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Research Report

Executive control in language production by children with and without language impairment

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Abstract

Background: Accumulating evidence suggests that the updating, inhibiting and shifting abilities underlying executive control are important for spoken language production in adults. However, little is known about this in children.
Aims: To examine whether children with and without language impairment differ in all or only some of these executive abilities, and whether they show corresponding differences when these abilities are engaged in language production.
Methods & Procedures: Thirty-three children with specific language impairment (SLI) and 41 typically developing (TD) children (age matched, aged 8–12 years) completed standard executive control tests that measure the updating, inhibiting and shifting abilities. All children were native speakers of Dutch. Moreover, they performed a noun–phrase production task involving picture description within a picture–word interference paradigm. We measured their production accuracy and speed to assess length, distractor and switch effects, which reflect the updating, inhibiting and shifting abilities underlying executive control.
Outcomes & Results: Compared with TD children, the children with SLI had lower scores on all executive control tests. Moreover, they were overall slower and made more errors in the noun–phrase production task. Additionally, the magnitude of the distractor and switch effects was larger for the SLI than for the TD group.
Conclusions & Implications: The results suggest that children with SLI have impaired language production and executive control abilities, and that some of the differences in the executive control abilities between SLI and TD groups were reflected in their language production.

Keywords: language production, executive control, language impairment.

What this paper adds

What is already known on the subject

SLI was long considered to be a purely linguistic deficit, but accumulating evidence suggests that there are also deficits in other domains, such as executive control. Executive control includes updating, inhibiting and shifting abilities.

What this paper adds to existing knowledge

It is still not fully clear whether children with SLI show deficits in all or only some of the executive control abilities. Moreover, it is unknown whether engagement of all or only some of the executive control abilities shows differences

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in the language production performance between children with SLI and TD children. Our findings provide evidence that children with SLI have impairments in all three executive control abilities. Moreover, some of the differences in the executive control abilities between SLI and TD groups were reflected in their language production.

What are the potential or actual clinical implications of this work?
All this points to a role of executive control in language production, but the causality and direction of the relationship remains to be determined.

Introduction

Most children acquire their native language without difficulty, but for some language does not develop normally. Specific language impairment (SLI) is a developmental disorder characterized by impaired language ability that cannot be explained by hearing, neurological or intellectual deficits (e.g., Bishop 2006; Leonard 2014). Recent studies have shown that children with SLI also have deficits in non-linguistic domains, including executive control (e.g., Henry *et al.* 2012; Im-Bolter *et al.* 2006; Engel de Abreu *et al.* 2014; Vissers *et al.* 2015). Given that the deficits are not restricted to language, the term ‘developmental language disorder’ has been proposed and is becoming prevalent (Bishop *et al.* 2017). Evidence suggests impairment in some components of executive control, but perhaps not in all (Henry *et al.* 2012; Im-Bolter *et al.* 2006).

The aim of the present study was to investigate executive control and language production in children with and without language impairment. First, we assessed children with SLI and typically developing (TD) children on executive control tests to see whether the children with SLI show deficits in all or only some of the executive control abilities. Second, we assessed their performance on a noun–phrase production task, as previously used in adult studies (Sikora *et al.* 2016), to investigate whether the engagement of all or only some of the executive control abilities will be reflected in differences in language production performance between children with SLI and TD children.

Influence of executive control on language production

According to a highly influential proposal by Miyake *et al.* (2000), executive control includes updating, inhibiting and shifting abilities. Updating is the ability to maintain and manipulate information in the working memory temporarily. In the context of language production, the updating ability is involved, for example, in keeping in mind the communicative goals while scheduling conceptual and linguistic processes (e.g., Levelt 1989; Piai and Roelofs 2013). Inhibiting is the ability to lower the activation of unimportant or unwanted information. In language production, inhibition is applied, for example, to competing words that are co-activated together with the intended word (e.g., Shao *et al.* 2014). Shifting is the ability to switch rapidly between tasks or types of information (e.g., Allport and Wylie 2000). In the context of language production, the shifting ability plays a role, for example, in switching between planning one utterance to planning another utterance (Sikora *et al.* 2016).

In examining the impact of updating, inhibiting and shifting, Shao *et al.* (2012) found in a picture-naming study that the updating and inhibiting abilities of adult participants correlated with the speed of naming pictures, whereas no correlation was found for shifting. Sikora *et al.* (2016) observed that all three components of executive control correlated with the speed of more complex language production by adults, namely noun–phrase production. We discuss this study and its design in some detail because we used the same design in the present study on children.

