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# Brain Imaging of Event Related Potentials in Children with Language Impairment

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ABSTRACT

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Event related potentials (ERPs) may provide specific information about how particular aspects of language are processed by the brain over time. This study investigated the electrophysiology of language processing in two children with language impairment (LI) when compared to five typically developing children. The N400, P600, and the early left anterior negativity (ELAN) were analyzed after participants listened to linguistically correct, syntactically incorrect, and semantically incorrect sentences. Participants were instructed to indicate whether the sentences were correct or incorrect. Latency and amplitude of the ERP components were compared between the two groups of participants and sentence types. Results from the current study concerning the typically developing children suggest that, at least by eight years of age, typically developing children may process linguistic information similarly to adults with regard to the areas of the brain that are activated during the processing of linguistic stimuli. When comparing results from participants with LI and their typically developing counterparts, results indicate that children with LI exhibit slower real-time language processing than typically developing children. Results also indicate that children with LI require more effort than typically developing children in processing linguistic information as indicated by the amplitude of the N400 and the ELAN. In analyzing the P600 in both groups of participants, results indicate that syntactic processing may be intact in children with LI as well as typical children. Results concerning the N400 and the ELAN were variable between the two participants with LI indicating that children with LI may be heterogeneous even in the presence of similar tasks. Results obtained from the ELAN may also indicate that the ELAN is not fully mature at eight years of age.

*Keywords*: P600, N400, ELAN, event related potentials, language impairment, semantics, syntax

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# DESCRIPTION OF STRUCTURE AND CONTENT

The body of this thesis is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. An annotated bibliography is presented in Appendix A.

## Introduction

Integrating and analyzing linguistic stimuli including phonetic, prosodic, syntactic, and semantic information is necessary for a listener to comprehend a spoken sentence. Event related potentials (ERPs) reflect the changes that occur in brain activity. As a measure of brain activity, ERPs have been useful in analyzing language comprehension as linguistic stimuli are processed by the brain over time. ERP waveforms elicited with different stimuli typically display a number of positive and negative peaks characterized by their latency and amplitude. Latency is a measure of cognitive processing and is important in reflecting cognitive processing time, whereas the amplitude is a measure of the extent or effort of cognitive processing (McPherson & Salamat, 2004). The scalp topography, or brain map, is another measure of the ERP that provides information on what areas of the brain are contributing to the response. Brain mapping allows differentiation of cognitive processes based on the activation of different neural structures. Changes within the dimensions of latency, amplitude, and scalp topography can help in forming conclusions about how participants are processing certain stimuli. Latency reflects the speed of cognitive processing, amplitude reflects the effort required of the participant for a particular process, and topography reflects changes in activity of a region to support a particular process (Kotz & Friederici, 2003).

### ERP Measurement

Three language-related ERPs can be used in the analysis of language processing in children with language impairment (LI). The N400, P600, and early left anterior negativity (ELAN) have been shown to be sensitive to semantic and syntactic processing (Friederici, 2004). There is evidence suggesting that children with LI experience deficits in a variety of linguistic domains including learning semantic and syntactic rules (Cummings & Ceponiene, 2010;

Friederici, 2006; Friedrich & Friederici, 2006; Sabisch, Hahne, Glass, Von Suchodoletz, & Friederici, 2006b; Weber-Fox, Leonard, Wray, & Tomblin, 2010). The N400 is typically associated with semantic processes, while the P600 and ELAN are highly correlated with syntactic processes (Friederici, 2004). Research using these three components has been directed more toward the adult population as well as typically developing children. However, research using children with LI may be beneficial in understanding their neurophysiological development of language.

**N400 as an indicator of semantic processing.** As a reflection of linguistic processing, the N400 is a negative waveform that peaks at around 400 ms after the onset of the critical stimulus and is correlated with lexical-semantic processes (Friederici, 2004). The N400 is sensitive to the appropriateness or the semantic relationship of a word within a given context. Generally, a larger N400 amplitude is elicited for words that are semantically incongruous to a given context, rather than words that are congruous. If a larger N400 amplitude is seen in the presence of semantically incongruent stimuli, it is known as the "semantic N400 effect" (Friederici, 2006, p. 943). When the semantic N400 effect is not present with semantically incongruent stimuli, this frequently indicates a deficit in semantic processing (Friederici, 2006). For example, in a longitudinal study by Friedrich and Friederici (2006), children that were at risk of developing LI, indicated by a family history of LI, were investigated. Participants of this study were first tested at 19 months of age, and again at 30 months. The results of the study showed that children who experienced poor expressive language skills at 30 months, and were also at risk for LI, failed to show a semantic N400 effect at the age of 19 months when presented with semantically incongruous stimuli (Friedrich & Friederici, 2006).

Studies by Kutas and Hillyard (1980a, 1980b, and 1983) also showed that the N400 is sensitive to semantic stimuli. These researchers examined the electrophysiological results of manipulating a word within a sentence and presenting the sentences to a group of young adults. Kutas and Hillyard found that when they replaced a word with a semantically inappropriate word, an increased negative peak was seen at approximately 400 ms. These studies also showed that the amplitude of the N400 was greater when the participant was not expecting the target word (Kutas & Hillyard, 1980a, 1980b, 1983).

Another study conducted by Polich (1985) resulted in similar findings when manipulating the semantic component of a sentence. The study consisted of two experiments. In the first, participants were required to read the sentences that were presented to them. In the second, the participants were asked to indicate whether the sentence presented to them did or did not end in a semantically appropriate word. In the second experiment, the N400 component was present when the sentences ended in a semantically inappropriate word (Polich, 1985).

The N400 has been observed in both visual and auditory modalities. However, the N400 demonstrates topographical differences as a function of presentation modality. When elicited visually, the N400's distribution is greater over the right hemisphere. When elicited auditorily, the N400's distribution is typically lateralized to the left hemisphere. It has also been shown that the N400 latency is shorter for auditory stimuli than for visual stimuli. There may be overlap in the processes that occur in both visual and auditory modalities, but these processes are not identical (Holcomb & Neville, 1990).

