Published in final edited form as:

Cortex. 2013 September ; 49(8): 2126–2139. doi:10.1016/j.cortex.2012.09.012.

Visual Attentional Engagement Deficits in Children with Specific Language Impairment and Their Role in Real-Time Language Processing

Marco Dispalдро^{1,*}, Laurence B. Leonard², Nicola Corradi³, Milena Ruffino⁴, Tiziana Bronte⁵, and Andrea Facoetti^{3,4,*}

¹Language Acquisition Lab, Dipartimento di Psicologia dello Sviluppo e Socializzazione, Università di Padova, Italy

²Child Language Research Lab, Speech, Language and Hearing Sciences Department, Purdue University, IN, USA

³Developmental & Cognitive Neuroscience Lab, Dipartimento di Psicologia Generale, Università di Padova, Italy

⁴Unità di Neuropsicologia dello Sviluppo, Istituto Scientifico “E. Medea” di Bosisio Parini, Lecco, Italy

⁵Centro Medico di Foniatria, Casa di Cura “Trieste”, Padova, Italy

Abstract

In order to become a proficient user of language, infants must detect temporal cues embedded within the noisy acoustic spectra of ongoing speech by efficient attentional engagement. According to the neuro-constructivist approach, a multi-sensory dysfunction of attentional engagement – hampering the temporal sampling of stimuli – might be responsible for language deficits typically shown in children with Specific Language Impairment (SLI). In the present study, the efficiency of visual attentional engagement was investigated in 22 children with SLI and 22 typically developing (TD) children by measuring attentional masking (AM). AM refers to impaired identification of the first of two sequentially presented masked objects (O1 and O2) in which the O1-O2 interval was manipulated. Lexical and grammatical comprehension abilities were also tested in both groups. Children with SLI showed a sluggish engagement of temporal attention, and individual differences in AM accounted for a significant percentage of unique variance in grammatical performance. Our results suggest that an attentional engagement deficit – probably linked to a dysfunction of the right fronto-parietal attentional network – might be a contributing factor in these children’s language impairments.

Keywords

Visual attention; Attentional masking; Non-spatial attention deficit; Specific Language Impairment; Parietal cortex

*Corresponding authors: Marco Dispalдро, Dipartimento di Psicologia dello Sviluppo e Socializzazione, Università di Padova, Via Venezia, 8, Padova 35131, Italy; marco.dispalдро@unipd.it, Andrea Facoetti, Dipartimento di Psicologia Generale, Università di Padova, Via Venezia 8, Padova 35131, Italy; andrea.facoetti@unipd.it.

1. Introduction

Children with Specific Language Impairment (SLI) show significant deficits in language abilities, without accompanying problems such as hearing impairment, neurological damage, or a deficit in nonverbal intelligence. These children show Performance IQs that fall within the normal range for their age, pass screening tests for hearing acuity, present no signs of neurological impairment, and do not display the typical symptoms of autism spectrum disorders (Leonard, 1998). Epidemiological studies suggest that the prevalence of SLI may be as high as 7% among 5-year-olds (Tomblin et al., 1997). In clinically referred studies, males outnumber females, by approximately 3 to 1 (Leonard, 1998). Children with SLI are two or three times more likely than typically developing children to have siblings with language problems or parents with a history of language problems.

The language impairment is not uniform in children with SLI; different areas within language tend to be more adversely affected than other areas. For many children, grammar is most seriously impaired, with somewhat milder limitations seen in vocabulary and phonology (Leonard, 1998). These children's comprehension of language is often more advanced than their language production abilities.

A central research question is whether this impairment is language-specific (e.g., Eyer and Leonard, 1995; Rice et al., 1995) or whether it derives from a more general deficit. According to general processing limitation approaches (e.g., Kail, 1994; Leonard, 1998; Leonard et al., 2007), children with SLI show difficulties in information processing as exhibited by restricted or inefficient working memory (Dollaghan and Campbell, 1998; Ellis Weismer et al., 1999; Gathercole and Baddeley, 1990; Marton and Schwartz, 2003; Montgomery, 2000), and sluggish speed of processing (Kail, 1994; Leonard et al., 2007; Miller et al., 2001). This deficit is viewed as general in nature because it is present in non-linguistic as well as linguistic tasks. Furthermore, deficits are seen in visual as well as auditory tasks.

Deficits in visual processing have been documented at least since the work of Tallal et al. (1981). These investigators found that children with SLI had difficulty relative to same-age peers in discriminating letter-like visual forms made visible through 75-msec light flashes. As part of evaluating Kail's (1994) generalized slowing hypothesis – that children with SLI are slower in all aspects of processing – several research teams have revealed slower response times (RTs) to visual stimuli of a non-linguistic nature on the part of children with SLI (Miller et al., 2001, 2006; Windsor et al., 2008). In some studies, the slowing has not been observed in all tasks. However, slower RTs have been seen for visual processing at least as often as for auditory processing. For example, Kohnert and Windsor (2004) found that children with SLI were slower than same-age peers on simple and choice visual detection tasks, but not simple auditory detection tasks.

Recent research has begun to focus on the role of attention during non-linguistic processing, in part because of the assumed importance of attention when performing timed tasks such as those used in speed of processing studies. For example, Schul et al. (2004) found that

children with SLI were slower on a visual attention task than a group of typically developing children matched for age. Finneran et al. (2009) found that children with SLI were less accurate than age controls on a visual task of sustained attention (see Ebert & Kohnert, 2011 for a recent review).

Weaknesses in visual processing are also reflected in tasks of visual working memory. Several studies have found deficits in children with SLI in this area of functioning (e.g., Bavin et al., 2005; Hoffman and Gillam, 2004). However, the findings for visual working memory may not be independent of those seen for visual attention. Models of working memory include attention as an essential process, as seen for example, in the model of Cowan (1999). It appears that brain mechanisms that control selective attention might also be those that refresh representations in working memory (Gazzaley and Nobre, 2012; Jonides et al., 2005). In a study employing fMRI, Ellis Weismer et al. (2005) found that children with SLI differed from typically developing peers in fronto-parietal regions associated with both attention and working memory.

One hypothesis, not yet fully explored in SLI, is related to the possibility that the impairment in language might also reflect a multi-sensory limitation associated with temporal engagement of attention, which refers to the ability to process an (auditory or visual) stimulus immediately followed by a second stimulus (see Hari and Renvall, 2001 for a review). In particular, a brief object that is clearly perceptible alone can be rendered invisible by the subsequent presentation of a second object nearby in time: i.e. object substitution masking (see Enns and Di Lollo, 2000 for a review). Despite the great amount of information flooding the scenes, we are able to engage our attentional resources on one object. Thus, attentional engagement can be thought of as a multi-sensory mechanism designed to enhance perception of a complex sensory world, by selecting a specific object to process further. Temporal engagement of attention is crucially involved in object substitution masking (Potter et al., 2002), and it could be specifically impaired not only in children with developmental dyslexia (DD; e.g., Facoetti et al., 2008; Ruffino et al., 2010) but also with SLI, as proposed by the “Sluggish Attentional Shifting” hypothesis of Hari and Renvall (2001).

According to the neuro-constructivist framework, in which development itself is the key to understanding developmental disorders (Karmiloff-Smith, 1998), a multi-sensory dysfunction of attentional engagement – hampering the temporal sampling of the relevant objects – might be responsible for the typical language deficits shown in children with SLI. Indeed, in order to become a proficient user of language, infants must detect temporal cues embedded within the noisy acoustic spectra of ongoing speech by rapid auditory processing (e.g., Benasich and Tallal, 2002; Goswami, 2011; Tallal, 1980, 2004; Wright et al., 1997). A multi-sensory sluggish attentional engagement can mimic a primary rapid signal processing deficit because the inefficient attentional window will expose object perception to major interference from near temporal noisy distracters.

The engagement of temporal attention can be studied by measuring the identification of the first object (O1) when the second object (O2) is presented. O1 accuracy is usually unimpaired at short O1-O2 intervals, (e.g., 180 msec) even when it is measured in elderly

normal individuals (Kavcic and Daffy, 2003). If attentional engagement toward O1 is not successfully completed by the time that O2 is presented, then O1 accuracy could be impaired (e.g., Facoetti et al., 2008; Kavcic and Daffy, 2003; Potter et al., 2002; Ruffino et al., 2010). It is known that when two visual stimuli are successively presented, they compete for processing resources (see Keysers and Perrett, 2002 for a review). When the O1-O2 interval is short, O2 is often the first to be identified, but as the O1-O2 interval increases, O1 is increasingly likely to be the first to be identified (Potter et al., 2002). Thus, an object attracts attentional processing resources rapidly, but in the first perceptual stage attentional engagement is labile, so detection of O2 draws resources away from O1 (Potter et al., 2002; Hommel and Akyürek, 2005). This O1 accuracy changes as a function of the O1-O2 interval and has been termed attentional masking (AM) (e.g., Facoetti et al., 2008; Kavcic and Daffy, 2003; Ruffino et al., 2010).