In their study, Sikora *et al.* (2016) measured the updating, inhibiting and shifting abilities of adult participants using standard tests of executive control. Moreover, they had to describe pictures of simple objects presented simultaneously with spoken distractor words. Pictures were line drawings presented with or without colour. In response to the black-and-white pictures, participants produced short phrases consisting of an article and a noun (e.g., ‘the glass’), and in response to the coloured pictures, participants produced long phrases consisting of an article, a colour adjective and a noun (e.g., ‘the red glass’), which require more updating. Sikora *et al.* found that the magnitude of the difference in response time (RT) between short and long phrases, the length effect, correlated with the participants’ updating ability ($r = -.35$). Moreover, the spoken distractor words presented simultaneously with the pictures could be either congruent (the same as the picture name) or incongruent (different from the picture name), which requires more inhibiting. The magnitude of the difference in RT between congruent and incongruent trials, the distractor effect, correlated with the participants’ inhibiting ability ($r = .45$). Two black-and-white pictures were followed by two coloured pictures, and vice versa. The shifting ability is more strongly engaged on switch trials (a picture preceded by a different picture type, such as a black-and-white picture preceded by a coloured picture) than on repeat trials (a picture preceded by the same picture type). The magnitude of the difference in RT between switch and repeat trials, the switch effect, was related to the participants' shifting ability ($r = .32$).

Executive control in SLI

Updating ability

Accumulating evidence suggests that children with SLI have a working memory deficit, which concerns the updating ability. Impaired verbal updating ability has been found in pre-school children (e.g., Chiat and Roy 2007; Petruccelli *et al.* 2012; Vissers *et al.* 2015) as well as in school-aged children (e.g., Archibald and Gathercole 2006; Freed *et al.* 2012; Montgomery *et al.* 2010). A meta-analysis conducted by Vugs *et al.* (2013) suggests that impairment in updating ability extents to the non-verbal domain. Moreover, Henry *et al.* (2012) found differences in both verbal and non-verbal updating ability between SLI and TD groups after controlling for non-verbal IQ, and differences in non-verbal updating ability even after controlling for verbal IQ.

Inhibiting ability

Several studies found that children with SLI perform more poorly than TD children on various tasks that measure inhibiting ability (e.g., Henry *et al.* 2012; Im-Bolter *et al.* 2006; Spaulding 2010; for a review, see Vissers *et al.* 2015; for a meta-analysis, see Pauls and Archibald 2016). Moreover, Victorino and Schwartz (2015) demonstrated that performance of children with SLI on an auditory distraction task was impaired regardless of whether a distractor was related or unrelated to the target stimuli. This suggests that children with SLI may have a broader problem with distractor processing, related or not to the task. Ratings by parents and teachers on the Behaviour Rating Inventory of Executive Function (BRIEF) seem to support this conclusion, showing that both teachers and parents rate children with SLI as having more problems with inhibiting (Cuperus *et al.* 2014; Vugs *et al.* 2014; but see Kuusisto *et al.* 2017 who found no difference in ratings between SLI and TD groups).

Shifting ability

While some studies have not found evidence for impaired shifting ability in children with SLI (Henry *et al.* 2012; Im-Bolter *et al.* 2006), other studies examining pre-school children demonstrated that the SLI group performed more poorly than controls on behavioural shifting tasks (Farrant and Maybery 2012; Roello *et al.* 2015; for a review, see Vissers *et al.* 2015). Additionally, BRIEF studies suggests that children with SLI show deficits in shifting ability (Kuusisto *et al.* 2017; Vugs *et al.* 2014). In a recent meta-analysis, Pauls and Archibald (2016) found only a small group effect.

To investigate further executive control and language production difficulties in SLI, we conducted a study in which we tested children with SLI and TD children on executive control tasks to see whether the children with SLI show deficits in all or only some of the executive control abilities. Additionally, we assessed their performance on a noun–phrase production task, as previously used in adult studies, to investigate whether the differences in the executive control abilities between SLI and TD groups would be reflected in their language production.

Outline of the present study

We examined children with SLI and TD children on four standard behavioural tests measuring executive control abilities. We used an operation-span task to assess verbal updating ability, an odd-one-out task to measure non-verbal updating ability, a stop-signal task to measure non-verbal inhibiting ability and an emotion–gender switching task to measure non-verbal shifting ability. We expected children with SLI to demonstrate lower scores on all four executive control tests. Moreover, we measured children's speed and accuracy using a picture description task and a picture–word interference paradigm, as in our previous studies on adults (Sikora *et al.* 2016). We measured errors and RTs in noun–phrase production, and assessed length, distractor and switch effects, which reflect the updating, inhibiting and shifting abilities. We expected children with SLI to have overall lower accuracy as well as to be slower across all conditions. Moreover, we expected that executive control difficulties in SLI will be manifest in the magnitude of the length, distractor and switch effects in noun–phrase production. Therefore we expected children with SLI to have larger length, distractor and switch effects compared with TD children.

