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Research Report

Picture naming in typically developing and language-impaired children: the role of sustained attention

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Abstract

Background: Children with specific language impairment (SLI) have problems not only with language performance but also with sustained attention, which is the ability to maintain alertness over an extended period of time. Although there is consensus that this ability is impaired with respect to processing stimuli in the auditory perceptual modality, conflicting evidence exists concerning the visual modality.
Aims: To address the outstanding issue whether the impairment in sustained attention is limited to the auditory domain, or if it is domain-general. Furthermore, to test whether children's sustained attention ability relates to their word-production skills.
Methods & Procedures: Groups of 7–9 year olds with SLI ($N = 28$) and typically developing (TD) children ($N = 22$) performed a picture-naming task and two sustained attention tasks, namely auditory and visual continuous performance tasks (CPTs).
Outcomes & Results: Children with SLI performed worse than TD children on picture naming and on both the auditory and visual CPTs. Moreover, performance on both the CPTs correlated with picture-naming latencies across developmental groups.
Conclusions & Implications: These results provide evidence for a deficit in both auditory and visual sustained attention in children with SLI. Moreover, the study indicates there is a relationship between domain-general sustained attention and picture-naming performance in both TD and language-impaired children. Future studies should establish whether this relationship is causal. If attention influences language, training of sustained attention may improve language production in children from both developmental groups.

Keywords: specific language impairment, sustained attention, language production, picture naming.

What this study adds?

What is already known on the subject?

It was long assumed that SLI was a purely linguistic deficit, but in recent years several studies have shown that children with SLI have problems in other cognitive domains like attention. Sustained attention—the ability to maintain alertness for a prolonged time—also seems to be affected. It remains unclear whether this is a domain-general impairment or specific to the auditory domain. Moreover, whether, and how, sustained attention relates to language production is unknown.

What this paper adds?

The findings of this study provide evidence for a domain-general sustained-attention impairment for children with SLI when compared with TD children. The second important finding is that sustained-attention ability correlates

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with language-production performance, such that children with poorer sustained attention are slower to name pictures than children with better sustained attention. Importantly, this holds for both groups of children. This points to a possible role of sustained attention during language production, but the causality and direction of the relationship remains to be determined.

Introduction

There has been increasing interest in the cognitive processes underlying specific language impairment (SLI). For a long time, SLI was considered to be a purely linguistic deficit as children with SLI are characterized by IQ levels similar to typically developing (TD) children, but their language abilities are far below the average level. Their linguistic problems range from phonology to syntax and semantics, both in language comprehension and production (for reviews, see Leonard 2014, and Schwartz 2009). This led many researchers to propose deficits in linguistic knowledge to explain SLI (e.g., Gopnik and Crago 1991, Novogrodsky and Friedmann 2006, Rice and Wexler 1996, Van der Lely 2005). However, several more recent studies have reported deficits in other cognitive domains such as attention and memory (e.g., Henry *et al.* 2012, Im-Bolter *et al.* 2006, Marton *et al.* 2007, Vugs *et al.* 2015). Some researchers have therefore suggested that domain-general deficits are the underlying cause of SLI or significantly contribute to it (e.g., Bishop 1992, Kail 1994, Leonard *et al.* 2007, Ullman and Pierpont 2005).

Sustained attention is an attentional component that has been put forward as one of the factors contributing to SLI. Sustained attention refers to the ability to maintain alertness for a prolonged period of time (e.g., Posner 2012, Sarter *et al.* 2001). We refer to Posner (2012) for a recent discussion of how sustained attention relates to other attentional abilities and how it develops. A number of studies have shown sustained attention to be impaired in children with SLI as compared with TD children (for a meta-analysis, see Ebert and Kohnert 2011), but the evidence is limited compared with other deficits that have been considered in SLI (e.g., Leonard 2014 for a review). Sustained attention is typically measured with a continuous performance task (CPT) where a response has to be made to an infrequent target, whereas no response is required for non-targets. On CPTs, children with SLI tend to make more errors than TD children, either by missing targets or by incorrectly responding to non-targets (false alarms). This is sometimes accompanied by longer reaction times (RTs) to targets for the SLI group as compared with the TD group. Moreover, children with SLI tend to show a larger performance decrement over time, which refers to an increase in errors and RTs as time on task increases. The overall pattern suggests a sustained-attention deficit in children with SLI, but only a small number of studies have been conducted. The meta-analysis of Ebert and Kohnert (2011) included 17 articles, with only four of these including RT measurements besides accuracy levels. Moreover, in most studies the sample sizes are small with groups including fewer than 20 children.