**ELAN as an indicator of syntactic processing.** A second component of ERPs that will be used in the current study is the ELAN. This ERP component typically occurs between 100 and 200 ms and displays an anterior distribution. The ELAN has been reported for phrase structure violations in the auditory domain (Friederici, 2004). In a study by Hahne, Eckstein, and Friederici (2004), participants were auditorily presented with correct, semantically incorrect, and syntactically incorrect sentences. Participants included in the study consisted of children ages 6 to 13. The participants were asked to indicate if the sentences were correct or incorrect. Results showed an ELAN for syntactic violations, but it was not observed in children between the ages of 6 and 10 years. Hahne et al. (2004) indicated that higher automatic structure building processes reflected in the ELAN gradually develop toward adult-like processing during the later years of childhood, reaching adult-like maturity at about 13 years. Canseco-Gonzalez (2000) stated that the ELAN is observed with outright syntactic violations or word category violations. Canseco-Gonzalez (2000) also stated that it is distinct from the N400 in that it has a more frontal distribution and a smaller amplitude than the N400.

**P600 as an indicator of syntactic processing.** The P600 is a late ERP component that is related to syntactic processing. The P600 is a positive wave elicited at about 600 ms post-stimulus and has been observed with violations of structural preferences, outright syntactic violations, and difficulty of syntactic processing (Friederici, 2004). In a study by Hahne et al. (2004), the P600 was analyzed after participants were presented with correct, semantically incorrect, and syntactically incorrect sentences. In this study, the P600 was elicited in response to syntactically incorrect sentences and was present in all groups of children from 7 to 13 years of age. However, the amplitude was smaller and the latency decreased as age increased. Because the amplitude of an ERP indicates the effort a participant uses to process a given stimulus, the results of this study may indicate that as a child ages, syntactic analysis becomes less difficult. Hahne et al. (2004) concluded that “As the P600 can be interpreted as a component related to the difficulty of syntactic integration, the present finding may point to high syntactic processing expenses, even for syntactically correct sentences" (Hahne et al., 2004, p. 1314).

Additional information about the elicitation of the P600 was obtained from Osterhout and Holcomb (1992). In this study, participants were presented with sentences that bring about the "garden-path effect" (Osterhout, 1992, p. 788). Osterhout and Holcomb (1992) explained the garden-path effect by stating that readers will typically construct a preferred syntactic representation in the initial stages of reading. When this preferred syntactic representation proves to be inappropriate, the reader will backtrack or reanalyze the sentence. This is what Osterhout and Holcomb (1992) refer to as the "garden-path effect". For example, in the sentences *The broker persuaded the man to sell the stock* and *The broker persuaded to sell the stock was sent to jail,* the first sentence is the syntactically preferred sentence. However, the second sentence shows an ambiguous interpretation and is not syntactically preferred. In this case, the brain would then backtrack and reanalyze the sentence (Osterhout, 1992).

**Language Impairment**

LI is a developmental disorder that affects language processing. Children with LI have been shown as slower in language processing when compared to typical children. They have also been shown as slow in language processing when compared to younger children who function at the same language level (Montgomery, 2006). Children with LI will have difficulty in tasks that involve the processing of syntactic or semantic information. Although they may show impairments in this area, children with LI typically have normal nonverbal intelligence. Likewise, children with LI do not have abnormalities in neurological, physical, or emotional domains (Sabisch et al., 2006b).

**Working memory.** Many studies of children with LI have sought to find a basis for the language deficits in these children. This may include deficits in attention, auditory processing, and grammatical or phonological processing (Mills & Neville, 1997). A well-known deficit suggested by researchers in children with LI is in working memory (Montgomery & Evans, 2009). Working memory refers to the ability to engage in processing and storing information simultaneously. A study performed by Montgomery and Evans (2009) sought to investigate the association of working memory with the comprehension of complex sentences in children with LI. In this study, school-age children with LI were compared to two groups of control children. One control group consisted of typically developing age-matched children, while the other group consisted of typically developing children who matched the LI group in receptive language and memory abilities. Each child was given a non-word repetition task, a competing language processing task, and a sentence comprehension task with both complex and simple sentences. Montgomery and Evans (2009) found that a significant amount of working memory is required for school-age children to comprehend both complex and simple grammar. It was noted that this becomes a mentally demanding activity for children with LI and requires that they access working memory resources (Montgomery & Evans, 2009).

**Auditory processing.** The diagnosis of children with LI does not include the presence of a peripheral hearing loss. However, deficits in auditory processing could be a possibility as to why children with LI struggle to process language and to discriminate sounds. Although there have been many studies that examined auditory processing abilities of children with LI, many of these studies have used non-linguistic stimuli (Bishop & McArthur, 2004, 2005; Weber-Fox et al., 2010). The use of non-linguistic stimuli may offer insights into the controversy about the role of auditory processing deficits in the linguistic processing of children with LI. Other areas of contribution include delayed maturation, which is part of the maturational hypothesis (Bishop & McArthur, 2005).

**Maturational hypothesis.** The maturational hypothesis suggests that any deficits seen in children with LI reflect a delay in the maturation of cortical development and is not attributed to a more permanent abnormality (Bishop & McArthur, 2005). This suggests that children with LI will reach the same level of their peers at some point in their development. In Bishop and McArthur (2004), age-inappropriate ERPs as well as decreased frequency discrimination thresholds were noted in children with LI. To test the maturational hypothesis, Bishop and McArthur (2005) compared the ERP waveforms and the frequency discrimination thresholds obtained from Bishop and McArthur (2004) to a control group of the same age, and then to a typically developing group of younger age. Results from Bishop and McArthur (2005) showed characteristics of the maturational hypothesis by finding that frequency discrimination thresholds for the group with LI improved over the 18 month period, while the age-matched control group's results were stable across the 18 months. The discrimination threshold results support the hypothesis that the group with LI was able to reach the level of the typically developing control group because these results are compatible with the idea that auditory skills show a maturational lag in children with LI. However, some results did not support the maturational hypothesis. In a subset of the children with LI, results in language processing showed that the ERPs studied continued to be age-inappropriate; these results were not compatible with the maturational hypothesis. Although the maturational hypothesis presumes that children with LI will reach the level of their peers at some point in development, it was also noted that a number of these children remain delayed in language development (Bishop & McArthur, 2005).

