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ERPs reveal atypical processing of subject versus object *Wh*-questions in children with specific language impairment

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Abstract

Background—Children with specific language impairment (SLI) show particular difficulty comprehending and producing object (*Who did the bear follow?*) relative to subject (*Who followed the tiger?*) *wh*-questions.

Aims—To determine if school-age children with SLI, relative to children with typical development (TD), show a more distinct unevenness, or *asymmetry*, in the comprehension of these questions. In addition, this study examined whether the sustained left-anterior negativity (LAN) in event-related potentials (ERP) could be used as a marker for atypical processing of these questions in children with SLI. The LAN effect signals the greater working memory processes for maintaining in memory the dislocated object in object *wh*-questions and reflects working memory capacity in adults. It was predicted that the amplitude of the LAN would be greater in children with SLI, reflecting the characteristic low working memory capacity in this population. The concomitance of these behavioural and electrophysiological effects would suggest that the subject–object asymmetry in SLI should be investigated in relation to poor working memory skills.

Methods & Procedures—Groups including 13 children with SLI, 17 same-age TD children and 18 normal adults completed an auditory sentence comprehension task requiring button responses while continuous electroencephalography (EEG) was collected. Accuracy for subject and object questions was calculated. The mean amplitude values of the ERP data for the *wh*-questions were examined to identify differential processing of subject and object questions.

Outcomes & Results—TD children demonstrated asymmetrical comprehension of subject and object *wh*-questions, whereas children with SLI comprehended both question types poorly and adults did not show subject–object asymmetry. ERP waveforms spanning the *wh*-dependency revealed a large and widespread sustained anterior *positivity* for object relative to subject questions in the TD group, indicating differential processing of these questions. This effect was attenuated and non-significant in the SLI group. The adults' grand average waveforms showed the expected LAN effect, which was opposite in polarity relative to the children, although it only approached significance.

Conclusions & Implications—The finding of less differential processing of subject and object *wh*-questions in SLI relative to TD children suggests inefficient maintenance of sentential

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information in working memory for object questions in SLI. Whereas behavioural methods did not identify subject–object asymmetry in SLI, the more fine-grained method of ERPs elucidated this effect. Further analysis of working memory as the basis for the subject–object asymmetry in SLI is critical for identifying appropriate intervention targets for this population.

Keywords

specific language impairment (SLI); *wh*-questions; working memory; event-related potentials (ERP)

Introduction

A relatively newfound characteristic of specific language impairment (SLI) in children is a marked unevenness, or *asymmetry*, in comprehending and producing subject versus object *wh*-questions. Off-line tasks have been used to evaluate general processing abilities (Deevy and Leonard 2004) and syntactic skills (van der Lely and Battell 2003, Wong *et al.* 2004) as bases for this uneven performance. The current study broadened this area of investigation by examining the electrophysiological brain responses that reflect the processing of subject and object *wh*-questions in children with SLI. The goals of this study were to determine if school-age children with SLI demonstrate distinct unevenness in comprehending subject versus object *wh*-questions and whether working memory ability is related to this asymmetry.

Subject and object *wh*-questions in typically developing and SLI children

English subject and object *wh*-questions have different levels of complexity, although they emerge in spontaneous speech at the same approximate age of 2;5 years; months (Stromswold 1995). Generally, typically developing (TD) preschool children comprehend object questions more poorly than subject questions (e.g. Tyack and Ingram 1977) and produce object questions less accurately than subject questions (e.g. Wilhelm and Hanna 1992). Error analyses have revealed that young children mis-assign subject interpretations to object *wh*-questions in comprehension tasks (Ervin-Tripp 1970) and erroneously produce subject *wh*-questions when they seemingly intend to produce object *wh*-questions in elicited production tasks (Wilhelm and Hanna 1992).

The subject–object asymmetry for comprehension and production of *wh*-questions is especially distinct in children with SLI. Deevy and Leonard (2004) found that in a picture-pointing task, English-speaking children with SLI, ages 4;3–6;10, were less accurate in comprehending object as compared with subject questions, whereas TD children did not show this difference for question type. Studies on the production of *wh*-questions in children with SLI have also revealed uneven performance for subject versus object questions. Wong *et al.* (2004) reported that Cantonese-speaking preschoolers with SLI and younger TD children were less accurate in producing object than subject *wh*-questions, whereas same-age TD children did not demonstrate this asymmetry.

Impaired production of *wh*-questions in SLI has also been exhibited by a unique subgroup of SLI children with a deficit restricted to grammatical abilities. Van der Lely *et al.* (2003) categorized these children as Grammatical-SLI (G-SLI). Van der Lely *et al.* tested *wh*-question production in a group of G-SLI children (mean = 14;10) and in two TD control groups: one matched on grammatical skills (mean = 6;7) and the other matched on vocabulary knowledge (mean = 7;9). The experimenter used prompts such as ‘Miss Scarlet saw someone in the lounge. Ask me who’ to elicit the question ‘Who did Miss Scarlet see in the lounge?’ The G-SLI group produced *who*, *what* and *which* object, as compared with subject, questions less accurately. The grammar-matched TD group showed this asymmetry,

OSV) causes them to be more difficult to process than subject *wh*-questions, which bear canonical word order (subject–verb–object —SVO). We refer to this proposal as the Canonicity Hypothesis. This account suggests that more comprehension errors arise for object as compared with subject *wh*-questions because the child's parser erroneously attempts to assign the canonical SVO structure to object *wh*-questions. This strategy results in a garden-path effect for object, but not subject, questions and consequently, poorer performance in comprehending object questions. According to this hypothesis, the subject–object asymmetry may also impact production because object *wh*-questions might be avoided by the child who has not developed competence in constructing OSV sentences.

The Canonicity Hypothesis has been discredited by evidence of subject–object asymmetry for the comprehension of long-distance *wh*-questions in monolingual preschoolers who speak Dutch, which freely allows both SVO and OVS surface word order for *wh*-questions (Philip *et al.* 2001). In addition, Wong *et al.* (2004) found that Cantonese-speaking preschoolers with SLI exhibited subject–object asymmetry for production of *who*-questions, in spite of the fact that the surface form of *who*-object questions follows the canonical SVO order of declarative sentences. Thus, the Canonicity Hypothesis does not appear to explain the subject–object asymmetry in children with SLI.

Syntactic Distance Hypothesis

A plausible explanation for the subject–object asymmetry is that it results from the longer syntactic distance between the *wh*-filler and its gap in object questions (Stromswold 1995, O'Grady 1997). This explanation is termed the Syntactic Distance Hypothesis. In processing a *wh*-question, the parser must ascribe a syntactic interpretation to each sentential element, beginning with the *wh*-filler. All linguistic information in the sentence must be maintained in working memory until it can be incorporated into the syntactic structure of the string. During processing of a subject question, the *wh*-filler can be interpreted as soon as the gap is identified, which is at the position of the subject noun phrase. In object questions, the gap is arrived at later, thus requiring that the *wh*-word be maintained in working memory for a longer duration. Moreover, the semantic and syntactic complexity of any verbal material intervening between the *wh*-filler and its gap further impacts the working memory system, drawing from its limited storage capacity. The higher working memory demand for object questions may give rise to a simplification strategy by which subject interpretations in comprehension and subject questions in natural and elicited production are favoured over their object counterparts.