Methods

Participants

Seventy-four children participated in the experiment: 33 with a diagnosis of SLI (mean age = 10;1 years; range = 101–144 months) and 41 TD children (mean age = 10;7 years; range = 96–146 months). Age did not differ significantly between groups, $t = -1.9$, $p > .05$. All children were native Dutch speakers and attended elementary school in the Netherlands. The children with

SLI were recruited from schools for special education of Royal Dutch Kentalis; TD children were recruited from regular elementary schools. Before educational placement, children were formally diagnosed with SLI according to the criterion of performing more than 1.5 SD (standard deviations) below normal in two language domains (i.e., speech production/perception, vocabulary, grammar or pragmatics abilities), while exhibiting non-verbal IQ scores in the average range. Moreover, we excluded children with hearing or pronunciation problems. However, we did not control for possible diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) or Autism Spectrum Disorder (ASD), which may be comorbid with SLI (e.g., Bishop *et al.* 2017; Reilly *et al.* 2014). All children were tested at the schools during school hours.

Raven's Colored Progressive Matrices

The Raven's Colored Progressive Matrices is a standard test to measure non-verbal intelligence in children under 12 years old (Van Bon 1986). The test consists of three subtests, each including 12 trials (36 in total). On each trial children were presented with a figure with a missing element and six or eight smaller figures that could complete the pattern. Children were instructed to point to the small figure that according to them completes the pattern the best.

The mean score of the children with SLI was 6.6 and the mean score of the TD children was 7.0. Statistical analysis showed that the SLI and TD groups did not differ significantly in their performance on the Raven test, $t = -1.04$, $p = .30$.

Clinical Evaluation of Language Fundamentals (CELF) test

We compared language abilities between SLI and TD groups with the CELF test. It assesses expressive and receptive language abilities (Kort *et al.* 2008). In our study, children completed three subtests of the Dutch version of the CELF-4 (i.e., the CELF-4-NL): (1) understanding and following instructions, (2) formulating sentences and (3) vocabulary knowledge consisting of receptive and expressive subtests. The SLI and TD groups differed significantly in all CELF scores. The children with SLI had lower scores on the comprehension subtest (i.e., understanding and following instructions), $t = -6.15$, $p < .001$, lower scores on the formulation subtest (i.e., formulating sentences), $t = -8.21$, $p < .001$, and lower scores on the tests of vocabulary knowledge, both receptive, $t = -5.54$, $p < .001$, and expressive, $t = -7.42$, $p < .001$. These differences were present even after correcting for multiple comparisons ($\alpha = .01$).

To conclude, language ability was lower for the children with SLI than the TD children, whereas non-verbal intelligence (as assessed by the Raven test) did not differ. This is the canonical pattern (e.g., Leonard 2014) and is in line with the linguistic and cognitive profile at the time of diagnosis.

Procedure and design

Parents of the children were given information about the purpose of the study and asked to sign a written consent form. Children participated in three experimental sessions on three different days and completed all the tasks in the same order (cf. Friedman *et al.* 2008; Miyake *et al.* 2000). In the first session, they performed the picture description task, in the second session the odd-one-out task and the emotion–gender switching task, and in the third session the stop-signal task, the operation-span task, and the Raven test. The three sessions together lasted about 2 h per child. Additionally, TD children participated in a fourth session to complete the CELF test, which is described above. The CELF scores of children with SLI were obtained from language therapists at the schools.

Tasks

Odd-one-out task

The odd-one-out task measures non-verbal updating ability (Conway *et al.* 2005). It consisted of 42 triples of drawings representing arbitrary shapes. For each triple, two shapes were identical and one was different. The three figures were presented on the computer screen and children were instructed to indicate by pressing one of three buttons which figure is different from the others (i.e., the odd one out). Moreover, children were told to remember the location of the odd-one-out figure on each trial. After a number of trials varying between two and five, children had to recall the location of all odd-one-out figures since the beginning of a set. Children indicated the recalled locations of the odd-one-out figures, in the correct order, by sequentially pressing the corresponding buttons.

Operation-span task

The operation-span task measures verbal updating ability (Conway *et al.* 2005). The operation-span task consisted of 27 mathematical operations and 27 Dutch words. Materials were presented on the computer screen. Each trial began with a fixation cross presented for 800 ms followed by a mathematical operation and a word presented in the middle of the screen (e.g., 5 – 4 = 3? Flower). Children were instructed to read aloud the mathematical operation and the word. Next, they had to indicate by a button press whether the mathematical operation was correct. After a random number of trials, varying between two and four, the children had to recall all words presented since the beginning of a set.