**Revised cohort theory.** According to Montgomery (2006), the revised cohort theory is a current word-recognition model that attributes slow language processing in children with LI to three possible sources. First, slow language processing in children with LI may be due to slower conversion of the acoustic signal into a recognizable word. Converting the acoustic signal into a recognizable word is known as acoustic-phonetic processing and is considered to be independent of linguistic analysis. There is evidence that supports the idea that listeners are able to use phonetic information they hear to facilitate word recognition (Montgomery, 2006). Second, children with LI may struggle with linguistic processing. For example, children with LI will be slow to retrieve and integrate the linguistic properties of incoming words into a coherent sentence representation. The first (slower conversion of acoustic signals) and second (deficit in linguistic processing) stand independent of each other. The third possibility combines the two deficits, in that children with LI may perform poorly in both acoustic-phonetic and linguistic processing. Montgomery (2006) suggests that children with LI are deficient in the second skill area, linguistic processing, and are slower to integrate linguistic properties into an evolving meaningful sentence.

## ERP Research in Children with Language Impairment

Although research has helped us understand the deficits such as working memory and auditory processing seen in children with LI, there is a limited amount of research involving ERPs in children with LI. The ERP studies that have been performed indicate that this population processes syntactic and semantic anomalies differently than typically developing children (Neville, Coffey, Holcomb, & Tallal, 1993; Sabisch et al. 2006b). Neville et al. (1993) found that children with LI presented a larger N400 component than their control group when auditorily presented with sentences that contained semantic incongruities. This study concluded that the semantic processing difficulties seen in children with LI led to an increased effort when processing the anomalies presented to them (Neville et al., 1993). Instead of presenting stimuli auditorily, Sabisch et al. (2006b) presented their participants with stimuli visually. In this study, the control group showed an N400 peak followed by a late positivity. The group with LI did not show an N400 peak, but did show a late and broadly distributed positivity. The researchers suggested that these results indicate that the children with LI had problems integrating lexical-semantic meaning (Sabisch et al., 2006b).

The aim of the present study was to provide a more complete description of language processing in children with LI by examining their N400, P600, and ELAN responses to correct, semantically incorrect, and syntactically incorrect spoken sentences. ERPs are an effective component in better understanding language disorders. Picton and Stuss (1984) discussed two different reasons for studying the event-related potentials of individuals with language disorders. The first is to describe the underlying pathology using neurophysiological measures; the second is to understand the neurophysiology using different types of pathology as experimental tools. Therefore, ERPs in individuals with LI can help in understanding the physiology of the impairment (Picton & Stuss, 1984). In the present study, comparisons of the N400, P600, and ELAN waveforms were made for measures of latency, amplitude, and topography to increase our understanding of language processing in children with LI. The results of the children with LI were compared to a group of typically developing children. In examining ERP responses across these conditions, conclusions could be drawn specific to syntactic and semantic language processing in children with LI.

# Method

## Participants

A total of seven participants were included in the study. Participants consisted of two children diagnosed with LI and five typically developing children. The participants with LI are referred to as LI-1 and LI-2. The typically developing children, acting as the control group, are referred to as the CG. All CG children were between 7 and 11 years of age. Both LI-1 and LI-2 were eight years of age. Each participant was required to meet the following criteria.

1. No known history of neuropsychiatric disorders.
2. Normal hearing as demonstrated with pure-tone thresholds of ≤ 15 dB HL at 250, 500, 1000, 2000, 4000, and 8000 Hz.
3. Hearing thresholds will not have greater than a 5 dB difference between ears and any of the corresponding test frequencies.
4. Normal immittance audiometry and otoacoustic emissions.
5. Each participant in the CG indicated a lack of evidence of language delay or disorder as determined by a standard score of at least 85 on a standardized language test.
6. The participants with LI demonstrated evidence of language delay or disorder as determined by a standard score of less than 85 on a standardized language test.
7. All participants showed evidence normal intellectual ability as determined by a report from parents or teachers regarding academic ability or grade level.

**Control group participants (CG).** Each child was administered either the Clinical Evaluation of Language Fundamentals-4 (CELF-4) or the Comprehensive Assessment of Spoken Language (CASL) to confirm eligibility for this study (Carrow-Woolfolk, 1999; Semel, Wiig, & Secord, 2004).

CG-1, a male participant, was 9:11 (years:months) at the time of testing. CG-1 was administered the CELF-4 and received a standard score of 100, placing him in the 50th percentile (Table 1). A report from his mother indicates that CG-1 is performing at grade level in school and requires no additional academic help.

CG-2, a male participant, was 10:2 at the time of testing. CG-2 was administered the CASL and received a standard score of 108, placing him in 70th percentile (Table 2). A report from his mother indicates that CG-2 is performing at grade level in school and requires no additional academic help. The mother also reported that CG-2 has passed the district language arts testing for the past three school years.

CG-3, a male participant, was 7:9 at the time of testing. CG-3 was administered the CELF-4 and received a standard score of 108, placing him in the 70th percentile (Table 3). A report from his mother indicates that CG-3 is performing at grade level in school and requires no additional academic help.

CG-4, a male participant, was 7:5 at the time of testing. CG-4 was administered the CELF-4 and received a standard score of 130, placing him in the 98th percentile (Table 3). A report from his mother indicates that CG-4 is performing at grade level in school and requires no additional academic help.

CG-5, a male participant, was 11:0 at the time of testing. CG-5 was administered the CELF and received a standard score of 96, placing him in the 39th percentile (Table 1). A report from his mother indicates that CG-5 is performing at grade level in school and requires no additional academic help.

**Language impaired participants (LI).** LI-1, a female participant, was administered the CASL and received a standard score of 79, placing her in the 8th percentile (Table 2). A report

Table 1

*Standard Scores for CG-1 and CG-5 (Ages 9-21)*

| Clinical Evaluation of Language Fundamentals-4 (Standard Scores) | | |
|---|---|---|
| | CG-1 | CG-5 |
| Concepts and Following Directions | 13 | 12 |
| Recalling Sentences | 7 | 7 |
| Formulated Sentences | 7 | 6 |
| Word Classes-Total | 14 | 12 |
| Standard Score | 100 | 96 |
| Percentile | 50 | 39 |

*Note:* Scores of the Clinical Evaluation of Language Fundamentals-4 are standard scores: $M$ = 100, $SD$ = 15.