Support for the Syntactic Distance Hypothesis is derived from evidence that adult comprehension is influenced by the length between a moved element and its gap in long-distance syntactic dependencies. For example, adults show greater difficulty processing object as compared with subject gap relative clauses (e.g. Wanner and Maratsos 1978). In addition, adults are more likely to interpret a displaced element at the closest viable gap (2a) rather than at a later gap position (2b; Clifton and Frazier 1989), thus demonstrating the impact of syntactic distance on processing (MacDonald 1989, Frazier and Clifton 1996). Similarly, there is evidence that an increase in syntactic distance adversely affects production of *wh*-questions in preschool children. Hildebrand (1987) demonstrated that 4-year-olds showed lower accuracy in producing *what*-object questions as the distance between the *wh*-word and its gap (indicated by —) increased (3). Aligned with this result, Yoshinaga (1996) observed that 3- and 4-year-olds were less accurate in producing long-distance *wh*-questions with embedded objects than embedded subjects, the former of which had a longer distance between the *wh*-filler and the gap in the embedded clause.

- (2) What did the cautious old man whisper^(a) to his fiancé about^(b) during the movie last night?

- (3)
 - a. *What* did the girl hit — with the block?
 - b. *What* did the girl play with — in the kitchen?
 - c. *What* did the boy read a story about — today?

The potential role of syntactic distance in subject–object asymmetry has also been examined in children with SLI. Deevy and Leonard (2004) manipulated question length by presenting short object and subject questions and the identical questions with the addition of two adjectives, which were intended to increase processing load during comprehension. The participants were required to answer subject and object questions (4) by pointing to animals presented in drawings. SLI children performed more poorly than normally developing children in comprehending long object questions, thus supporting the notion that syntactic distance underlies the imbalanced comprehension of subject and object questions in SLI.

- (4)
 - a. Short subject question: Who is washing the dog?
 - b. Short object question: Who is the dog washing?
 - c. Long subject question: Who is washing the happy brown dog?
 - d. Long object question: Who is the happy brown dog washing?

Working Memory in the Syntactic Distance Hypothesis

Working memory is a dedicated, multi-component, capacity limited system that enables a small amount of information to be maintained and processed simultaneously for a short duration as a task is performed (Baddeley 1986). The relationship between working memory and syntactic distance is backed by evidence that adults' poorer processing of object as compared with subject relatives interacts with individual working memory capacity (King and Just 1991, Just and Carpenter 1992, King and Kutas 1995, Fiebach *et al.* 2002). The specific nature of the verbal working memory system engaged in these tasks, though, remains a matter of controversy (Waters and Caplan 2004).

Syntactic distance may constitute an especially strong influence on the comprehension of *wh*-questions in SLI children, considering that SLI is characterized by deficits in working memory (Gillam *et al.* 1998, Ellis Weismer *et al.* 1999, Montgomery 2000, Marton and Schwartz 2003, Leonard *et al.* 2007, Montgomery and Evans 2009). For example, Bishop (1992) explained SLI children's lower accuracy in comprehending complex relative to simple sentences as a function of the sentential words that needed to be maintained in working memory before a grammatically correct interpretation could be achieved. Similarly, Montgomery (1995, 2000) observed that SLI children comprehended sentences with redundant verbal material less accurately than shorter, non-redundant sentences that were otherwise similar in form and meaning. This finding was interpreted as an indication of deficient working memory for sentence processing in children with SLI.

Poor working memory may account for SLI children's difficulty in processing object relative to subject questions considering that object questions have a greater gap-filler distance. To evaluate this proposal, we measured the processing of subject and object *wh*-questions using event-related potentials (ERP). ERPs provide a fine-grained, on-line record of changes in the electrical activity of the brain in response to a particular stimulus.

Event-related potentials and working memory

Various studies have revealed an association between working memory and a left anterior negativity (LAN) in adults. For example, Kluender and Kutas (1993) and Kluender and Münte (1998) found a correlation between object, but not subject, *wh*-questions in German and a large LAN at the filler and gap positions. Fiebach *et al.* (2002) similarly observed a

sustained LAN for German indirect object versus subject *wh*-questions with long, but not short, filler-gap distances. Notably, the LAN was modulated by individual differences in working memory capacity, as measured by Daneman and Carpenter's (1980) reading span task. Individuals with low relative to high working memory capacity exhibited stronger and earlier sustained negativities that were more broadly distributed across the scalp. In addition, Felser *et al.* (2003) observed a LAN for German sentences containing an object gap as compared with a gap-free control condition. These LAN effects were attributed to the higher working memory demand of maintaining the filler active for a longer duration in object questions. In view of this support for the LAN as an electrophysiological index of working memory load during filler-gap dependency processing, we used this ERP component to answer the following question: Is the processing of subject versus object *wh*-questions distinctly different in school-age children with SLI, relative to TD children, as reflected by the LAN effect?

Predictions

Both TD and SLI children were expected to demonstrate lower accuracy in comprehending object relative to subject questions. Prior evidence (Deevy and Leonard 2004) suggested that this asymmetry would be somewhat more marked in SLI children. Given the complexity of the questions, as detailed below, we predicted that typical adults might also exhibit subject-object asymmetry, but to a lesser degree than TD and SLI children. In addition, we projected that SLI children would demonstrate poorer comprehension of both subject and object *wh*-questions than age-matched TD children (Montgomery 2000).

ERP waveforms were expected to reveal a sustained LAN over the filler-gap distance for object relative to subject *wh*-questions (e.g. Fiebach *et al.* 2002). It was anticipated that this effect would span the entire *wh*-dependency, as measured via multiword ERPs, in view of previous studies that detected this effect in ERPs spanning whole clauses (King and Kutas 1995, Fiebach *et al.* 2002). This finding would signify maintenance of the dislocated *wh*-filler in working memory until it fills its gap. In addition, we predicted that the amplitude of the LAN would be greater in SLI than TD children. This expectation was rooted in evidence that low working memory capacity, a characteristic of SLI, is correlated with a greater LAN effect for processing of object questions in adults, relative to the effect in adults with high working memory capacity (Fiebach *et al.* 2002). Thus, it was assumed that the amplitude of the LAN indexes the allocation of working memory in processing of *wh*-questions; individuals with low working memory capacity are presumably less efficient in processing *wh*-questions and should therefore show greater LAN responses. A larger LAN effect in the SLI relative to the TD group would support the Syntactic Distance Hypothesis as an explanation for the subject-object asymmetry in children with SLI.

Method

Participants

Thirty children and 18 adults participated in this study. Thirteen children were classified as having SLI (five females, eight males). These children had a mean age of 10;1 (SD = 15 months). Seventeen children (seven females, ten males) had TD language skills and had a mean age of 10;4 (SD = 12 months). Two children from each group were left-handed. The 18 adults (11 females, seven males) had a mean age of 30 (SD = 3.5 years). One adult was left-handed. The participants were recruited through online and local advertisements in the New York metropolitan area.

All children were healthy individuals with normal or corrected vision whose only spoken language was English. Eligibility criteria for all child participants included: (1) normal

hearing sensitivity, as determined via a hearing screening based upon guidelines by the American Speech–Language–Hearing Association (1997), (2) at least average (85) non-verbal IQ on the Test of Non-verbal Intelligence — Third Edition (TONI-3) (Brown *et al.* 1997), and (3) normal articulation and phonological skills in conversational speech, as judged by a speech–language pathologist (SLP). Children were not eligible to participate if they had any of the following conditions according to parent questionnaires: (1) frank neurological impairments, (2) seizure disorders, (3) motor deficits, (4) psychological or emotional disorders or (5) neurodevelopmental disorders besides for SLI, such as attention deficit disorder.