Stop-signal task

The stop-signal task measures non-verbal inhibiting ability (Verbruggen *et al.* 2008). The task consisted of 75% 'go' trials and 25% 'stop' trials. Each go trial began with a fixation point presented in the middle of the screen for 250 ms, followed by a target stimulus. The target stimulus was either a square or a circle. Children were instructed to respond to the stimuli by pressing one button when they saw a circle and another button when they saw a square. The stimuli remained on the screen until the children responded but not longer than for 1250 ms. Children were told to respond to the stimuli as quickly and accurately as possible. On the stop trials also an auditory stimulus (a beep) was presented. The auditory stimuli followed the visual stimuli. Children were instructed to inhibit their response to the visual stimuli on the trials when the auditory stimuli were presented. First, the auditory stimuli were presented 250 ms after onset of the visual stimuli (the stop-signal delay). After each successful stop trial, the stop-signal delay was increased with 50 ms, while after each unsuccessful stop trial the stop-signal delay was decreased with 50 ms. The task consisted of one practice and three experimental blocks. The practice block included 32 trials and each experimental block included 64 trials.

Emotion–gender switching task

We modelled the emotion–gender switching task after the shape–colour task that measures non-verbal shifting ability (Miyake *et al.* 2000). The stimuli consisted of a set of four pictures presenting girl and boy faces (indicated by the hair style), either happy or sad (indicated by the shape of the mouth). Children were instructed to respond to the gender or to the emotion of the presented faces. A task cue underneath the picture reminded the children of the task to be performed on the stimuli. Children were instructed to respond to the gender of the face when the task cue was a picture of girl and boy faces (emotion neutral), and to respond to the emotion when the presented task cue was a picture of happy and sad faces (gender neutral, i.e., a face without hair). Children had to press a right button as a response to the pictures depicting either a girl or a sad face, and they had to press a left button as a response to the picture depicting either a boy or a happy face. There were three practice blocks and two experimental blocks. Participants were able to perform all practice blocks. Both experimental blocks were mixed-task blocks and consisted of 128 trials. In the mixed blocks, the task changed every second trial.

Picture-description task

In this task, the children had to describe a picture presented in the middle of a computer screen while trying to ignore a spoken distractor word that was played via headphones. The responses of the children were recorded via a microphone and each response was stored as a separate audio file. Later, we used Praat computer software (Boersma 2002) to determine the RT for each response. Each trial began with a spoken distractor word and a picture presented with the same onset. The picture remained on the screen for 300 ms followed by a blank screen for 3500 ms. Each picture was presented with a congruent or an incongruent distractor word. A congruent distractor word was the name of the presented picture and an incongruent distractor word was the name of one of the other three pictures. Each distractor was presented an equal number of times in the experiment and there was an equal number of congruent and incongruent trials. The stimulus list was randomized using the program Mix (Van Casteren and Davis 2006) with the restriction that pictures, colours or auditory distractors were not repeated on consecutive trials. The set of stimuli consisted of four pictures, namely a couch, a lamp, a cupboard and a chair, and four spoken distractors, which were the names of these objects. All spoken distractors were monosyllabic Dutch words: *bank* (couch), *lamp* (lamp), *kast* (cupboard) and *stoel* (chair). The spoken words were recorded by a female native speaker of Dutch.

The pictures were either black-and-white line drawings or coloured line drawings, either blue or red. The children were instructed to produce determiner-noun phrases (e.g., 'de kast') when the presented picture was a black-and-white drawing (the short-phrase condition). When the picture was presented in one of the two colours, the children had to produce a phrase that included an article, a colour adjective and the name of the object (e.g., 'de blauwe kast', the long-phrase condition). All picture names had the same grammatical gender in Dutch so that the determiner was always the same definite article. The number of trials for the short- and long-phrase conditions was the same. The pictures were presented such that the required phrase type changed every second trial. Thus, in the trial sequence, two black-and-white pictures were followed by two coloured pictures, which were followed by two black-and-white pictures, etc. This designed allowed us to measure picture description accuracy and RTs on repeat trials (which repeat a previous phrase type, i.e., a long phrase following a long phrase or a short phrase following a short phrase) and switch trials (which do not repeat a previous phrase type, i.e., a short phrase following a long phrase or a long phrase following a short phrase). The number of trials for the repeat and switch conditions was equal: 80 for each condition.

There were two practice blocks and five experimental blocks of trials. Each practice block consisted of 16 trials and each experimental block consisted of 32 trials. In total there were 160 experimental trials.

Data analysis

Odd-one-out task

Scores for the odd-one-out task were calculated following the guidelines of Conway *et al.* (2005). The number of correctly recalled locations of the odd figures in a set was calculated. The number of figures in a set varied between two and five. The children received 1 point for each correctly recalled set. There were in total 12 sets. The score for each set was calculated as the proportion of the correctly recalled locations and the total number of locations to be recalled within the set. Higher total scores on the odd-one-out task indicate better non-verbal updating ability.

Operation-span task

Scores for the operation-span task were also calculated following the guidelines of Conway *et al.* (2005). The scores of two children (SLI group) were excluded from the analysis as one child had lower than 85% accuracy for the mathematical operations (based on the guideline of Conway *et al.* to exclude the data set of the participants with accuracy < 85%) and another child did not correctly follow the instructions. The number of correctly recalled words for each set was calculated. The number of the words in each set varied between two and four. In total there were nine sets. Children received 1 point for each correctly recalled set. The score for each set was calculated as the proportion of the correctly recalled words and the total number of words to be recalled within the set. Higher total scores for the operation-span task indicate better verbal updating ability.