Attentional engagement deficit is probably a multi-sensory dysfunction present in auditory as well as visual domains. Regarding auditory tasks, primary school-age children with SLI and developmental dyslexia (DD) often exhibit an impairment in the processing of rapid sound sequences (e.g., Helenius et al., 1999; Merzenich et al., 1996; Montgomery et al., 2005; Tallal, 1980, 2004; Tallal et al., 2004; Wright et al., 1997; Vandermosten et al., 2011; but see Studdert-Kennedy, 2002). As proposed by Hari and Renvall (2001), the deficit in processing sound sequences could be due to a prolonged auditory engagement of temporal attention (e.g., Facoetti et al., 2005, 2010; Petkov et al., 2005). Indeed, children with SLI and DD have shown substantial speech-sound perception deficits caused by very serious problems with auditory noise exclusion, which can have tragic consequences for normal linguistic development (Geiger et al., 2008; Ziegler et al., 2005, 2009). Moreover, children with DD have also exhibited deficits in the visual noise exclusion process (Geiger et al., 2008; Sperling et al., 2005, 2006). Visual attentional deficits have been also described in DD with poor phonological decoding skills (e.g., Cestnick & Coltheart, 1999; Facoetti et al., 2006; Facoetti et al., 2010; Ruffino et al., 2010). To our knowledge, no study has investigated visual attentional engagement in children with SLI.

Given the temporal nature of language processing over multiple time scales such as phonemic, syllabic and prosodic (e.g., Goswami, 2011; Hari and Renvall, 2001; Zion Golumbic et al., in press), it is reasonable to ask what role the time-course of attentional engagement might play in ongoing language processing in children with SLI. For example, in the case of the lexicon, children might identify and predict word initial segments and selectively engage attention to those points in time to aid in processing. Similar processes may enable listeners to engage attention where inflectional morphemes or pronouns might appear in the sentences (see Stevens and Bavelier, 2012, for a recent review).

Our hypothesis is that if individuals with SLI require more time to engage attention, then it is less likely they will be able to accurately process a rapid sequence of linguistic stimuli (see Hari and Renvall, 2001). To date, no studies have investigated the relationship between the time-course required to engage visual attention and the fine-tuned ability of processing linguistic information in children with SLI. A relationship between the visual and linguistic domains could suggest that children with SLI have a multi-sensory limitation in information processing.

In summary, two main research questions were investigated in the present study: (i) Is the time-course of visual attentional engagement sluggish in children with SLI? (ii) Is there any relationship between a deficit in visual attentional engagement and the deficit in language ability in children with SLI?

2. Methods

2.1. Participants

Forty-four Italian children were recruited, aged 4;7 to 7;8 (years; months). Twenty-two of the children were diagnosed with SLI; the remaining 22 children exhibited typical development (TD) and were matched with the children with SLI according to chronological age (within 2 months) and performance IQ (within 10 points). The performance IQ was evaluated using the Italian version of the Wechsler Preschool and Primary Scale of Intelligence–III (WPPSI, Fancello and Cianchetti, 2008) for the SLI group, whereas the Italian version of the Raven's Coloured Progressive Matrices (CPM) (Belacchi et al., 2008) was used for the TD group. Several studies have found high correlations, ranging from .67 (e.g., Nehring and Court, 1992; Raven et al., 1998) to .87 (James, 1984), between the CPM and the WPPSI. No differences were found in either mean age or performance IQ between the groups: age (SLI: $M = 6;3$; $SD = 1;0$; range = 4;9–7;8; TD: $M = 6;2$; $SD = 0;11$; range = 4;7–7;8; $t(42) = .206$ $p = .838$); performance IQ (SLI: $M = 99$; $SD = 13$; range = 85–128; TD: $M = 102$; $SD = 12$; range = 90–130; $t(42) = .977$ $p = .334$).

Children with SLI were recruited through a Health Service in Padua (Centro Medico di Foniatria) and were diagnosed by psychologists and speech therapists employed by this agency. Following Leonard's (1998) criteria, children were included in the SLI group only if they did not present with other conditions that could potentially cause or contribute to their language impairment. Thus, children with SLI showed: typical cognitive abilities on a psychological assessment (WPPSI); normal hearing; and the absence of both neurological and psychiatric disorders. Six standardized language tests were used by therapists to identify below age-level receptive and expressive language skills in the areas of vocabulary and grammar. The test data for each participant with SLI can be seen in Table 1. The tests for receptive vocabulary were: the Italian version of the PPVT-R (Stella et al., 2000) or Test di Valutazione del Linguaggio (Cianchetti and Fancello, 2003). For receptive morphosyntax, the tests were Test di Comprensione Grammaticale per Bambini (Chilosi and Cipriani, 1995) or the Italian version of the TROG-2 (Suraniti et al., 2009). The tests for expressive vocabulary were: Test di Valutazione del Linguaggio (Cianchetti and Fancello, 2003) or the Italian version of the Boston Naming Test (Riva et al., 2000). Regarding expressive morphosyntax, this skill was evaluated by therapists through a spontaneous language sample. All participants had qualified for enrollment in speech-language therapy in the National Health Service, but no child had yet begun therapy at the time of the experiment.

Typically developing children were recruited from preschools and primary schools in Padua. According to parent and teacher report, children had: normal language; typical cognitive developmental; normal or corrected-to-normal vision; and the absence of both neurological and psychiatric disorders. Normal hearing was tested by pure-tone hearing screening bilaterally (20 dB HL) at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz (American Speech-

Language-Hearing Association, 1997). Finally, a standardized nonword repetition task was administered to children with TD (VAUMeLF, Bertelli and Bilancia, 2006), revealing age-appropriate performance. In Italian, nonword repetition tasks are an accurate means of identifying children as language impaired or free of language impairment (Bortolini et al., 2006).

Experimental procedures were conducted according to guidelines for the protection of human participants of the University of Padua; parental consent was obtained for each child before inclusion in the study.

2.2. Material and Procedure

Three tasks were administered to all participants – an attentional masking task, and two language comprehension tasks. The tasks were administered separately over two or three sessions in random order (one session per day), each lasting 30 minutes. The children were tested individually in a quiet room, with only the examiner present.

All tasks were presented on a Toshiba Satellite Pro laptop computer. To perform the tasks we used E-Prime software (Schneider et al., 2002).

2.2.1 Attentional Masking (AM) Task—The experiment was conducted in a dimly lit (luminance of 1.5 cd/m^2) and quiet room. Participants were seated in front of a monitor; viewing distance was 40cm. The fixation mark was a cross presented in the center of the screen (.3 deg of visual angle). The mask was a ‘white noise’ mask. Stimuli were non-verbal objects, obtained by removing three line segments from an 8-like figure ($1.6 \times 2.7 \text{ deg}$), comprising seven line segments; four objects were used (see Figure 1). Participants viewed the sequence of stimuli binocularly. All visual stimuli were black ($.6 \text{ cd/m}^2$), whereas the background was white (119 cd/m^2). Each trial began with the onset of the fixation mark (duration 1000) ms). Participants were instructed to keep their eyes on the fixation mark throughout the entire duration of the trial.

Three conditions were planned and training was provided at the beginning of the experimental session (see Figure 1 for a schematic representation of the stimulus sequence for the AM task). The three conditions were the following:

1. **Unmasked Condition (UC;** see Figure 1A). In order to control for visual perceptual abilities, a single object (O) was displayed (duration 100 msec) and followed by a blank (duration 400 msec). The participants had to identify the object, choosing between the four possible object stimuli displayed on the screen until their responses were given. The participants responded by pointing, and the experimenter entered the response by pressing the corresponding key on the computer keyboard. No feedback was provided. The session consisted of 8 trials.
2. **Masked Condition (MC;** see Figure 1B). In this condition, a mask was presented for a variable and randomized time interval (175 and 225 msec) to maintain the subject’s alertness. The mask was followed by the target (duration 100 msec), followed, in turn, by the post-mask (duration 500 msec). The participants had to identify the object by choosing among the four possible object stimuli displayed on

the screen. Again, pointing responses were required, and the experimenter entered the response by pressing the corresponding key on the computer keyboard. No feedback was provided. The session consisted of 8 trials.

3. **Attentional Masking Condition** (AMC; see Figure 1C). In order to measure the time-course of temporal attention, the children's accuracy in identifying the first object of two sequentially masked objects was recorded. After 1000 msec, the mask was presented for a variable and randomized time interval (175 and 225 msec). The O1 was then presented for a duration of 100 msec at the central location and replaced by the post-mask. The O2 was then displayed for 100 msec after a variable time interval (i.e., 40, 160, 280 and 1000 msec) and immediately replaced by the mask which, in turn, was displayed for 500 msec. The O1-O2 interval between the two objects was 140, 260, 380 and 1100 msec. The O1 and O2 were selected at random (with replacement) among the four possible symbols. At the end of the trial, participants were required to identify the target (O1) by choosing among the four possible object stimuli displayed on the screen. These four objects came onto the screen immediately following the 500 msec post-mask. Each participant was instructed to use all the time needed to identify the target as accurately as possible. The pointing responses of the children were recorded by the experimenter without providing feedback to the children. The experimental session consisted of 32 trials (8 trials $\times$ 4 O1-O2 intervals).