Table 2

*Standard Scores for LI-1 and CG-2*

| Comprehensive Assessment of Spoken Language (Standard Scores) | | |
|---|---|---|
| | LI-1 | CG-2 |
| Antonyms | 83 | 93 |
| Syntax Construction | 66 | 116 |
| Paragraph Comprehension | 85 | 101 |
| Nonliteral Language | 96 | 122 |
| Pragmatic Judgment | 84 | 103 |
| Total Language Score | 79 | 108 |
| Percentile | 8 | 70 |

*Note:* Scores of the Comprehensive Assessment of Spoken Language are standard scores: $M$ = 100, $SD$ = 15.

from her mother indicates that LI-1 is performing at grade level. The only specialized service LI-1 receives outside of class is speech therapy. It is offered at the school, and LI-1 attends a twenty minute session twice per week.

LI-2, a male participant, was administered the CELF-4 and received a standard score of 69, placing him in the 70th percentile (Table 3). A report from his mother indicates that LI-2 scores below peers in his grade level in reading and that LI-2 receives tutoring outside of class for reading. LI-2 was also administered the Wechsler Intelligence Scale for Children IV (WISC-IV), which is a nonverbal performance scale that is normed for children from 6 to 16 years of age (Wechsler, Pearson Education, & Psychological Corporation, 2003). LI-2 received an average standard score of 87.8 on five subtests, which is less than 1 standard deviation from the mean. This qualified LI-2 for this study. LI-2 only had one score greater than 1 standard deviation below the mean (standard score of 77), which was on the Working Memory Index (WMI) subtest.

Table 3

*Standard Scores for LI-2, CG-3, and CG-4 (Ages 5-8)*

| Clinical Evaluation of Language Fundamentals-4 | | | |
|---|---|---|---|
| | LI-2 | CG-3 | CG-4 |
| Concepts and Following Directions | 3 | 11 | 14 |
| Word Structure | 6 | 11 | 14 |
| Recalling Sentences | 4 | 10 | 17 |
| Formulated Sentences | 6 | 13 | 15 |
| Standard Score | 69 | 108 | 130 |
| Percentile | 2 | 70 | 98 |

*Note:* Scores of the Clinical Evaluation of Language Fundamentals-4 are standard scores: $M$ = 100, $SD$ = 15.

**Instrumentation**

An electrode cap (Electrocap International) was used in this study to place silver-silver chloride electrodes over participant's scalps at 32 electrode positions according to the 10-20 International System (Jurcak, Tsuzuki, & Ippeita, 2007). Electrode impedances were below 3000 ohms. Eye movements were monitored during data collection by placing electrodes on the outer canthus on one eye and above the supra-orbital foramen of the opposite eye. During post-hoc averaging, trials containing eye movement were rejected from analysis.

Hearing screenings were performed for each participant using a Grason-Stadler model GSI-61 audiometer. A NeuroScan computer using Scan 4.0 software was used to collect the ERPs (Compumedics Neuroscan, 2008). The raw electrical potentials were band-passed between DC and 300 Hz. A 1900 ms sample was taken from the onset of the last word of each sentence. Sentences were presented using a forced choice procedure in which participants' responses would trigger the presentation of the next sentence. The GSI-61 audiometer was used to present stimuli through Etymotic ERA-3 insert phones. Each participant was seated comfortably in a reclining chair in a sound-treated test room. The ambient noise did not exceed ANSI S3.1-1991 maximum permissible levels for air conduction testing with ears uncovered during operation of electronic equipment.

A female native English speaker produced the sentences used in this study. The sentences were digitally recorded in a sound-isolated chamber using a low-impedance dynamic microphone (DPA 4011). The microphone was positioned approximately six inches from the participant's mouth. An A/D converter (Mini-me) by Apogee Systems was used to convert the stimuli. All recordings were made at a sampling rate of 44.1 kHz with 24-bit quantization. The sentences were down-sampled to 18-bit quantization and segmented with Adobe Audition Software to interface with NeuroScan software. Selections were cut at a zero-crossing and ramped over the initial and ending 25 ms of the waveform. In addition, all files were high-pass filtered to eliminate any extraneous noise below 65 Hz. To make the tokens relatively equivalent with regard to intensity, the average RMS of each token was measured and digitally adjusted to a standard level. This was done to avoid above peak recording levels. Two tokens were digitally edited to eliminate noise artifacts that may have been produced during recording. As a final step, the sentences were listened to and judged auditorily to be clear with no sudden changes in loudness or extraneous noises. The loudness level of each sentence was determined to be perceptually equivalent by three separate judges.

**Stimuli**

Sentences were presented to the participants binaurally and were presented through insert phones (ER3-A) at 65 dB HL in a sound–attenuated chamber using a GSI-61 audiometer. Sentences were taken from Houghton Mifflin English Textbooks and were determined to be at the comprehension level of a typically developing five year-old child (Level 3 Houghton Mifflin English: Teacher's Edition, 1990; Level 2 Houghton Mifflin English: Teacher's Edition, 1995) . One hundred two sentences were used to create the stimuli. Three versions of each sentence were used, which totaled 306 sentences. One version of the sentences was correct, one contained a semantic error, and the third contained a syntactic error. Syntactic errors included one of the following: (a) a plural noun error, (b) a past tense *–ed* verb error, (c) a past tense irregular verb error, or (d) a third person verb error. The errors were consistent with the participants' regional dialect. All syntactic and semantic errors occurred in the final word of the sentence. The correct and incorrect versions of the same sentence were randomized and never occurred consecutively.

Each participant listened to a different version of the sentences binaurally. The presentation order of these versions was randomized between participants. Each participant was given a five-minute training period in which they were instructed to listen carefully to each sentence, decide if the sentence was correct or incorrect, and push the corresponding response button (a smiley-face was attached to the button for a correct sentence and a frowny-face was attached to the button for an incorrect sentence). After the first and second presentations of sentences, each participant was offered a five-minute break. Examples of the sentences are listed below (see Appendix B for the complete set):

***No syntactic or semantic errors.***

1. The sleeves covered both hands.
2. The girl laughed.
3. The plane flew.
4. Trees and flowers grow.

***Semantic error.***

1. The sleeves covered both *moons*.
2. The show *laughed*.
3. The plane *cried*.
4. Trees and flowers *quack*.

***Syntactic error.***

1. The sleeves covered both *hand* (plurality error).
2. The girl *laugh (*past tense regular verb error or omission of auxiliary "be" followed by progressive –ing).
3. The plane *flied* (past tense irregular verb error).
4. Trees and flowers *grows* (third person verb error).