Stop-signal task

Scores were calculated following the instructions of Verbruggen *et al.* (2008). The stop-signal reaction time (SSRT) was calculated for each child. The SSRT is equal to the difference between the mean RT of all go-trials and the mean stop-signal delay. Smaller SSRTs indicate better non-verbal inhibiting ability.

Table 1. Mean scores (standard errors) for the executive control tasks

Executive control task	SLI group	TD group
Odd one out	.76 (.02)	.85 (.01)
Operation span	.38 (.03)	.72 (.02)
Operation span (no order)	.60 (.02)	.80 (.02)
Stop signal	331 (22)	248 (11)
Emotion–gender switching	231 (54)	91 (24)

Notes: The scores for the odd-one-out and operation-span tasks are proportionally correct, and the scores for the stop-signal and emotion–gender switching tasks are latencies (ms).
SLI, specific language impairment; TD, typically developing.

Emotion–gender switching task

Mean RTs for the switch and repeat trials were calculated. The switching score was obtained by subtracting the mean RT for the repeat trials from mean RT for the switch trials. Smaller switching scores indicate better non-verbal shifting ability.

Picture-description task

Responses were categorized as errors if the produced phrase did not match the correct phrase, when the response included any kind of phonological error, misarticulation or disfluency, was not initiated within 1000 ms, or was not completed before the end of a trial. Mean error rate was calculated for six conditions: long phrase, short phrase, congruent, incongruent, repeat and switch. Additionally, we calculated RTs for each condition. Responses were excluded from the RT analysis if an error occurred on a trial, as just defined. Repeated-measures analyses of variance (ANOVAs) were conducted on errors and RTs to test for main effects and interactions. Three main effects were defined: length (short versus long phrase), distractor (congruent versus incongruent), switch (repeat versus switch trials) treated as within-participant factors, and group (SLI versus TD) as between-participant factor. Moreover, we used *t*-tests for post-hoc analysis to examine the observed interactions further.

Results

Executive control tests

The mean scores for each of the executive control tests for the SLI and TD groups are presented in table 1. Compared with TD children, the children with SLI had lower scores on the odd-one-out task, measuring non-verbal updating ability, $t = -4.10$, $p < .001$. They scored lower on the operation-span task, measuring verbal updating ability, both when the scores were calculated including all correctly recalled words, $t = -7.53$, $p < .001$, and when the scores were calculated including only the words that were recalled in the correct order, $t = -9.64$, $p < .001$. Children with SLI had a larger magnitude of the SSRT than TD children on the stop-signal task, measuring non-verbal inhibiting ability, $t = 3.48$, $p < .001$. Children with SLI had a larger switch effect than TD children on the emotion–gender switching task, representing non-verbal shifting ability, $t = 2.62$, $p < .05$ These differences between groups remained present after correcting for multiple comparisons ($\alpha = .01$). The scores of the executive control tasks did not correlate among each other for both SLI and TD children, all *p*s > .05.

Picture-description performance

The mean error rates and mean RTs for each of the conditions of the picture-description task are presented in table 2.

Errors

We found significant main effects for length, distractor and switch. That is, across groups, the mean error rate differed between the short and long phrases (length effect), $F(1, 72) = 25.16$, Mean square error (MSE) = .028, $p < .001$, $\eta_p^2 = 0.26$, between the congruent and the incongruent trials (distractor effect), $F(1, 72) = 283.12$, MSE = .008, $p < .001$, $\eta_p^2 = .80$, and between the repeat and the switch trials (switch effect), $F(1, 72) = 37.25$, MSE = .05, $p < .001$, $\eta_p^2 = .34$. Moreover, there were interactions between distractor and group, between switch and group, but not between length and group. That is, there was a significant difference in the magnitude of the distractor effect between the children with SLI and the TD children (i.e., the difference between congruent and incongruent trials was 18% error for the SLI group versus 8% error for the TD group), $F(1, 72) = 44.09$, MSE = .08, $p < .001$, $\eta_p^2 = .38$. Also, there was a significant difference in the magnitude of the switch effect between the SLI and TD groups (i.e., the difference between repeat and switch trials was 4% error for the SLI group versus 2% error for the TD group), $F(1, 72) = 4.22$, MSE = .05, $p < .05$, $\eta_p^2 = .055$. However, the magnitude of the length effect did not differ between the SLI and TD groups (i.e., the difference between short and long phrases was 7% error for both groups).