Besides the limited evidence for a sustained-attention deficit in children with SLI, only two studies have tried to relate sustained attention ability directly to linguistic abilities in children with SLI. Montgomery *et al.* observed that children with SLI performed worse than TD children on an auditory sustained-attention task. Moreover, sustained attention accounted for variance in performance on a sentence comprehension task for the SLI group, but not for the TD group (Montgomery *et al.* 2009). Evidence from Duinmeijer *et al.* (2012) suggests that sustained attention is not only important for successful language comprehension but for language production as well. Within a group of children with SLI, sustained-attention ability correlated with the generation of plot elements when telling a picture story, such that children with better sustained attention generated more plot elements in their stories. These studies provide evidence for a role of sustained attention in the language performance of children with SLI.

The present study intends to contribute to this line of research by examining sustained attention in SLI and TD children in relation to their word-production skills. Children with SLI tend to be slower than TD children in naming pictures (e.g., Coady 2013, Lahey and Edwards 1996). Moreover, they tend to make more errors, and proportionally more often these errors are semantically or phonologically related to the picture name (e.g., Lahey and Edwards 1999). In adults, it has already been shown that picture naming and picture description require sustained attention (Jongman *et al.* 2015a, 2015b). Correlations between sustained-attention ability and picture naming in adults are observed for only a subset of the trials, namely for picture-naming trials with long RTs only. Language skills are highly practiced in adults, but less so in children. We therefore suspected sustained-attention ability to play an even more important role in picture naming by children than by adults. This was investigated by assessing SLI and TD children on picture-naming performance and on their sustained-attention ability, and by testing for correlations between picture-naming and sustained-attention performance. We expected to obtain correlations between sustained-attention performance and picture naming for most of the naming trials rather than for trials with long RTs only, as we further explain below.

Sustained-attention performance on CPTs can be characterized by several measures. In the present study, we used the following four measures to characterize individuals' performance, namely mean RT, hit rate (correctly identified targets), false alarm rate (incorrect responses to non-targets), and performance decrement (increase in RT over time). We expected that children with SLI would show lower hit rates and more false alarms than TD children. Whether they would also show longer RTs was an open question. Children with SLI tend to be slower on a range of tasks, both linguistic and non-linguistic ones (e.g., Leonard *et al.* 2007, Miller *et al.* 2001). Yet, the meta-analysis on sustained attention in SLI by Ebert and Kohnert (2011) seems to indicate that RTs are not consistently affected. However, it must be noted that in general there are only very few responses required on sustained-attention tasks, as targets are presented infrequently. If only 20% of the trials require a response, and children miss some of these targets, only few trials are left for calculating the mean RT. This could explain the lack of consistent RT differences between SLI and TD children. In the current study, 40% of the trials were targets, which allowed for a better estimation of mean RTs and RT performance decrement. We expected to find longer RTs for SLI than for TD children.

Picture-naming performance can be characterized by mean naming RTs and error rates. We expected children with SLI to take longer in naming pictures and to make more naming errors than TD children. In assessing picture-naming performance, we did not only look at mean naming RTs but examined entire RT distributions by performing ex-Gaussian analyses. Picture-naming RTs are typically not normally distributed but their distributions are positively skewed (i.e., the distribution tail is longer for the slow responses than for the fast responses). The ex-Gaussian consists of a convolution of a Gaussian and an exponential distribution, which captures both the normal part (parameter μ) and the longer right tail of a distribution (parameter τ). The mean RT is equal to $\mu + \tau$. Ex-Gaussian analyses may be used to assess to what extent RT effects are present on most of the trials (reflected by μ) or on the trials with the slowest responses (reflected by τ). Effects in μ reflect distributional shifting and effects in τ reflect distributional skewing (e.g., Balota *et al.* 2008).

In previous experiments with adults, it was shown that sustained attention correlated with the τ parameter and not the μ parameter of picture-naming and picture description RTs (e.g., word and phrase production; Jongman *et al.* 2015a, 2015b). This reveals that adults with poorer sustained attention are not consistently slower in naming pictures than adults with better sustained attention, but they show a larger number of very slow responses. Here, we assessed whether the same pattern is obtained in children between the age of 7 and 9 years, or whether they needed to maintain attention more consistently during language production. During this stage of development, word production could be more effortful than it would be for adults, and children might depend on sustained attention more strongly. This would be revealed by a correlation between sustained-attention performance and the μ parameter of picture-naming RTs.

We also wanted to examine whether or not children with SLI show a dissociation between performance on sustained-attention tasks that differ in stimulus modality. Impaired sustained-attention performance in the auditory domain is relatively well attested (Ebert and Kohnert 2011). Whether sustained attention in the visual domain is impaired is unclear. Several studies showed impaired performance on auditory CPTs in children with SLI, but no difference in performance on visual CPTs between SLI and TD children was found (Dodwell and Bavin 2008, Noterdaeme *et al.* 2001, Spaulding *et al.* 2008). This led Spaulding *et al.* to postulate separate sustained-attention abilities for different perceptual modalities, that is, separate visual and auditory sustained-attention systems. However, conflicting evidence was obtained by Finneran *et al.* (2009), who found a sustained-attention deficit for children with SLI on a visual CPT. The contradictory findings could be due to differences in task parameters, as suggested by Ebert and Kohnert (2011). They showed that studies that failed to find a deficit in the visual modality for children with SLI used longer stimulus durations than Finneran *et al.* (2009). Corkum and Siegel (1993) suggested that longer stimulus durations placed less of a demand on attentional capacities. Therefore, it is possible that a domain-general sustained-attention system of children with SLI was not strained enough in those visual CPT studies that failed to find impaired performance, so that existing differences with TD children were not revealed.

