Manuscript Type: Regular Research Articles

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Article Title: PROCEDURAL VISUAL LEARNING IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

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Submitted 4 may 2011

Abstract

Purpose: According to the Procedural Deficit Hypothesis (PDH), difficulties in the Procedural Learning (PL) system may contribute to the language difficulties observed in children with Specific Language Impairment (SLI).

Method: Fifteen children with SLI and their typically developing (TD) peers were compared on visual PL tasks: specifically, deterministic Serial Reaction Time (SRT) tasks. In a first experiment, children with SLI and their TD peers performed the classical SRT task using a keyboard as response mode. In a second experiment, they performed the same SRT task but gave their responses through a touchscreen (instead of a keyboard) to reduce the motor and cognitive demands of the task.

Results: Although in Experiment 1, children with SLI demonstrated learning, they were slower and made more errors than their TD peers. Nevertheless, these relative weaknesses disappeared when the nature of the response mode changed (Experiment 2).

Conclusions: This study reports that children with SLI may exhibit sequential learning. Moreover, the generally slower RTs observed in previous deterministic SRT studies may be explained by the response mode used. Thus, our findings are not consistent with the predictions of the PDH, and suggest that language impairments in SLI are not sustained by poor procedural learning abilities.

Keywords: procedural learning, sequential learning, specific language impairment, child language disorder, serial reaction time

General introduction

Several theories concerning the cause of SLI have been proposed. Some theoretical accounts of SLI have centered exclusively on linguistic disorders (van der Lely, 2003), while others have concentrated on more general processing or cognitive mechanisms that might be impaired in SLI. It has been suggested that poor language abilities could result directly from a cognitive deficit of a non-linguistic nature, such as the slowing down of auditory temporal processing (Tallal et al., 1996), limited working memory capacity (Gathercole & Baddeley, 1990, 1993; Ellis Weismer, Evans, & Hesketh, 1999), a slower general speed of processing (Miller, Kail, Leonard, & Tomblin, 2001), or processing capacity limitations (Ellis Weismer et al., 2000). In addition, several studies have suggested that children with SLI have problems with motor skills, particularly with those involving sequences (Bishop, 2002; Hill, 2001; Preis, Schittler, & Lenard, 1997; Ullman & Pierpont, 2005). Ullman and Pierpont (2005) proposed the Procedural Deficit Hypothesis (PDH) in order to explain both the linguistic and non-linguistic problems observed in children with SLI. The PDH is based on the Declarative/Procedural model of language learning (Ullman, 2001), according to which lexical acquisitions are closely associated to declarative memory, whereas procedural learning supports several aspects of grammar (i.e., the learning and use of rule-governed aspects of grammar, across syntax, morphology and phonology: Ullman, 2001; 2004). On this view, declarative memory processes the binding of conceptual, phonological, and semantic representations, while procedural memory, which is one of several systems involved in implicit acquisition, underlies aspects of rule-learning (Knowlton, Mangels, & Squire, 1996; Poldrack, Prabhakaran, Seger, & Gabrieli, 1999), and is particularly important for the acquisition and use of skills involving sequences – whether the sequences are abstract, sensorimotor, or cognitive (Aldridge & Berridge, 1998; Eichenbaum & Cohen, 2001; Squire & Knowlton, 2000; Willingham, 1998). Ullman and Pierpont (2005) suggested that language impairments (particularly grammar problems) in children with SLI may be largely explained by abnormalities in brain structures underlying procedural memory (i.e., the basal ganglia). Most importantly, it predicts impairments not only in procedural memory itself, leading to deficits in implicit sequence learning, including some aspects of grammar, but also in non-procedural functions that depend on the basal ganglia/frontal circuitry, such as working memory, auditory processing, and lexical retrieval. In contrast, the medial temporal lobe structures that underlie learning and consolidation in declarative memory are thought to remain largely intact, and expected to play a compensatory role, at least to some extent, for functions such as rule-governed aspects of grammar that are normally mainly supported by procedural memory.

Although the PDH could explain the language difficulties of children with SLI, only a handful of studies have investigated this topic (Evans, Saffran, & Robe-Torres, 2009; Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011; Hedenius et al., 2011; Kemény & Lukács, 2010; Lum, Gelgec, & Conti-Ramsden, 2010; Lum, Conti-Ramsden, Page, & Ullman, in press; Plante, Gomez, & Gerken, 2002; Tomblin, Mainela-Arnold, & Zhang, 2007). Most of these investigations on implicit learning in individuals with spoken language learning difficulties in general, and in children with SLI, in particular, have been restricted to the verbal domain in tasks that depend on procedural memory structures (Plante et al., 2002; Evans et al., 2009). The main reason for this is the apparent similarity of these verbal tasks to real-life language learning contexts, in which linguistic structures are widely involved. For example, Plante et al. (2002) showed that college students with language/learning disabilities (L/LD) were less able than controls to recognize word order cues, by using an Artificial Grammar Learning (AGL) task (Reber, 1989). Relatedly, Evans et al. (2009) compared the performance of children with or without SLI in a statistical learning task. They also found that the computational mechanism that allows unimpaired children to use statistical information to discover word boundaries is not as effective in children with SLI. Although children with SLI were able to track the transitional probabilities in the speech condition after a double exposure (42 minutes instead of 21 minutes), they were unsuccessful at differentiating newly learned target words from highly similar-sounding foils during the testing phase of the task. Moreover, they were not able to track the transitional probabilities in a non-linguistic (tone) condition, even in the double exposure condition.

Nonverbal procedural memory, which is the focus of the present paper, has been explored in the learning of both probabilistic sequences (i.e., sequences with some irregularities inserted: Schvaneveldt & Gomez, 1998; Gabriel et al., 2011; Hedenius et al., 2011; Kemény & Lukács, 2010) and deterministic sequences (sequences containing only regularities: Lum et al., 2010; Lum, Conti-Ramsden, Page, & Ullman, in press; Tomblin et al., 2007). Procedural learning impairment in SLI has mainly been assessed using implicit visuo-spatial Serial Reaction Time (SRT) tasks: performance on these tasks depends on procedural memory (Knopman & Nissen, 1991; Nissen & Bullemer, 1987; Siegert, Taylor, Weatherall, & Abernethy, 2006). In a typical SRT task, participants are asked to react as quickly and as accurately as possible to stimuli that appear on a computer screen by pressing one of four keys on the keyboard, where each key corresponds to a stimulus location on the screen. Unbeknownst to the participant, rather than appearing in random locations, the stimuli follow a repeated sequence. In this task, learning of the sequence is shown by longer reaction times (RTs) in a transfer block in which a different sequence of stimuli is presented (e.g., Meulemans, Van der Linden, & Perruchet, 1998).

Three studies have assessed PL abilities with probabilistic tasks in children with SLI. These studies found contrasting results: while one study reported impairment in probabilistic category learning (Kemény & Lukàcs, 2010), others did not show clear initial sequence learning deficits (Gabriel et al., 2011; Hedenius et al., 2011). In contrast, all studies that have assessed PL abilities using deterministic SRT tasks have reported sequence learning deficits in children with SLI (Lum et al., 2010; Lum, Conti-Ramsden, Page, & Ullman, in press; Tomblin et al., 2007).

