are affected according to experimental results.

## Attention

A number of studies suggest that children with SLI have problems in both selective and sustained attention. Problems have been documented in sustained attention in preschool children (4 to 6 years) in the visual (Finneran, Francis, & Leonard, 2009) and in the auditory domain (Spaulding, Plante, & Vance, 2008), together with deficits in the temporal engagement of attention (in 5- to 8-year-old children; Dispaldro et al., 2013).

## Planning

The few studies addressing the question of planning suggest problems in this domain as well. Marton (2008) observed more perseverative errors, failures to develop a rule, rule violations, and more impulsive responses in children with SLI between 5 and 7 years than in typically developing (TD) children on both the Wisconsin Card Sorting Test and the Tower of London test. Weyandt and Willis (1994) also found impaired planning performance on the Tower of Hanoi in a group of children with developmental language disorder (6 to 12 years). As successful planning relies on several other executive functions, these results probably reflect deficits not only in planning, but also in controlled attention, switching, inhibition, and goal maintenance.

## Inhibition

Evidence for inhibition difficulties in SLI is controversial, but most results show problems with inhibitory control. Bishop and Norbury (2005) found deficits on tasks testing both verbal and nonverbal inhibition of prepotent responses in school-age children with SLI. Im-Bolter, Johnson, and Pascual-Leone (2006) documented impairment in an antisaccade task and also on incompatible trials of the children's trail making task (with intact switching) in 7- to 12-year-old children with SLI. In a continuous performance task, Finneran et al. (2009) found a reduced capacity to monitor the target stimulus and inhibit distractor stimuli in preschool children with SLI. On the other hand, Noterdaeme, Amorosa, Mildenberger, Sitter, and Minow (2001) found no group differences on the go/no-go task in school-age children and adolescents with SLI.

Preschool children with SLI, according to Spaulding's (2008, 2010) results, were more susceptible to distraction by speech, environmental sounds, and visual stimuli. They more frequently made incorrect button presses on stop trials in a stop signal task, and fewer correct button presses on go trials. Distractibility and inhibition scores also correlated with standardized language tests, showing that attention and inhibition play an important role in language processes.

## Updating

Updating as an EF is defined as the monitoring of the contents of working memory, and the replacement of old information with new content. Children with SLI (between 7 and 12 years) were poorer than controls on the one-back condition in a dot-pattern recognition N-back task, and both groups performed at chance on the two-back task (Im-Bolter et al., 2006).

## Executive-Loaded Working Memory

Tasks associated with executive-loaded working memory functions require storage and manipulation of information at the same time. Results from complex span tasks show impaired verbal abilities between 7 and 12 years (Marton & Schwartz, 2003; Montgomery et al., 2010; Weismer, Evans, & Hesketh, 1999), while results for nonverbal abilities are controversial. In Marton's (2008) study, preschool children with SLI and TD children did not differ in visuospatial short-term memory, but SLI children's performance lagged behind controls on the executive-loaded visuospatial tasks. Archibald and Gathercole (2007), on the other hand, did not find any evidence for spatial short-term and working memory deficits in school-age children with SLI.

## Switching (Shifting)

As explained above, problems with planning may also indicate a switching deficit, although Im-Bolter and colleagues (2006) found no shifting deficits in the SLI group. Dibbets, Bakker, and Jolles (2006) examined task-switching in a functional MRI study in the nonverbal domain. At the behavioral level, they observed no group differences, but children with SLI showed larger compensatory activations in areas associated with cognitive control.

## Fluency

There are surprisingly few studies of (even verbal) fluency in SLI, and the results are controversial too. Some studies found no group differences in the number of items listed in a semantic fluency task in children between 6 and 13 (Kail & Leonard, 1986; Weyandt & Willis, 1994). In the nonverbal domain, Bishop and Norbury (2005) also failed to find a deficit in an ideational fluency task. On the other hand, Weckerly, Wulfeck, and Reilly (2001) showed both semantic and phonemic fluency impairment in SLI at school age, while performance patterns, and clustering and switching strategies were similar in the two groups. As these latter measures are more closely associated with frontal executive functions, Weckerly and colleagues (2001) account for the deficit in terms of a linguistic information processing deficit.

In light of this controversial pattern of findings, a recent comprehensive study by Henry, Messer, and Nash (2012) systematically tested verbal and nonverbal aspects of executive functions in 41 children with SLI between 8 and 14 years and TD peers. Using

10 tasks, they compared group performances while controlling for age, nonverbal, and verbal IQ. They were tested on measures of executive-loaded working memory (the listening recall subtest of Working Memory Test Battery for Children by Pickering & Gathercole, 2001 in the verbal domain, and the odd-one-out task by Henry, 2001 in the nonverbal domain), fluency (verbal and nonverbal fluency subtests of Delis-Kaplan Executive Function System [D-KEFS]; Delis, Kaplan, & Kramer, 2001), planning (verbal and nonverbal tasks on the sorting test of D-KEFS), inhibition (a new verbal inhibition, motor inhibition test with verbal and nonverbal subtests developed by the authors), and switching in the verbal (trail-making test from D-KEFS) and nonverbal (switching test was intra/extradimensional shift from Cambridge Neuropsychological Test Automated Battery; Cambridge Cognition, 2006) domain. Children with SLI lagged behind nonlanguage-impaired controls on six tasks, and performed comparable with TD children on verbal and nonverbal switching, verbal planning, and verbal inhibition.