In the present study, two CPTs were used that differed only in perceptual modality, modelled after the task used by Finneran *et al.* (2009). If a domain-general sustained-attention system is impaired in children with SLI, we should replicate results obtained by Finneran *et al.* and find worse performance on the visual CPT (VCPT) as well as the auditory CPT (ACPT) for children with SLI as compared with TD children. If we fail to replicate this finding and only find a deficit for the ACPT, this would be in favor of separate attentional systems as proposed by Spaulding *et al.* (2008). Note, however, that a specific deficit in the auditory domain could also be due to impaired auditory processing skills, as children with SLI are often reported to have auditory processing deficits (APD; for reviews, see Leonard 2014, Rosen 2003, Wright *et al.* 2000). As argued by Murphy *et al.* (2014), poor performance on the ACPT could arise from poor auditory perceptual processing, creating increased difficulty in discriminating between the target and non-target tone, even with good sustained-attention ability.

In summary, we aimed to address four questions:

- Do children with SLI perform the same or worse than TD children on picture naming?
- Do children with SLI perform the same or worse on sustained-attention tasks than TD children?
- If they do worse, is this true for both auditory and visual modalities, or only for the auditory domain?
- Does sustained-attention ability correlate with picture-naming performance, and are there differences in correlations between perceptual modalities or between SLI and TD groups?

Method

Participants

Fifty-five Dutch children between the ages of 7 and 9 years participated in the study. The children with SLI ($N = 31$, mean age = 8;4 years, nine female) were recruited from a special education school for children with speech and language disorders of Royal Dutch Kentalis in the east of the Netherlands. These children were previously diagnosed with SLI and receive special education. The control group ($N = 24$, mean age = 7;8 years, 17 female) were selected from a primary school in the south-eastern part of the Netherlands. The TD children were selected for relatively good reading and language skills as identified by their scores on tests which are part of the regular curriculum of the primary school. This selection criterion was included to ensure children in the control group did not have any undetected language problems. IQ scores were available only for the children with SLI, measured by the Snijders–Oomen Nonverbal Intelligence Test (Tellegen and Laros 2011) with a mean IQ score of 102 (range 87–117). In both groups, all children were monolingual speakers of Dutch, and none of the children were diagnosed with dyslexia, autism, or an attention deficit disorder. Ethical approval for the study was granted by the Ethics Board of the Faculty of Social Sciences of the Radboud University Nijmegen.

General procedure

Children were individually tested in a quiet, empty room in their school. They were seated in front of a laptop (15.6 inch screen, HP EliteBook 8540P), next to the experimenter. The experimenter told the children they were going to play three games. Children first named pictures and then they performed the two sustained-attention tasks. The order of the auditory and visual CPTs was counterbalanced across participants. Breaks were held between each task, the break duration was determined by the children. An entire session lasted between 40 and 60 min.

Picture-naming task

Materials and design

Twenty common objects were selected from a database of normed pictures (Severens *et al.* 2005). The object names were selected for an early age of acquisition (mean 4.7 years) and high frequency (mean lemma frequency: 108 tokens per million; CELEX database; Baayen *et al.* 1995). Amongst adults, all pictures were named with high agreement (mean 96% in the norming study by Severens *et al.* 2005). All words were monosyllabic and none started with a consonant cluster (see appendix A for a list of the words).

Pictures were presented as black line drawings on a white background, in the middle of the screen, 300 × 300 pixels. Each picture was presented five times, first once in a practice block and then once in each of four experimental blocks. During the practice block, the experimenter provided the name of the object if the child did not know the correct word after approximately 10 s. In each block, the 20 pictures were pseudo-randomized such that participants never named two objects starting with the same phoneme or belonging to the same semantic category in a row.

Procedure

A trial started with the presentation of a fixation cross in the middle of the screen for 500 ms, followed by a blank screen of 250 ms. The picture would then be presented until the end of the trial. A trial ended when the experimenter pressed one of three buttons to indicate whether the response was correct, incorrect, or whether the child hesitated before giving the correct response (buttons ‘g’, ‘f’ and ‘h’, respectively). Children were given maximally 10 s to respond. If no response were given the trial was coded as an incorrect response. A blank screen of 250 ms was shown before the next trial started. Spoken utterances were recorded with a Sennheiser ME64 microphone.