**Analysis**

The auditory evoked potential waveforms obtained for each participant were averaged for both linguistically correct and deviant conditions (syntactically and semantically incorrect). The latency of the N400 was defined as the prominent negative peak within the latency range of 300-

600 ms at the central midline (Cz) recording site or at recording sites adjacent to the Cz recording site. The magnitude of the N400 was obtained by measuring the amplitude of the waveform from the baseline to the peak amplitude of the N400. The latency of the ELAN was defined as a prominent negative peak within the latency range of 150 to 300 ms at the Cz recording site or at adjacent recording sites. The magnitude of the ELAN was obtained by measuring the amplitude of the waveform from the baseline to the peak amplitude of the ELAN. The latency of the P600 was defined as the prominent positive peak within the latency range of 500 to 800 ms at the Cz recording site or at recording sites adjacent to Cz. The magnitude of the P600 was obtained by measuring the amplitude of the waveform from the baseline to the peak amplitude of the P600.

From the raw EEG data, epochs were created. A three point baseline correction and smooth function was then performed. Averages were taken for the three separate ear conditions from -200 to 1700 ms post-stimulus. It was then determined that by visually inspecting each of the averages that there were no significant ERPs that occurred after 800 ms. Descriptive statistics, including means and standard deviations, were determined for the N400, ELAN, and P600 latency and amplitude for each age group in all sentence conditions. Grand average waveforms were also created for each group in all sentence conditions.

## Results

### Brain Mapping

Brain mapping results consist of grand average waveforms for the CG and z-score derived brain maps for LI-1 and LI-2. The figures used were gathered as participants listened to the three sentence types.

**Control group participants.** Figures 1, 2, and 3 show the grand average waveforms of the CG for the three sentence types used in the current study. Figure 1 shows the grand average scalp distribution of the CG for linguistically correct sentences. Early processing is seen primarily over the left parietal occipital region from 62 to 125 ms (Figure 1a-b). During this same timeframe, frontal temporal processing is observed. These processing areas are diminished by 125 ms. Strong left frontal and left temporal processing is seen from 375 to 499 ms (Figure 1g-h). There is little change in activity until about 874 ms (Figure 1o), where high levels of activity are observed over the left temporal region. This activity then spreads to the left frontal region from 937 to 1000 ms (Figure 1p).

Figure 2 shows the grand average scalp distribution of the CG for syntactically incorrect sentences. This distribution is similar to the processing seen in Figure 1. This is contrasted by a more general processing seen initially over the left frontal and left temporal areas beginning at about 375 ms (Figure 2g). A broader distribution then occurs over the mid-frontal and central-parietal areas from 400 to 560 ms (Figures 2h-i). Later processing is seen occurring over the left frontal and left temporal regions from about 812 to 1000 ms (Figures 2n-p). This activity is similar to that seen in Figure 1, except the processing occurs earlier, beginning at about 812 ms (Figure 2n) instead of about 874 ms.

Figure 3 shows the grand average scalp distribution of the CG for semantically incorrect sentences. Figure 3 includes some early left posterior temporal processing at approximately 60 ms (Figure 3a). Little activity is seen occurring until about 874 ms when higher levels of activity occur over the left anterior temporal region that continues to occur until about 1000 ms (Figure 3o-p).