As the above literature review shows, it is difficult to draw a clear picture of executive problems in SLI. The aim of this paper is to extend previous findings and present results from verbal and nonverbal tasks examining executive functions in Hungarian-speaking children with SLI and their age-matched TD peers. Because the concept and components of executive functions are still subjects of considerable debate in the literature (e.g., Anderson, 2002; Baddeley, 1996; Engle & Kane, 2004; Miyake et al., 2000; Smith & Jonides, 1999) and it is difficult to find tasks that are associated with only one EF subcomponent, instead of taking a theoretical stance, we rely on tasks that are associated with at least partially different aspects of EF. We designed this study to extend systematic studies of EF in SLI following Henry et al.'s (2012) logic in developing verbal and nonverbal tasks for several functions, trying to focus on tasks that build relatively little on other executive functions. Children were tested on verbal and nonverbal versions of simple and complex span tasks, fluency, N-back, and Stroop tasks. Simple span tasks were included to allow controlling for their potential contribution to EF deficits. This design allows us to examine whether (a) deficits in specific executive functions are only manifest when they are mediated by verbal stimuli, or they point to domain-general dysfunctions that are present in nonlinguistic tasks as well; (b) there is a general EF deficit in SLI, or there are selectively vulnerable specific subfunctions like inhibition or updating.

## Method and Measures

### Participants

Thirty-one children with SLI participated in the study (eight girls, 23 boys).[1] Demographic and screening data for the two groups are shown in Table 1. They were recruited from two special school classes and two special preschool groups for children with language impairment. Children were referred to these groups and classes by speech and language therapists working in clinical practice. In each institution, recruitment took between 2 and 3 months. No eligible children declined participation. All children met inclusive and exclusive criteria for SLI that are standardly used in selecting SLI children in research (see, e.g., Dollaghan, 2007; Leonard, 1998/2014, Tager-Flusberg and Cooper, 1999). Each child scored above 85 on the Raven Colored Progressive Matrices (Raven, Court, & Raven, 1987), a measure of nonverbal intelligence. No child had a hearing impairment or a history of neurological impairment. No children in the SLI group had any known comorbidities. Each child scored at least 1.25 *SD*s below age norms on at least two of four language tests administered. The four tests included two receptive tests: the Hungarian standardizations of the Peabody Picture Vocabulary Test (Csányi, 1974) and the Test for Reception of Grammar (Bishop, 1983, 2012; Lukács, Győri, & Rózsa, 2012) and two expressive tests: the Hungarian Sentence Repetition Test (Magyar Mondatutánmondási Teszt; Kas & Lukács, in preparation), and a nonword repetition test (Racsmány, Lukács, Németh, & Pléh, 2005). The 31 children in the control group were TD children matched on chronological age (each child in the TD group was within 3 months of age of a child in the SLI group) and nonverbal IQ (children from a larger group of age-matched TD children were only included in the control group if their IQ scores were within 5 points of their match in the SLI group). TD children were recruited from three schools and two preschools with no special selection processes for children. All children were tested with the informed consent of their parents, in accordance with the principles set out in the Declaration of Helsinki and the stipulations of the local Institutional Review Board.

### Simple and Complex Span Tasks

As a baseline, we included simple span tasks in our design together with complex span tasks that require concurrent storage and processing involving executive-loaded working memory. All span tasks were similar in that they contained sequences of different length, and each length was associated with four items. Sequences were presented in increasing length, and the child had to repeat at least two out of four items to proceed to the next length level. If the participant made three errors in one block, testing was terminated, and the span of the participant was established as sequence-length of the block before the last, that is, the maximum length that was completed. Testing started with sequences of two items in all tasks; the longest possible sequence contained nine items in the simple and six items in the complex span tasks.

### Simple Span: Digit Span and Corsi Blocks

In the digit span task, participants are auditorily presented with a sequence of numbers (using a computerized task), and they are asked to repeat the numbers in the same order as they heard them.

The Corsi blocks task measures spatial span with the help of nine cubes in random arrangement on a tray. The experimenter touches a certain number of cubes in a given sequence, and the participant is asked to touch the same cubes in the same order.