Tomblin et al. (2007) compared the performance of 15-year-olds with and without SLI in a SRT task with a button box as the response mode. They showed that both groups learnt the 10 element sequence, although the sequential learning rates were slower for adolescents with SLI in comparison with TD peers. These data suggest that although adolescents with SLI were able to learn the sequence, they required significantly more trials to do. Moreover, Tomblin et al. also reorganized the initial groups of adolescents with or without SLI into two other binary groupings based on scores on either lexical tests or grammar tests. Only the high and low grammar groups showed a difference in sequential learning rate. Lum et al. (2010) obtained similar results, by reporting that the magnitude of the difference between the last learning block and the transfer block was significantly larger for the children with TD than for the children with SLI, even after removing the variance related to children's motor speed. More recently, Lum, Conti-Ramsden, Page, and Ullman (in press) replicated the results that they obtained in 2010, even when working memory was held constant. Moreover, Lum et al. (in press) showed that grammatical abilities were associated with procedural memory in the TD children, but with declarative memory in children with SLI. Overall, therefore, deterministic SRT studies seem to confirm the predictions of the PDH, based on the observation of slower learning rates in children with SLI in addition to associations between grammatical abilities and both procedural (Tomblin et al., 2007) and declarative memory (Lum, Conti-Ramsden, Page, & Ullman, in press) that support the predictions of the PDH (i.e., declarative memory partly compensates for grammar learning, which is impaired in SLI due to a procedural deficit).

However, two issues in relation to the deterministic SRT studies of Tomblin et al. (2007) and Lum et al. (2010; in press) must be addressed. First, these studies investigated PL with a small number of learning trials in comparison to the usual number of presentations required in implicit learning. Indeed, the sequence is traditionally repeated between 84 and 120 times (e.g., Destrebecqz & Cleeremans, 2001; Russeler, Gerth, & Münte, 2006; Stefaniak, Willems, Adam, &

Meulemans, 2008), while it was repeated only 20 times in Tomblin et al.'s (2007) study, and 36 times in the studies of Lum et al. (2010; in press), which could explain the absence of sequence-specific learning observed in some of their participants. Secondly, Tomblin et al.'s (2007) and Lum et al.'s (2010; in press) studies used an unambiguous 10-element-long sequence in which some locations are presented more often than others (e.g., location 4 occurs 4 times while location 1 occurs only once in the study of Tomblin et al.). Consequently, it is not clear whether children with SLI showed slower learning rates because they are not able to learn quite simple information (i.e., some locations occur more often) or more complex procedural information (e.g., the relationships between occurrences at different locations).

In the present study, we decided to investigate procedural learning in children with SLI by making two main methodological changes with respect to the studies of Tomblin et al. (2007) and Lum et al. (2010; in press): (a) we presented the to-be-learned sequence 48 times, which is closer to the number of presentations used in most studies on SRT in children; (b) we used an ambiguous sequence (i.e., each stimulus position could be followed by two different locations; Cohen, Ivry, & Keele, 1990), in which specific sequence learning effects could only be explained by knowledge of second-order conditional associations, and not by knowledge of simple associations or item frequency, as in the case of non-ambiguous sequences.

Furthermore, given that the SRT task involves not only procedural memory but also several other cognitive and motor processes, it could be hypothesized that the differences between children with and without SLI are related to these other motor or cognitive constraints. Given that the SRT task is predominantly a motor task (Deroost & Soetens, 2006a, 2006b) and that an association between generalized motor impairment and language impairment has been reported (Bishop, 2002; Bishop & Edmundson, 1987; Hill, 1998; 2001; Powell & Bishop, 1992; Preis, Schittler, & Lenard, 1997; Robinson, 1991; Schwartz & Regan, 1996; Webster, Majnemer, Platt, & Shevell, 2005), we could hypothesize that the difficulties of children with SLI on this task are only due to fine motor difficulties (Jancke, Siegenthaler, Preis, & Steinmetz, 2006; Powell & Bishop, 1992; Zelaznik, Goffman, 2010). Moreover, the use of a gamepad (Lum et al., 2010; in press), a response box (Tomblin et al., 2007) or a keyboard requires processing to match the location of the stimulus on the screen with the corresponding key. This processing could be impaired in children with SLI. Indeed, when performing the SRT task with a gamepad or a button box, the stimuli on the screen must be phonologically recoded in order to press the corresponding key (e.g., if the stimulus appears at this first location, I must push on the "c" key). This means that participants have to maintain the relation between the location on the screen and the corresponding key in short-term memory throughout the entire task. This is problematic for children with SLI since Gillam, Cowan and Marler (1998) found that children with SLI were impaired on a similar short-term memory task. Thus, it might be hypothesized that differences between the children with SLI and TD is related to differences not in procedural learning but due to the involvement of phonological representations in the recoding between the location and the motor response.

Aims

The aim of this study is to assess the PDH in children with SLI using the SRT paradigm, by setting up an experimental situation characterized by more learning trials than in previous studies, and by using a learning sequence that, more specifically, would test the children's ability to learn complex (i.e., second order) statistical regularities within the sequence. To achieve this, two sequence implicit learning studies were conducted. First, a classical SRT (Nissen & Bullemer, 1987) task was used. We predicted that, if poor procedural learning ability is a core deficit in children with SLI, sequential learning difficulties should still be observed even when more learning trials are administered. On the other hand, comparable performance levels between children with SLI and their TD peers under this adaptation of the SRT task would attest to some preserved procedural abilities.

Then, in order to rule out the possibility that differences observed between children with and without SLI might be related to fine motor and/or cognitive constraints, we conducted a second experiment in which a touchscreen was used as response mode. The advantage of the touchscreen is that fine motor constraints were weaker, since the movements required are not finger movements but arm movements. The research question on the second experiment was thus to investigate whether the longer RTs and higher error rates reported in previous studies (e.g. Lum et al., 2010; in press; Tomblin et al., 2007) are related to the response mode. Contrary to Experiment 1, which involved a bimanual response mode, this second experimental task used a unimanual response mode. Here, children had to use their preferred hand to touch the location on the screen where the target appeared instead of pressing the corresponding key on the keyboard. In fact, a single-hand response mode might be of particular interest: previous research has shown a callosal transfer deficit in SLI (Fabbro, Libera, & Tavano, 2002), which could impair the integration and coordination of the activity of the two cerebral hemispheres required when both hands are used (as is the case on the classical SRT task using the keyboard as response mode). Furthermore, the cognitive constraints are also reduced, given that this task requires children to push directly on the visual stimulus itself, which means that phonological recoding between the location on the screen and the corresponding key is no longer required.

This study is the first to adopt this approach, directly testing sequential learning abilities with a touchscreen as response mode. According to the PDH, children with SLI should continue to present difficulties in sequence-specific learning in comparison with TD children. Conversely, if a short-term memory and/or manual dexterity impairment explained previous results, the performance of children with SLI on the touchscreen-based SRT task should be similar to that of TD children.

Finally, like Tomblin et al. (2007), we wanted to investigate whether individual differences in SRT learning are more strongly associated with individual differences in grammatical than in lexical abilities. If the PDH is to explain SLI, a positive correlation should be found between performance on grammatical tasks and the SRT learning effect (i.e., children who suffer from grammatical disabilities should show poor learning effects on the SRT task).