2.2.2. Language Comprehension Tasks—We evaluated two kinds of linguistic abilities in the comprehension domain: the first was a simple lexical comprehension task, whereas the second was a more complex clitic pronoun comprehension task. For all children, the two tasks were administered separately over two sessions in random order (one session per day). In each task, two different colored objects were displayed simultaneously on a computer screen, one on the left side and one on the right side. The two pictures remained visible on the computer screen for the entire duration of the trial. The examiner described the two objects to be sure that the children recognized the objects. The child was seated in front of the screen and listened to a recorded target sentence. Only one of the two objects displayed on the screen matched the sentence target. The auditory stimuli were presented binaurally by computer over Sony headphones (at 60dB).

The following procedure was used to prepare the stimuli. A female speaker with a neutral dialect read the stimuli using a high-quality microphone connected to a computer in an isolated acoustic room. Targets were read at a normal rate and with a normal prosodic variation. Then, each record was edited in a waveform using an Audacity software package to identify the acoustic onset and offset of each target.

The tasks required the child to judge which of the two objects on the computer screen matched the target. The children were instructed to respond by striking the specific key on the keyboard that matched the appropriate picture (/a/, marked with a pink dot, coincided with the picture on the left side of the screen, whereas /l/, marked with a green dot, coincided with the picture on the right side of the screen). The children were instructed to rest their forefingers on the two keys. Moreover, the children were instructed to always

respond as quickly and accurately as possible. A set of practice trials preceded each task. The examiner repeated the practice trials as many times as necessary to ensure that the child understood the task. The dependent variables were accuracy and response time (RT).

2.2.2.1. Lexical comprehension task: The lexical task aimed to measure the children's ability to access words, including their phonological and semantic features. In particular, the children had to judge which of two pictures displayed on the screen was the target word based on hearing the (single) word (e.g., 'luna' [moon]). Each word pair was presented twice. For example, for the pair 'moon/dog' the target was 'moon' on one trial and 'dog' on another trial. The order of the pictures on the screen (left/right) was random. This design feature was intended to avoid any effects of a child's preference for one of the two pictures, or for one side of the screen over the other. All words were appropriate for 5-year-olds' comprehension and production abilities. In each word pair, the two words were matched for syllable length (2 or 3 syllables); moreover, each word in a pair differed in terms of segment onset, semantic features (e.g., animacy), and rhyme (e.g., /lu na/ vs. /ca ne/ [moon vs. dog] or /pe ko ra/ vs. /ta vo lo/ [sheep vs. table]) (see Appendix B).

The experimental session consisted of 32 trials (16 word pairs in 2 blocks). For each trial, RTs were measured beginning immediately with the first phoneme of the word (e.g., timing began with /l/ in the two-syllable word /luna/ 'moon'). In this way, children who were sensitive to the phonological difference between the two words could respond immediately after the onset of the target. Pressing of the response key stopped the clock. Responses occurring prior to the first phoneme of the word were scored as false alarms (negative RT). Responses in which children were not focused on the trial were considered as unscorable.

2.2.2.2. Pronoun comprehension task: The third person of the direct object clitic pronoun in Italian marks person (third), number (singular or plural), and grammatical gender (masculine or feminine). In particular, clitic pronouns assume two singular forms (masculine 'lo' and feminine 'la') and two plural forms (masculine 'li' and feminine 'le'). Importantly, the number and gender of the clitic pronoun is based on the number and gender to which it refers. That is, nouns are always inflected by the final vowel, which marks gender (masculine or feminine) and number (singular or plural). For example, for feminine 'cake' vs. 'cakes' the corresponding singular vs. plural forms are 'torta' and 'torte', respectively; for masculine 'tomato' vs. 'tomatoes' the singular vs. plural forms are 'pomodoro' and 'pomodori', respectively. Gender and number information in nouns is mastered at approximately three years of age by typically developing Italian children (e.g., Caselli et al., 1994).

Given a sentence such as 'il bambino la mangia' (the boy eats it) listeners can understand which kind of food the boy is eating (e.g., cake or tomato) only by processing the clitic pronoun. In this example, the clitic pronoun 'la' denotes a feminine noun. As can be seen, then, the pronoun comprehension task was designed to measure the children's ability to access the grammatical features of number (singular vs. plural) and gender (masculine vs. feminine) of the clitic pronoun and apply this information to determine the appropriate referent on the computer screen.

In this task, the children had to process separately the gender and number of the pronouns. When an item required a distinction in number, the singular referent was depicted by a single object (e.g., one cake) and the plural referent was depicted by two objects (e.g., two bananas) of the same type. When an item required a distinction in gender, the masculine and feminine referents were either one object each (e.g., one apple and one ice cream cone) or two objects each (e.g., two candies and two melons).

For all items in the pronoun comprehension task, the children listened to target sentences of the same syntactic structure (il bambino + clitic pronoun + mangia, ‘the boy [clitic pronoun] eats’). Thus, responses were based solely on the number and gender of the clitic pronoun.

The task consisted of 32 trials (4 word pairs $\times$ 4 clitic pronouns $\times$ 2 blocks) (see Appendix C). The order of item presentation was random. Across the 32 trials, the location of the target picture appeared equally often at the left and right side of the screen. For each trial, RTs were measured immediately after the pronoun. For example, for the sentence ‘il bambino le mangia’, timing began immediately after the clitic le. Responses occurring prior to the end of the pronoun were scored as false alarms (negative RT), and those responses in which children were not focused on the trial were considered as unscorable.

3. Results

3.1. Attentional masking task

The mean percentages of O1 accuracy identification, and the corresponding standard deviations for the three conditions (Unmasked, Masked and Attentional Masking) are shown in Table 2.

In order to ensure that group differences were not due simply to problems with perceptual masking, a mixed 2×2 ANOVA was calculated, with mean accuracy in the Unmasked Condition and Masked Condition as a within-subjects factor and participant group (SLI and TD) as a between-subjects factor. The results showed no difference between groups ($F < 1$), or between conditions, $F < 1$. Moreover, no significant interaction was found, $F(1,42) = 3.47$, $p = .069$, $\eta^2 = .07$.

The interference caused by O2 on O1 (Attentional Masking Condition) was then analyzed with a mixed 4×2 ANOVA that had O1-O2 interval (140, 260, 380 and 1100 msec) as a within-subjects factor and Group (SLI and TD) as a between-subjects factor. Since the O1-O2 interval factor was not linear, a logarithmic transformation was applied to the data. The results showed that the O1-O2 interval main effect was significant $F(3,126) = 36.62$, $p < .001$, $\eta^2 = .49$, whereas the Group main effect was not significant, $F(1,42) = 1.41$, $p = .173$, $\eta^2 = .05$. Importantly, the Group $\times$ O1-O2 interval interaction was significant, $F(3,126) = 3.72$, $p = .013$, $\eta^2 = .08$ (see Figure 2), indicating that the time-course of the attentional engagement differed between the two groups.

To verify the crucial Group $\times$ O1-O2 interaction, we compared the slope of the time-course of attentional engagement between SLI and TD children using the mean percentages of accurate responses. To meet this aim, for each participant a linear regression with the raw

scores expressed as a function of the O1-O2 interval was computed. A t -test on the regression coefficients (standard β) showed that AM was steeper for the children with SLI (mean = .44, SD = .28) than for the TD children (mean = .28, SD = .22), $t(42) = 2.08$, $p = 0.04$, $d = .57$.

To obtain a general index of the attentional engagement deficit, the mean between the accuracy at 140 msec and at 1100 msec of the O1-O2 interval was calculated (AM effect). The accuracy at 140 msec is an index of the maximum degree of interference caused by O2 on O1, whereas the accuracy at 1100 msec is an index of the duration of attentional engagement. To control for any effects attributable to perceptual masking, the masked effect was removed by subtracting the AM effect from accuracy scores in the Masked Condition.

The AM effect could be an informative measure of the interference caused by O2 on O1 due to sluggish attentional engagement: the larger the AM effect, the slower the engagement of temporal attention. Pairwise comparisons showed a significant difference between the SLI and TD groups in the AM effect (SLI = .33, SD = .21; TD = .19, SD = .17), $t(42) = 2.45$, $p = .02$. $d = .66$.

The pattern of substitutions was also of our interest for the interference caused by O2 on O1: if the AM effect was related to sluggish attentional engagement on O1 then children should identify O2 more frequently than chance level (i.e., with three possible substitutes, chance was assumed to be .33). The children with SLI show a specific bias to O2 with a percentage (.58) significantly greater than chance, $t(21) = 5.03$, $p < .0001$, 95% confidence interval 0.48–0.68. On the contrary, in children with typical development, the relative percentage of O2 (.39) was not significant, $t(21) = .88$, $p = .39$, 95% confidence interval 0.25–0.54.

3.2. Language comprehension task

Prior to analysis of the children's RTs, two type of responses were excluded. The first type came from trials in which the response was incorrect. The second type of response involved RTs less than 10 msec and were considered to be too short to be genuine responses to the stimuli (Leonard et al., 2007). The mean of the remaining RTs for each participant was then calculated and then outliers removed (Kail, 1994). Outliers were defined as any RTs greater than 2 SD above or below the mean. This procedure was repeated until no outlier was present. Using this outlier procedure all RTs below 300 msec were removed from the pronoun task data. For the lexical task data, since shorter RTs are common in such tasks both in children with SLI and in TD group, the lower limit was 250 msec.