### Complex Span Tasks: Listening Recall and Odd-One-Out

In the listening recall task, participants listen to sets of short sentences. After hearing a sentence, they have to tell whether it is true or false, and at the end of each set, they are asked to recall the

[1] Boys are systematically more vulnerable to SLI, estimates vary between 3–4:1 for boys:girls (e.g., Robinson, 1991; Cheuk et al., 2005).

Table 1
*Demographic Data and Scores for Screening Tests in the SLI and TD Groups*

| | TD | | SLI | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* | *F* | Sig | $\eta_p^2$ |
| Age (years) | **7.81** | 1.81 | **7.84** | 1.81 | 0.004 | 0.949 | 0.000 |
| Raven IQ (standard score) | **107.06** | 13.39 | **103.10** | 12.01 | 1.508 | 0.224 | 0.025 |
| Nonword repetition (span) | **5.90** | 1.35 | **2.97** | 1.58 | 61.799 | <.001 | 0.507 |
| Peabody Picture Vocabulary Test (raw scores) | **110.45** | 24.7 | **86.39** | 21.83 | 16.518 | <.001 | 0.216 |
| Test for Reception of Grammar blocks (raw scores) | **16.77** | 2.33 | **11.90** | 3.13 | 48.164 | <.001 | 0.445 |
| Sentence repetition (raw scores) | **35.35** | 6.35 | **17.90** | 9.31 | 74.384 | <.001 | 0.554 |

*Note*. STL = specific language impairment; TD = typically developing; Sig = significiant. Means are highlighted in boldface.



final word of each sentence in the set in the correct order. Our Hungarian version of the task was modeled after the listening recall task from Working Memory Test Battery for Children (Pickering & Gathercole, 2001).

The odd-one-out task is a nonverbal analogue of the listening recall task developed by Henry (2001). Participants are presented with sets of horizontal arrays of three nonsense shapes and are asked to spot the odd one out in each array. At the end of the set, they have to recall the location of the odd one out by pointing to the left, middle, or right box in an array of three empty boxes in the case of each trial of the set in the correct order. The span version of the odd-one-out task has a reliability of .80 (Henry, 2001).

## N-Back Tasks

N-Back tasks are most strongly associated with updating, but correct performance often also relies on monitoring and inhibition. In order to minimize the role of inhibition and focus on updating in this task, we did not include lures in the design.

In the N-back tasks, participants are presented with a sequence of stimuli, and their task is to indicate (by pressing "Enter") when the current stimulus matches the one presented *n* steps earlier. Stimuli were presented electronically using the E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2012). We used one- and two-back conditions for each stimulus type, in two blocks with about a 1-min break between them. Each block consisted of 60 trials, from which 10 were N-back trials (i.e., stimuli that match the ones presented *n* before).

We developed a verbal and a nonverbal version of the task. In the verbal condition, stimuli were letters (participants typically use a strategy where they rehearse the letters with their names instead of just relying on their visual shape), and in the nonverbal condition, stimuli were pictures (pictures of fractals that are difficult to verbalize). The design of the task and the instructions were the same for both types.

We calculated the number of hits (when the participant correctly presses the Enter on an "N-back trial," i.e., when the current item is identical to the target item, with a maximum of 10 hits per block) and the number of false alarms (the participant presses Enter on a not "N-back trial," i.e., the actual stimulus is not identical to the one presented *n* before) for one-back and two-back blocks separately.

## Stroop Tasks

Stroop tasks are designed to tap into inhibition. We created two versions, a verbal and a nonverbal. In both versions, pictures of animals appear on the screen with a simultaneously presented auditory stimulus. The auditory stimulus was either the name of an animal (verbal condition) or the recorded sound of the animal. Stimuli were presented electronically using the E-Prime 2.0 software (Schneider et al., 2012). There were four pictures: a picture of a cow, a horse, a rooster, and a cat. In accordance, there were four animal names in the verbal, and four recorded animal sounds in the nonverbal condition. The auditory name or sound matches the picture (e.g., a picture of a cow appears and the word *cow* or a cow sound is heard) in the congruent condition, but does not match it in the incongruent condition (e.g., a picture of a cow appears and the word *horse* or a horse sound is heard). In the verbal control condition, there is no sound presented with the pictures, whereas participants only hear sounds in the nonverbal control condition. Participants have to press a button (marked with stickers of the animals) corresponding to the picture they see in the verbal task and the voice they hear in the nonverbal task. There are three blocks (control, incongruent, congruent) of 60 trials in the tasks. The order of the trials is random within blocks, and the three blocks also follow each other in a random order. We had two measures for both the verbal and the nonverbal version of the task. For accuracy measures, the number of correct answers for the incongruent items was subtracted from the number of correct answers for the congruent items. In the case of reaction times (RTs), we subtracted the median RT for the congruent items from the median RT for the incongruent items.