Experiment 1

Methods

Participants

Fifteen French-speaking children with SLI aged 6 to 12 years (mean age = 123 months; SD = 19; range = 93 – 147) and 15 typically developing children (mean age = 125 months; SD = 19; range= 91 – 151) participated in the study. No participant had previously taken part in any other implicit learning study. Participants were originally identified as having either normal learning development or SLI. TD children were recruited from schools near the University of Liège, Belgium. Children with SLI were recruited in a special educational setting for children with severe language disabilities, where they had received a previous clinical diagnosis of SLI by professionals (speech-language pathologists and child neurologists). All children were Caucasian and came from families with a low or middle-class socio-occupational background, which was determined by their parents' profession (INSSE, 2003). Four children with SLI and four children without SLI came from a lower-SES background where the parents were unemployed or homemaker. Eleven children with SLI and 11 children without SLI came from a middle-SES background, where at least one parent was a skilled or unskilled worker but not manager.

The parents were asked to complete a medical history questionnaire in order to ensure that all children were French monolingual speakers, had no history of psychiatric or neurological disorders, and had no neurodevelopmental delay or sensory impairment (e.g., gross motor coordination disorder, visual impairments). We did not carry out motor or visual screening, but it can be argued that performance on the SRT task was not influenced by these factors: indeed, children with SLI performed as quickly and accurately as typically developing children in pre-tests for the SRT task (which consisted of a series of 20 randomly generated practice trials): all children performed at substantially above-chance levels on this pre-test. Moreover, TD children presented no language impairment and no other more general learning impairments. The parents of all children gave informed consent.

Children were tested individually in a quiet setting at their school. Each child with SLI was matched with a child with TD based on socioeconomic status (i.e., matching was based on the level of education required to perform the parents' job), gender (11 boys), Perceptual Reasoning Index (+/- 8 points; WISC IV; Wechsler, 2005), and chronological age (+/- 3 months). Thus, the children with or without SLI did not significantly differ in terms of age, t (28) < 1, n.s., or nonverbal reasoning abilities (Perceptual Reasoning Index of the WISC-IV, Wechsler, 2005), *t* (28) < 1, n.s. (see Table 1). However, they differed in their phonological abilities ($t(28) = 8.83$, $p= .009$, Student's *t*-test with Welch's correction) as measured by the word repetition task from the Evaluation du Language Oral (Khomsi, 2001), lexical abilities ($t(28) = 14.99$, $p= .0006$, Student's t-test with Welch's correction) as measured by the French adaptation of the Peabody Picture Vocabulary Test (Echelle de Vocabulaire en Images Peabody: Dunn, Thériault-Whalen, & Dunn, 1993), receptive grammatical abilities ($t(28) = 22.74$, $p=.0001$, Student's t-test with Welch's correction) as measured by the French adaptation of the TROG (Epreuve de COmpréhension Syntaxico-SEmantique; Lecocq, 1996).

We applied diagnostic criteria for SLI in line with those typically used in studies of SLI in English-speaking children: that is, scores lower or equal to 1.25 *SD* below the mean in two or more of four language tests in conjunction with Perceptual Reasoning Index scores of 80 or higher (WISC IV; Wechsler, 2005). Perceptual Reasoning Index was calculated on the basis of three subtests (Matrix Reasoning, Block design, and Picture completion). We also administered a verbal Reasoning Index (WISC IV; Wechsler, 2005) and a hearing test. All children had normal hearing.

The criteria for normal hearing were the ASHA 1997 guidelines for hearing screening (at 500, 1000, 2000, and 4000 Hz and 20 dB). A significant challenge for the identification of specific language-impaired French speaking children relies on the scarcity of reliable specific standardized tests. Thus, we administered both a battery of standardized and non-standardized language tests to children with SLI in order to establish a profile of weaknesses for each child with SLI and to examine the relationships between SLI in French and procedural learning. The children with SLI exhibited significant difficulties in producing and/or understanding language materials; specific difficulties were observed in phonology, grammar, and narrative. In order to allow the assessment of the PDH, all children with SLI had to present at least one grammatical deficit. Four language tests were administered: 2 receptive tests (*Echelle de Vocabulaire en Images Peabody,* EVIP, Dunn, Thérault-Whalen, & Dunn, 1993; *Epreuve de COmpréhension Syntaxico-SEmantique,* ECOSSE, Lecocq, 1998) and 2 expressive tests (sentence production and word repetition, *Evaluation du langage oral,* ELO; Khomsi, 2001). The EVIP (Dunn, Thériault-Whalen, & Dunn, 1993), which is a French adaptation of the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981), measures lexical knowledge. The ECOSSE (Lecocq, 1998), a French adaptation of the Test for Reception of Grammar (Bishop, 1989), measures receptive grammatical knowledge. We also administered two subtests of the Clinical Evaluation of Language (word repetition and sentence production) from the ELO battery (Khomsi, 2001). The word repetition task measures repetition performance for late-acquired phonemes, complex phonological patterns and multisyllabic words. The sentence production task measures productive morphosyntactic abilities by assessing the children’s ability to complete the sentence produced by the examiner.

TD children were administered the same tests as children with SLI, except the sentence production component of ELO and the Verbal IQ test. These children were reported to exhibit typical development in all areas assessed. Participant characteristics are reported in Table 1.

< INSERT TABLE 1 ABOUT HERE >

No participants were excluded from the study. The classical SRT task was administered to the children in one session lasting approximately twenty minutes. We did not control for the participants' handedness; the response panel used in our second SRT task required children to press a button with either their right hand or their left hand according to their handedness.

Stimulus materials and procedure

The experiment consisted of 7 blocks of four-choice RT tasks. One experimental block consisted of an 8-element-long sequence repeated eight times. Thus, each block involved 64 trials. There were six learning blocks (Block 1 to Block 6) and one transfer block (Block 7). The same 8-element-long sequence (1-3-4-2-3-1-2-4) was repeated from Block 1 to Block 6. Thus, there were 384 learning trials. Within the transfer block, another ambiguous 8-element-long sequence (4-2-1-3-2-4-3-1) was repeated eight times. In total, the children participated in 448 trials, divided up into 7 blocks. In each trial, a stimulus (a sorcerer) appeared in one of four possible locations (one of the four corner windows of a castle). The 8-element-long sequence is an ambiguous sequence because each position could be followed by two different possible locations (Cohen, Ivry, & Keele, 1990). Thus, in our experimental sequences "1-3-4-2-3-1-2-4", if 4 comes before 2, then 2 will be followed by 3. Nevertheless, 2 will follow 4 or 1 with a probability of 0.50 and it will follow 1 with a probability of 0. Half of the participants were trained using the first ambiguous sequence ("1-3-4-2-3-1-2-4") for Blocks 1-6, with the second ambiguous sequence being used for Block 7 (the transfer block: "4-2-1-3-2-4-3-1"); this design was reversed for the other half of the participants. Learning of the sequence in Blocks 1–6 is attested by longer RTs in Block 7 than in Block 6. Moreover, the visual stimulus appeared in each window on the computer screen the same number of times as in Blocks 1–6. The sequences were made equivalent with respect to location frequency (each location occurred twice).