All children completed two standardized language tests. The Clinical Evaluation of Language Fundamentals — Fourth Edition (CELF-4) (Semel *et al.* 2003) was administered to assess receptive and expressive language skills; and the Peabody Picture Vocabulary Test — Revised (PPVT-R; Dunn and Dunn 1981) assessed single-word receptive vocabulary knowledge.

Children were classified as having SLI if they scored -1.5 SD below the mean or lower on at least one of the composite scores (Receptive Language Score (RLS) or Expressive Language Score (ELS)) of the CELF-4. This criterion was used, rather than classification based on subtests, because composite scores are more reliable than subtest scores. Two children who had two subtest scores close to -1.5 SD and one child with a composite score close to -1.3 SD who did not meet the aforementioned criterion but were diagnosed as SLI by a licensed SLP were classified as SLI. Children who scored above -1 SD from the mean on the composite receptive (CELF-4 RLS) and expressive (CELF-4 ELS) language scores were classified as TD. No eligibility criteria were set for performance on the PPVT-R. In the SLI group, four children were African American, three were White, four were Hispanic, and two were Asian. Within the TD group, six children were African American, seven were White, and four were Hispanic. Possible dialectical variations in the African American children were considered by assessing responses on the expressive subtests of the CELF-4 according to the dialectical variations delineated by Washington and Craig (1994).

As demonstrated in table 1, the SLI and TD groups differed significantly on all subtests and composite scores of the standardized language tests ($p < 0.01$). The SLI and TD groups did not differ significantly on nonverbal intelligence, as measured by the TONI-3 ($p > 0.05$).

The adult participants were healthy college graduates with normal or corrected vision who met the following inclusion criteria: (1) the individual's primary spoken language was English, (2) reported normal hearing abilities, and (3) reported normal language skills. Adults were not eligible to participate if they reported a history of (1) frank neurological impairments, (2) seizure disorders, (3) psychological or emotional disorders, or (4) neurodevelopmental disorders. Three of the adults were African American and 15 were White. One adult was left-handed.

Stimuli

Two sets of comprehension questions based on preceding sentences were selected as the experimental stimuli. The sentences comprised 64 quadruplets, adapted from Love and Swinney (1997), totalling 256 (64×4) sentences. Each quadruplet included three grammatical sentences (e.g. 5) and one ungrammatical sentence. All of the sentences included a relative clause. The sentence sets comprised 32 unique verbs situated in the trace/object position and 32 unique sets of animal names. Each verb was used twice but with different combinations of animal names. The three types of grammatical sentences were designed to examine ERP responses to filled gaps, the data of which will be reported elsewhere. The ungrammatical sentences were constructed by inserting a noun phrase in the

predicted gap position to examine ERP responses to violations of the parser's expectations. The data for the ungrammatical sentences will also be reported elsewhere.

- (5) *Grammatical*: The bear that the gorilla followed in the woods hid behind the tree.

Four types of questions (6) were asked for each sentence: a question about the subject of the sentence (*subject*), a question about the object of the sentence (*object*), a *yes/no object* question, and a *yes/no filler* question. The analyses for the first two question types only are reported here.

- (6)
<i>subject</i> :	a. Who followed the gorilla?
<i>object</i> :	b. Who did the bear follow?
<i>yes/no object</i> :	c. Did the lion follow the bear?
<i>yes/no filler</i> :	d. Did you hear the word fence?

Following each of the 256 sentences, one of 16 exemplars of each question type was presented. The 16 exemplars from each of the four question categories were repeated once for each of the four sentence types ($16 \times 4 = 64$ quadruplets). In addition, a set of 37 filler sentences (14 declaratives + 23 relative clauses) from Love and Swinney (1997) was included to decrease the predictability of the sentences. The filler sentences were followed by comments, such as, 'That's really nice' and 'I like that.' The two lists of stimuli totalled 320 (256 experimental plus 64 (randomly selected from 37) filler) trials and were presented as two consecutive sessions, each including 160 (320/2) trials. In each session, four blocks including 32 experimental and eight filler trials were presented. The data described below pertain to the 48 subject questions and 48 object questions that followed the grammatical sentences (64 grammatical and ungrammatical sentences – 16 ungrammatical sentences = 48 sentences per question type). An analysis of questions following ungrammatical sentences was performed separately because these sentences were infelicitous.

The stimuli were digitally recorded from two female speakers; one speaker produced the sentences and a second speaker produced the questions. The mean duration of the questions was 1516 ms for subject questions and 1812 ms for object questions.

Procedure

Once fitted for ERP recording (see Electrophysiological Recording, below), participants were comfortably seated in a sound- and electrically shielded booth. They faced a computer screen positioned at eye level at a distance of 75 cm. The stimulus presentation and behavioural response collection were executed by a PC with E-Prime software and a serial response box from Psychology Software Tools (Schneider *et al.* 2002). The stimuli were presented over a loudspeaker at 65 dB SPL. Participants were instructed to position the index and fourth finger of their right hand on a response box with labelled buttons. To increase the motivation of the child participants, they were told that at the conclusion of testing, they would receive a small prize commensurate with their performance. In addition, all participants were asked to minimize blinking during presentation of the sentences and questions.

The two lists of stimuli were presented in two consecutive sessions on the same day, each including 160 trials and lasting approximately 45 min. The sessions were separated by a 5–10-min break. One SLI child and one adult completed the sessions on 2 separate days within a couple of weeks, the child due to fatigue and the adult due to equipment complications. The order of the two stimulus lists was counterbalanced across participants. Each session was divided into four blocks of 40 (32 experimental, 8 filler) trials. In each block, 32 experimental trials were randomly drawn from each of three sentence lists for the current

session and eight fillers were randomly drawn from the total of 37 fillers. Alternation of test and filler sentences was randomized. The experimental sentences were followed by random presentation of one of the four question types. Following auditory presentation of each question, two white boxes were displayed on the right and left sides of the computer screen. One of the boxes always contained either a colour picture of an animal (following *wh*-questions) or the word *Yes* or *No* (following yes/no questions) in large, bold letters. The other box always contained a picture of a male stick-figure with a question mark above his head, referred to as the *confused man*. The position of each response type on the screen was counterbalanced. Participants were instructed to listen to each question, think of the answer, and then look on the screen to check if their answer was present. In the event that their answer was not present, they were to select the button on the response box corresponding to the *confused man*, thereby reflecting their confused state. The purpose of this manipulation was twofold. Firstly, inclusion of the *confused man* was intended to allow for a felicitous response to questions based on ungrammatical sentences. This response was an option for questions following all sentence types so that participants would not ascertain the nature of the ungrammatical sentences on the basis of the response alternatives. Secondly, the *confused man* was included because a pilot study indicated that this constant response choice simplified the task, as reflected by increased accuracy scores.

Each experimental trial proceeded as follows: First, a picture of an eye, serving as a fixation aid, appeared in the centre of the computer screen for 2000 ms and remained there during the auditory presentation of the sentence. Following the sentence, a 1000 ms gap of silence ensued, after which a question was auditorily presented. Next, two response options were depicted for 7000 ms. Following a response, or the 7000 ms allowed, accuracy feedback for the trial and cumulative accuracy were displayed for 1500 ms as percentages along with a happy face if the subject responded correctly or a sad face if the subject responded incorrectly.