## Fluency Tasks

In the verbal fluency task, children were asked to generate as many (a) actions or things that people do, (b) things they can buy at a supermarket, and (c) words starting with *k* as they can in 1 min for each condition. Nonverbal fluency was tested by the design fluency subtest of D-KEFS (Delis et al., 2001). This task uses a booklet containing boxes with dot patterns, and the child is asked to draw as many different designs (each in a separate box) as he or she can in 1 min, connecting the dots with four lines. In Condition A, there are only filled dots, in Condition B, boxes contain both empty and filled dots, and the task is to connect empty dots only. Condition C also contains empty and filled dots, and the task is to connect them in an alternating sequence by the four lines. Cronbach's alpha is 0.915 for the nonverbal task (Delis et al., 2001). For both tasks, we calculated the overall number of correct answers and the number of errors for each participant.

# Results

## Statistical Analysis

We had a verbal and a nonverbal version for all tasks. For each task, we conducted a 2 × 2 mixed-model analysis of variance (ANOVA) with type (Verbal vs. Nonverbal) as the within-subjects variable, and group (SLI vs. TD) as the between-subjects variable. Simple spans were tested to control for their potential contribution to complex tasks by including them as a covariate in case of significant group differences. Table 2 summarizes results for all tasks in the two groups, and results of one-way between group comparisons. To control for Type I errors, we divided the alpha level by the number of executive functions tested in the current study. We focused on five functions: simple span, complex span, Stroop, N-back, and fluency, hence the alpha value was set to 0.01.

## Simple Span: Digit Span and Corsi Blocks

The ANOVA revealed that children had higher spans on the nonverbal than on the verbal task, as shown by a marginally significant type main effect, $F(1, 60) = 6.550$, $p = .013$, $\eta_p^2 = 0.098$. Children with SLI showed a significantly lower performance, as revealed by a main effect of group, $F(1, 60) = 10.384$, $p = .002$, $\eta_p^2 = 0.148$. The interaction of Type × Group was also significant, $F(1, 60) = 26.199$, $p < .001$, $\eta_p^2 = 0.304$.

To further analyze the Type × Group interaction, we conducted two separate univariate ANOVAs with digit span/Corsi span as a dependent variable, and group (TD vs. SLI) as between-subjects variable. The ANOVAs revealed that the control group outperformed the clinical group on the digit span task, $F(1, 60) = 34.055$, $p < .001$, $\eta_p^2 = 0.362$, but not on the nonverbal Corsi blocks task ($p = .892$). Because there were no group differences on Corsi span, it was not included as a covariate in group comparisons of nonverbal tasks below.

## Complex Span: Listening Span and the Odd-One-Out

The 2 × 2 mixed-model ANOVA revealed a significant main effect of type, $F(1, 60) = 51.921$, $p < .001$, $\eta_p^2 = 0.464$, with generally higher performance on the nonverbal odd-one-out task. The TD group outperformed the SLI group, $F(1, 60) = 8.961$, $p = .004$, $\eta_p^2 = 0.130$. The Type × Group interaction was also approaching significance, $F(1, 60) = 8.961$, $p = .081$, $\eta_p^2 = 0.050$.

To further analyze the interaction, we conducted a separate ANOVA for each task with group as the between-subjects variable. The ANOVAs revealed that performance of the TD group was significantly higher on the verbal listening span task, $F(1, 60) = 17.024$, $p < .001$, $\eta_p^2 = 0.221$, but not on the nonverbal odd-one-out task ($p = .144$).

To investigate whether the group difference in the verbal task is due to limitations in simple span, we reran the above analysis on listening span with digit span as covariate. This way, the main effect of group was not significant ($p = .109$).

Table 2

*Means and SDs for the Measures of the Different Tasks for the TD and SLI Groups, Together With Results of One-Way ANOVAs as Group Comparisons*