3.2.1. Lexical comprehension—The accuracy of the children with SLI (mean = .96, SD = .05) on the lexical comprehension task was similar than that of the TD children (mean = .98, SD = .02), $t(42) = -1.95$, $p = .058$, with an effect size of $d = -.45$. Because RT is not meaningful if children's accuracy is at chance levels, we included only those children performing above the level of chance (i.e., above .65; binomial test, $\alpha = .10$, one tailed). For the lexical comprehension task, all participants were included. The RTs were normally distributed for both groups (Kolmogorov-Smirnov test, all $ps. > .05$). For this task, the children with SLI showed significantly slower RTs than the TD children (SLI: mean = 1180

msec, $SD = 308$, median = 1050 msec; TD: mean = 972 msec, $SD = 220$, median = 931 msec): $t(42) = 2.57$, $p = .014$, $d = -.67$.

A significant negative correlation was found ($r = -0.331$, $p = .028$) between accuracy and RTs, indicating that children who were slower were also less accurate. We then calculated for each participant the inverse efficiency (IE; e.g., Kennett et al., 2001; Townsend and Ashby, 1983), obtained by dividing the mean RT by the proportion of correct responses. The measure of IE can be considered as a measure of how much time the children needed to correctly respond; thus both speed and accuracy were taken into account with this measure. Children with SLI (mean IE = 1236, $SD = 359$) showed less efficient access to lexical representations than the TD group (mean IE = 989, $SD = 225$), $t(42) = 2.73$, $p = .008$, $d = -1.10$.

3.2.2. Pronoun comprehension—On the pronoun comprehension task, the children with SLI were less accurate (mean = .65, $SD = .15$) than the TD children (mean = .91, $SD = .11$), $t(42) = -6.43$, $p < .001$, $d = -1.68$. Given our requirement for above-chance accuracy for inclusion in the analysis of RTs, only 12 children with SLI were included in RT analyses. In contrast, all TD children scored above chance levels and were therefore included. The RTs were normally distributed for both groups (Kolmogorov-Smirnov test, all $ps > .05$). The children with SLI appeared to be somewhat slower than the TD children, but this difference was not significant (SLI: mean = 1760 msec, $SD = 595$, median = 1855 msec; TD: mean = 1461 msec, $SD = 574$, median = 1242 msec), $t(32) = 1.43$, $p = .163$, $d = .50$).

A significant negative correlation was found between accuracy and RTs ($n = 34$, $r = -0.429$, $p = .036$), indicating that children who were slower were also less accurate. Analysis based on the IE revealed that the children with SLI ($n = 12$) were significantly less efficient than the TD children ($n = 22$) (SLI: mean = 2341, $SD = 926$; TD: mean = 1667, $SD = 831$), $t(32) = 2.17$, $p = .037$, $d = -.81$).

3.3. The relationship between AM and language comprehension

3.3.1. AM and lexical comprehension—All 44 children could be included in the examination of the relationship between AM and lexical comprehension, as all children performed above the level of chance on the lexical task. Correlation coefficients between the AM effect, age, performance IQ, and IE of the lexical comprehension task in 22 children with SLI and 22 TD children were performed (see Table 3). For the children with SLI, the results showed a highly significant correlation between the AM effect and all other variables. Moreover, as expected, a significant correlation between age and IE was found. For the TD children, age and IE were correlated with the AM effect. A correlation between age and IE was also found.

On the basis of the results reported in Table 3, we planned a series of regression analyses to explore in a more stringent way the relationship between the AM effect and lexical comprehension. Given that our children ranged in age from 4;7 to 7;8, and that age was highly correlated with IE, we wanted to explore the contribution of the AM effect to lexical processing, controlling for the effect of age. For this reason, one fixed-order entry multiple regression analysis was performed for each group (see Table 4). For each regression, the

outcome variable was the IE of lexical comprehension, the first predictor was age, and the second predictor was the AM effect.

For the children with SLI, age accounted for a significant 56% of the variance, whereas the AM effect did not explain any additional variance. For the TD children, age accounted for a significant 44% of the variance; the AM effect failed to account for any additional variance.

3.3.2. AM and pronoun comprehension—Recall that only 12 children with SLI (and all 22 TD children) performed above the level of chance on the pronoun comprehension task and could therefore be included in the examination of the relationship between the AM effect and pronoun comprehension. Correlation coefficients between the AM effect, age, performance IQ and IE of the lexical comprehension task were performed, separately for the SLI and TD groups (see Table 5). For the children with SLI, the results showed that age and IE were correlated with the AM effect. For the TD children, age and IE were correlated with the AM effect; a relation between IE and age was also found.

To explore the relationship between the AM effect and pronoun comprehension while controlling for the effect of age, we conducted the same set of fixed-order entry multiple regression analysis used above (see Table 6). For children with SLI the AM effect significantly accounted for 48% of the variance beyond that explained by age. For the TD children, age accounted for a significant 18% of the variance. The AM effect failed to account for any additional variance.

4. Discussion

4.1. Is the time-course of visual attentional engagement sluggish in children with SLI?

The main aim of the present study was to investigate the attentional engagement efficiency in children with SLI by measuring their identification of the first of two rapidly masked objects. An object attracts attentional processing resources rapidly, but in the first perceptual stage, the attentional engagement is labile. Thus the O1 identification is reduced because the detection of O2 draws resources away from O1 (i.e., object competition or interference).

Our results showed that children with SLI had a deeper AM than TD at the shortest O1-O2 interval (140 msec), suggesting that attentional engagement could be weak and/or less resistant to a rapidly following competitive object. Moreover, the different slopes of the time-course of attentional engagement between SLI and TD children appear to confirm this interpretation. These results suggest that in children with SLI, the temporal window in which the object is engaged appears to be abnormally sluggish, hampering the efficient sampling of the perceptual object necessary to understand ongoing information flow. This result is compatible with two previous studies exploring AM in children with developmental dyslexia (Facoetti et al., 2008; Ruffino et al., 2010). According to these studies, dyslexia arises, not only from deficits in systems that are exclusively linguistic in nature, but also from a visual attentional impairment, which, in turn, can lead to a language disorder.

The AM effect observed in the present study cannot be attributed to group differences in pure visual-perceptual abilities. The SLI group, like the TD group, showed a clear ability to perceive O1 in the Unmasked Condition and at longest O1-O2 interval.

Moreover, these results also appear to rule out a visual persistence deficit (e.g., Di Lollo et al., 1983) because in the Masked Condition and at longest O1-O2 interval the O1 identification was similar in the children with and without SLI. This result also allows us to exclude a simple backward masking deficit (e.g., Montgomery et al., 2005; Wright et al., 1997) or a general perceptual noise-exclusion deficit (e.g., Geiger et al., 2008; Ziegler et al., 2005, 2009). Although it has long been maintained that backward masking reflects a perceptual phenomenon, it is now clear that target and mask stimuli compete for processing resources (i.e., the “object substitution” theory; for a review see Enns and Di Lollo, 2000). Thus, deployment of multi-sensory temporal attention could be crucially involved in allowing perceptual identification of an object (target) immediately followed by a second object (mask). Importantly, multi-sensory backward masking is also strongly modulated by spatial as well as temporal attention (e.g., Enns, 2004; Zhang and Formby, 2007).

Finally, these results cannot be explained in term of restricted or inefficient working memory (WM) (e.g., Dollaghan and Campbell, 1998; Gathercole and Baddeley, 1990; Marton and Schwartz, 2003; Montgomery, 2000), because O1 perception was different between the two groups only when O2 was displayed at the shortest O1-O2 interval, but not at longer intervals. Indeed, it would be expected that a WM deficit would impair the O1 identification when a longer, rather than shorter time separated it from O2 presentation. Moreover, recent models (Cowan et al., 2005; Gazzaley and Nobre, 2012) have indicated that individual differences in WM are associated with variation in selective attentional abilities and that factors that limit attentional capacity can impair performance on WM tasks. For these reasons, a pure WM disorder does not appear to be an accurate explanation of the AM deficits described here.

In summary, as our O2 substitution finding suggested, the results are consistent with a sluggish engagement of temporal attention in the children with SLI rather than with a basic perceptual or WM deficit in these children. It appears that the temporal window during which the engagement of attention toward a visual stimulus is labile appears to be longer in children with SLI than in TD children.

The ventral regions of the right fronto-parietal circuit are the cortical regions controlling multi-sensory attentional engagement in humans (e.g., Battelli et al., 2007; Corbetta and Shulman, 2002, 2011; Downar et al., 2000). Functional magnetic resonance imaging (fMRI) studies have demonstrated predominantly right fronto-parietal activations associated with engagement of temporal attention (e.g., Giesbrecht and Kingstone, 2004; Marois et al., 2000). In addition, attentional disengagement may be prolonged even four-fold in patients with left-side neglect due to damage of the right parietal lobe (Husain et al., 1997). Interestingly, patients with right inferior parietal damage show a severe loss in the perception of apparent motion also in their “good” right visual field (Battelli et al., 2003). These deficits are probably due to a bilateral impairment in temporal attention to the transient events that drive the apparent motion percept. It is interesting that this motion

perception deficit is similar to that shown by children with SLI and DD (e.g., Cestnick and Coltheart, 1999; Sperling et al., 2006). The multi-sensory order of events, whether two events are seen as simultaneous or successive, is also crucial for language development. Judgment of temporal order, simultaneity and high-level motion are all compromised following right parietal lesions and degraded after transcranial magnetic stimulation over the right parietal but not elsewhere (see for a review Battelli et al., 2007). The right parietal lobe could serve as part of a “when pathway” for both visual and auditory attention.