In addition, we obtained an interaction between length and distractor, $F(1, 72) = 4.14$, MSE = .01, $p < .05$, $\eta_p^2 = .054$. The length effect was larger on congruent than on incongruent trials. Moreover, there was an interaction of length, distractor and group, $F(1, 72) = 11.49$, MSE = .01, $p < .001$, $\eta_p^2 = .14$. We examined this triple interaction further using *t*-tests. The children with SLI had a significant length effect on the congruent trials (the difference between the short and long phrases was 11% error), $t = -3.60$, $p < .001$, effect size $r = .54$, but not on the incongruent trials (2%), $t = .75$, $p = .46$, while the TD children had significant length effects on both congruent trials (the difference between the short and long phrases was 6%), $t = -6.95$, $p < .001$, $r = .73$, and on incongruent trials (9%), $t = -5.88$, $p < .001$, $r = .68$. On the congruent trials, the magnitude of the length effect was larger for the children with SLI than the TD children (differences between short and long phrases of 11% error versus 6% error, respectively), $t = 1.80$, $p < .05$, $r = .20$.

Response times

We found significant main effects for distractor and length. As concerns distractor, across groups, mean RTs differed between the congruent and the incongruent condition (distractor effect), $F(1, 70) = 90.91$, MSE = 24,623, $p < .001$, $\eta_p^2 = 0.57$. Moreover, there was an interaction between distractor and group, $F(1, 70) = 4.71$, MSE = 24,623, $p < .05$, $\eta_p^2 = .063$. The interaction reflects a larger distractor effect for children with SLI than for TD children (distractor effects of 155 versus 97 ms, respectively). As concerns length, across groups, mean RTs differed between the short and long phrases (length effect), $F(1, 70) = 3.93$, MSE = 28,127, $p < .05$, $\eta_p^2 = .053$. However, this main effect was due to the RTs being longer for short than for the long phrases, which in the opposite direction than expected. Moreover, there was an interaction between length and group, $F(1, 70) = 11.22$, MSE = 28,127, $p < .001$, $\eta_p^2 = 0.14$. The interaction was present because a reverse length effect was obtained for the SLI group (RTs were longer on the short- than on the long-phrase trials by 75 ms), $t = 2.85$, $p < .01$, $r = .44$, but there was no significant length effect for the TD group (the difference between short- and long-phrase trials was only 19 ms), $t = 1.55$, $p = .65$. Moreover, we found an interaction between length and distractor, $F(1, 70) = 12.28$, MSE = 6158, $p < .001$, $\eta_p^2 = 0.15$. There was a significant reverse length effect on the incongruent trials, $t = -2.302$, $p < .001$, $r = .26$, but there was no length effect on the congruent trials, $t = -.084$, $p = .93$. Moreover, there was an interaction of length, distractor and group, $F(1, 70) = 4.48$, MSE = 6158, $p < .05$, $\eta_p^2 = 0.06$. The SLI group was slower in producing the short than the long phrases on the incongruent trials (a reverse length effect of 112 ms), $t = -3.37$, $p < .001$, $r = .52$, but there was no significant length effect on the congruent trials (a non-significant difference in RTs of 38 ms), $t = -1.44$, $p = .16$. The TD group, however, was faster in producing the short than the long phrases on the congruent trials (a regular length effect of 28 ms), $t = 2.60$, $p < .01$, $r = .38$, while there was no length

Table 2. Mean error percentage (E%) and response time (RT) (standard errors) in the length, distractor and switch conditions of the picture-description task for the SLI and TD groups