Electrophysiological recording

EEG data were collected using an Electrical Geodesics 200 system with a 65-channel Geodesic Sensor Net comprising silver/silver chloride (Ag/AgCl)-plated electrodes encased in electrolyte-wetted sponges (for the correspondence between this system's electrode placements and the International 10–10 system, see Luu and Ferree 2000). One additional electrode was placed under each eye to monitor eye blinks and eye movements. The EEG was continuously recorded at a sampling rate of 200 Hz, referenced to Cz. The data were re-referenced to linked mastoids off-line to ease comparison between our findings and those of similar studies. Electrode impedances were maintained below 40 k Ω , which is appropriate for EEG recording with a modern high input impedance amplifier (Ferree *et al.* 2001). Impedances were rechecked and adjusted as necessary between the two sessions. The EEG signal was filtered using a hardware band-pass filter set at 0.1–41.3 Hz and was digitized using 12-bit resolution.

Following recording, the questions from the continuous EEG were segmented into 1450 ms epochs using a 100 ms pre-stimulus baseline of silence and a 1350 ms segment time. A 1350 ms epoch was selected because the shortest subject question was 1355 ms in length and therefore, a cut-off of 1350 ms was approximately the last point at which ERPs for subject and object questions could be compared. The onset of each *wh*-word was aligned with 0 ms.

Data analysis

For the behavioural data, a mixed-model repeated-measures analysis of variance (ANOVA) was calculated to determine whether the expected *question type* (subject, object) effect was observable in each group for accuracy to comprehension questions. This was followed up by

an ANOVA with the within-subjects variable *question type* (subject, object) and the between-subjects variable *group* (TD, SLI) for accuracy. The effect sizes for all significant findings are reported as partial eta-squared, η_p^2 . Only questions following grammatical sentences ($48 \times 4 = 192$ of 256 trials) were included in this analysis.

ERP analysis could not be limited to trials with correct answers to comprehension questions because this would have decreased the statistical power of the design below acceptable levels. All electrophysiological segments for each participant underwent artefact decontamination procedures. Net Station (EGI) software was used to mark channels as contaminated if the fast average amplitude exceeded $200 \mu\text{V}$, if the differential amplitude exceeded $100 \mu\text{V}$, or if the channel had zero variance. Channels marked as contaminated in 20% of the trials were subsequently marked as such in all trials. These channels were deleted and replaced with data by means of the spherical spline interpolation. Trials that contained greater than ten contaminated channels or that contained lateral eye movements accounting for amplitudes greater than $100 \mu\text{V}$ were marked for rejection. Next, single-subject recordings underwent an eye-blink subtraction procedure based on independent component analysis (ICA) (Bell and Sejnowski 1995) by means of the ICA Blink Toolbox 1.21 and EEGLAB (Delorme and Makeig 2004). Net Station artefact detection software was then used to re-examine the recordings.

Following artefact detection, the data from each participant's remaining trials per condition were averaged. The data of participants with fewer than 20 trials ($20/64 = 31.25\%$) retained for either condition were excluded, which applied to two adults. The ERP data of two additional adults were contaminated by excessive noise and were therefore excluded from the ERP analyses. The mean numbers of averaged trials for subject and object questions, respectively, with their corresponding standard deviations were 41 (11.44) and 42 (11.19) in the TD group, 49 (9.13) and 46 (9.81) in the SLI group, and 54 (10.90) and 55 (11.20) in the adult group. The number of trials retained did not differ significantly between the TD and SLI groups (the primary between-group comparison) for subject questions, $t(28) = -1.89$, $p = 0.07$, or object questions, $t(28) = -1.03$, $p = 0.312$. The averaged trials were re-referenced to the newly computed average. For visualization purposes, a low-pass filter with a cut-off frequency of 15 Hz was used to smooth the ERP waveforms.

Visual inspection of the grand average waveforms for the TD and SLI groups revealed an anterior effect for question type. Anterior electrodes were divided into sets of left (EGI 12, 13, 9, 16), midline (EGI 7, 3, 8, 4), and right (EGI 2, 62, 57, 58) electrodes. Mean voltages were computed for these electrode sets for five time windows. The first time window was set at 400 ms post-question onset, by which time the *wh*-filler was expected to have been processed. Each of the first four time windows spanned 200 ms and the last time window spanned 150 ms, terminating at 1350 ms, the approximate end of the questions. The mean voltages for the three sets of electrodes were used as dependent measures.

Mixed-model repeated-measures ANOVAs were first computed to determine whether the TD and SLI groups individually demonstrated differential processing of subject and object questions throughout the *wh*-dependency. A follow-up ANOVA was performed with the within-subjects factors *question type* (object, subject), *time* (400–600, 600–800, 800–1000, 1000–1200, 1200–1350 ms), and *site* (left-, midline-, right-anterior) and the between-subjects factor *group* (TD, SLI).

Grand average waveforms for the adults suggested the presence of a question-type effect at frontal left (EGI 11 and 12), midline (EGI 10 and 7), and right (EGI 6 and 2) anterior electrodes. Mean amplitude values at these sites were entered into a repeated-measures ANOVA with the within-subjects factors *question type* (object, subject), *time* (400–600,

600–800, 800–1000, 1000–1200, 1200–1350 ms), and *site* (left-, midline-, right-anterior). A two-tailed significance level of $p = 0.05$ was adopted for all analyses. The effect sizes for all significant ERP results are reported as partial eta-squared, η_p^2 .

Results

Behavioural performance

Table 2 shows the percentage of correct responses for the comprehension questions per condition. The mean accuracy for comprehension of subject questions was significantly above chance level (50%) in all of the groups. By contrast, the mean accuracy for comprehension of object questions was above chance level in the TD and adult groups, whereas the SLI group's comprehension of object questions did not differ significantly from chance level, $t(12) = 0.62$, $p = 0.546$.

ANOVAs within each group for accuracy in comprehension revealed a significant effect of question type in the TD group $F(1, 16) = 13.34$, $p = 0.002$, $\eta_p^2 = 0.455$, due to lower accuracy for comprehension of object questions. In the SLI group, the question-type effect was not significant, $F(1, 12) = 3.35$, $p = 0.092$, although the same pattern of lower performance for object questions was demonstrated. This effect was not significant in the adult group, $F(1, 17) = 1.75$, $p = 0.203$. A follow-up ANOVA with the data of the TD and SLI groups revealed a significant main effect of group, $F(1, 28) = 12.49$, $p = 0.001$, $\eta_p^2 = 0.308$; the SLI children comprehended *wh*-questions more poorly than the TD children. In addition, a main effect of question type was found, $F(1, 28) = 14.54$, $p < 0.001$, $\eta_p^2 = 0.342$, due to lower accuracy for comprehension of object questions. The interaction between question type and group was not significant, $F(1, 28) = 2.45$, $p = 0.129$. An additional ANOVA revealed that both groups of children scored significantly lower than the adults on the two question types combined, $F(2, 45) = 34.94$, $p < 0.001$, $\eta_p^2 = 0.608$.