A sluggish deployment of temporal attention in children with SLI could be compatible with a mild dysfunction of the right inferior parietal cortex. In agreement with the present results, showing a clear prolongation of engagement of attention in children with SLI, psychophysical and behavioral results (i.e., temporal order judgment between visual hemifields, perception of a line motion illusion and spatial cueing tasks) suggest that dyslexic adults and children suffer from a left-side “minineglect” (e.g., Facoetti et al., 2001; Hari et al., 2001).

Thus, our data are compatible with a right inferior parietal dysfunction in SLI that could impair the temporal selection mechanism of multi-sensory attention crucially involved in the development of an efficient sampling of syllabic-objects perception (see Goswami, 2011 for a recent review).

4.2 Is there any relationship between a deficit in attentional engagement and the deficit in language ability in children with SLI?

Before discussing the relationship between AM and language processing, it is important to note that the results of the lexical and pronoun comprehension tasks replicated previous findings for Italian-speaking children with SLI. Earlier studies have shown that children with SLI are more likely to err on clitic pronouns than younger typically developing children whose mean lengths of utterance are similar to those of the children with SLI (Bortolini et al., 1997; Leonard and Bortolini, 1998). Furthermore, difficulty with this feature has proven to be an especially accurate index of identifying language impairment in Italian; measures of clitic pronoun use have shown very good sensitivity and specificity (Bortolini et al., 2001, 2006). In contrast, as is well known, lexical ability does not constitute as much of a problem as grammatical ability in children with SLI (e.g., Leonard, 1998). In the present study, the children with SLI and the TD children showed 96% and 98% accuracy, respectively, on the lexical comprehension task (medium effect size d of $-.45$), whereas the two groups showed 65% and 91% accuracy on the clitic pronoun comprehension task (very large effect size d of -1.68). The fact that the lexical task did not reveal group differences, notwithstanding the fact that some children with SLI in our sample showed vocabulary weaknesses (see Table 1), could be due to the fact that our lexical comprehension task was not sufficiently sensitive to capture such differences.

The RT findings for lexical comprehension and pronoun comprehension were also in line with previous research. Several studies have shown slower RTs by children with SLI on picture naming tasks (e.g., Leonard et al., 1983), sentence-embedded word recognition tasks (Montgomery, 2006, 2008) and on receptive lexical tasks as well (Miller et al., 2001). We are not aware of studies that have specifically examined RTs for clitic pronouns. However,

slower RTs for other types of grammatical items are readily seen in the literature (e.g. Leonard et al., 2009; Miller, et al., 2001; Montgomery and Leonard, 2006; Wulfeck and Bates, 1995). In the present study, the lack of RT differences between groups in the pronoun task should be not surprising in light of the small number of children with SLI participating in the task ($n=12$) relative to the much larger numbers of participants in previous RT studies (e.g., Kail, 1994; Miller et al., 2001; Leonard et al., 2007).

Collectively, these findings indicate that the SLI and TD participants in the present study were representative, giving us confidence that relating the children's language processing performance to the AM results is quite appropriate.

Regarding the link between AM and language processing, we showed that the time-course that children needed to engage their attention had a relationship with the time needed to correctly process linguistic information. This result suggests that temporal attention limitations may have an adverse effect on higher level linguistic processing. As Miller et al. (2001) proposed, the operations central to language learning, such as the parsing and extraction of special linguistically relevant details in the speech stream, are strongly time-dependent. In fact, in order to become a proficient user of language, infants must detect temporal cues embedded within the noisy acoustic spectra of ongoing speech by efficient auditory processing (e.g., Benasich and Tallal, 2002; Tallal, 1980, 2004; Wright et al., 1997). Given the temporal nature of language, a sluggishness in engagement of temporal attention could have a detrimental impact when time-dependent information must be processed. In Italian, this may be the case for clitic pronouns; one important physical property of these morphemes is their short duration. According to findings from several different laboratories (Bortolini and Leonard, 1996; Gerken, 1991, 1994; Gerken et al., 1990; Leonard and Bortolini, 1998), children with SLI have greater difficulty in processing unstressed syllables when these elements immediately follow another weak syllable. This is precisely the context in which clitic pronouns often appear, as seen in the weak syllable – weak syllable sequence *no la* in *Il bambinola mangia*. Considering the sluggish attentional engagement in children with SLI, the brief duration of the pronoun could be a crucial factor because brief morphemes must be perceived and processed quickly given that there is a little time before new material will appear. If individuals require more time to engage attention, then it is unlikely they will be able to accurately complete tasks involving the rapid presentation of stimuli, which is typically the case for clitic pronouns.

In the case of the lexicon, the relationship between AM and lexical comprehension was not found. This might be because the lexicon might not be as highly time dependent. In fact, as Miller et al. (2001) have shown, RTs for picture naming and picture matching tasks are not as slow as RTs for grammatical tasks. However, it is important to stress that this result could be altered by the ceiling effect found in lexical accuracy.

Finally, regarding children with typical language development, the regression analyses showed that age was the only significant predictor of performance on both the lexical and pronoun tasks. This result was expected given the age range studied here (5 to 7 years), a period when children are still developing language and not yet at mastery levels (e.g., Fenson et al., 1994; Tomasello, 2003).

5. Conclusion

In the present study, a sluggish engagement of visual temporal attention was observed in children with SLI relative to typically developing children with similar chronological ages and nonverbal IQ scores. In addition, individual differences in temporal engagement of attention predicted the grammatical performance across participants with SLI. Given this relationship, it seems that this slower engagement might be a contributing factor in the inefficient processing of rapid sequences of linguistic objects in the input. Among the processes that are necessary for syllabic and phonemic object perception, speech-sound segmentation may be linked to the selection mechanism of general temporal attention.

Attention is considered to be a system that is deeply involved in language processing (Conner et al., 2000); for this reason, it is not surprising if a language-learning impairment seem to be associated with an attentional dysfunction. In fact, recently, several researchers (Finneran et al., 2009; Im-Bolter et al., 2006; Montgomery, 2006, 2008; Rose et al., 2001; Spaulding et al., 2008) have begun to specifically relate attention (in particular the focus of attention and the ability to sustain attention) to language impairments in both the visual and auditory modalities.

Finally, we hypothesize that the neural basis of temporal engagement deficits in children with SLI could be a mild right fronto-parietal dysfunction.

Acknowledgments

This work was supported by grant from the University of Padova (Assegno di Ricerca Senior 2011). We are grateful to the children who participated in the study and their parents who gave their consent. Finally, we thank Anna Ruggiero for her help in data collection.

References

- Battelli L, Cavanagh P, Martini P, Barton JJS. Bilateral deficits of transient visual attention in right parietal patients. *Brain: A Journal of Neurology*. 2003; 126:2164–2174. [PubMed: 12821511]
- Battelli L, Pascual-Leone A, Cavanagh P. The 'when' pathway of the right parietal lobe. *Trends in Cognitive Sciences*. 2007; 11:204–210. [PubMed: 17379569]
- Bavin E, Wilson P, Maruff P, Sleeman F. Spatio-visual memory of children with specific language impairment: Evidence for generalized processing problems. *International Journal of Language and Communication Disorders*. 2005; 40:319–332. [PubMed: 16195191]
- Belacchi, C.; Scalisi, TG.; Cannoni, E.; Cornoldi, C. *Coloured Progressive Matrices*. Firenze: Giunti O.S.; 2008.
- Benasich AA, Tallal P. Infant discrimination of rapid auditory cues predicts later language impairment. *Behavioural Brain Research*. 2002; 136:31–49. [PubMed: 12385788]
- Bertelli, B.; Bilancia, G. *Batterie per la Valutazione dell'Attenzione Uditiva e della Memoria di Lavoro Fonologica nell'Età Evolutiva*. Firenze: Giunti O.S.; 2006.
- Boden C, Giaschi D. M-stream deficits and reading related visual processes in developmental dyslexia. *Psychological Bulletin*. 2007; 133:346–366. [PubMed: 17338604]
- Bortolini U, Arfé B, Caselli MC, Degasperi L, Deevy P, Leonard LB. Clinical markers for specific language impairment in Italian: The contribution of clitics and nonword repetition. *International Journal of Language and Communication Disorders*. 2006; 41:695–712. [PubMed: 17079223]
- Bortolini U, Caselli MC, Leonard L. Grammatical deficits in Italian-speaking children with specific language impairment. *Journal of Speech and Hearing Research*. 1997; 40:809–820.