Procedure. The control of image presentation and the recording of response speed and accuracy were performed using the E-Prime Software (version 1.2). Participants were seated in front of a computer screen, at an average eye/screen distance of 70 cm. The SRT task was designed in order to make the task attractive for children. More specifically, a picture of a castle with four windows (i.e., the locations where the stimuli might appear) was used, which remained constantly displayed on a 15’’ PC screen. Two windows were in the tower of the castle (upper left and right) and two windows were placed on the ground floor (lower left and right). The horizontal and vertical distances between the windows was respectively 25 and 14.5 centimeters. For each of the locations, the corresponding key on the French AZERTY keyboard was spatially compatible (i.e., the D key for the upper left, the J key for the upper right, the C key for the lower left, and the N key for the lower right). They were instructed to use the middle and index fingers of both hands. The task was presented as a game in which the child was a knight who had to fight sorcerers to liberate his/her friends. In order to accomplish their mission, the children had to press the corresponding key as quickly and as accurately as possible. The task was a continuous choice reaction time procedure. The sorcerer was removed once a key had been pressed, or when 4000 ms had elapsed. No feedback was given to the participant when s/he made an error. The next sorcerer appeared after a 250 ms response-stimulus interval (Meulemans et al., 1998). Participants were given a break after each experimental block. The task began with a series of 20 randomly generated practice trials. Participants were not informed of the presence of a sequence. Because the trials were so highly constrained, differences between the learning and transfer blocks cannot be explained by the frequency of the locations or first-order transitions. Instead, they must reflect learning of more complex aspects of the sequence such as segments of three consecutive elements (second-order transitions).

Results and Discussion

First, we ensured that no “outliers” (i.e., RTs or accuracies that were 2 *SD*s from the mean of their group) were included in the analyses. No children could be considered as outliers. Because the distribution of our reaction time data was normal (last learning block: $W = .95$, $p = .25$;

transfer block: $W = .94$, $p = .13$), parametric analyses could be performed on these results. On the other hand, the normality of the correct response distribution was violated (last learning block: $W = .64$, $p < .001$; transfer block: $W = .70$, $p < .001$); therefore, the data were transformed using a logarithmic transformation prior to further analysis.

RT analyses. The mean of the median response RTs for correct responses was calculated for each block, as is common practice in studies using an SRT task (Nissen & Bullemer, 1987). We first performed an Analysis of Variance (ANOVA) using Block (6 levels: Blocks 1-6) as a within-participants variable and Group (2 levels: TD vs. SLI) as a between-participants variable. The results show that children with SLI were slower overall than TD children, $F(1, 28) = 6.74$, $MSE = 136391$, $p < .05$, $\eta_p^2 = .19$, that RT improvement from Block 1 to Block 6 was significant, $F(5, 140) = 18.73$, $MSE = 8874$, $p < .001$, $\eta_p^2 = .40$, and that this improvement was similar in the two groups, as shown by the non-significant interaction, $F(5, 140) = .55$, $MSE = 8874$, $p = .73$, $\eta_p^2 = .019$ (see Figure 1).

Since learning is considered to be sequence-specific when RTs slow down from the last learning block (i.e., Block 6) to the transfer block (i.e., Block 7), we performed an ANOVA with Block (2 levels: Block 6 vs. Block 7) as a within-participants variable, and Group (2 levels: TD vs. SLI) as a between-participants variable. This analysis once again showed that children with SLI were significantly slower than TD children, $F(1, 28) = 11.46$, $MSE = 22503$, $p < .005$, $\eta_p^2 = .29$, and also that Block 6 was processed faster than Block 7, $F(1, 28) = 16.81$, $MSE = 12172$, $p < .001$, $\eta_p^2 = .37$. However, the interaction was not found to be significant, $F(1, 28) = 0.0005$, $MSE = 12172$, $p = .98$, $\eta_p^2 < .001$, suggesting that both groups demonstrated a significant increase in their RTs from Block 6 to Block 7.

However, because the children with SLI responded significantly more slowly than TD children (as in the studies of Tomblin et al., 2007, and Lum et al., 2010, in press), we calculated a learning index that has been used in previous studies in order to control for this kind of difference in RT baselines: (Block 7 – Block 6) / (Block 6 + Block 7) (e.g. Thomas & Nelson, 2001). A *t*-test showed that the difference in learning indices between the groups was not statistically significant (.09 and .11 respectively for children with SLI and TD children), $t(28) = 0.40$, $p = .69$. The absence of difference cannot be attributed to a lack of power, as confirmed by the small effect size (d=0.06; Cohen, 1988).

< INSERT FIGURE 1 ABOUT HERE >

Analyses of correct responses. In order to ensure that the absence of difference between the RT decreases observed in both groups was not related to differences in accuracy, we conducted an ANOVA with Block (2 levels: Block 6 vs. Block 7) as a within-participants variable, and Group (2 levels: TD vs. SLI) as a between-participants variable on the logarithms of correct responses. These analyses revealed that children with SLI made fewer correct responses than TD children, $F(1, 28) = 5.99$, $MSE = 146.9$, $p < .05$, $\eta_p^2 = .17$. This analysis showed an absence of difference between the last learning block (Block 6) and the transfer block (Block 7), $F(1, 28) = 2.54$, $MSE = 8.0$, $p = .12$, $\eta_p^2 = .08$) in both groups (non-significant interaction, $F(1,28) = .019$, $MSE = 8.0$, $p = .89$, $\eta_p^2 = .00067$. The mean proportion of correct responses for both Block 6 and 7 was respectively 0.88 (*SD*= 0.13) and 0.86 (*SD*= 0.12) for children with SLI. The mean proportion of correct responses for both Block 6 and 7 was respectively 0.95 (*SD*= 0.04) and 0.94 (*SD*= 0.04) for children with TD. Thus, these results show that children with SLI made fewer correct responses than controls, but also that this difference was stable between Block 6 and Block 7 for each group. In other words, accuracy analyses do not rule out the possibility that, the similarity between the learning curves of children with SLI and TD children could be due to the fact that the SLI children produced a greater number of errors.

As a whole, the learning indices seem to indicate that children with SLI are capable of specific sequence learning when they are exposed to a greater number of learning trials and given a sequence in which each sequence element is presented equally. However, our results also show that children with SLI were slower and made more errors than their control peers. Therefore, although these findings are the first to show specific sequence learning indices in children with SLI, these results must be interpreted with caution since these learning indices could be an artefact of differences in accuracy. The idea that children with SLI present a preserved learning of motor sequences would be more convincingly supported if both groups responded with similar RT and accuracy.

Experiment 2.

Methods

Participants

The thirty children who participated in Experiment 1 were recruited 2 months later to participate in Experiment 2. This variant of the SRT task was also administered to the children in a single session lasting approximately twenty minutes.

Stimulus materials and procedure

The same materials and procedure as in Experiment 1 were used for Experiment 2, except for the response mode: children now had to touch the location on the screen where the sorcerers appeared as quickly and accurately as possible instead of pressing the corresponding key on the keyboard. At the beginning of this SRT task, participants were free to spontaneously choose one arm according to their hand preference. Once they had chosen their hand, the children were not allowed to use the other hand afterward during the task. Therefore, the children could not vary their handedness across learning trials. As shown in Figure 2, the touchscreen was placed on the laptop screen and was of the same size. The laptop screen was lowered so that the touchscreen was at the same level as the keyboard (i.e., the angle between the keyboard and the laptop screen was 180°) and the picture of the castle was reversed. This position allowed the child to see the castle the right way up and to press the touchscreen with his/her elbow on the table, so that the situation was as comfortable as possible for the child.

The sequences used in Experiment 2 were different from those in Experiment 1, although they had the same level of complexity. As in Experiment 1, half of the participants were trained with the first sequence (“2-1-4-3-4-1-2-3”) for Blocks 1-6, with a second sequence for Block 7 (the transfer block: “1-2-4-3-4-2-1-3”); this design was reversed for the other half of the participants.

< INSERT FIGURE 2 ABOUT HERE >

Results and discussion

As in Experiment 1, the distribution of our RT data was found to be normal (Block 6: W = .98, p = .89; Block 7: W = .98, p = .85), and so we computed parametric analyses on these results. On the other hand, to correct for non-normality in the correct response distribution (Block 6: W = .40, p <.001; Block 7: W = .77, p <.001), the data were transformed using a logarithmic transformation.