Multiword ERPs to subject and object questions

For the TD group, an ANOVA with mean voltages of multiword ERPs spanning the *wh*-dependency (400–1350 ms) showed a significant main effect of question type $F(1, 16) = 5.97$, $p = 0.027$, $\eta_p^2 = 0.272$, due to greater negativity for subject questions. A significant main effect of site was also found, $F(2, 32) = 3.43$, $p = 0.045$, $\eta_p^2 = 0.177$, reflecting increasing negativity from left- to midline- to right-anterior sites. The main effect of time was not significant, $F(4, 64) = 0.21$, $p = 0.934$. A significant interaction between time and site was found, $F(8, 128) = 2.72$, $p = 0.008$, $\eta_p^2 = 0.146$. Interactions between the following variables were not significant: time and question type, $F(4, 64) = 0.64$, $p = 0.634$, site and question type, $F(2, 32) = 0.56$, $p = 0.575$, and time, site, and question type, $F(8, 128) = 0.84$, $p = 0.573$.

An ANOVA for the SLI group revealed the absence of a significant main effect of question type, $F(1, 12) = 0.22$, $p = 0.65$, site, $F(2, 24) = 0.97$, $p = 0.394$, and time, $F(4, 48) = 1.73$, $p = 0.158$. There were no significant interactions between the following variables: time and site, $F(8, 96) = 0.78$, $p = 0.621$, time and question type, $F(4, 48) = 1.11$, $p = 0.362$, site and question type, $F(2, 24) = 1.98$, $p = 0.16$, and time, site, and question type, $F(8, 96) = 0.76$, $p = 0.635$.

ANOVAs of the individual groups of children were followed up by an ANOVA that examined whether effects between these groups were present throughout the duration of the *wh*-dependency. The interaction between question type and group was not significant, $F(1,$

28) = 2.1, $p = 0.159$. There were no significant interactions between site and group, $F(2, 56) = 0.84$, $p = 0.437$, and among site, question type, and group, $F(2, 56) = 1.72$, $p = 0.188$. The main effect of question type was significant, $F(1, 28) = 4.22$, $p = .049$, $\eta_p^2 = 0.138$, reflecting greater negativity for subject questions. The ERP waveforms increased in negativity from left-to midline- to right-anterior sites, $F(2, 56) = 3.65$, $p = .032$, $\eta_p^2 = 0.115$. Lastly, the main effect of group was not significant, $F(1, 28) = 0.23$, $p = 0.635$.

Differential processing of subject and object questions was observable in the adult grand average waveforms at frontal left (EGI 11 and 12), midline (EGI 10 and 7), and right (EGI 6 and 2) anterior electrodes. An ANOVA for mean voltages of multiword ERPs at these sites was performed with the within-subjects factors *question type* (object, subject), *time* (400–600, 600–800, 800–1000, 1000–1200, 1200–1350 ms), and *site* (left-, midline-, right-anterior). The interaction between time and question type was marginally significant, $F(4, 56) = 2.38$, $p = 0.063$, $\eta_p^2 = 0.145$, reflecting greater negativity for object than subject questions. The main effects of question type $F(1, 14) = 0.20$, $p = 0.659$, site $F(2, 28) = 1.28$, $p = 0.295$, and time $F(4, 56) = 1.75$, $p = 0.152$, were not significant. The interaction between time and site $F(8, 112) = 2.03$, $p = 0.049$, $\eta_p^2 = 0.127$, was significant, due to greater differences among the sites over time. No significant interactions were found between question type and site $F(2, 28) = 0.70$, $p = 0.505$, and among question type, time, and site $F(8, 112) = 0.86$, $p = 0.553$.

As shown in figure 1, the grand average waveforms for the TD group revealed a distinct sustained anterior positivity for object relative to subject questions, which was significant. In comparison, the SLI group showed this pattern characterized by a smaller amplitude difference in a small portion of the right-anterior region only, but this effect was not significant. The adult group demonstrated a sustained frontal anterior negativity for object as compared with subject questions, although this effect only approached significance (figure 2). Thus, the TD and SLI children showed group differences in the amplitude and spatial topography of ERP responses to subject and object *wh*-questions. Secondly, the child groups differed from adults in the amplitude, polarity, and topography of the ERP responses under study.

Discussion

The purpose of this investigation was to determine if school-age children with SLI show marked asymmetry for comprehension of subject and object *wh*-questions accompanied by a sustained LAN. This ERP effect purportedly indexes the higher working memory demand in processing object relative to subject questions. Our behavioural task of responding to comprehension questions with the simultaneous collection of ERP recordings produced several substantive findings. We consider them in relation to our predictions.

As anticipated, TD children exhibited behavioural subject–object asymmetry, characterized by lower accuracy for object questions. We expected to observe marked subject–object asymmetry in SLI relative to TD children, consistent with the results of Deevy and Leonard (2004). Our SLI group, though, comprehended object questions at chance level. This floor effect and the SLI group's poor comprehension of subject questions resulted in the absence of a question-type effect in this group. The discrepancy between our results and those of Deevy and Leonard may be due to differences in the tasks employed in each study. Deevy and Leonard's task required participants to respond to *wh*-questions based on drawings by pointing to animals in the drawings. In contrast, participants in the current study responded to *wh*-questions based on sentences which contained relative clauses and were therefore syntactically complex. Furthermore, the sentences were presented auditorily without any

pictorial support. Thus, it may be the greater complexity of our task that bred results highlighting SLI children's difficulty in comprehending subject and object questions. The floor effect shown by the SLI group may have masked subject–object asymmetry and this finding underscores the benefit of employing the more fine-grained method of ERPs in this study. Although the adults' scores indicate that they found the task complex, they did not demonstrate asymmetrical comprehension of subject and object questions. Apparently, the difficulty of the comprehension task for the adults was not rooted in the different syntactic working memory processes for subject versus object questions.

ERP waveforms revealed differential processing of subject and object questions in both the TD and SLI groups, although this effect was only statistically significant in the TD group. In the TD children, object *wh*-questions elicited a sustained anterior *positivity* over the filler-gap distance relative to subject *wh*-questions. Contrastingly, numerous studies have reported associations between a left anterior *negativity* and working memory effects in adults (e.g. Kluender and Kutas 1993, King and Kutas 1995, Kluender and Münte 1998, Münte *et al.* 1998, Fiebach *et al.* 2002). Previous investigations, though, have also found polarity differences between child and adult populations (Kok and Rooijakkers 1985) and these morphological differences have been attributed to the geometry or location of brain generators underlying cognitive processing (Courchesne 1977, 1978, Friedman *et al.* 1982). Therefore, we assume that this child–adult contrast is due to developmental differences. In contrast to previous findings (e.g. Fiebach *et al.* 2002), the adults exhibited a frontal anterior negativity for object as compared with subject questions that only approached significance. The smaller LAN effect in the adults compared with previous studies may indicate that their parsers were not impacted by the working memory load induced by the dislocated object, perhaps due to the short duration and syntactic simplicity of the sentences. Prior studies observed the LAN in *wh*-questions and object relativized clauses that were substantially longer and of greater syntactic complexity (e.g. Fiebach *et al.* 2002).

Notably, the question-type effect in the TD group was widely distributed throughout the left and right anterior regions, whereas previous studies reported this effect mainly in the left anterior region in adults. It is well documented that children commonly recruit more diffuse frontal brain regions than adults (Casey *et al.* 2005, Durston and Casey 2006, Luna and Sweeney 2004) because frontal brain areas have a protracted course of development and, therefore, this finding is in fact not surprising.