			Switch					
			Repeat		Switch		Total	
Group	Length	Distractor	E%	RT	E%	RT	E%	RT
SLI	Short	Congruent	10 (1.2)	1045 (40)	13 (1.6)	1086 (39)	12 (1.3)	1065 (39)
		Incongruent	30 (2.4)	1231 (52)	37 (2.3)	1283 (53)	34 (2.2)	1257 (51)
		Total	25 (1.7)	1138 (45)	20 (1.6)	1185 (45)	23 (1.6)	1161 (44)
	Long	Congruent	21 (2.1)	1020 (35)	25 (2.2)	1034 (34)	23 (2)	1027 (33)
		Incongruent	33 (2.4)	1161 (48)	39 (2.9)	1128 (46)	36 (2.3)	1145 (46)
		Total	27 (2.1)	1091 (39)	32 (2.3)	1081 (38)	30 (2)	1086 (38)
	Total	Congruent	16 (1.3)	1032 (35)	19 (1.4)	1060 (36)	17 (1.2)	1046 (35)
		Incongruent	32 (1.9)	1196 (48)	38 (2.1)	1205 (47)	35 (1.8)	1201 (47)
		Total	24 (1.5)	1114 (40)	28 (1.6)	1133 (40)	26 (1.5)	1124 (40)
TD	Short	Congruent	2 (1.1)	844 (34)	3 (1.4)	859 (34)	2 (1.1)	852 (34)
		Incongruent	9 (2.1)	946 (45)	8 (2.1)	970 (46)	8 (2)	958 (45)
		Total	5 (1.5)	895 (39)	5 (1.4)	914 (39)	5 (1.4)	905 (38)
	Long	Congruent	6 (1.9)	886 (30)	10 (1.9)	875 (30)	8 (1.8)	880 (28)
		Incongruent	14 (2.1)	976 (42)	19 (2.6)	961 (40)	17 (2.1)	968 (40)
		Total	10 (1.8)	931 (34)	15 (2)	918 (33)	12 (1.8)	924 (33)
	Total	Congruent	4 (1.2)	865 (41)	6 (1.2)	867 (31)	5 (1.1)	866 (30)
		Incongruent	12 (1.7)	961 (42)	14 (1.9)	965 (41)	13 (1.7)	963 (41)
		Total	8 (1.3)	913 (35)	10 (1.4)	916 (35)	9 (1.3)	914 (35)
Total	Short	Congruent	6 (0.8)	944 (31)	8 (1.1)	973 (26)	7 (0.8)	959 (26)
		Incongruent	22 (1.5)	1089 (35)	19 (1.6)	1126 (35)	21 (1.5)	1108 (34)
		Total	13 (1.1)	1017 (30)	15 (1.1)	1050 (30)	14 (1.1)	1033 (29)
	Long	Congruent	13 (1.4)	953 (23)	17 (1.5)	955 (23)	15 (1.3)	954 (22)
		Incongruent	24 (1.6)	1068 (32)	29 (2)	1044 (31)	26 (1.6)	1056 (30)
		Total	19 (1.4)	1011 (26)	23 (1.5)	999 (25)	21 (1.3)	1005 (25)
	Total	Congruent	10 (0.9)	949 (23)	13 (0.9)	964 (24)	11 (0.8)	956 (23)
		Incongruent	22 (1.3)	1079 (32)	26 (1.4)	1085 (31)	24 (1.2)	1082 (31)
		Total	16 (1)	1014 (27)	19 (1.1)	1024 (27)	18 (1)	1019 (26)

Note: SLI, specific language impairment; TD, typically developing.

effect on the incongruent trials (a difference of 10 ms), $t = 0.61$, $p = .55$. Finally, there was an interaction between length and switch, $F(1, 70) = 12.27$, MSE = 5613, $p < .001$, $\eta_p^2 = 0.15$. This interaction occurred because the switch effect was present for the short phrases, $t = -3.46$, $p < .001$, $r = .37$, but not the long phrases, $t = -1.26$, $p = .21$. This interaction corresponds to that observed by Sikora *et al.* (2016) for adult speakers.

General discussion

We found significant differences between the SLI and TD groups for all four executive control tasks. These results suggest that children with SLI have deficits in verbal and non-verbal updating, non-verbal inhibiting, and non-verbal shifting abilities. These findings are consistent with previous studies that have shown that children with SLI exhibit limitations in verbal updating and inhibiting abilities (e.g., Henry *et al.* 2012; Im-Bolter *et al.* 2006; Victorino and Schwartz 2015; Vugs *et al.* 2014). Moreover, our findings are in line with the results from the meta-analysis by Vugs *et al.* (2013), which showed that children with SLI are also impaired in non-verbal updating ability. Additionally, we obtained evidence that the shifting ability is impaired in children with SLI, too. To our knowledge, only two previous behavioural studies demonstrated that SLI children are impaired in shifting ability (Farrant and Maybery 2012; Roello *et al.* 2015).

Another aim of the present study was to examine whether differences between SLI and TD groups in all or only some of the executive control abilities are present when these abilities are engaged in language production. To address this question, we used a noun–phrase production task to measure length, distractor and switch effects, which relate to the updating, inhibiting and shifting abilities, respectively (Sikora *et al.* 2016). Across groups, we obtained length, distractor and switch effects in the error rates, and a distractor effect in the RTs. This is in line with previous studies that suggested an impact of executive control on language production in adults (Sikora *et al.* 2016). The current study extends those findings to children.

Although we did not obtain a main switch effect in the RTs, we did obtain an interaction between switch and length. In particular, we found a switch effect on the short- but not on the long-phrase trials. These findings for children replicate our earlier results for adults (Sikora *et al.* 2016). We proposed that the asymmetrical switch effect arises because speakers have to prevent the tendency inadvertently to produce a short phrase (e.g., 'the chair') in response to a coloured picture requiring a long phrase (e.g., 'the red chair'). This may be prevented by inhibiting the task set for short phrases or enhancing the task set for long phrases. In contrast, on trials with black-and-white pictures requiring a short phrase, prevention of the inadvertent production of a long phrase is not needed because the pictures only allow a short-phrase response. As a consequence, disengagement from the previous task set or overcoming previous inhibition of the now needed task set will take longer in switching to a short than to a long phrase, which yields the asymmetrical switch effect that we observed both for adults and children.