| | TD | | SLI | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* | *F* | Sig | $\eta_p^2$ |
| Digit span | 4.58 | 0.92 | 3.39 | 0.67 | 34.055 | <.001 | 0.362 |
| Corsi span | 4.29 | 1.01 | 4.26 | 0.86 | 0.018 | 0.892 | 0.000 |
| Listening recall | 2.23 | 0.92 | 1.29 | 0.86 | 17.024 | <.001 | 0.221 |
| Odd-one-out | 2.97 | 1.30 | 2.52 | 1.09 | 2.188 | 0.144 | 0.035 |
| Accuracy verbal Stroop | −3.00 | 6.76 | −5.61 | 13.08 | 0.976 | 0.327 | 0.016 |
| Accuracy nonverbal Stroop | −8.55 | 15.37 | −11.29 | 16.18 | 0.468 | 0.497 | 0.008 |
| RT verbal Stroop | 324 | 290 | 306 | 359 | 0.048 | 0.827 | 0.001 |
| RT nonverbal Stroop | 397 | 371 | 317 | 337 | 0.795 | 0.376 | 0.013 |
| Verbal one-back hit | 8.84 | 1.83 | 8.35 | 2.39 | 0.803 | 0.374 | 0.013 |
| Nonverbal one-back hit | 9.23 | 1.12 | 8.90 | 1.70 | 0.780 | 0.381 | 0.013 |
| Verbal one-back false alarm | 0.48 | 1.15 | 2.16 | 4.75 | 3.655 | 0.061 | 0.057 |
| Nonverbal one-back false alarm | 3.81 | 7.91 | 3.81 | 8.78 | 0.000 | 1.000 | 0.000 |
| Verbal two-back hit | 5.48 | 2.63 | 3.97 | 2.70 | 5.010 | 0.029 | 0.077 |
| Nonverbal two-back hit | 4.65 | 2.67 | 4.58 | 2.87 | 0.008 | 0.927 | 0.000 |
| Verbal two-back false alarm | 1.39 | 1.99 | 2.87 | 5.99 | 1.714 | 0.195 | 0.028 |
| Nonverbal two-back false alarm | 2.90 | 3.00 | 7.32 | 11.67 | 4.172 | 0.045 | 0.065 |
| Verbal fluency correct | 31.55 | 12.26 | 22.45 | 11.16 | 9.329 | 0.003 | 0.135 |
| Nonverbal fluency correct | 8.84 | 5.01 | 10.10 | 6.45 | 0.735 | 0.395 | 0.012 |
| Verbal fluency errors | 1.48 | 2.79 | 2.19 | 2.63 | 1.063 | 0.307 | 0.017 |
| Nonverbal fluency errors | 7.48 | 5.53 | 6.06 | 5.46 | 1.033 | 0.314 | 0.017 |

*Note.* TD = typically developing; SLI = specific language impairment; Sig = significance; RT = reaction time. Calculation method for each measure is described in the text.

## Stroop Tasks

The ANOVA revealed no significant effects on either accuracy (number of correct answers for the incongruent items subtracted from number of correct answers for the congruent items; $p = .033$ for the type main effect, $p = .233$ for the group main effect and $p = .980$ for the Type × Group interaction) or RT measures (median RT for congruent items subtracted from the median RT for incongruent items in milliseconds; all $p$ values $> 0.436$).

## N-Back Tasks

In the case of one-back condition, no effects were significant for hit rate: all $p$ values $>0.111$. Both groups of children produced a significantly higher number of false alarms in the nonverbal task, as revealed by a main effect of type, $F(1, 60) = 8.059$, $p = .006$, $\eta_p^2 = 0.118$. Neither the main effect of group ($p = .542$), nor the Type × Group interaction was significant ($p = .342$).

In the two-back condition, no effects were significant for accuracy measures ($p = .760$ for type, $p = .181$ for group, and $p = .053$ for the Type × Group interaction).

The number of false alarms was significantly higher in the nonverbal two-back task, $F(1, 60) = 13.084$, $p < .001$, $\eta_p^2 = 0.179$. Results revealed no significant differences by group, $F(1, 60) = 3.784$, $p = .056$, $\eta_p^2 = 0.059$, and no Type × Group interaction either, $F(1, 60) = 3.166$, $p = .080$, $\eta_p^2 = 0.050$.

## Fluency

Fluency results were analyzed on composite measures calculated by summing up the three measures for both the verbal and the nonverbal task. We calculated the sum of correct answers, the sum of incorrect answers, and the sum of repetitions.

In the case of correct answers, the ANOVA revealed a significant main effect of type, $F(1, 60) = 153.330$, $p < .001$, $\eta_p^2 = 0.719$, with significantly higher number of correct responses on the verbal task. There was also a significant interaction between type and group, $F(1, 60) = 13.371$, $p < .001$, $\eta_p^2 = 0.182$, while the main effect of group was not significant, $F(1, 60) = 4.380$, $p = .041$, $\eta_p^2 = 0.068$.

Further post hoc ANOVAs showed that there was a significant difference between the groups on the verbal, $F(1, 60) = 9.329$, $p = .003$, $\eta_p^2 = 0.135$, but not on the nonverbal task ($p = .395$). The former was eliminated by simple span as covariate ($p = .505$ for the group main effect).

In the case of category errors, there was a significant main effect of type, $F(1, 60) = 46.770$, $p < .001$, $\eta_p^2 = 0.438$, with a higher number of errors in the nonverbal task. Neither the group main effect ($p = .671$), nor the Type × Group interaction ($p = .145$) was significant. No effects were significant in the case of repetition errors: all $p$ values $>0.273$.