Analyses

Naming errors and hesitations were coded online and the affected trials were discarded from the analyses of

RTs. Children's naming latencies for correct trials were determined offline. Vocal responses were recorded and RTs were measured manually using the programme Praat (Boersma and Weenink 2012). Naming latencies were analyzed with a linear mixed-effects model using R (R Core Team 2012) and the R packages *lme4* (Bates *et al.* 2013) and *languageR* (Baayen 2011). Group and block were included as fixed effects including their interaction. Fixed effects were centred and the dependent measures were log transformed because of positive skewing. Participant and item were included as random effects. To capture additional variability, random slopes for block were included at the subject level and for group, block, and their interaction at the item level. The model provides estimates, standard errors, and *t*-values for each coefficient; factors with a *t* greater than the absolute value of 2 were considered to contribute significantly to explaining the dependent variable (Baayen 2008). Age and gender were added as factors to a first model, and if they did not make a significant contribution, they were not included in the final model. Moreover, the effect of IQ was tested for the SLI group only, as information on IQ was not available for the TD children. A similar model was run to the one just described, excluding the factor group as we could not compare the two groups of children but only look at the SLI group.

Continuous performance tasks

Materials and design

The target stimulus for the VCPT was a red circle and the non-target was a red square. Stimuli were 150 × 150 pixels. The red stimuli in the VCPT were presented on a white background using Presentation Software (Version 16.2; see www.neurobs.com). The ACPT used a high tone (800 Hz) as the target and a low tone (300 Hz) as the non-target stimulus. The tones were played through headphones (Sony MDR 301).

Before each task, the children were presented with the targets and non-targets twice each and the experimenter explained that the game was to press the button only when seeing the target. Then they performed two practice blocks (before the first task and before the second task). In the first, four targets and four non-targets were randomly presented and children received both visual feedback (a traffic light turning green when they correctly responded to a target and withheld a response to a non-target, light turning red for an incorrect response) and oral feedback from the experimenter. In a second practice block of 20 trials (eight targets), the children no longer received feedback. Before the start of the experimental trials, the experimenter repeated the instructions. Now targets were presented with a probability of 40%. In each task, there were 320 trials, divided into eight blocks for analysis purposes. Each block therefore consisted of 16 targets and 24 non-targets, presented randomly.

Procedure

The procedure for the two CPTs was identical. Stimuli were presented for 400 ms each. Participants responded to the target stimuli with a button press using their dominant hand. The inter-stimulus interval ranged from 1100 to 1600 ms. Each experimental session took approximately 10 min.

Analyses

RTs were measured and errors were divided into misses and false alarms with the former being failures to respond to targets and the latter being responses to non-targets. A logit mixed model was conducted for both hits (i.e., correct responses to targets) and for false alarms (Jaeger 2008). The models included group, modality, and block and their interactions as fixed effects. Factors were mean-centred. Participant was included as a random factor, with intercepts and slopes for modality and block. The interaction was also included in the model for hits, but not in the model for false alarms due to failure to converge. The models provide estimates, standard errors, *z*-values and *p*-values for each coefficient.

For the correct RTs to targets, a linear mixed-effects model was run with identical fixed and random effects as the logit mixed model for hits as just described. RTs were log-transformed to reduce the influence of positive skewing.

For all models, as with the picture-naming model, age and gender were added as factors to a first model, but if they did not make a significant contribution, they were excluded from the final model. The effect of IQ was tested for the SLI group only, with three models similar to the ones just described, but without the factor group.

Analyses of individual differences

We assessed whether children's mean naming latencies were correlated with their performance on the two sustained-attention tasks by computing Pearson's product-moment coefficients. The two groups were analyzed together to increase power, but we also tested whether correlations were different between groups. The naming latencies were additionally characterized by two parameters, the μ parameter reflecting the normal part of the RT distribution and the τ parameter reflecting the tail end of the distribution. These ex-Gaussian parameters were estimated using quantile maximum likelihood estimation proposed by Heathcote *et al.*

(2002). In contrast to the linear mixed-effect analyses, latencies were not log-transformed for the ex-Gaussian analysis. The parameters were estimated for each child individually using the program QMPE (Heathcote *et al.* 2004). We tested whether the parameters μ and τ of the naming RTs were correlated with performance on the CPTs. These tests included mean RT, hit rate, false alarm rate and performance decrement (mean RT second half minus mean RT first half) for both CPTs.

Results

Data from five participants had to be excluded, three from the SLI group and two from the control group. One SLI child failed to finish the ACPT, another the VCPT. For the other three children the microphone failed to work. This left data from 28 SLI and 22 TD children.