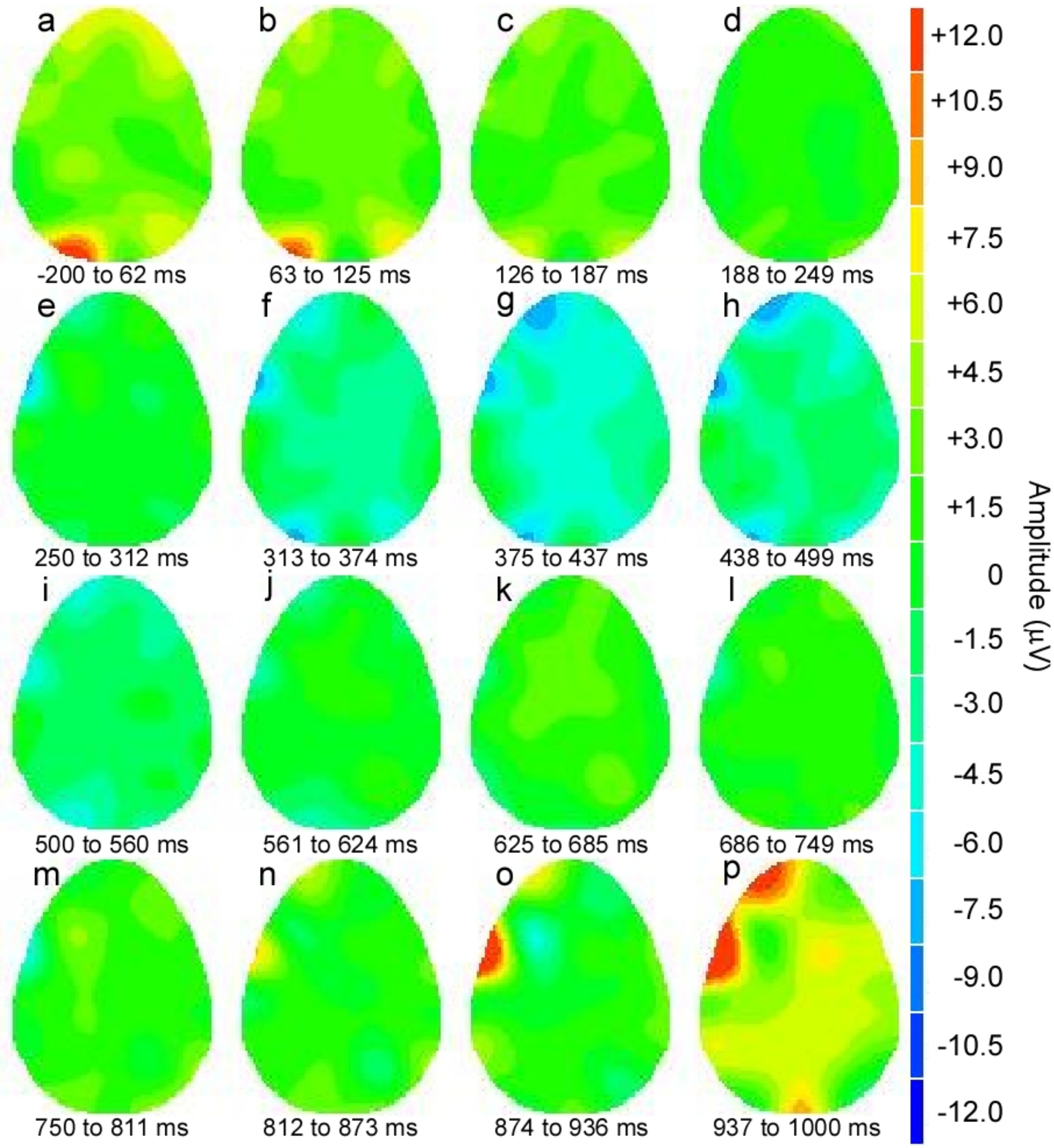


*Figure 1.* Average scalp distribution of the CG while listening to linguistically correct sentences. Orange/red indicates areas of greatest positivity (≥ 12.0 µV) and blue indicates areas of greatest negativity (≤ -12.0 µV).

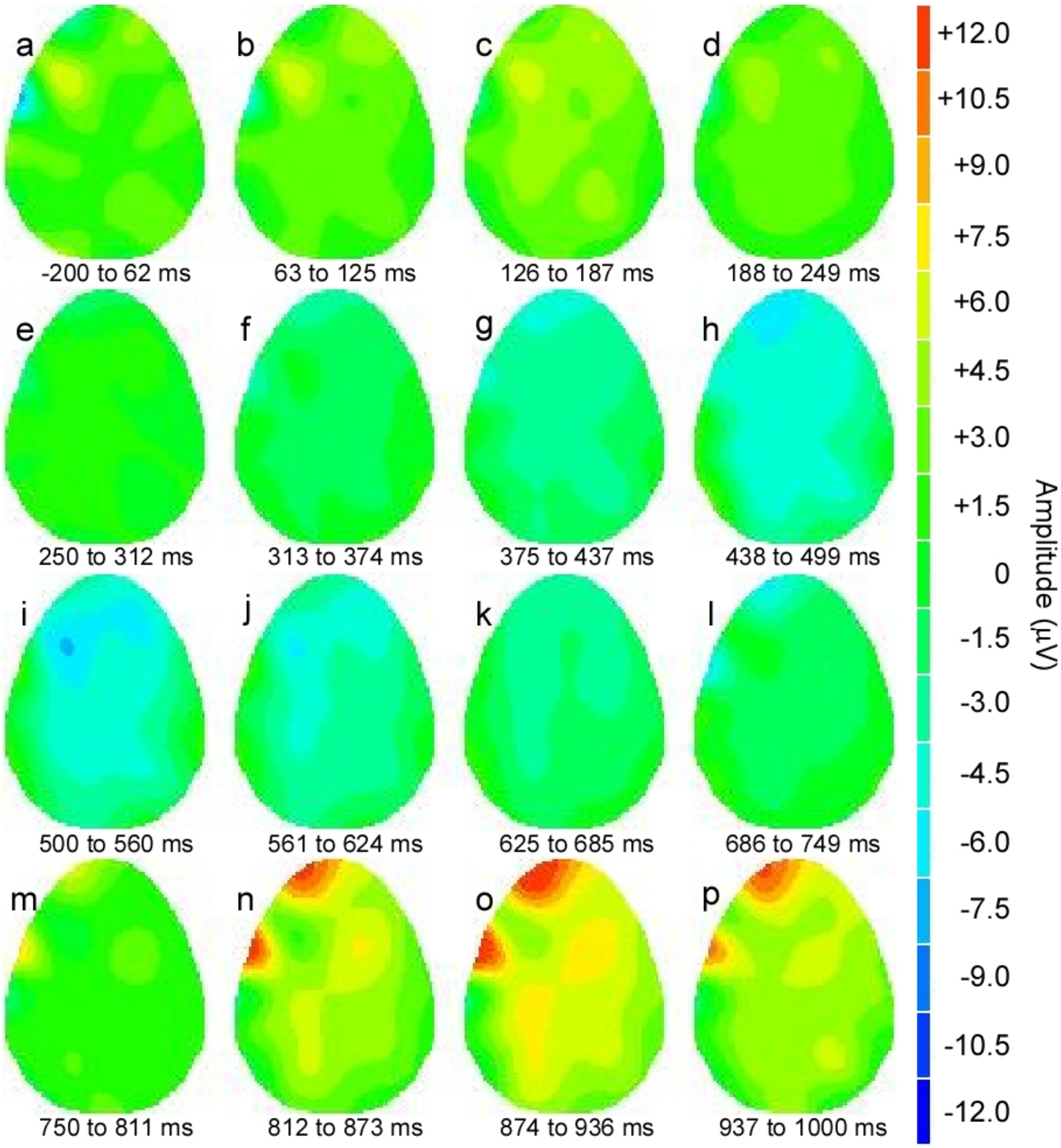


*Figure 2.* Average scalp distribution of the CG while listening to syntactically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ 12.0 μV) and blue indicates areas of greatest negativity (≤ -12.0 μV).