Importantly, although length, distractor and switch effects were obtained for both children with SLI and TD children, there were also differences between groups. First, we found that the children with SLI made overall more errors and had longer RTs than the TD children. Moreover, we found that the children with SLI had a larger distractor effect in errors and RTs and a larger switch effect in errors than the TD children. These findings demonstrate that children with SLI had more difficulty overcoming distractor interference and switching between phrase types. The length effect in the errors did not differ between groups. However, we observed an interaction of length and distractor in both errors and RTs, which differed between groups. In particular, for the SLI group, there was a length effect in the errors on congruent trials but not on incongruent trials, whereas for the TD group, the length effect in the errors occurred on both congruent and incongruent trials. Moreover, for the SLI group, there was a reverse length effect in the RTs on incongruent trials, whereas for the TD group, no length effect was obtained in the RTs on incongruent trials and a regular length effect occurred on congruent trials.

A speculative account for the observed interaction of length, distractor and group might be the following. In planning to say a short phrase on an incongruent trial, such as in planning to say 'the chair' while hearing the incongruent distractor word 'couch', children with SLI will experience a lot of interference from the incongruent distractor because of their inhibiting deficit (e.g., Henry *et al.* 2012; De Hoog *et al.* 2015; Im-Bolter *et al.* 2006; Epstein *et al.* 2014; Roello *et al.* 2015; Spaulding 2010). Given that 'chair' is the first content word to be produced in the phrase, the incongruent distractor 'couch' will delay the response if a child wants to prevent an error. In planning to say the long phrase 'the red chair' while hearing the incongruent distractor word 'couch', interference will also occur, but now 'chair' is the last content word to be produced in the phrase. This allows the children to start the production of 'the red' while resolving the interference from the distractor 'couch' during articulation of 'the red'. Distractor interference on short-phrase trails may prolong the RT such that it is longer than the RT on long-phrase trials, yielding a reverse length effect, as we observed. On congruent trials (e.g., hearing 'chair'), there is no such interference, and a regular length effect is expected to be obtained. Instead, we observed a regular length effect in the error rates, and numerically (but not significantly) a reverse length effect in the RTs. This suggests that children with SLI are negatively affected even by congruent distractors, in line with the observations of Victorino and Schwartz (2015). Given that TD children have a better inhibiting ability than children with SLI, they are less influenced by distractor words (as revealed by their smaller distractor effect in the RTs and errors), and the difference in distractor impact between short- and long-phrase trials will be less. As a consequence, regular length effects may be obtained in the RTs and errors, as we observed. To conclude, we obtained an interaction of length, distractor and group. The interaction suggests that children with SLI are more affected by distractor words than TD children, yielding a reverse length effect on incongruent trials for the SLI group.

Our results add to the evidence that deficits in non-linguistic abilities such as executive control are also observed in the language performance of children with SLI. However, the directionality of the influence is not known yet. It is possible that the executive control deficits in SLI contribute to the language impairment, the language impairment in SLI contributes to the executive control deficits, or a deficit in a third factor contributes to the deficits in both executive control and language (Bishop *et al.* 2014). The three possibilities are not mutually exclusive, and it remains possible, of course, that all three types of influences are present in SLI. The directionality of the influence is a topic for future research.

The executive control tasks used in this study are known tasks used to measure executive control in verbal and non-verbal domains (Miyake *et al.* 2000). However, we cannot exclude that the non-verbal tasks might to some extent involve verbal mediation through the use of inner speech.

Moreover, a possible limitation of our study is that we did not control for ADHD or ASD diagnosis in the SLI or TD groups. Considering observed comorbidity of ADHD and ASD with SLI (e.g., Bishop *et al.* 2017; Reilly *et al.* 2014), it is possible that some of the children in our SLI group had an additional disorder. This should be taken into consideration, especially when interpreting our results concerning the inhibiting ability. The poorer performance on the stop-signal task and the larger distractor effect for the SLI than the TD group could perhaps be attributed to the presence of ADHD or ASD. However, previous studies that did control for comorbid diagnosis of ADHD and ASD also observed that children with SLI have reduced inhibiting ability (Henry *et al.* 2012; Im-Bolter *et al.* 2006), making it unlikely that comorbid disorders caused the group differences that we observed.

Summary and conclusions

We found that, compared with TD children, children with SLI have lower scores or longer latencies on executive control tasks testing for verbal as well as non-verbal updating, non-verbal inhibiting and non-verbal shifting abilities. In examining both the speed and accuracy of language production performance, we observed that children with SLI were overall slower and made more errors than TD children in a noun–phrase production task. Moreover, the magnitude of the distractor and switch effects was larger for the SLI than the TD group (differences in the length effect between groups were more complicated). Together, these results suggest that children with SLI have impaired language production and executive control abilities, and that some of the differences in the executive control between SLI and TD groups were reflected in the language production. Further research may investigate whether training of the updating, inhibiting, and shifting abilities would be beneficial for the language production performance of children with SLI (Vugs *et al.* 2017).

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