Picture-naming task

Very few naming errors were made, only 2.0% in the SLI group and 0.6% in the TD group. Hesitations occurred in 0.7% (SLI) and 0.9% (TD) of the trials. Due to the small number of errors, no error analysis was run. The error trials were removed from the naming latencies analysis. Naming latencies beyond 4 s were also removed (0.2%). The linear mixed-effects model revealed a significant effect of group (ß = 0.19, SE = 0.05, $t = 4.15$) and age (ß = –0.07, SE = 0.03, $t = -2.82$). Block or the interaction of block and group did not reach significance (ß = 0.00, SE = 0.01, $t = 0.29$ and ß = –0.01, SE = 0.01, $t = -0.43$, respectively). Children with SLI named pictures slower than TD children (978 versus 789 ms (figure 1), and younger children had longer naming RTs than older children. Speed of naming remained consistent throughout an experimental session for both groups.

IQ was included as a factor in a model involving only the SLI group. However, IQ was not a significant predictor of naming latencies.

Continuous performance tasks

Neither age nor gender showed a significant effect in explaining variation in performance in any of the models. These variables were therefore not included in the final models. For the SLI group only, analyses were run including IQ as a factor. IQ was not a significant predictor of hit rate, false alarm rate, or RTs of the CPTs.

The logit mixed model of hits showed a main effect of group and block, and a significant interaction between group and modality (table 1). Children with SLI had a lower hit rate than TD children, namely 0.91 versus 0.97. Moreover, SLI group performed better in the visual modality than in the auditory modality (VCPT: 0.93, ACPT: 0.89), whereas TD children showed the reverse pattern (VCPT: 0.96, ACPT: 0.98). Note that the hit rate in both modalities was lower for the SLI group than for the TD group. Both groups showed a decrease in hit rate over time.

The logit mixed model of false alarms showed a main effect of group and modality. Moreover, there was an interaction between group and modality, as well as between modality and block. Table 1 lists the model parameters. The false alarm rate for children with SLI was 0.12, whereas it was 0.04 for the TD group. The number of false alarms was higher in the visual modality, and the difference between the two modalities was larger for the TD children (VCPT: 0.07 versus ACPT: 0.02) as compared with the SLI group (VCPT: 0.13 versus ACPT: 0.11). Note that in both modalities the false alarm rate was higher for the SLI group than for the TD group. The interaction between block and modality showed a slightly larger decrease in false alarm rate for the auditory domain (0.09 to 0.06) than for the visual domain (0.11 to 0.09).

The RT analysis showed main effects of modality and block. Moreover, group interacted with block. Table 2 summarizes the results for the linear mixed-effects analyses. Children responded faster in the visual task than in the auditory task (561 ms versus 663 ms). Performance decreased over time, and to a larger degree for the SLI group as compared with the TD group (SLI: first block 573 ms, last block 660 ms; TD: first block 573 ms, last block 607 ms).

Individual differences

For both perceptual modalities, mean RT, hit rate, and false alarm rate of the CPT correlated significantly with picture-naming latencies. This was also true for the performance decrement on the VCPT, but not for the ACPT. These correlations were observed not only for the mean picture-naming RTs but also for the μ and τ parameters. Table 3 lists the correlations between all measures of sustained attention and picture naming. We tested whether the correlations differed between the SLI and TD groups using Fisher's z-statistic. When correcting for multiple comparisons, none of the significant correlations in table 3 differed between groups. Thus, both visual and auditory sustained-attention ability correlated with picture-naming performance for both SLI and TD children.

Discussion

In the present study, we examined the role of sustained attention in picture naming by SLI and TD children. Groups of 7–9 year olds performed a picture-naming