# Discussion

Extensive examination of executive functions in a group of children with SLI revealed impairments in some, but not all executive functions, mostly in the verbal domain. The SLI group showed difficulties in verbal complex span (Listening span task), and fluency, but not in inhibition (Stroop tasks) and updating (N-back tasks) relative to TD age-matched children. While group differences were observed in initial analyses on these two verbal tasks, including measures of simple verbal span (digit span) as a covariate eliminated them, suggesting that fundamental difficulties in short-term memory (STM) contribute to difficulties in verbal complex working memory and other executive functions (e.g., fluency). Although difficulties were most evident in the verbal domain, they were also observed in simple group comparisons in one measure in the nonverbal domain: children with SLI made a higher number of false alarms in the nonverbal N-back task. This result suggests that in spite of the fact that we did not find difficulties with inhibition in a direct test of inhibition (the Stroop task), with increasing task difficulty and higher working memory demand, these might become evident too.

Our results extend previous studies on executive function in SLI in important ways. Examining EF in everyday situations (Hughes et al., 2009; Wittke et al., 2013) suggests deficits in different areas of executive functions, and experimental studies of attention (Dispaldro et al., 2013; Finneran et al., 2009; Spaulding et al., 2008) point to a deficit in SLI despite testing different groups and using different tasks. As our review in the introduction illustrates, results on EF in other areas are more controversial in this relatively new area of research, and perhaps as more studies are conducted with larger and well-defined groups in different age-ranges, we will gain a better picture. The current study was a step in that direction. Our findings show that deficient performance on verbal EF tasks can in fact be a secondary phenomenon rooted in verbal short-term memory impairment, and also suggest that problems with executive functions might only become apparent when the task is complex and involves higher working memory load as well as engaging other executive functions.

Results presented in the paper are not easy to integrate with the earlier set of findings in the literature. Because these findings were controversial and used different tasks and age groups in most areas, instead of reiterating them in the light of our own findings, we try to speculate on the reasons behind such a mixed picture. First, it is well-known that SLI is a category that includes children of different age, different patterns of symptoms, different severity of impairment, and potentially of different etiology too. Language impairment is often associated with other developmental disorders, most frequently with attention-deficit/hyperactivity disorder, dyslexia, and autism spectrum disorder (for a review, see Leonard, 1998/2014), all of which are known to involve impairments in several executive functions and working memory. Although the definition of SLI excludes some of these associated problems, the boundaries are not clear-cut, and this results in a lot of heterogeneity across samples and studies. Second, studies of executive functions in SLI use different tasks that differ in their complexity and difficulty: sometimes a lack of a group difference could be due to applying a task that is very easy even for children with SLI or too difficult even for TD children (e.g., a three-back task).

Third, most tasks involve more than just one EF subfunction. For example, although the N-back task is often used to test updating, to successfully respond, participants also need to inhibit responses to distractor stimuli. Even the subfunctions themselves are often dependent on each other, and may differ greatly in their complexity: planning and shifting, for example, seem to essentially build on inhibition and updating. The fuzziness of the theoretical constructs (both of SLI and executive functions) makes it difficult to establish the nature of the deficits. As all three factors are general problems in the area of research on SLI on the one hand, and on EF on the other, they are among the limitations of our study as well.

Also, as pointed out by one of the reviewers of the manuscript, childhood socioeconomic status (SES) influences EF (see, e.g., Hackman, Gallop, Evans, & Farah, 2015). Children with SLI were not matched to TD peers on SES in our study. Although this is not an issue that is usually addressed in studies of children with SLI, this could be a concern, but we have no reason to believe that there were significant differences between children with SLI and TD children in this regard (e.g., schools and preschools were in similar neighborhoods in both groups). Besides taking SES into account, future research should focus on larger and more homogeneous groups of children with language impairment, as well as try and tease apart EF subcomponents more effectively.

## Conclusion

Children with SLI were found to be impaired on several verbal measures of EF, but these differences were largely due to more fundamental deficits in verbal short-term span. In the nonverbal domain, inhibition deficits were only present when the task involved a high working memory load. Future studies should explore the exact nature of deficits in nonverbal EFs in SLI. Also, when verbal and nonverbal functions seem to be affected in SLI, it is important to examine whether they contribute to language deficits, or are only associated with them. Our pattern of findings together with earlier results suggests that diagnosis and therapy of SLI should also consider potential limitations in executive functions.

## References


Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology, 8,* 71–82. http://dx.doi.org/10.1076/chin.8.2.71.8724

Archibald, L. M. D., & Gathercole, S. E. (2007). Nonword repetition in specific language impairment: More than a phonological short-term memory deficit. *Psychonomic Bulletin & Review, 14,* 919–924. http://dx.doi.org/10.3758/BF03194122

Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 49,* 5–28. http://dx.doi.org/10.1080/713755608

Bishop, D. V. M. (1983). *Test for Reception of Grammar*. Manchester, United Kingdom: Medical Research Council.

Bishop, D. V. M. (2012). *TROG—Test for Reception of Grammar handbook*. Budapest, Hungary: OS Hungary Tesztfejlesztő Kft.