- Bortolini U, Caselli MC, Deevy P, Leonard LB. Specific language impairment in Italian: First steps in the search of a clinical marker. *International Journal of Language and Communication Disorders*. 2002; 37:77–93. [PubMed: 12012618]
- Bortolini U, Leonard LB. Phonology and grammatical morphology in specific language impairment: Accounting for individual variation in English and Italian. *Applied Psycholinguistics*. 1996; 17:85–104.
- Caselli MC, Brutti G, Campagnoli Golgi MG, Leonard LB. Produzione e comprensione di alcuni aspetti grammaticali dell'italiano in bambini tra i 2 anni e mezzo e i 5 anni. *Giornale Italiano di Psicologia*. 1994; 5:789–811.
- Cestnick L, Coltheart M. The relationship between language processing and visual processing deficit in developmental dyslexia. *Cognition*. 1999; 71:231–255. [PubMed: 10476605]
- Chilosi, AM.; Cipriani, P. *Test di Comprensione Grammaticale per Bambini*. Tirrenia: Del Cerro; 1995.
- Cianchetti, C.; Fancello, GS. *Test di Valutazione del Linguaggio*. Trento: Erikson; 2003.
- Conner LT, Albert ML, Helm-Estabrooks N, Obler LK. Attentional modulation of language performance. *Brain and Language*. 2000; 71:52–55. [PubMed: 10716805]
- Corbetta M, Shulman GL. Spatial neglect and attention networks. *Annual Review of Neuroscience*. 2011; 34:569–599.
- Corbetta M, Shulman GL. Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*. 2002; 3:201–215.
- Cowan, N. Embedded-process model of working memory. In: Miyake, A.; Shah, P., editors. *Models of working memory: Mechanisms of active maintenance and executive control*. Cambridge, England: Cambridge University Press; 1999. p. 62–101.
- Cowan N, Elliott EM, Saults JS, Morey CC, Mattox S, Hismjatullina A, Conway ARA. On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*. 2005; 51:42–100. [PubMed: 16039935]
- Di Lollo V, Hanson D, McIntyre JS. Initial stages of visual information processing in dyslexia. *Journal of Experimental Psychology: Human Perception and Performance*. 1983; 6:923–935. [PubMed: 6227701]
- Dollaghan C, Campbell T. Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research*. 1998; 41:1136–1146.
- Downar J, Crawley AP, Mikulis DJ, Davis KD. A multimodal cortical network for the detection of changes in the sensory environment. *Nature Neuroscience*. 2000; 3:277–283.
- Ebert KD, Kohnert K. Sustained attention in children with primary language impairment: A meta-analysis. *Journal of Speech, Language, and Hearing Research*. 2011; 54:1372–1384.
- Ellis Weismer S, Evans J, Hesketh L. An examination of verbal working memory capacity in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 1999; 42:1249–1260.
- Ellis Weismer S, Plante E, Jones M, Tomblin JB. A functional magnetic resonance imaging investigation of verbal working memory in adolescents with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2005; 48:405–425.
- Enns JT, Di Lollo V. What's new in visual masking? *Trends in Cognitive Science*. 2000; 4:345–352.
- Enns JT. Object substitution and its relation to other forms of visual masking. *Vision Research*. 2004; 44:1321–1331. [PubMed: 15066393]
- Eyer J, Leonard LB. Functional categories and specific language impairment: A case study. *Language Acquisition*. 1995; 4:177–203.
- Facoetti A, Lorusso ML, Cattaneo C, Galli R, Molteni M. Visual and auditory attentional capture are both sluggish in children with developmental dyslexia. *Acta Neurobiologiae Experimentalis*. 2005; 65:61–72. [PubMed: 15794032]
- Facoetti A, Paganoni P, Turatto M, Marzola V, Mascetti GG. Visuo-spatial attention in developmental dyslexia. *Cortex*. 2000; 36:109–123. [PubMed: 10728901]
- Facoetti A, Ruffino M, Peru A, Paganoni P, Chelazzi L. Sluggish engagement and disengagement of non-spatial attention in dyslexic children. *Cortex*. 2008; 44:1221–1233. [PubMed: 18761136]

- Facoetti A, Trussardi AN, Ruffino M, Lorusso ML, Cattaneo C, Galli R, Molteni M, Zorzi M. Multisensory spatial attention deficits are predictive of phonological decoding skills in developmental dyslexia. *Journal of Cognitive Neuroscience*. 2010; 22:1011–1025.
- Facoetti A, Turatto M, Lorusso ML, Mascetti GG. Orienting of visual attention in dyslexia: evidence for asymmetric hemispheric control of attention. *Experimental Brain Research*. 2001; 138:46–53. [PubMed: 11374082]
- Facoetti A, Zorzi M, Cestnick L, Lorusso ML, Molteni M, Paganoni P, Umiltà C, Mascetti GG. The relationship between visuospatial attention and non-wordreading in developmental dyslexia. *Cognitive Neuropsychology*. 2006; 23:841–855. [PubMed: 21049356]
- Fancello, G.; Gianchetti, C. Wechsler Preschool and Primary Scale of Intelligence – III. Firenze: O.S.; 2008.
- Finneran D, Francis A, Leonard LB. Sustained attention in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2009; 52:915–929.
- Gathercole SE, Baddeley AD. Phonological memory deficit in language-disordered children: is there a causal connection? *Journal of Memory and Language*. 1990; 29:336–360.
- Gazzaley A, Nobre AC. Top-down modulation: bridging selective attention and working memory. *Trends in Cognitive Sciences*. 2012; 16:129–135. [PubMed: 22209601]
- Geiger G, Cattaneo C, Galli R, Pozzoli U, Lorusso ML, Facoetti A, Molteni M. Wide and diffuse perceptual modes characterized dyslexics in vision and audition. *Perception*. 2008; 37:1745–1764. [PubMed: 19189736]
- Gerken LA. A metrical template account of children's weak syllable omissions from multisyllabic words. *Journal of Child Language*. 1994; 21:565–584. [PubMed: 7852473]
- Gerken LA, Landau B, Remez RE. Function morphemes in young children's speech perception and production. *Developmental Psychology*. 1990; 26:204–216.
- Giesbrecht B, Kingstone A. Right hemisphere involvement in the attentional blink: evidence from a split-brain patient. *Brain and Cognition*. 2004; 55:303–306. [PubMed: 15177801]
- Goswami U. A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Science*. 2011; 15:3–10.
- Hari R, Renvall H. Impaired processing of rapid stimulus sequences in dyslexia. *TRENDS in Cognitive Sciences*. 2001; 5:525–532. [PubMed: 11728910]
- Hari R, Renvall H, Tanskanen T. Left minineglect in dyslexic adults. *Brain*. 2001; 124:1373–1380. [PubMed: 11408332]
- Helenius P, Uutela K, Hari R. Auditory stream segregation in dyslexic adults. *Brain*. 1999; 122:907–913. [PubMed: 10355675]
- Hoffman L, Gillam R. Verbal and spatial information processing constraints in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2004; 47:114–125.
- Hommel B, Akyürek EG. Lag-1 sparing in the attentional blink: benefits and costs of integrating two events into a single episode. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*. 2005; 58:1415–1433.
- Husain M, Shapiro K, Martin J, Kennard C. Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature*. 1997; 385:154–156. [PubMed: 8990117]
- Im-Bolter N, Johnson J, Pascual-Leone J. Processing limitations in children with specific language impairment: The role of executive function. *Child Development*. 2006; 77:1822–1841. [PubMed: 17107463]
- James R. A correlational analysis between the Raven's Matrices and WISC-R performance scales. *Volta Review*. 1984; 86:336–341.
- Jonides J, Lacey S, Nee D. Processing of working memory in mind and brain. *Current Directions in Psychological Science*. 2005; 14:2–5.
- Kail R. A method for studying the generalized slowing hypothesis in children with specific language impairment. *Journal of Speech and Hearing Research*. 1994; 37:418–421. [PubMed: 8028323]
- Karmiloff-Smith A. Developmental itself is the key to understanding developmental disorders. *Trends in Cognitive Science*. 1998; 2:389–398.