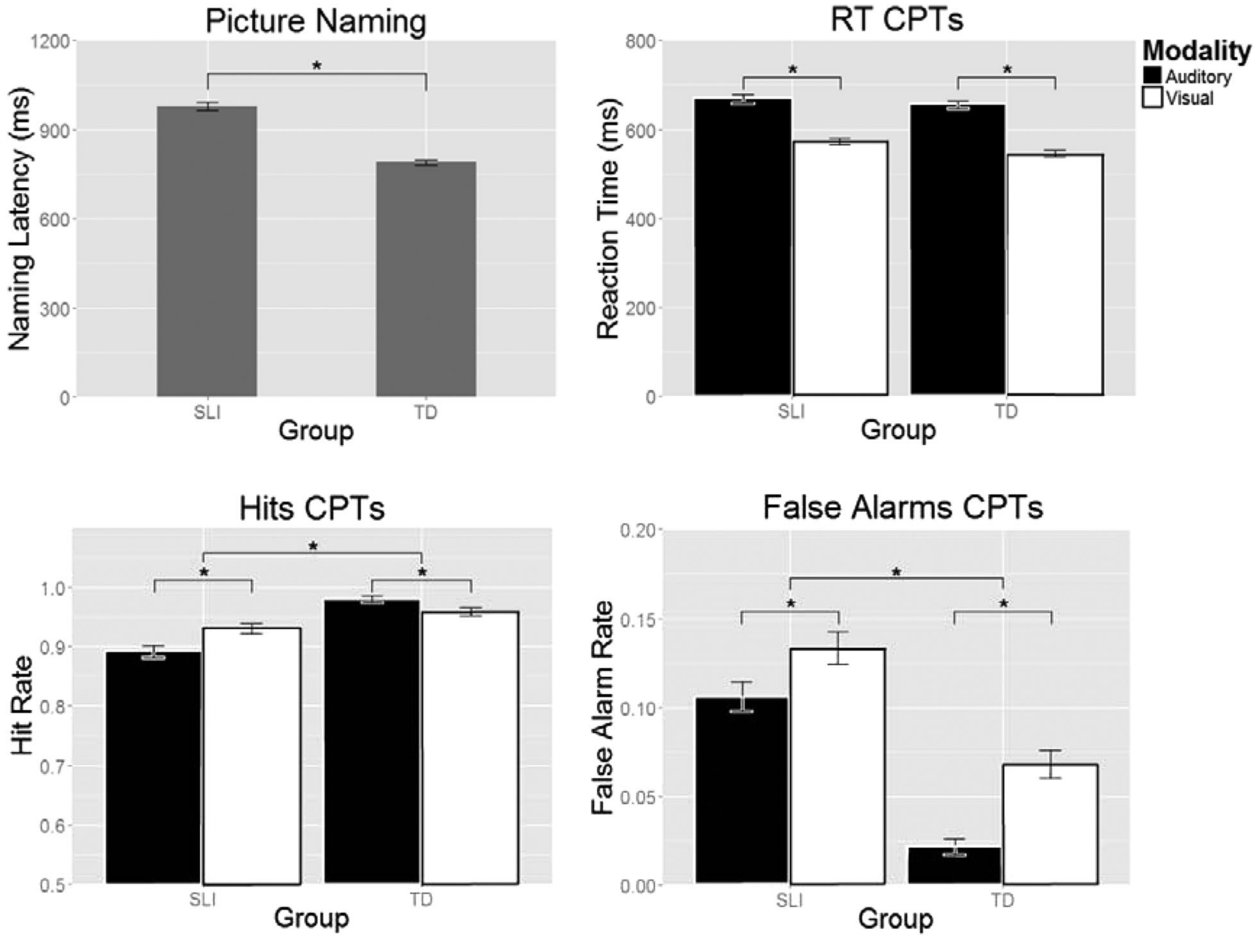

Figure 1. Mean naming latencies for the picture-naming task and the mean response latencies, hits and false alarms for the auditory (black) and visual (white) continuous performance tasks for both developmental groups.

task and auditory and visual CPTs. We made the following key observations with regard to our four main questions. First, we observed that the SLI group performed worse than TD children on picture naming. Second, children with SLI performed worse on the sustained-attention tasks than TD children. Third, this held true for both visual and auditory modalities rather than only for the auditory domain. Fourth, sustained-attention ability correlated with picture-naming performance, across perceptual modalities and developmental groups. In the remainder, we discuss these finding and their implications in more depth.

First, we observed that children with SLI were slower to name pictures than TD children. Both groups made very few errors, even though higher error rates for children with SLI, together with increased naming latencies, are usually reported (e.g., Coady 2013, Lahey and Edwards 1996, 1999). The low error rate in the current study, even for children with SLI, can be due to several factors. First, we selected pictures that were relatively easy to name: All object names were monosyllabic, of high frequency, had a low age of acquisition, and did not contain any initial consonant clusters. We chose these object names intentionally because we wanted to use a relatively simple production task so that children with SLI would be able to finish the task. Moreover, pictures were repeated five times because for ex-Gaussian analyses of the naming latencies many data points are required (for quantile maximum likelihood estimation as used here at least 40 trials). The low error rate could also have been due to the initial practice phase, where children were given the correct name by the experimenter in case they did not produce it after approximately 10 s. Without a practice phase, we would undoubtedly have seen more errors in both groups of children.

Second, we observed that children with SLI had poorer sustained-attention ability than TD children. Relatively few studies have investigated sustained-attention ability in children with SLI. Our study extends the existing research as we provide more evidence for a deficit in sustained attention in SLI. This impairment was evident from several sustained-attention

Table 1. Results of logit mixed model analyses of the hits and false alarms for the two continuous performance tasks: estimated coefficient (ß), standard error (SE), *z*-value (*z*) and *p*-value (*p*)

Measure	Factor	ß	SE	*z*	*p*
Hits	Intercept	3.51	0.16	21.10	<. 001[a]
	Group	−1.13	0.32	−3.45	<. 001[a]
	Modality	−0.23	0.21	−1.07	.28
	Block	−0.18	0.03	−5.47	<. 001[a]
	Group × Modality	1.09	0.41	2.69	.007[a]
	Group × Block	−0.00	0.06	−0.05	.96
	Modality × Block	0.02	0.07	0.38	.71
	Group × Mod × Block	−.15	.11	−1.36	.17
False alarms	Intercept	−2.97	0.13	−22.74	<. 001[a]
	Group	1.20	0.26	4.57	<. 001[a]
	Modality	0.75	0.18	4.08	<. 001[a]
	Block	0.00	0.02	0.14	.89
	Group × Modality	−0.88	0.37	−2.37	.02[a]
	Group × Block	−0.07	0.04	−1.48	.14
	Modality × Block	–0.10	0.03	–3.32	<. 001[a]
	Group × Mod × Block	0.01	0.06	0.23	.82

Note: [a]A coefficient is a significant predictor at $p < .05$.