RT analyses. The types of analyses used were identical to those performed in Experiment 1. We first performed an ANOVA on the mean of the median RTs for correct responses with Block (6 levels: Blocks 1-6) as a within-participants variable and Group (2 levels: TD vs. SLI) as a between-participants variable. Results showed that, in contrast to Experiment 1, the RTs of children with SLI were similar to those of TD children, $F(1, 28) = .04$, MSE = 124817, p = .82, η_p^2 = .001, that the RT decrease from Block 1 to Block 6 was significant, $F(5, 140) = 19.11$, MSE = 9440, $p < .001$, η_p^2 = .40, and that this decrease was similar for both groups, as shown by the non-significant interaction, $F(5, 140) = .25$, MSE = 9440, p = .93, η_p^2 = .009 (see Figure 3).

We also performed an ANOVA with Block (2 levels: Block 6 vs. Block 7) as a within-participants variable and Group (2 levels: TD vs. SLI) as a between-participants variable. This analysis showed that the two groups’ RT’s were not significantly different, $F(1, 28)$= .29, MSE = 37950, p = .58, η_p^2 = .01, that Block 6 was processed faster than Block 7, $F(1, 28) = 30.37$, MSE =

10543, $p < .001$, $\eta_p^2 = .52$, and that the Block x Group interaction was non-significant, $F(1, 28) = 2.59$, $MSE = 12172$, $p =.11$, $\eta_p^2 <.08$.

< INSERT FIGURE 3 ABOUT HERE >

Thus, we show that the RT improvement between Block 1 and Block 6 is strictly equivalent in both groups; we also show that, in Block 6, the RTs were similar in the two groups, $t(28) = .29$, $p = .77$. If children with SLI are considered to show impairment in sequence-specific implicit learning, then how should the similarity between their learning curves (from Block 1 to Block 6) and those of children with TD be explained? Indeed, when a procedural learning impairment is diagnosed, the usual pattern of results shows a significant difference in RTs between groups for the last learning block, and an absence of difference for the transfer block (Vicari et al., 2003). In the present study, there was no difference in the last learning block between the groups, while the difference between the last learning block and the transfer block was more pronounced for the TD group even though it was not significant, $t(28) = 1.14$, $p = .26$. Moreover, for Block 6, the absence of difference cannot be due to a lack of power, since the effect size is small ($d = .11$). This small difference could be reliably detected only if a huge sample was recruited (i.e., 1250 participants). Thus, we can argue that the non-significant interaction between our groups cannot simply be accounted for by a lack of power, and that the results cannot be interpreted as reflecting an impairment in procedural sequence learning.

Analyses of correct responses. We conducted the same analysis on the correct responses as in Experiment 1. This analysis showed an absence of difference between groups, $F(1, 28) = .93$, $MSE = .002$, $p = .34$, $\eta_p^2 = .03$. We observed an absence of difference between the last learning block (Block 6) and the transfer block (Block 7), $F(1, 28) = 3.66$, $MSE = .0007$, $p = .06$, $\eta_p^2 = .11$, and a non-significant interaction, $F\ (1, 28) = .19$, $MSE = .0007$, $p = .66$, $\eta_p^2 = .0068$. The mean proportion of correct responses for both Block 6 and 7 was respectively 0.96 (*SD*= 0.10) and 0.93

(*SD*= 0.08) for children with SLI. The mean proportion of correct responses for both Block 6 and 7 was respectively 0.98 (*SD*= 0.03) and 0.95 (*SD*= 0.06) for children with TD.

As a whole, the findings of this second experiment indicated that children with SLI were able to perform this task as quickly and accurately as their TD peers. These findings suggest that children with SLI may be able to learn new motor sequential information in procedural memory with the use of an appropriate response mode.

We also wondered whether the nature of the response mode (keyboard vs. touchscreen) had an impact on the children's reaction times. Our prediction was that TD children would respond faster with the keyboard due to the time devoted to moving the hand or the arm from one corner of the screen to another. For children with SLI it was more difficult to predict what effect the response mode could have on their RTs: we hypothesized that this effect would be less pronounced, or even that there would be no effect of response mode. To answer this question, we performed an Analysis of Variance (ANOVA) with Block (3 levels: Blocks 1, 6, and 7) and pointing task (2 levels: keyboard vs. touchscreen) as within-participants variables, and Group (2 levels: TD vs. SLI) as a between-participants variable. Results showed an absence of Group effect, $F(1, 28) = 2.19$, $MSE = 68685$, $p = .15$, $\eta_p^2 = .072$, a significant pointing task effect in favor of the keyboard, $F(1, 28) = 5.22$, $MSE = 37917$, $p<.05$, $\eta_p^2 = .15$ and a significant Block effect reflecting the usual difference between the last learning block and the transfer block, $F(2, 56) = 43.77$, $MSE = 16826$, $p < .001$, η_p^2 ^{2} = .60. The pointing task by group interaction was significant, $F(1, 28)= 6.12$, $MSE = 37917$, $p<.05$, $\eta_p^2 = .18$. As predicted, this interaction was due to the fact that TD children responded faster on the classical SRT task than on the adapted SRT task, $F(1, 28) = 11.33$, $p<.01$, while the RTs of children with SLI were similar for both response modes, $F(1, 28) <1$. This last result confirms the hypothesis that thanks to the touchscreen, children with SLI responded with latencies similar to TD children, $F(1, 28) <1$, while in the keyboard condition, children with SLI were slower than TD children, $F(1,28) = 6.34$, $p<.05$. Thus, these results could reflect either impairment of fine manual (digital) dexterity, or difficulty in the processing required to match keys on the keyboard (or gamepad, or button box) with locations on the screen, or even a callosal transfer deficit as suggested by several authors (Fabbro et al., 1998; Njiokiktjien, 1983; 1990). The other interactions did not reach significance.

Reaction time and vocabulary or grammar status.

Following the study of Tomblin et al. (2007), we wanted to investigate the specific predictions of the PDH, according to which procedural learning problems should be more strongly associated with grammar deficits than with lexical or broader language deficits. In Lum et al.'s (in press) study, associations between procedural memory and language variables were examined with correlations (Pearson's *r*) computed for each language ability measure, separately for children with TD and children with SLI.. For procedural memory, we used the *z*-score of the SRT learning indices (Block 6 – Block 7) / (Block 6 + Block 7). For lexical abilities, we used the *z*-score for the receptive (EVIP) test. Likewise, for grammatical abilities, we used the *z*-score for the expressive (ELO: sentence production) grammar test and the *z*-score of the receptive (ECOSSE) grammar test.

The receptive lexical abilities (EVIP) of participants with SLI were not correlated with SRT learning indices (touchscreen: $r = 0.19$, $p = .49$; keyboard $r = -0.06$, $p = .81$). SRT learning indices were also not correlated with either expressive grammatical abilities (ELO) (touchscreen: $r = -0.20$, $p = .47$; keyboard $r = -0.11$, $p = .69$) or receptive grammatical abilities (ECOSSE) (touchscreen: $r = -0.18$, $p = .51$; keyboard $r = 0.27$, $p = .32$).