- Kavcic V, Daffy CJ. Attentional dynamics and visual perception: mechanisms of spatial disorientation in Alzheimer disease. *Brain*. 2003; 126:1173–1181. [PubMed: 12690056]
- Kennett S, Eimer M, Spence C, Driver J. Tactile-visual links in exogenous spatial attention under different postures: convergent evidence from psychophysics and ERPs. *Journal of Cognitive Neuroscience*. 2001; 13:462–478. [PubMed: 11388920]
- Keysers C, Perrett DI. Visual masking and RSVP reveal neural competition. *Trends in Cognitive Science*. 2002; 6:120–125.
- Kohnert K, Windsor J. The search for common ground: Part II. Nonlinguistic performance by linguistically diverse learners. *Journal of Speech, Language, and Hearing Research*. 2004; 47:891–903.
- Leonard, LB. Children with specific language impairment. Cambridge, MA: MIT Press; 1998.
- Leonard L, Bortolini U. Grammatical morphology and the role of weak syllables in the speech of Italian-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 1998; 41:1363–1374.
- Leonard L, Ellis Weismer S, Miller C, Francis D, Tomblin JB, Kail R. Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research*. 2007; 50:408–428.
- Leonard L, Miller C, Finneran D. Grammatical morpheme effects on sentence processing by school-aged adolescents with specific language impairment. *Language and Cognitive Processes*. 2009; 24:450–478. [PubMed: 19690626]
- Leonard L, Nippold M, Kail R, Hale C. Picture naming in language-impaired children. *Journal of Speech and Hearing Research*. 1983; 26:609–615. [PubMed: 6668948]
- Marois R, Chun MN, Gore JC. Neural correlates of the attentional blink. *Neuron*. 2000; 28:299–308. [PubMed: 11087002]
- Marton K, Schwartz R. Working memory capacity and language processes in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2003; 46:1138–1153.
- Merzenich MM, Jenkins WM, Johnston P, Schreiner C, Miller ST, Tallal P. Temporal processing deficits of language-learning impaired children ameliorated by training. *Science*. 1996; 271:77–80. [PubMed: 8539603]
- Miller C, Kail R, Leonard L, Tomblin JB. Speed of processing in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2001; 44:416–433.
- Miller C, Leonard LB, Kail R, Zhang X, Tomblin JB, Francis D. Response time in 14-year-olds with language impairment. *Journal of Speech, Language, and Hearing Research*. 2006; 49:712–728.
- Montgomery CR, Morris RD, Sevcik RA, Clarkson MG. Auditory backward masking deficits in children with reading disabilities. *Brain and Language*. 2005; 95:450–456. [PubMed: 16298671]
- Montgomery J. Role of auditory attention in the real-time processing of simple grammar by children with specific language impairment: a preliminary investigation: a preliminary investigation. *International Journal of Language and Communication Disorders*. 2008; 43:499–527. [PubMed: 22612629]
- Montgomery J. Real-time language processing in school-age children with specific language impairment. *International Journal of Language and Communication Disorders*. 2006; 41:275–291. [PubMed: 16702094]
- Montgomery J. Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2000; 43:293–308.
- Montgomery J, Leonard LB. Effect of Acoustic Manipulation on the Real-Time Inflectional Processing of Children With Specific Language Impairment. *Journal of Speech, Language, and Hearing Research*. 2006; 49:1238–1256.
- Nehring, D.; Court, J. An update on the psychometrics of the Raven Progressive Matrices; Paper presented at the XXV International Congress of Psychology; Brussels. 19 – 24 July, 1992;
- Petkov CI, O'Connor KN, Benmoshe G, Baynes K, Sutter ML. Auditory perceptual grouping and attention in dyslexia. *Cognitive Brain Research*. 2005; 24:343–354. [PubMed: 15993772]
- Potter MC, Staub A, O'Connor DH. The time course of competition for attention: attention is initially labile. *Journal of Experimental Psychology: Human Perception and Performance*. 2002; 28:1149–1162. [PubMed: 12421061]

- Raven, J.; Raven, JC.; Court, JH. Raven manual, Section 1 (General overview), Section 2 (Coloured Progressive Matrices) and Section 6 (The Crichton Vocabulary Scale). Oxford, UK: Oxford Psychologists Press; 1998.
- Rice M, Wexler K, Cleave P. Specific language impairment as a period of extended optional infinitive. *Journal of Speech and Hearing Research*. 1995; 38:850–863. [PubMed: 7474978]
- Riva D, Nichelli F, Devoti M. Developmental aspects of verbal fluency and confrontation naming in children. *Brain and Language*. 2000; 71:267–284. [PubMed: 10716861]
- Roach NW, Hogben JH. Attentional modulation of visual processing in adult dyslexia: a spatial-cuing deficit. *Brain*. 2007; 130:771–785. [PubMed: 17237361]
- Rose CL, Murphy LB, Schickedantz B, Tucci J. The effects of event rate and signal probability on children's vigilance. *Journal of Clinical and Experimental Neuropsychology*. 2001; 23:215–224. [PubMed: 11309675]
- Ruffino M, Trussardi AN, Gori S, Finzi A, Giovagnoli S, Menghini D, Benassi M, Molteni M, Bolzani R, Vicari S, Facoetti A. Attentional engagement deficits in dyslexic children. *Neuropsychologia*. 2010; 48:3793–3801. [PubMed: 20833191]
- Schneider, W.; Eschman, A.; Zuccolotto, A. E-Prime user's guide. Pittsburgh: Psychology Software Tools Inc.; 2002.
- Schul R, Stiles J, Wulfeck B, Townsend J. How 'generalized' is the 'slowed processing' in SLI? The case of visuospatial attentional orienting? *Neuropsychologia*. 2004; 42:661–671. [PubMed: 14725803]
- Skottun BC. The magnocellular deficit theory of dyslexia: the evidence from contrast sensitivity. *Vision Research*. 2000; 40:111–127. [PubMed: 10768046]
- Spaulding TJ, Plante E, Vance R. Sustained selective attention skills of preschool children with specific language impairment: Evidence for separate attentional capacities. *Journal of Speech, Language, and Hearing Research*. 2008; 51:16–34.
- Sperling AJ, Lu ZL, Manis FR, Seidenberg MS. Motion-Perception Deficits and Reading Impairment. It's the Noise, Not the Motion. *Psychological Science*. 2006; 17:1047–1053. [PubMed: 17201786]
- Sperling AJ, Lu ZL, Manis FR, Seidenberg MS. Deficits in perceptual noise exclusion in developmental dyslexia. *Nature Neuroscience*. 2005; 8:862–863.
- Stella G, Pizzioli C, Tressoldi PE. Peabody – Test di Vocabolario Recettivo - P.P.V.T.-R. Peabody Picture Vocabulary Test – Revised. Omega Edizioni. 2000
- Stevens C, Bavelier D. The role of selective attention on academic foundations: A cognitive neuroscience perspective. *Developmental Cognitive Neuroscience*. 2012; 2:30–48.
- Studdert-Kennedy M. Deficits in phoneme awareness do not arise from failures in rapid auditory processing. *Reading and Writing: An Interdisciplinary Journal*. 2002; 15:5–14.
- Suraniti, S.; Ferri, R.; Neri, V. Test for Reception of Grammar Version 2 (TROG-2). Firenze: O.S.; 2009.
- Tallal P. Improving language and literacy is a matter of time. *Nature Reviews Neuroscience*. 2004; 5:721–728.
- Tallal P. Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language*. 1980; 9:182–198. [PubMed: 7363063]
- Tallal, P.; Miller, SL.; Fitch, H. Neurobiological basis of speech: a case for the pre-eminence of temporal processing. Temporal information processing in the nervous system: special reference to dyslexia and dysphasia. In: Tallal, P.; Galaburda, AM., editors. *Annals of the New York Academy of Sciences*. Vol. 692. New York, NY, US: New York Academy of Sciences; 1993. p. 27-47.
- Tallal P, Stark R, Kallman C, Mellits D. A re-examination of some nonverbal perceptual abilities of language-impaired and normal children as a function of age and sensory modality. *Journal of Speech and Hearing Research*. 1981; 24:351–357. [PubMed: 7300276]
- Tomasello, M. Constructing a language. A Usage-Based Theory of Language Acquisition. Cambridge: Harvard University Press; 2003.
- Tomblin JB, Records N, Buckwalter P, Zhang X, Smith E, O'Brien M. Prevalence of specific language impairment in kindergarten children. *Journal of Speech, Language, and Hearing Research*. 1997; 40:1245–1260.

- Townsend, JT.; Ashby, FG. Stochastic modeling of elementary psychological processes. New York: Cambridge University Press; 1983.
- Vandermosten M, Boets B, Luts H, Poelmans H, Wouters J, Ghesquière P. Impairments in speech and nonspeech sound categorization in children with dyslexia are driven by temporal processing difficulties. *Research in Developmental Disabilities*. 2011; 32:593–603. [PubMed: 21269803]
- Vidyasagar TR, Pammer K. Dyslexia: A deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Science*. 2010; 14:57–63.
- Windsor J, Kohnert K, Loxtercamp A, Kan PF. Performance on nonlinguistic visual tasks by children with language impairment. *Applied Psycholinguistics*. 2008; 29:237–268.
- Windsor J, Milbrath R, Carney E, Rakowski S. General slowing in language impairment: Methodological considerations in testing the hypothesis. *Journal of Speech, Language, and Hearing Research*. 2001; 44:446–461.
- Wright BA, Lombardino LJ, King WM, Puranik CS, Leonard CM, Merzenich MM. Deficits in auditory temporal and spectral resolution in language-impaired children. *Nature*. 1997; 387:176–178. [PubMed: 9144287]
- Wulfeck, B.; Bates, E. Grammatical sensitivity in children with language impairment. Technical Report CND-9512. University of California at San Diego: Center for Research in Language; 1995.
- Zhang T, Formby C. Effects of cueing in auditory temporal masking. *Journal of Speech, Language, and Hearing Research*. 2007; 50:564–575.
- Ziegler JC, Pech-Georgel C, George F, Alario FX, Lorenzi C. Deficits in speech perception predict language learning impairment. *Proc. Natl. Acad. Sci. U S A*. 2005; 102:14110–14115. [PubMed: 16162673]
- Ziegler JC, Pech-Georgel C, George F, Lorenzi C. Speech-perception in noise deficits in dyslexia. *Developmental Science*. 2009; 12:732–745. [PubMed: 19702766]
- Zion Golumbic E, Poeppel D, Schroeder CE. Temporal context in speech processing and attentional stream selection: A behavioral and neural perspective. *Brain and Language*. in press.