Whereas the behavioural data of the current study did not reveal a subject–object difference in the SLI group, the ERP waveforms suggest that children with SLI may have processed the question types differently, although this finding was not statistically significant. The SLI group also exhibited a sustained anterior positivity over the filler-gap distance for object relative to subject *wh*-questions, but only in a small portion of the right anterior region. This group difference in spatial distribution warrants explanation. One possibility is that right hemispheric structures are engaged when supplementary, non-automatic mechanisms for comprehension are needed during language processing. Deviant neurophysiological asymmetry (right > left activity) in children with SLI may reflect a reliance on augmentative mechanisms in the right hemisphere. These mechanisms may be invoked when processing subject and object questions due to the complexity of these questions for the SLI child. Aligned with this notion are the results of a study that examined the ERP correlates of discourse processing in children with TD and SLI (Shafer *et al.* 2000). Children with SLI showed reduced activation at left temporal sites and increased activation at right temporal sites as compared with TD children.

As anticipated, the ERP waveforms of the subject and object questions did not diverge until the point at which processing of the first word following the *wh*-word presumably began, at

approximately 325 ms post-onset of the *wh*-word. The positivity in TD children was sustained from this point until the conclusion of the questions. We interpret this as reflecting maintenance of the dislocated *wh*-filler in working memory until it was linked with its gap.

The sustained positivity effect indexing maintenance of the *wh*-filler in working memory for object questions was considerably diminished in amplitude and spatial topography in the SLI relative to the TD group, as described above. A study of the LAN reported earlier, stronger, and more broadly distributed sustained negativities in normal adults with low working memory capacity (Fiebach *et al.* 2002). This effect was interpreted as a reflection of the greater amount of working memory processes required and therefore, invested by individuals with low working memory capacity. Clearly, this interpretation cannot be applied to the current results, as TD children showed a greater and more broadly distributed sustained effect relative to SLI children. No direct assessments of working memory were conducted in the present study and therefore, interpretation of the current results in relation to working memory is speculative and requires further research. The smaller sustained positivity effect in the SLI group concurs with abundant evidence of working memory limitations in children with SLI (Gillam *et al.* 1998, Ellis Weismer *et al.* 1999, Marton and Schwartz 2003, Leonard *et al.* 2007, Montgomery and Evans 2009), particularly in relation to sentence comprehension (Bishop 1992, Montgomery 2000). We interpret the sustained positivity as indexing the *expenditure* of working memory resources, which is greater in TD children because they either have more of these resources available or are more aware of when to use these resources. This finding is consistent with the Syntactic Distance Hypothesis, which attributes the subject–object asymmetry in children with SLI to the greater syntactic distance and consequently, greater working memory load, in object relative to subject questions.

It is also possible that the attenuated effect in the SLI group reflects a lack of attention, or disengagement. Whereas TD children may have expended greater working memory resources for object questions, indexed by greater positivity, SLI children may have disengaged from the task due to its length and repetitive nature. This proposal is consonant with evidence of poor attentional skills in children with SLI (e.g. Noterdaeme *et al.* 2001). If the diminished ERP response in the SLI children re-flects disengagement, we would expect these children to have demonstrated a decline in comprehension accuracy over the duration of the experiment. Notably, though, this was not the case. Comprehension accuracy for the TD children was 67.95 (SD = 7.65) in session 1 and 66.48 (SD = 10.36) in session 2 and for the SLI children, was 57.3 (SD = 10.03) in session 1 and 53.12 (15.88) in session 2. A repeated-measures ANOVA revealed a significant effect of group, $F(1, 28) = 12.21$, $p = 0.002$, $\eta_p^2 = 0.304$, but no significant effect of session (one versus two), $F(1, 28) = 1.63$, $p = 0.212$, or interaction between group and session, $F(1, 28) = 0.37$, $p = 0.546$.

There is an alternative interpretation that warrants consideration. The sustained positivity effect might re-flect the incremental process of integrating each sentential word into the phrase structure representation during syntactic structure building. Object questions may evoke more computational processes than subject questions due to their non-canonicity. The sustained positivity effect might therefore be engendered by the more costly integration of words in object relative to subject questions, rather than reflecting syntactic working memory demands. Given that both integration and working memory processes contribute to the reconstruction of sentence structure during comprehension, these processes are highly interconnected. Fiebach *et al.* (2002) dissociated integration costs from syntactic distance, providing support for the Syntactic Distance Hypothesis as the basis for the sustained LAN in adults.

In view of the complexity of our task, as confirmed by low comprehension accuracy during piloting, it was not feasible to vary the filler-gap distance and thereby dissociate integration costs from syntactic distance. The possibility that the sustained positivity effect in our study reflects both working memory and syntactic integration thus remains viable. Future research should consider how sentence length might be manipulated without further compromising children's comprehension accuracy. Manipulation of the gap-filler distance in object questions would also enable an examination of whether the magnitude of the sustained positivity in children is length-dependent, which would be expected if the effect indexes working memory processes.

Furthermore, it would be beneficial to examine ERPs for subject and object questions that conclude with a prepositional phrase (e.g. *Who did the lion see in the forest?*), permitting the examination of syntactic integration of the *wh*-filler and its gap once the verb is processed. As found in adult studies (e.g. Fiebach *et al.* 2002), this would presumably be reflected by disappearance of the sustained working memory effect and might be indexed by the P600, an ERP component that reflects the difficulty of syntactic integration (Kaan *et al.* 2000). These ERP effects were not observable in the current study because processing of the sentence-final verb continued beyond the question segment and therefore could not be examined, especially in view of the shorter length of the subject questions.

Future research should combine electrophysiological and neuroimaging methods to examine the brain processes and generators involved in syntactic and working memory processes. Neuroimaging evidence from a study of adults' processing of German indirect *wh*-questions suggests that Broca's area, situated in the left hemisphere, plays a pivotal function in syntactic working memory during online sentence comprehension (Fiebach *et al.* 2005). Similar studies have yet to be conducted with developmental populations. Furthermore, our study presents new data suggesting a polarity difference for the subject-object asymmetry in children relative to adults. To confirm that the difference in polarity for subject-object asymmetry between children and adults arises from developmental differences, studies that directly assess ERP correlates of working memory in child and adult populations are necessary.

In addition, a behavioural measure of auditory verbal working memory would be beneficial for observing whether the ERPs sustained over the filler-gap distance interact with individual differences in working memory capacity, as has been found in adults (Fiebach *et al.* 2002). Future studies are also necessary to determine whether the observed effects, presumed to reflect the difference in working memory load between subject and object questions, can be accounted for by the mere non-canonicity of object questions or the challenge of assigning thematic roles in non-canonical sentences.

We predicted that children with SLI would perform more poorly than TD children in comprehending both subject and object *wh*-questions and this was confirmed. One reason why comprehension of *wh*-questions may have been problematic for the SLI children is that these structures not only require syntactic knowledge, but also demand the ability to use this knowledge to direct attention to subjects and objects that are not explicitly identified (for a discussion of this possibility in relation to infants, see Seidl *et al.* 2003). Both subject and object questions have a focus of attention that is contained within deep structure, relative to syntactic structures that can be comprehended by processing of surface features alone. The weakness that SLI children demonstrate in comprehending *wh*-questions may reflect a difficulty in attending to deep structure information. Children with SLI may have a preference for parsing language based on surface or semantic features, rather than based on syntactic strategies, such as *wh*-movement. Further studies are needed to evaluate this possibility.