The receptive grammatical abilities (ECOSSE) of TD children were also not correlated with SRT learning indices (touchscreen: $r = 0.24$, $p = .37$; keyboard $r = 0.28$, $p = .31$). Finally, TD children's receptive lexical abilities (EVIP) were not correlated with SRT learning indices for the keyboard ($r = .34$, $p = .20$), but this correlation was significant with the touchscreen ($r = -0.75$, $p < .05$) as response mode.

Overall, these data do not appear to be congruent with the prediction of the PDH (Ullman & Pierpont, 2005) that grammatical impairments, contrary to lexical ones, should be strongly associated with procedural learning deficits (see also Tomblin et al., 2007). In the present study, only poor receptive lexical abilities were associated with poor procedural memory in TD children, and this correlation was only significant with the touchscreen response mode.

General discussion

Most previous studies on procedural learning in SLI have supported the predictions of the PDH, reporting impairments in linguistic domains such as statistical learning of verbal stimuli (Evans et al., 2009) and artificial grammar learning (Plante et al., 2002), but also in non-linguistic domains such as procedural grapho-motor learning (Adi-Japha, Strulovich-Schwartz, & Julius, in press), probabilistic category learning (Kemény & Lukàcs, 2010) and deterministic sequence learning (Lum et al., 2010, in press; Tomblin et al., 2007). Only two recent studies, which investigated probabilistic sequence learning in the SRT task, did not report clear sequence learning deficits in children with SLI (Gabriel et al., 2011; Hedenius et al., 2011).

In the present study, Experiment 1 aimed to replicate previous deterministic results (Lum et al., 2010, in press; Tomblin et al., 2007) by controlling two methodological issues in order to better support the predictions of the PDH. First, we wanted to investigate whether children with SLI could reach similar learning levels as controls when the sequence is presented a greater number of times than in previous studies (Tomblin et al., 2007; Lum et al., 2010, in press). In the current study, the sequence was presented almost twice as many times as in the studies of Lum et al. Second, we wanted to investigate implicit sequence learning by using an ambiguous sequence, for which specific sequence learning effects could only be explained by knowledge of second-order conditional associations, contrary to the unambiguous sequences used in the studies fo Tomblin et al. and Lum et al.

The results of Experiment 1 showed a specific sequential learning effect in children with SLI, although their responses were still slower and they made more errors than their TD peers. These results presented discrepancies with studies suggesting that statistical sequence learning is impaired in SLI when a deterministic sequence is used (Lum et al., 2010, in press; Tomblin et al., 2007). Our results show that children with SLI may be able to learn not only probabilistic (Gabriel et al., 2011; Hedenius et al., 2011) but also deterministic sequences on an SRT task. According to Hedenius et al., sequential learning may be easier for children with SLI in the probabilistic SRT task than in the traditional deterministic SRT tasks, as neither of the studies using the probabilistic sequence reported clear initial sequence learning deficits, whereas such deficits did appear in the three studies that used a deterministic sequence (Lum et al., 2010, in press; Tomblin et al., 2007). This hypothesis seems unlikely for two reasons. First, as Schvanelvedt and Gomez (1998) point out, probabilistic sequences are more difficult to learn than deterministic sequences. Second, the learning of the 10-element sequence might only reflect location frequency knowledge (i.e., some locations are presented more often), while this cannot be the case with the 8-element sequence used here, where each location appears with equal probability and learning must rely on some kind of higher-order knowledge. Nevertheless, as long as children with SLI had not been found to exhibit learning of a deterministic sequence similar to that of TD children, this hypothesis could not be totally rejected.

The results of Experiment 1 provided some evidence that undermines the hypothesis of Hedenius et al. (2011). These data suggest that children with SLI can present a sequence learning index on a non-linguistic deterministic SRT task, at least when each sequence element in the sequence is presented an equal number of times, unlike in some previous studies. Therefore, children with SLI demonstrate learning of sequences that relies on some kind of higher-order knowledge about them (such as the ambiguous 8-element sequence used in this current study, where each location appears with the same frequency) rather than a simple learning of frequency information (such as the 10-element sequence used in both Tomblin et al.'s (2007) and Lum et al.'s (2010, in press) studies, in which some elements occur more often than others).

However, it is difficult to determine exactly whether differences in performance between our study and those of Tomblin et al. and Lum et al. could be related to differences concerning the difficulty of the sequence that subjects were required to learn. Indeed, we used an ambiguous sequence (i.e., a sequence in which each position could be followed by two different possible locations; Cohen, Ivry, & Keele, 1990), which is known to be more difficult to learn than a non-ambiguous one like those used by Tomblin et al. and Lum et al. On the other hand, these authors used a longer sequence (10 elements) than the one we used (8 elements), and the possibility that the sequence length had an effect on performance as well cannot be rejected.

Second, we found this sequence learning effect to appear when children with SLI saw the sequence a greater number of times. Our results suggest that children with SLI are able to learn deterministic regularities but may require greater exposure to do it in comparison to typically developing children. Therefore, the learning abilities of children with SLI may be related to frequency or degree of exposure. Other studies have reported that increased input brings children with SLI closer to peers. Bavin, Wilson, Maruff and Sleeman (2005) reported that during a paired associates learning test, it took children with SLI more attempts to learn a pattern-location association than normal learners. Evans et al. (2009) also showed that children with SLI were able to track transitional probabilities in the speech condition with increasing input. Finally, Tomblin et al. (2007) also found that adolescents with grammar impairments required significantly more trials to learn sequential elements in their SRT task than their grammar-normal peers. Nevertheless, the recent SRT study of Lum and Bleses (2012), which reports comparable levels in Danish-speaking children with or without SLI on the same procedural memory task used by Lum et al. (2010), is not consistent with this interpretation. In this context, it may be hypothesized that children with

SLI responded more and more quickly not because they learnt the sequence but because they made more and more errors.

The findings of Experiment 1 are not sufficient to challenge the PDH because, although the learning indices computed on the RTs were similar in the two groups, children with SLI actually made more errors than TD children. If the children with SLI presented similar speeds and accuracies as TD children, then such results would present a more convincing challenge to the PDH.

In order to better understand the origins of the relative slowness and higher error rate of children with SLI, we carried out a second experiment that aimed to investigate whether these difficulties might be explained by motor (Bishop & Edmundson, 1987; Schwartz & Regan, 1996) or cognitive weaknesses, such as the processing required to match the location of the stimulus on the screen to the corresponding key on the keyboard (or gamepad or button box). In order to avoid a possible effect of a deficit of manual dexterity (Bishop & Edmundson, 1987; Schwartz & Regan, 1996) and/or matching on SRT performance in children with SLI, in Experiment 2 we changed the response mode, replacing the keyboard with a touchscreen. Contrary to Experiment 1, the results of Experiment 2 showed not only significant learning effects in children with SLI, but also RTs and accuracies similar to those of their TD peers. Although these results are not sufficient to definitely confirm that children with SLI present procedural learning abilities similar to those of TD controls, these results present a more straightforward challenge to the PDH than those of the first experiment. These results emphasize the importance of taking into account the specific difficulties of the population that is being investigated. Concerning children with SLI, our results suggest that in order to study procedural learning abilities, it is important (and sometimes critical) to make sure that the response mode is adapted to the difficulties of these children. Indeed, when the children with SLI responded using a touchscreen, their speed and accuracy were similar to that of TD children, which was not the case when a more classical response mode such as a keyboard (in our Experiment 1) or a gamepad (Lum et al., 2010; Lum et al., in press) was used. These data rule out the hypothesis according to which SLI results from a generalized impairment in speed of processing (Miller, Kail, Leonard, & Tomblin, 2001) since the speed of children with SLI was equivalent to that of their TD peers with an appropriate response mode. Another explanation could be related to the callosal transfer deficit that has been reported in SLI (Fabbro et al., 2002; Njipkikjien, 1983, 1990). Indeed, when children with SLI responded using a unimanual response mode such as a touchscreen, their speed and accuracy were similar to those of TD children (i.e., no difference was observed, even in Block 1), which was not the case when a bimanual response mode such as a keyboard (see Experiment 1) was used. A bimanual response mode may place increased demands on the corpus callosum. Given the callosal transfer deficit in SLI reported in previous studies, this could explain why children with SLI were slower and made more errors on Experiment 1 than TD children. Nevertheless, the results of Lum et al. (Lum et al., 2010; Lum et al., in press) and Tomblin et al. (1997) using a unimanual response mode such as a gamepad or a button box failed to show similarities in RTs and error rates between the two groups.