Bishop, D. V. M. (2014). Ten questions about terminology for children with unexplained language problems. *International Journal of Language & Communication Disorders, 49,* 381–415. http://dx.doi.org/10.1111/1460-6984.12101

Bishop, D. V. M., & Norbury, C. F. (2005). Executive functions in children with communication impairments, in relation to autistic symptomatology. 2: Response inhibition. *Autism: The International Journal of Research and Practise, 9,* 29–43. http://dx.doi.org/10.1177/1362361305049028

Burgess, P. W. (2000). Strategy application disorder: The role of the frontal lobes in human multitasking. *Psychological Research, 63,* 279–288. http://dx.doi.org/10.1007/s004269900006

Cambridge Cognition. (2006). *The Cambridge Neuropsychological Test Automated Battery (CANTAB): Test–retest reliability characteristics*. Cambridge, England: Author.

Cheuk, D. K. L., Wong, V., & Leung, G. M. (2005). Multilingual home environment and specific language impairment: A case-control study in Chinese children. *Paediatric and Perinatal Epidemiology, 19,* 303–314.

Csányi, F. I. (1974). *Peabody Szókincs-Teszt*. Budapest, Hungary: Bárczi Gusztáv Gyógypedagógiai Főiskola.

Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan Executive Function System (D-KEFS) examiner's manual*. San Antonio, TX: The Psychological Corporation.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378,* 279–281. http://dx.doi.org/10.1038/378279a0

Dibbets, P., Bakker, K., & Jolles, J. (2006). Functional MRI of task switching in children with Specific Language Impairment (SLI). *Neurocase, 12,* 71–79. http://dx.doi.org/10.1080/13554790500507032

Dispaldro, M., Leonard, L. B., Corradi, N., Ruffino, M., Bronte, T., & Facoetti, A. (2013). Visual attentional engagement deficits in children with specific language impairment and their role in real-time language processing. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 49,* 2126–2139. http://dx.doi.org/10.1016/j.cortex.2012.09.012

Dollaghan, C. A. (2007). *The handbook of evidence-based practice in communication*. Baltimore, MD: Brookes.

Engel de Abreu, P. M. J., Gathercole, S. E., & Martin, R. (2011). Disentangling the relationship between working memory and language: The roles of short-term storage and cognitive control. *Learning and Individual Differences, 21,* 569–574. http://dx.doi.org/10.1016/j.lindif.2011.06.002

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 44, pp. 145–159). New York, NY: Academic Press.

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. http://dx.doi.org/10.1044/1092-4388(2009/07-0053)

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., Defries, J. C., & Hewitt, J. K. (2006). Not all executive functions are related to intelligence. *Psychological Science, 17,* 172–179. http://dx.doi.org/10.1111/j.1467-9280.2006.01681.x

Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). Behavior Rating Inventory of Executive Function–PreSchool version. Lutz, FL: Psychological Assessment Resources, Inc.

Guy, S. C., Isquith, P. K., & Gioia, G. A. (2004). *Behavior. Rating inventory of executive function-self-report version*. Lutz, FL: Psychological Assessment Resources.

Hackman, D. A., Gallop, R., Evans, G. W., & Farah, M. J. (2015). Socioeconomic status and executive function: Developmental trajectories and mediation. *Developmental Science*. Advance online publication.

Henry, L. A. (2001). How does the severity of a learning disability affect working memory performance? *Memory, 9,* 233–247. http://dx.doi.org/10.1080/09658210042000085

Henry, L. A., Messer, D. J., & Nash, G. (2012). Executive functioning in children with specific language impairment. *Journal of Child Psychology and Psychiatry, 53,* 37–45. http://dx.doi.org/10.1111/j.1469-7610.2011.02430.x

Hughes, D. M., Turkstra, L. S., & Wulfeck, B. B. (2009). Parent and self-ratings of executive function in adolescents with specific language impairment. *International Journal of Language & Communication Disorders, 44,* 901–916.

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. http://dx.doi.org/10.1016/j.neuropsychologia.2006.01.010

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. http://dx.doi.org/10.1111/j.1467-8624.2006.00976.x

Kail, R., & Leonard, L. B. (1986). Word-finding abilities in language-impaired children. *Asha Monographs, 25,* 1–39.

Kas, B., & Lukács, Á. (in preparation). *Magyar Mondatutánmondási Teszt*.

Leonard, L. (1998/2014). *Children with specific language impairment*. Cambridge, MA: The MIT Press.

Lewis, R. L., Vasishth, S., & Van Dyke, J. A. (2006). Computational principles of working memory in sentence comprehension. *Trends in Cognitive Sciences, 10,* 447–454. http://dx.doi.org/10.1016/j.tics.2006.08.007

Lukács, Á., Győri, M., & Rózsa, S. (2012). A TROG pszichometriai jellemzőinek magyar vizsgálata, a normák kialakítása. In D. V. M. Bishop (Ed.), *TROG—Test for Reception of Grammar handbook* (pp. 47–86). Budapest, Hungary: OS Hungary Tesztfejlesztő Kft.