Conclusion

In the current study, an ERP measure interpreted as reflecting the expenditure of working memory processes revealed a difference between the processing of subject and object *wh*-questions in TD children; in children with SLI, this effect was attenuated in amplitude and spatial topography. Whereas the behavioural data of this study did not reveal these processing differences due to chance performance for comprehension of object questions in the SLI group, ERPs demonstrated sensitivity in distinguishing sentence processing in SLI relative to TD children. This finding underscores the advantage of employing ERPs in the study of SLI, as well as in studies of sentence comprehension in children. Furthermore, the present study revealed new evidence suggesting a polarity difference for the subject–object asymmetry in children relative to adults.

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References

- American Speech–Language–Hearing Association. Guidelines for Audiologic Screening. 1997. (available at: <http://www.asha.org/policy>)
- Baddeley, AD. The articulatory loop. In: Baddeley, AD., editor. Working Memory. Oxford: Oxford Science; 1986. p. 75–101.
- Bell AJ, Sejnowski TJ. An information-maximization approach to blind separation and blind deconvolution. *Neural Computation*. 1995; 7(6):1129–1159. [PubMed: 7584893]
- Bishop D. The underlying nature of specific language impairment. *Journal of Child Psychology and Psychiatry*. 1992; 33:3–66. [PubMed: 1737831]
- Brown, L.; Sherbenou, RJ.; Johnsen, SK. Test of Nonverbal Intelligence. 3. Austin, TX: PROED; 1997.
- Casey BJ, Tottenham N, Liston C, Durston S. Imaging the developing brain: what have we learned about cognitive development? *Trends in Cognitive Sciences*. 2005; 9(3):104–110. [PubMed: 15737818]
- Chomsky, N. Barriers. Cambridge, MA: MIT Press; 1986.
- Clifton, C., JR; Frazier, L. Comprehending sentences with long-distance dependencies. In: Carlson, G.; Tanenhaus, MK., editors. Linguistic Structure in Language Processing. Dordrecht: Kluwer; 1989. p. 273–317.
- Courchesne E. Event-related brain potentials: a comparison between children and adults. *Science*. 1977; 197:589–592. [PubMed: 877575]
- Courchesne E. Neurophysiological correlates of cognitive development: changes in long-latency event-related potentials from childhood to adulthood. *Electroencephalography and Clinical Neurophysiology*. 1978; 45:468–482. [PubMed: 81749]
- Daneman M, Carpenter PA. Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*. 1980; 19:450–466.
- Deevy P, Leonard LB. The comprehension of *Wh*-questions in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2004; 47:802–815.
- Delorme A, Makeig S. Eeglab: an open source tool-box for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*. 2004; 134:9–21. [PubMed: 15102499]
- Dunn, LM.; Dunn, LM. Circle Pines. American Guidance Service; MN: 1981. Peabody picture vocabulary test-revised.
- Durston S, Casey BJ. What have we learned about cognitive development from neuroimaging? *Neuropsychologia*. 2006; 44 (11):2149–2157. [PubMed: 16303150]

- 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.
- Ervin-tripp, S. Discourse agreement: how children answer questions. In: Hayes, JR., editor. *Cognition and the Development of Language*. New York, NY: Wiley; 1970. p. 79-106.
- Felser C, Clahsen H, Münte TF. Storage and integration in the processing of filler-gap dependencies: an ERP study of topicalization and *wh*-movement in German. *Brain and Language*. 2003; 87:345–354. [PubMed: 14642537]
- Ferree TC, Luu P, Russell GS, Tucker DM. Scalp electrode impedance, infection risk, and EEG data quality. *Clinical Neurophysiology*. 2001; 112:536–544. [PubMed: 11222977]
- Fiebach CJ, Schlesewsky M, Friederici AD. Separating syntactic working memory costs and syntactic integration costs during parsing: The processing of German WH-questions. *Journal of Memory and Language*. 2002; 47:250–272.
- Fiebach CJ, Schlesewsky M, Lohmann G, von Cramon DY, Friederici AD. Revisiting the roles of Broca's area in sentence processing: syntactic integration versus syntactic working memory. *Human Brain Mapping*. 2005; 24:79–91. [PubMed: 15455462]
- Frazier, L.; Clifton, C, JR. *Construal*. Cambridge, MA: MIT Press; 1996.
- Frazier L, Flores D'Arcais GB. Filler driven parsing: a study of gap filling in Dutch. *Journal of Memory and Language*. 1989; 28:331–344.
- Friedman, D.; Brown, C.; Sutton, S.; Putnam, L. Cognitive potentials in a picture-matching task: comparison of children and adults. In: Rothenberger, A., editor. *Event-Related Potentials in Children*. Amsterdam: Elsevier; 1982. p. 325-335.
- Gibson E. Linguistic complexity: locality of syntactic dependencies. *Cognition*. 1998; 68(1):1–76. [PubMed: 9775516]
- Gillam RB, Cowan N, Marler JA. Information processing by school-age children with specific language impairment: evidence from a modality effect paradigm. *Journal of Speech, Language, and Hearing Research*. 1998; 41:913–926.
- Hildebrand J. The acquisition of preposition stranding. *Canadian Journal of Linguistics*. 1987; 32:65–85.
- Just MA, Carpenter PA. A capacity theory of comprehension: individual differences in working memory. *Psychological Review*. 1992; 99:122–149. [PubMed: 1546114]
- Kaan E, Harris A, Gibson E, Holcomb P. The P600 as an index of syntactic integration difficulty. *Language and Cognitive Processes*. 2000; 15(2):159–201.
- King J, Just MA. Individual differences in syntactic processing: the role of working memory. *Journal of Memory and Language*. 1991; 30:580–602.
- King JW, Kutas M. Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience*. 1995; 7:376–395.
- Kluender R, Kutas M. Bridging the gap: evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience*. 1993; 5:196–214.
- Kluender, R.; Munte, TF. Subject/object asymmetries: ERPs to grammatical and ungrammatical *wh*-questions. Poster presented at the 11th Annual CUNY Conference on Human Sentence Processing; New Brunswick, NJ. 1998.
- Kok A, Rooijakkers JAJ. Comparison of event-related potentials of young children and adults in a visual recognition and word reading task. *Psychophysiology*. 1985; 22:11–23. [PubMed: 3975315]
- Leonard LB, Ellis Weismer S, Miller CA, Francis DJ, Tomblin JB, Kail RV. Speed of processing, working memory, and language impairment in children. *Journal of Speech, Language, and Hearing Research*. 2007; 50:408–428.
- Love, T.; Swinney, D. Real-time processing of object-relative constructions by pre-school children. Paper presented at the 10th Annual CUNY Conference on Human Sentence Processing; Los Angeles, CA. 1997.
- Luu, P.; Ferree, T. Determination of the Geodesic Sensor Nets' Average Electrode Positions and Their 10–10 International Equivalents. Technical Note. 2000. (available at: http://ueleeglabwiki.pbworks.com/f/200_ElectrodePositions.pdf)