The current study extends the literature on procedural sequence learning in children with SLI by suggesting that children with SLI may present no particular difficulty in learning procedurally novel associations within the visual domain. These findings challenge the predictions of the PDH (Ullman & Pierpont, 2005) by demonstrating that the previously slower sequential learning rate in children with SLI could be partly explained by methodological constraints such as the response mode selected in deterministic SRT tasks or the number of times that a target sequence is encountered.

Finally, although the response mode seems to explain the globally slower RTs observed in children with SLI in previous deterministic SRT studies (Lum et al., 2010, in press; Tomblin et al., 2007), other factors, such as diagnostic criteria, could also figure in an explanation of the discrepancy between our results and previous ones. It is impossible to be sure that children with

SLI present the same severity of language problems across all SRT studies. For that matter, Spaulding et al. (2006) demonstrated that even if studies used the same cut-off criteria to define language impairment, this approach would not guarantee equivalency with respect to diagnostic accuracy because standardized tests differ across language in specificity and sensitivity. Spaulding et al. (2006) emphasized the fact that the sensitivity and specificity required to identify language impairments accurately were often not available. As proposed by Lum and Bleses (2012), differences in the language profile of the participants could also explain discrepancies observed between the different deterministic SRT studies (Lum et al., 2010, in press; Tomblin et al., 2007).

In conclusion, the pattern of results reported here has the potential to stimulate productive debate about what procedural learning is and how it can be measured in a nuanced way. Although this study fails to isolate which specific factor contribute to children with SLI either exhibiting or not exhibiting difficulties in deterministic SRT learning, it leads to new perspectives for a better understanding of the inconsistencies observed in previous studies (Lum et al., 2010, Lum et al., in press; Tomblin et al., 2007). Thus, procedural learning studies carried out in children with SLI reveal an uneven profile of procedural memory function, which could be related to the difficulty of assessing procedural learning. Children with SLI sometimes demonstrate preserved procedural performance in visual sequential learning, at least when certain methodological conditions have been controlled for. Thus, this study presents an important addition to the procedural learning deficit literature by refining the PDH (Ullman & Pierpont, 2005): children with SLI may present procedural deficits, but these may depend on the in which their procedural learning abilities are assessed. Therefore, the relevant question is not whether procedural learning is or not present in SLI, but how and under what conditions. In fact, the use of the term “procedural memory,” suggesting a unitary entity, could itself be challenged. Procedural memory should perhaps not be viewed as a single memory system, but rather as a set of learning situations and tasks involving different cognitive and sensory-motor processes (Willingham & Goedert, 2001). So, the idea of a general procedural deficit has to be taken with caution. Even within a single task, subtle methodological differences might lead to differences in the processes involved (see for example Haaland et al., 1997). Children with SLI who cannot learn some sequential motor tasks could show normal learning of other sequential motor skills. Future studies on procedural learning involving non-linguistic artificial grammar learning or statistical learning tasks will be necessary to better understand the association between procedural learning and the acquisition of certain components of natural language.

In terms of clinical implication, this study shows that it is relevant to include an adapted response mode to specific difficulties of the population that is being investigated. Indeed, when the children with SLI had to respond by means of a touchscreen, they responded as quickly and as accurately as their TD counterparts, while this was not the case when the keyboard was used as response mode. In addition, it is appropriate to take account of the degree of exposure. Our data have reported that increased input brings children with SLI closer to their peers (see also Bavin et al., 2005; Evans et al., 2009; Tomblin et al., 2007). The present study contributes to the discovering of the conditions facilitating sequence implicit learning in children with SLI and provides useful information for future developments of intervention programs.

In summary, this study challenges the hypothesis that poor language abilities in SLI are directly associated with poor procedural learning abilities for non-verbal sequences. These results present an interesting parallel with studies showing intact procedural learning abilities in children with other developmental disorders such as developmental dyslexia (Kelly, Griffiths, & Frith, 2002; Roodenrys & Dunn, 2007; Russeler, Gerth, & Munte, 2006). The lack of support for the procedural deficit hypothesis does not disprove it. Further work should examine this issue in greater detail to determine whether, and under what conditions, sequence learning difficulties can be observed in children with SLI and to establish their relation to the children’s language difficulties. Finally, this study emphasizes the importance of adapting the conditions for those performing a non-linguistic task by decreasing the cognitive load, to allow children with SLI to make the best use of their intact learning abilities.

ACKNOWLEDGMENTS

Support for this research was provided by the University of Liège (doctoral fellowship for fields not eligible for FRIA). We would also like to thank the teachers, children and the families who generously contributed their time. Any correspondence concerning this article should be addressed to A. Gabriel, Department of Cognitive Science, rue de l'Aunaie, 30, 4000 Liège, Belgium.

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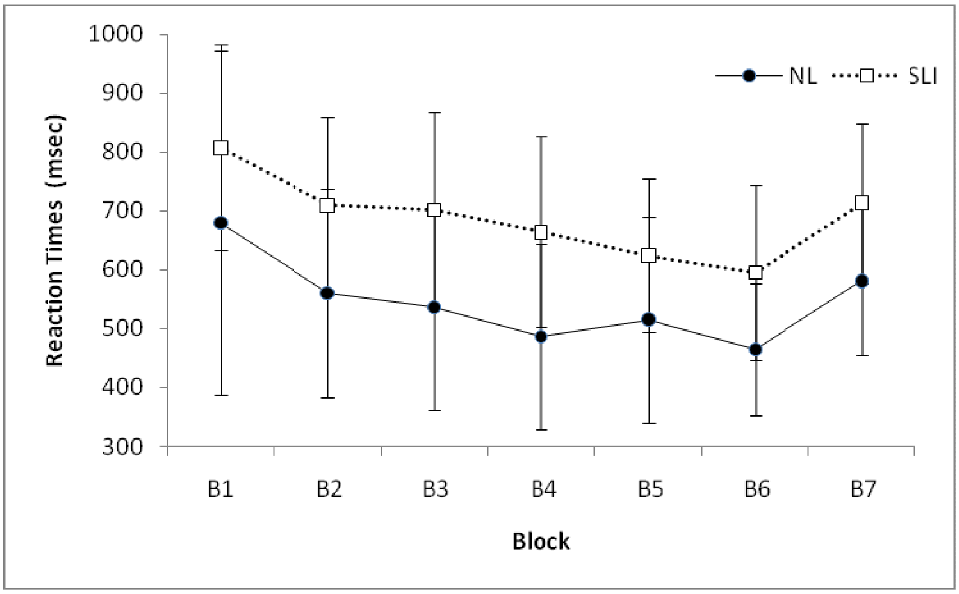
Figure Caption

Figure 1: Mean of median reaction times (RTs) for each block for children with SLI (square) and TD children (circle) during the classical SRT task. Blocks 1–6: learning blocks; Block 7: transfer.