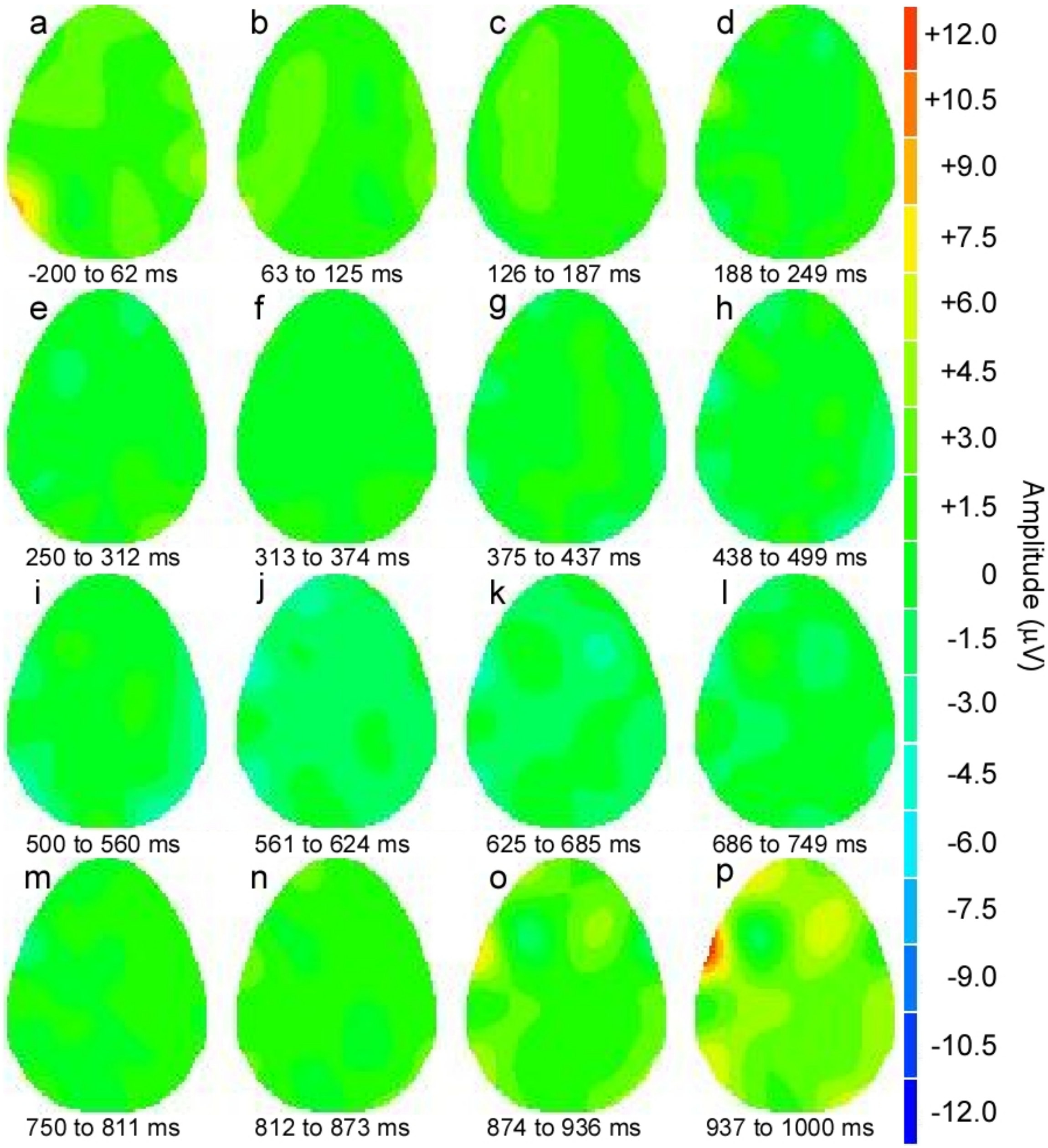


*Figure 3.* Average scalp distribution of the CG while listening to semantically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ 12.0 µV) and blue indicates areas of greatest negativity (≤ -12.0 µV).

**Z-score distributions.** Figure 4, 5, and 6 are z-score derived brain maps comparing the brain maps of the CG to the brain maps of LI-1. Figure 4 shows the z-score distribution between the CG and LI-1 for linguistically correct sentences. Additional processing is seen over the left temporal region between 438 to 499 ms (Figure 4h) with processing differences through approximately 560 ms (Figure 4i). These processing differences spread to the mid-temporal and parietal regions. No other differences are seen between the CG and LI-1 for linguistically correct sentences.

Figure 5, the responses to syntactically incorrect sentences, does not show any processing differences between the CG and LI-1.

Figure 6 shows the z-score distribution between the CG and LI-1 for semantically incorrect sentences. LI-1 has an interesting and dramatic patterning of differences between 438 and 499 ms (Figure 6h). In this time frame, differences are seen over the frontal, left mid-temporal, mid-central, left central parietal, and anterior occipital regions. No other processing differences are observed.

Figure 7, 8, and 9 are z-score derived brain maps comparing the brain maps of the CG to the brain maps of LI-2. Figure 7 shows the z-score distribution between the CG and LI-2 for linguistically correct sentences. Differences are primarily seen over the left posterior parietal region from 438 to 499 ms (Figure 7h). Some additional processing is seen between 560 and 749 ms, mainly over the mid-temporal and mid-parietal regions.

Figure 8 shows the z-score distribution between the CG and LI-2 for syntactically incorrect sentences. Processing differences occur over the right frontal region from 188 to 249 ms (Figure 8d). A more general spread of activity over the left and right mid-temporal regions as well as the left and right mid-parietal regions occurs between 250 and 312 ms (Figure 8e). A