- Luna B, Sweeney JA. The emergence of collaborative brain function: FMRI studies of the development of response inhibition. *Annals of the New York Academy of Sciences*. 2004; 1021(1):296–309. [PubMed: 15251900]
- Macdonald MC. Priming effects from gaps to antecedents. *Language and Cognitive Processes*. 1989; 4:35–36.
- Marinis T, Van der Lely HKJ. On-line processing of wh-questions in children with G-SLI and typically developing children. *International Journal of Language and Communication Disorders*. 2007; 42(5):557–582. [PubMed: 17729146]
- Marton K, Schwartz RG. Working memory capacity and language processes in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2003; 46:1138–1153.
- Montgomery J. Sentence comprehension in children with specific language impairment: the role of phonological working memory. *Journal of Speech and Hearing Research*. 1995; 38:187–199. [PubMed: 7731209]
- Montgomery JW. Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2000; 43:293–308.
- Montgomery JW, Evans JL. Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2009; 52:269–288.
- Münste TF, Matzke M, Johannes S. Brain activity associated with syntactic incongruencies in words and pseudowords. *Journal of Cognitive Neuroscience*. 1998; 9:318–332.
- Noterdaeme M, Amorosa H, Mildenerger K, Sitter S, Minow F. Evaluation of attention problems in children with autism and children with specific language disorder. *European Child and Adolescent Psychiatry*. 2001; 10:58–66. [PubMed: 11315537]
- O'Grady, W. *Syntactic Development*. Chicago, IL: University of Chicago; 1997.
- Philip, W.; Coopmans, P.; van Atteveldt, W.; van der Meer, M. Subject–object asymmetry in child comprehension of Wh-questions. In: Do, AH-J.; Dominguez, L.; Johansen, A., editors. *Proceedings of the 25th Boston University Conference on Language Development*. Somerville, MA: Cascadia; 2001. p. 587-598.
- Rizzi, L. *Technical Reports in Formal and Computational Linguistics*. Geneva: University of Geneva; 1991. Residual Verb Second and the wh-Criterion.
- Schneider, W.; Eschman, A.; Zuccolotto, A. *E-Prime Reference Guide*. Pittsburgh, PA: Psychology Software Tools; 2002.
- Seidl A, Hollich G, Jusczyk P. Early understanding of subject and object Wh-questions. *Infancy*. 2003; 4(3):423–436.
- Semel, E.; Wiig, EH.; Secord, WA. *Clinical Evaluation of Language Fundamentals*. 4. Toronto, ON: Psychological Corporation; 2003.
- Stromswold K. The acquisition of subject and object Wh-questions. *Language Acquisition: Journal of Developmental Linguistics*. 1995; 4:5–48.
- Shafer VL, Schwartz RG, Morr ML, Kessler KL, Kurtzberg D. Deviant neurophysiological asymmetry in children with language impairment. *Neuroreport*. 2000; 11 (17):3715–3718. [PubMed: 11117478]
- Tyack D, Ingram D. Children's production and comprehension of questions. *Journal of Child Language*. 1977; 4:211–224.
- Van der Lely H, Battell J. WH-movement in children with grammatical SLI: a test of the RDDR hypothesis. *Language*. 2003; 79:153–181.
- Van der Lely HKJ, Howard D. Children with specific language impairment: linguistic impairment or short-term memory deficit? *Journal of Speech and Hearing Research*. 1993; 36:1193–1207. [PubMed: 8114487]
- Wanner, E.; Maratsos, M. An ATN approach to comprehension. In: Halle, M.; Bresnan, J.; Miller, G., editors. *Linguistic Theory and Psychological Reality*. Cambridge, MA: MIT Press; 1978. p. 117-161.
- Washington JA, Craig HK. Dialectal forms during discourse of poor, urban, African American preschoolers. *Journal of Speech and Hearing Research*. 1994; 37:816–823. [PubMed: 7967568]

- Waters GS, Caplan D. Verbal working memory and on-line syntactic processing: evidence from self-paced listening. *Quarterly Journal of Experimental Psychology*. 2004; 57:129–163. [PubMed: 14681007]
- Wilhelm A, Hanna K. On the acquisition of Wh-questions. *Calgary Working Papers in Linguistics*. 1992; 15:87–102.
- Wong AMY, Leonard LB, Fletcher P, Stokes SF. Questions without movement: a study of Cantonese-speaking children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2004; 47:1440–1453.
- Yoshinaga, N. Unpublished doctoral dissertation. University of Hawaii; Manoa: 1996. WH questions: A comparative study of their form and acquisition in English and Japanese.

What this paper adds**What is already known on the subject?**

Children with SLI demonstrate marked difficulty comprehending and producing object relative to subject *wh*-questions and the basis for this asymmetry is not clearly understood.

What this study adds

To elucidate the subject–object asymmetry in children with SLI, this study examined how these children comprehend and process object and subject *wh*-questions, as measured behaviourally and via event-related potentials (ERP). Poor comprehension of both question types in children with SLI was observed alongside atypical processing of subject versus object questions based on ERP waveforms. This ERP finding warrants examination of whether the subject–object asymmetry in children with SLI is due to poor maintenance of sentential information in working memory over the *wh*-dependency of object questions. Evidence of a working memory deficit as the basis for poor comprehension and processing of object questions would inform treatment of children with SLI.

Figure 1.

Grand average multiword ERPs for subject and object questions in the left anterior (Electrical Geodesics Inc. (EGI) 12, 13, 9, 16) and right anterior (EGI 2, 62, 57, 58) regions in TD ($n = 17$) and SLI ($n = 13$) children.

Figure 2. Grand average multiword ERPs for subject and object questions in the left anterior (Electrical Geodesics Inc. (EGI) 11 & 12) and right anterior (EGI 6 & 2) regions in ADULTS (n = 14).

Table 1

Standardized test scores for the SLI and TD groups

Group	Age (months)	CFD ^{a*}	WC-R ^{a*}	RLS ^{b*}	RS ^{a*}	FS ^{a*}	WC-E ^{a*}	ELS ^{b*}	PPVT-R ^{b*}	TONI-3 ^b
<i>SLI</i>										
Mean	10;1	5.54	7.62	79.92	6.08	5.54	8.00	76.38	85.54	98.23
SD	1.28	1.94	2.66	13.71	2.22	2.63	0.71	11.67	9.44	15.83
Range	8;5–12;4	3–9	3–13	51–102	2–9	1–11	7–9	49–95	70–101	80–135
<i>TD</i>										
Mean	10;4	10.71	12.06	108.56	10.81	10.63	12.25	105.50	104.63	107.38
SD	1.02	2.52	2.79	12.13	3.39	2.22	2.12	13.42	12.15	12.12
Range	8;4–12;3	7–15	9–16	88–125	6–19	7–14	10–17	89–133	86–129	90–130

Notes: Clinical Evaluation of Language Fundamentals — Fourth Edition subtests: CFD = Concepts and Following Directions (receptive subtest); WC-R = Word Classes — Receptive; RLS = Receptive Language Score; RS = Recalling Sentences (expressive subtest); FS = Formulated Sentences (expressive subtest); WC-E = Word Classes — Expressive; ELS = Expressive Language Score. PPVT-R = Peabody Picture Vocabulary Test — Revised; TONI-3 = Test of Nonverbal Intelligence — Third Edition.

^aStandard scores with mean = 10; SD = 3.

^bStandard scores with mean = 100, SD = 15.

* Significant group difference (two-tailed *t* test) at *p* < 0.01.

Table 2

Accuracy rate (% correct) for comprehension questions per condition

	TD			SLI			Adults		
	Mean ^a	Range	SD	Mean	Range	SD	Mean	Range	SD
Subject	72.31	56-85	8.05	56.81	40-82	11.14	82.03	67-94	8.03
Object	61.87	44-79	10.46	52.44	24-71	14.17	79.27	65-96	8.12

Note:

^a $p < 0.05$.