Marton, K. (2008). Visuo-spatial processing and executive functions in children with specific language impairment. *International Journal of Language & Communication Disorders, 43,* 181–200. http://dx.doi.org/10.1080/16066350701340719

Marton, K., & Schwartz, R. G. (2003). Working memory capacity and language processes in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 46,* 1138–1153. http://dx.doi.org/10.1044/1092-4388(2003/089)

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167–202. http://dx.doi.org/10.1146/annurev.neuro.24.1.167

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49–100. http://dx.doi.org/10.1006/cogp.1999.0734

Montgomery, J. W., Magimairaj, B. M., & Finney, M. C. (2010). Working memory and specific language impairment: An update on the relation and perspectives on assessment and treatment. *American Journal of Speech-Language Pathology, 19,* 78–94. http://dx.doi.org/10.1044/1058-0360(2009/09-0028)

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation. Advances in research and theory* (pp. 1–18). New York, NY: Plenum Press. http://dx.doi.org/10.1007/978-1-4757-0629-1_1

Noterdaeme, M., Amorosa, H., Mildenberger, K., Sitter, S., & Minow, F. (2001). Evaluation of attention problems in children with autism and children with a specific language disorder. *European Child & Adolescent Psychiatry, 10,* 58–66. http://dx.doi.org/10.1007/s007870170048

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective & Behavioral Neuroscience, 5,* 263–281. http://dx.doi.org/10.3758/CABN.5.3.263

Novick, J. M., Trueswell, J. C., & Thomspon-Schill, S. L. (2010). Broca's area and language processing: Evidence for the cognitive control connection. *Language and Linguistics Compass, 4,* 906–924. http://dx.doi.org/10.1111/j.1749-818X.2010.00244.x

Pickering, S. J., & Gathercole, S. E. (2001). *Working memory test battery for children*. London, England: Psychological Corporation.

Racsmány, M., Lukács, Á., Németh, D., & Pléh, C. (2005). A verbális munkamemória magyar nyelvű vizsgálóeljárásai. *Magyar Pszichológiai Szemle, 60,* 479–506. http://dx.doi.org/10.1556/MPSzle.60.2005.4.3

Raven, J., Court, J., & Raven, J. (1987). *Raven's Progressive Matrices and Raven's Colored Matrices*. London, England: H. K. Lewis.

Reilly, S., Tomblin, B., Law, J., Mckean, C., Mensah, F., Morgan, A., . . . Wake, M. (2014). SLI: A convenient label for whom? *International Journal of Language & Communication Disorders, 49,* 415–433.

Robinson, R. J. (1991). Causes and associations of severe and persistent specific speech and language disorders in children. *Developmental Medicine and Child Neurology, 33,* 943–962.

Schneider, W., Eschman, A., & Zuccolotto, A. (2012). *E-Prime user's guide*. Pittsburgh, PA: Psychology Software Tools.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science, 283,* 1657–1661. http://dx.doi.org/10.1126/science.283.5408.1657

Spaulding, T. J. (2008). *Attentional control in preschool children with specific language impairment*. Doctoral dissertation, University of Arizona.

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. http://dx.doi.org/10.1044/1092-4388(2009/09-0041)

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. http://dx.doi.org/10.1044/1092-4388(2008/002)

Tager-Flusberg, H., & Cooper, J. (1999). Present and future possibilities for defining a phenotype for specific language impairment. *Journal of Speech, Language, and Hearing Research, 42,* 1275–1278. http://dx.doi.org/10.1044/jslhr.4205.1275

Weckerly, J., Wulfeck, B., & Reilly, J. (2001). Verbal fluency deficits in children with specific language impairment: Slow rapid naming or slow to name? *Child Neuropsychology, 7,* 142–152. http://dx.doi.org/10.1076/chin.7.3.142.8741

Weismer, S. E., Evans, J., & Hesketh, L. J. (1999). An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 42,* 1249–1260. http://dx.doi.org/10.1044/jslhr.4205.1249

Weyandt, L. L., & Willis, W. G. (1994). Executive functions in school-aged children: Potential efficacy of tasks in discriminating clinical groups. *Developmental Neuropsychology, 10,* 27–38. http://dx.doi.org/10.1080/87565649409540564

Wittke, K., Spaulding, T. J., & Schechtman, C. J. (2013). Specific language impairment and executive functioning: Parent and teacher ratings of behavior. *American Journal of Speech-Language Pathology, 22,* 161–172. http://dx.doi.org/10.1044/1058-0360(2012/11-0052)

Received August 27, 2014
Revision received May 27, 2015
Accepted June 22, 2015 ■