Table 2. Results of mixed-effects model analyses of the log-transformed reaction times for the two continuous performance tasks: estimated coefficient (ß), standard error (SE) and *t*-value (*t*)

	ß	SE	*t*
Intercept	6.35	0.02	284.78[a]
Group	0.02	0.04	0.37
Modality	−0.15	0.02	−7.05[a]
Block	0.01	0.00	5.84[a]
Group × Modality	0.03	0.04	0.80
Group × Block	0.01	0.00	2.06[a]
Modality × Block	0.01	0.00	1.62
Group × Mod × Block	0.01	0.01	0.87

Note: [a]A coefficient is a significant predictor at $p < .05$ using the criterion that $|t| > 2$.

Table 3. Correlations between the mean reaction times (RT), hit rate (HR), false alarm rate (FAR) and performance decrement (DECR) of the two continuous performance tasks and the mean latencies (*M*) and the mu (μ) and tau (τ) parameters for picture naming

Modality	Measure	*M*	μ	τ
Auditory	RT	.35[a]	.32[a]	.27
	HR	−.48[c]	−.43[b]	−.40[b]
	FAR	.41[b]	.31[a]	.37[b]
	DECR	.03	−.22	.15
Visual	RT	.40[b]	.43[b]	.29[a]
	HR	−.48[c]	−.34[a]	−.44[b]
	FAR	.37[b]	.14	.41[b]
	DECR	.34[a]	.30[a]	.28[a]

Note: Correlation significant at [a].05 level, [b]0.1 level, [c].001 level.

performance measures, namely from hit and false alarm rates and the performance decrement in RTs. Children with SLI tended to miss more targets, more often responded incorrectly to non-targets, and their responses became slower over time to a larger extent than found in TD children. The only CPT measure that showed no difference between the two groups was mean RT. The lack of a difference for mean RT has been reported previously. The meta-analysis by Ebert and Kohnert (2011) showed that only one out of thirteen tasks that measured RTs revealed a difference between SLI and TD children. Our results indicate that there is in fact a deficit, but it is a more subtle one. Whereas the mean RT does not differentiate SLI and TD children, the change of RT over time does.

Third, the difference in sustained-attention ability between SLI and TD children held true for both visual and auditory modalities rather than for the auditory modality only. Some previous studies found a deficit for children with SLI in the auditory modality only, and not in the visual modality (Dodwell and Bavin 2008, Noterdaeme *et al.* 2001, Spaulding *et al.* 2008). In the present study, sustained-attention performance was tested both in the visual and auditory domain, and apart from modality the two tasks were identical. We found impaired performance not only on the auditory CPT but also on the visual CPT, replicating Finneran *et al.* (2009). This suggests that a specific deficit in the auditory modality does not hold. Our results argue against separate sustained-attention systems for the auditory and visual modality as proposed by Spaulding *et al.* (2008).

However, it must be noted that there were differences in performance between CPT tasks. For both groups of children, the false alarm rate was higher in the visual modality than in the auditory modality: It was harder to withhold a response to a visual non-target than to an auditory non-target. This was accompanied by the finding that children were faster to respond in the VCPT than the ACPT. This suggests a speed–accuracy trade-off, but why children shifted their response criterion is unclear. It might be related to the fact that during the visual task their eyes had to be focused on the screen, whereas during the auditory CPT they could look anywhere, causing a slight difference in task demands. Whatever the reason for the possible criterion shift, it argues neither for nor against separate domain-specific sustained-attention systems.

Finally, the hit rate was lower on the auditory task than on the visual task for the SLI group, whereas the reverse held for the TD group. This could indicate a stimulus processing problem in the auditory as compared with the visual modality for children with SLI. This would be consistent with the finding that children with SLI often show impaired auditory processing (Rosen 2003, Wright *et al.* 2000). Murphy *et al.* (2014) therefore suggested that ACPTs are not suitable for assessing sustained-attention ability in SLI. The VCPT does not tap into auditory perceptual processes, and thus would seem to be a better measurement of sustained attention in children with SLI.