Note: Bars represent standard deviations of the mean.

Figure Caption

Figure 2: Schematic of computer display for the Serial Reaction Time (SRT) task used in Experiment 2. On each trial, a sorcerer appeared at one of four possible locations (one of the four corner windows of the castle): Position 1 (upper left), position 2 (upper right), position 3 (lower left) and position 4 (lower right).

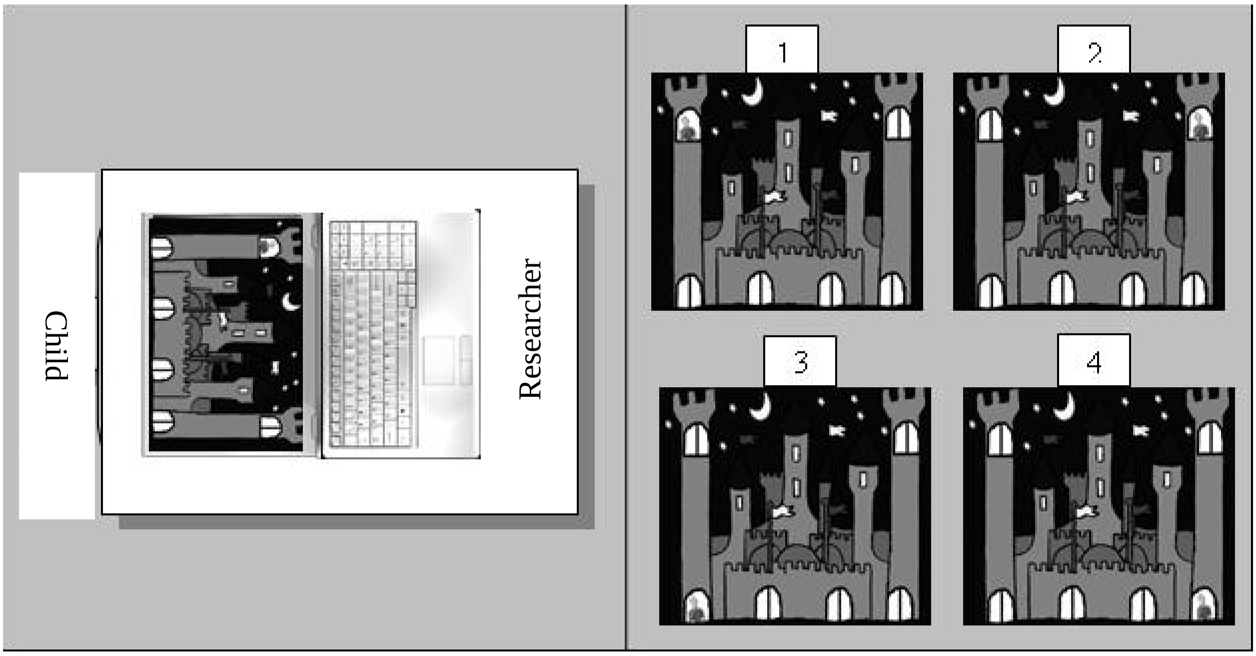
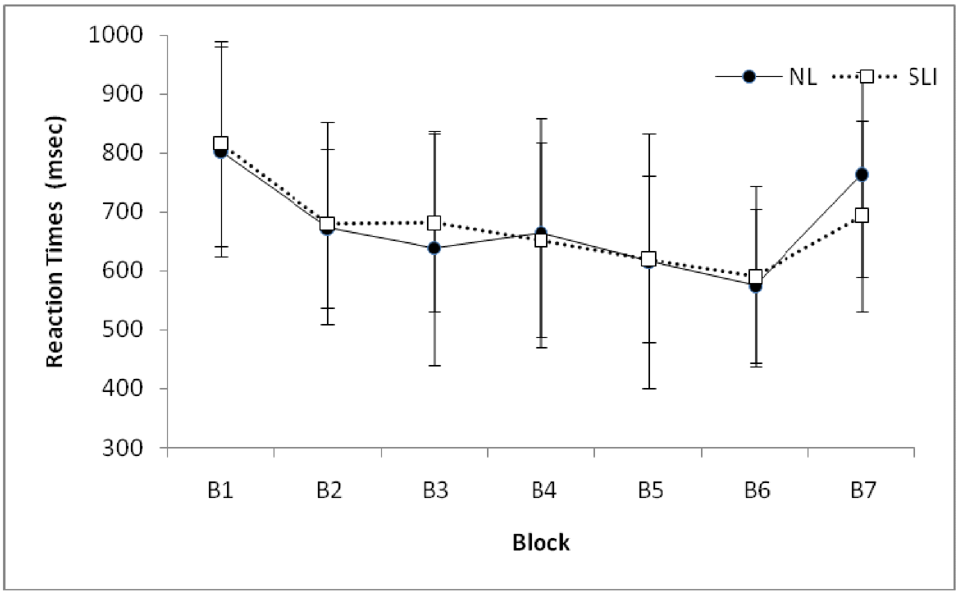


Figure Caption

Figure 3: Mean of median reaction times (RTs) for each block for children with SLI (square) and TD children (circle) during the adapted SRT task. Blocks 1–6: learning blocks; Block 7: transfer.



Note Bars represent standard deviations of the mean.

Table 1

Descriptive Statistics for the Different Measures Administered.

	Age (months)	Perceptual RI	Verbal RI	EVIP	E.CO.S.SE	ELO	
						Word repetition	Sentence production
SLI							
Mean	123	92.26	68.8	-0.68	-1.49	-29.33	-3.28
SD	19	10.12	10.51	0.96	1.12	39.17	1.47
Range	93-147	81-111	51-84	-2.60 – 0 .46	-3.23 – 0.20	-1.06 – 0.75	-5.64 – -1.04
TD							
Mean	125	93.13	N/A	0.45	0.25	-0.25	N/A
SD	19	9.33	N/A	0.66	0.47	1.90	N/A
Range	91-151	81-111	N/A	-0.46 – 1.6	-0.25 – 1.11	-5 – 1.67	N/A

Note. RI = Reasoning Index; N/A = not applicable.
EVIP, French version of the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981), standard scores with *M*=0, *SD*=1;
Perceptual Reasoning Index = Block Design, Picture Completion, and Matrix Reasoning subtests of the Wechsler Primary Scale of Intelligence – Revised (Wechsler, 4th Edition), standard scores with *M*=100, *SD*=15;
ECOSSE, French adaptation of the Test for Reception of Grammar (TROG: Bishop, 1989), Z-scores with *M*=0, *SD*=1 (minimum 0 and maximum 92);
ELO, *Evaluation du language oral* (Khomsi, 2001), Z-scores with *M*=0, *SD*=1 (sentence production: minimum 0 and maximum 25; word repetition: minimum 0 and maximum 32). This task measures repetition performance for late-acquired phonemes, complex phonological patterns and multisyllabic words (Khomsi, 2001). The very poor word repetition performance observed in children with SLI is due to the lack of errors expected in older children. Whereas older TD children present a ceiling effect on a phonological task, older children with SLI continue to produce phonological mismatches. Therefore, the distance between the both groups increases, explaining otherwise incredible-seeming statistical scores.