Appendix A. Lexical Comprehension task

1. /'lu na/ vs. /'ka ne/ [moon - dog]
2. /'le :to/ vs. /'to po/ [bed - mouse]
3. /'fjo re/ vs. /'por ta/ [flower - door]
4. /'tre no/ vs. /'li bro/ [train - book]
5. /'ste :la/ vs. /'bor sa/ [star - bag]
6. /'pe ko ra/ vs. /'ta vo lo/ [sheep - table]
7. /lu 'ma ka/ vs. /ka 'pe :lo/ [snail - hat]
8. /'so le/ vs. /mu 'ka/ [sun - cow]
9. /'ga :to/ vs. /'mo to/ [cat - motorcycle]
10. /'lu po/ vs. /'go :na/ [wolf - skirt]
11. /'ti gre/ vs. /'bar ka/ [tiger - boat]
12. /ma 'ti ta/ vs. /ko 'ni ðo/ [pencil - rabbit]
13. /di 'va no/ vs. /ma 'ja le/ [sofa - pig]
14. /ka 'va :lo/ vs. /pe 'ne :lo/ [horse - brush]

15. /ga 'li na/ vs. /o 'kja li/ [chicken - glassess]

16. /pa pe ra/ vs. /ki 'ta :ra/ [gosling - guitar]

Appendix B. Pronoun Comprehension task

1. mela vs. gelato [apple – ice-cream] (GENDER: “il bambino la mangia” vs. “il bambino lo mangia”)
2. panino vs. pesca [sandwich - peach] (GENDER: “il bambino lo mangia” vs. “il bambino la mangia”)
3. zucchini vs. cipolle [courgette - onions] (NUMBER: “il bambino la mangia” vs. “il bambino le mangia”)
4. finocchi vs. cavolo [fennels - cabbage] (NUMBER: “il bambino li mangia” vs. “il bambino lo mangia”)
5. pizza vs. pomodoro [pizza - tomato] (GENDER: “il bambino la mangia” vs. “il bambino lo mangia”)
6. biscotto vs. carota [cookie - carrot] (GENDER: “il bambino lo mangia” vs. “il bambino la mangia”)
7. pesci vs. salsicce [fishes - sausages] (GENDER: “il bambino li mangia” vs. “il bambino le mangia”)
8. salami vs. frittate [salamis - omelettes] (GENDER: “il bambino li mangia” vs. “il bambino le mangia”)
9. torta vs. banane [cake - bananas] (NUMBER: “il bambino la mangia” vs. “il bambino le mangia”)
10. pollo vs. peperoni [chicken - paprikas] (NUMBER: “il bambino lo mangia” vs. “il bambino li mangia”)
11. patate vs. funghi [potatos - mushrooms] (GENDER: “il bambino le mangia” vs. “il bambino li mangia”)
12. fragole vs. bistecca [strawberries - steak] (NUMBER: “il bambino le mangia” vs. “il bambino la mangia”)
13. caramelle vs. meloni [candies - melons] (GENDER: “il bambino le mangia” vs. “il bambino li mangia”)
14. carciofi vs. formaggino [artichokes - cheese](NUMBER: “il bambino li mangia” vs. “il bambino lo mangia”)
15. arance vs. cioccolata [oranges - chocolate] (NUMBER: “il bambino le mangia” vs. “il bambino la mangia”)
16. jogurt vs. limoni [jogurt - lemons] (NUMBER: “il bambino lo mangia” vs. “il bambino li mangia”)

Figure 1.
A schematic representation of the stimulus sequence used in the Attentional Masking task: A - Unmasked Condition (UC); B - Masked Condition (MC); C - Attentional Masking Condition (AMC)

Figure 2. Mean O1 accuracy and standard error (after logarithmic transformation) as a function of group (children with SLI and TD) and O1-O2 intervals.

Table 1

Expressive and receptive language of participants with SLI: summary scores

Child ^a	Age ^b	Expressive Language			Receptive Language		
		Lexicon	Grammar	EM ^f	Lexicon	Grammar	Grammar
		TVL ^d	BNT ^e		PPVT ^g	TVL ^h	TCGB ⁱ
1 *	4;9	109	1°	H	78		< 50°
2	4;11	94	1°	L		15°	< 25°
3	5;0	128	5°	H		55°	< 50°
4	5;2	85	1°	H		1°	< 10°
5 *	5;2	90	1°	L	71		< 25°
6 *	5;4	87	1°	H		1°	< 10°
7 *	5;5	85	45°	H		55°	< 10°
8	5;8	95	1°	H	73		< 25°
9 *	5;8	85	35°	H	84		14°
10	6;0	106	1°	L	67		34°
11 *	6;2	104	1°	H		35°	< 10°
12	6;6	97	5°	H	81		< 50°
13 *	6;6	97	1°	H		5°	< 10°
14 *	6;8	85	-1.07 SD	H	89		< 25°
15	6;9	117	1°	H		5°	< 25°
16 *	6;10	104	-1.27 SD	H	65		< 10°
17	7;5	85	-.99 SD	L	93		< 10°
18	7;5	96	-1.72 SD	H	86		< 10°
19	7;6	85	-1.72 SD	L	103		16°
20	7;7	118	5°	H	75		< 10°
21	7;7	111	-1.28 SD	H	86		< 10°
22 *	7;8	106	-3.28 SD	L	77		10°

NOTE:

^a Child: Children indicated with an asterisk were excluded from analysis of the pronoun comprehension task data.^b AGE is expressed in years;months.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

- ^cPIQ (Performance IQ, WPPSI-III) has a mean of 100 and a SD of 15 (Fancello & Cianchetti, 2008)
- ^dTVL (Test di Valutazione del Linguaggio): Expressive vocabulary is expressed in 11 centile points (1°, 5°, 15°, 25°, 35°, 45°, 55°, 65°, 75°, 85°, 95°) (Cianchetti & Fancello, 2003).
- ^eBNT (Italian version of the Boston Naming Test): Six-years of age: mean for correct responses is 26.59 (SD 7.9) for males and 25.36 (SD 5.02) for females. Seven-years of age: mean for correct responses is 34.81 (SD 6.85) for males and 33.88 (SD 4.22) for females (Riva et al., 2000).
- ^fEM: Expressive Morphosyntax was evaluated by clinicians through spontaneous language samples as adequate (A), lightly inadequate (L) or highly inadequate (H).
- ^gPPVT has mean of 100 and a SD of 15 (Stella et al., 2000)
- ^hTVL (Test di Valutazione del Linguaggio): Receptive vocabulary is expressed in 11 centile points (1°, 5°, 15°, 25°, 35°, 45°, 55°, 65°, 75°, 85°, 95°) (Cianchetti & Fancello, 2003).
- ⁱTCGB (Test di Comprensione Grammaticale per Bambini): results are expressed in 5 centile points (< 10°, < 25°, < 50°, < 75°, < 95°) (Chilosi and Cipriani, 1995).
- ^jTROG-2: results are expressed in centile points.

Table 2

Mean accuracy (and standard deviation) as a function of group (children with SLI and TD) and condition (Unmasked, Masked and Attentional Masking)

Group	Condition						
	Unmasked		Masked	Attentional Masking			
				140 msec	260 msec	380 msec	1100 msec
SLI	.89 (.14)	.93 (.13)		.39 (.28)	.61 (.29)	.72 (.30)	.82 (.25)
TD	.94 (.12)	.90 (.17)		.58 (.28)	.73 (.26)	.76 (.26)	.85 (.19)
total	.92 (.13)	.92 (.15)		.49 (.29)	.67 (.28)	.74 (.28)	.83 (.22)

Table 3

Correlation coefficients between AM, age, performance IQ, and IE on the lexical comprehension task in 22 children with SLI (shaded) and 22 TD children (unshaded).

TD (n = 22)	SLI (n = 22)			
	AM	AGE	P-IQ	IE
AM	–	–.472 *	–.461 *	.452 *
AGE	–.423 *	–	.114	–.751 **
P-IQ	–.208	.227	–	.007
IE	.423 *	–.665 **	–.321	–

NOTE:

*
p < .05;

**
p < .01

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 4

Multiple regression analysis on Inverse Efficiency in Lexical Comprehension

Lexical Comprehension						
SLI (n = 22)				TD (n =22)		
	R ² change	β	p	R ² change	β	p
Step 1: AGE	.564	-.751	< .001	.442	-.665	.001
Step 2: AM	.012	.125	.471	.024	.172	.363

Table 5

Correlation coefficients between AM, age, performance IQ and IE on the pronoun comprehension task in 12 children with SLI (shaded) and in 22 TD children (unshaded).

	TD (n = 22)	SLI (n = 12)			
		AM	AGE	P-IQ	IE
AM	–	–	–.567*	–.404	.831**
AGE	–.423*	–	–	–.043	–.454
P-IQ	–.208	.227	–	–	–.135
IE	–.366	–.428*	.254	–	–

NOTE:

*
p < .05;

**
p < .01

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 6

Multiple regression analysis on Inverse Efficiency in Pronouns Comprehension

Pronoun Comprehension						
SLI (n = 12)				TD (n =22)		
	R ² change	β	p	R ² change	β	p
Step 1: AGE	.206	-.454	.138	.183	-.428	.047
Step 2: AM	.484	.845	.005	.042	.225	.326