It should be emphasized, however, that we observed CPT performance in terms of hit rate and false alarms to be poorer for the SLI than for the TD group in *both* the auditory and visual modality. Based on a CPT difference (for false alarms) in the auditory but not the visual modality for children with speech sound disorder as compared with TD children, Murphy *et al.* (2014) argued that auditory CPTs were not suitable for testing sustained-attention ability in children with SLI given that they often have auditory processing deficits. However, we observed that SLI children exhibited poorer CPT performance regardless of the modality (e.g., visual or auditory), which excludes the possibility that the SLI children performed less well than the TD children just because of an auditory processing deficit. Moreover, we observed that both visual and auditory CPT scores correlated with naming performance, whereas Murphy *et al.* observed no correlation between sustained attention and language performance. This suggests a different role for sustained-attention ability in children with SLI (as examined in our study) than in children with speech sound disorder (as examined by Murphy *et al.*). To conclude, compared with TD children, children with SLI exhibited poorer CPT performance regardless of sensory modality, which suggests that their poorer performance was related to a sustained-attention deficit rather than an auditory processing deficit.

Fourth, we observed that all measures of sustained attention, except the performance decrement in the auditory CPT, correlated with the mean picture-naming latency. This suggests that children with poorer sustained attention (as indicated by longer RTs, lower hit rates, more false alarms, and larger decrements over time) were slower to name pictures than children with better sustained attention. This held for both visual and auditory CPTs. Moreover, correlations were present for both SLI and TD groups, and these correlations did not differ between groups. This further corroborates the view that children with SLI are impaired in a domain-general sustained-attention ability, and that this ability is correlated with naming performance, just as it is for TD children.

Sustained-attention ability was not only correlated with mean picture-naming latencies, but also with parameters characterizing the normal part (μ) and the right tail (τ) of the underlying RT distribution. In previous research on adults, the relationship between sustained-attention ability and picture-naming performance was evident only for the τ parameter. Adult individuals with worse sustained attention were not consistently slower to name but showed a larger number of very slow responses, as compared with adult individuals with better sustained attention (Jongman *et al.* 2015a, 2015b). The current study shows that the relationship between sustained attention and picture naming in children diverges from that of adults, as the correlations were not only found for the τ parameter but also for the μ parameter. Children with poorer sustained attention were slower in naming the pictures on most of the trials (as evident from the correlation with μ) and they had a larger proportion of very slow responses than children with better sustained attention (as evident from the correlation with τ). This indicates that sustained attention might play a more important role in naming in children, when language is still developing, than in adults.

How exactly sustained attention supports language production needs to be investigated further. Our experiment tested the role of sustained attention during online language processes. One possible interpretation of our results is that in children with poor sustained attention, more lapses of attention occurred during the picture-naming task. Whilst preparing to name the picture, the child may forget the goal—to name the picture—because attention wanes, and naming preparation needs to be initiated again, resulting in slow naming. A comparison between the results of the present child study and similar studies run with adults (Jongman *et al.* 2015a, 2015b) suggests that in children lapses of attention during a language production task occur regularly (as suggested by the μ effect), whereas adults have very few lapses of attention (as suggested by the τ effect). This is consistent with findings showing development of sustained attention throughout childhood (for a review see Gomes *et al.* 2000, Posner 2012). It would be interesting to see whether the age at which adult-like performance in sustained-attention tasks is reached coincides with less involvement of sustained attention in language production tasks (e.g., a shift from μ to τ-only correlations).

The present study has some limitations. First, the two groups were rather small for a correlational approach. Moreover, correlation does not prove causation. In order to establish whether there is a causal link between sustained-attention ability and language production skills, one could conduct training studies and observe whether training-induced improvements of sustained-attention ability lead to improved speech production skills. If improvement of language production by attention training occurs, it would be interesting to see whether this holds for both SLI and TD children. Our correlational results suggest that children in both groups, particularly those children with relatively poor sustained attention, might benefit from sustained-attention training. Such a finding would be relevant not only for clinicians working with children with SLI, but also for classroom teaching. A second limitation of the current study is that no attention or linguistic abilities were assessed other than sustained attention and picture naming (see Posner 2012 for a discussion of other attentional abilities, including orienting and executive control). Thus, a follow-up study should include additional tests to see whether the relationship between attention and language holds only for sustained attention and word production, or whether other attentional abilities contribute to children's language production.

To conclude, we observed that children with SLI perform worse than TD children on picture naming and on both auditory and visual sustained-attention tasks. Moreover, children with poorer sustained-attention performance took longer to name pictures, which held regardless of perceptual modality (auditory, visual) and developmental group (SLI, TD). These results provide evidence for a relationship between domain-general sustained-attention and picture-naming performance in both TD and language-impaired children.

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Appendix A: Target names of pictures, with English translation

aap (monkey), *arm* (arm), *bed* (bed), *boot* (boat), *bus* (bus), *deur* (door), *duim* (thumb), *ei* (egg), *kerk* (church), *kip* (chicken), *lamp* (lamp), *mes* (knife), *muur* (wall), *neus* (nose), *oor* (ear), *paard* (horse), *pan* (pan), *ring* (ring), *touw* (rope), *zon* (sun).