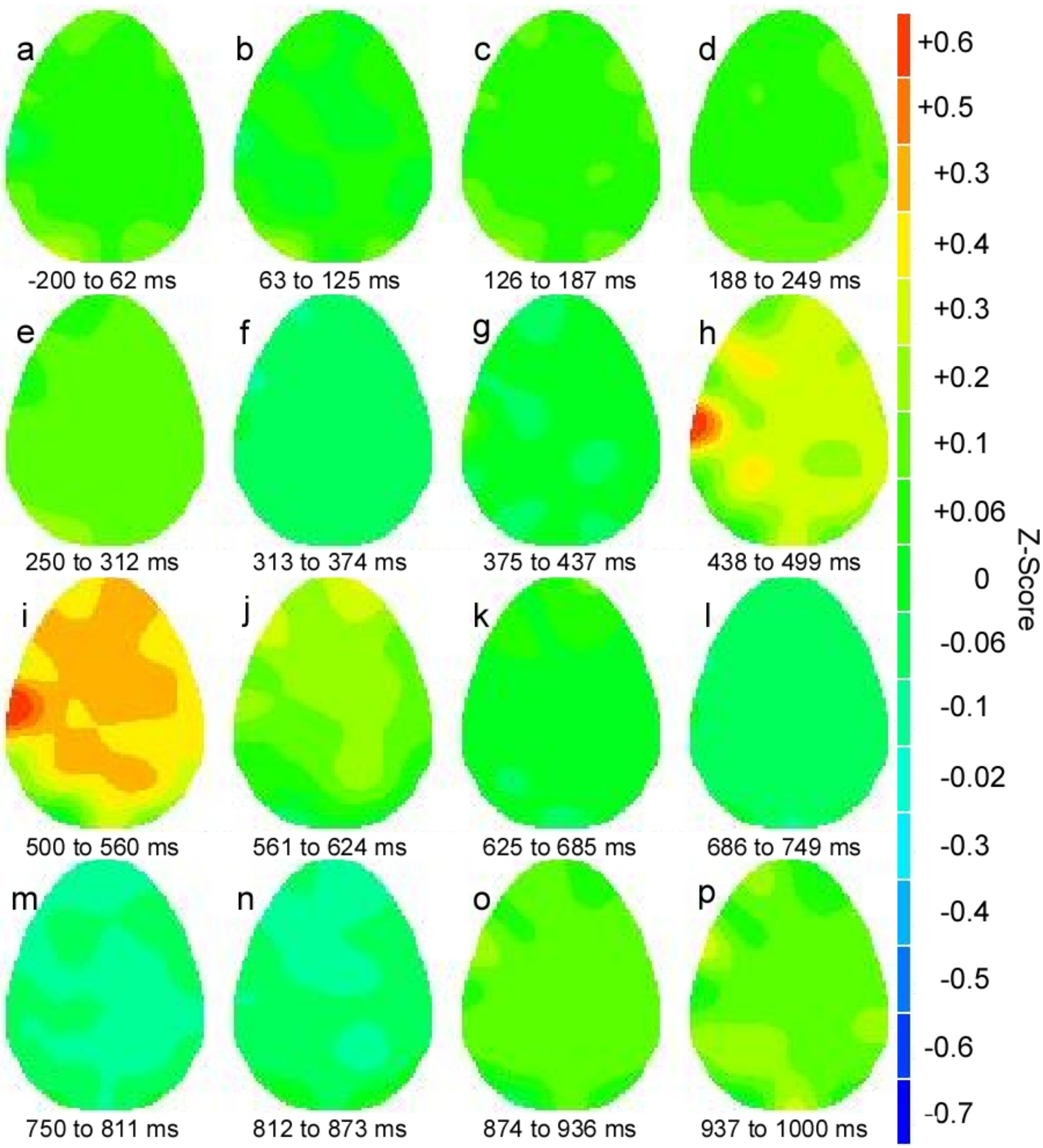


*Figure 4.* Z-score distribution between the CG and LI-1 when listening to linguistically correct sentences. Orange/red indicates areas of greatest positivity (≥ .6 μV) and blue indicates areas of greatest negativity (≤ -.7 μV).

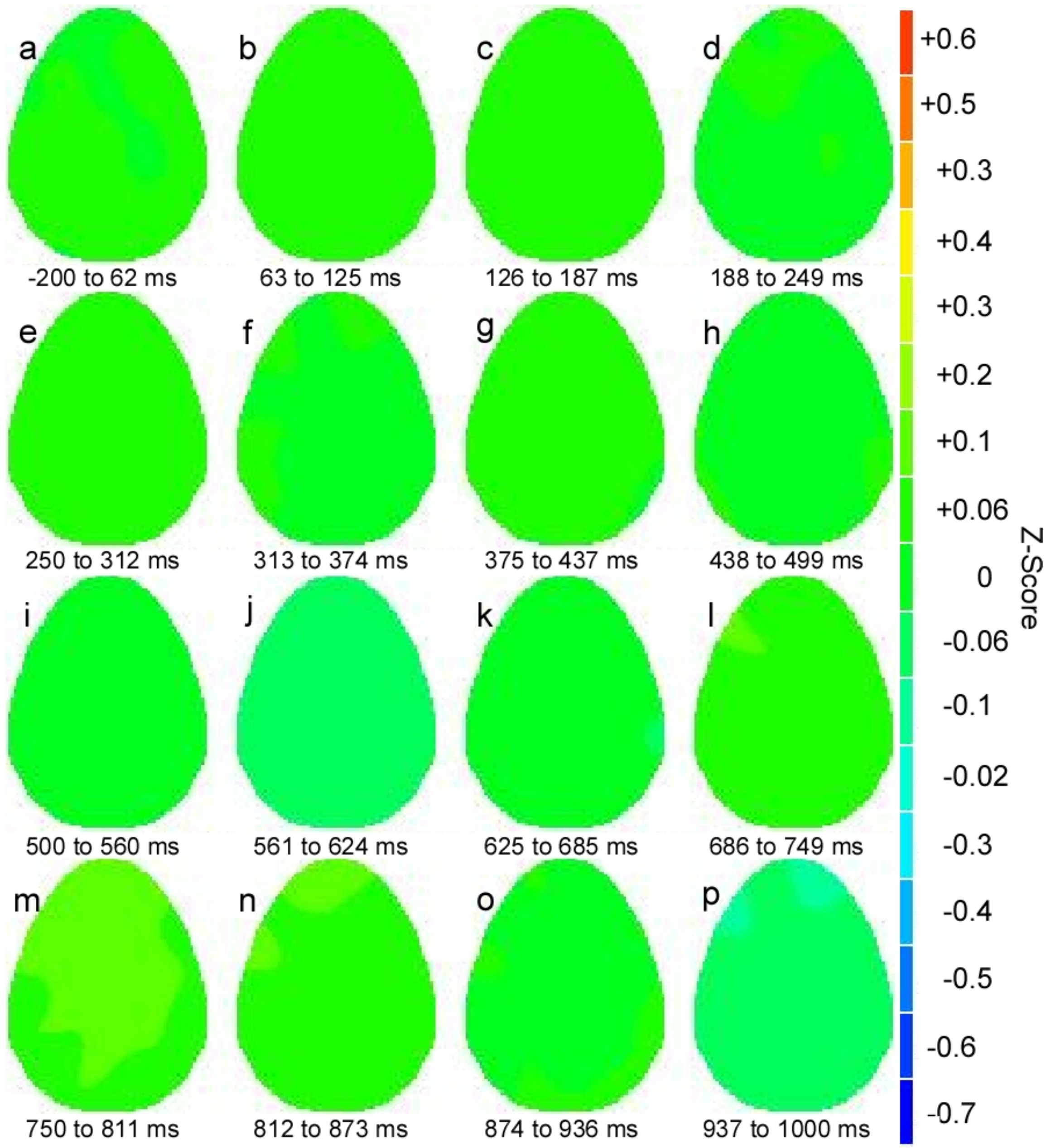


*Figure 5.* Z-score distribution between the CG and LI-1 when listening to syntactically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ .6 μV) and blue indicates areas of greatest negativity (≤ -.7 μV).

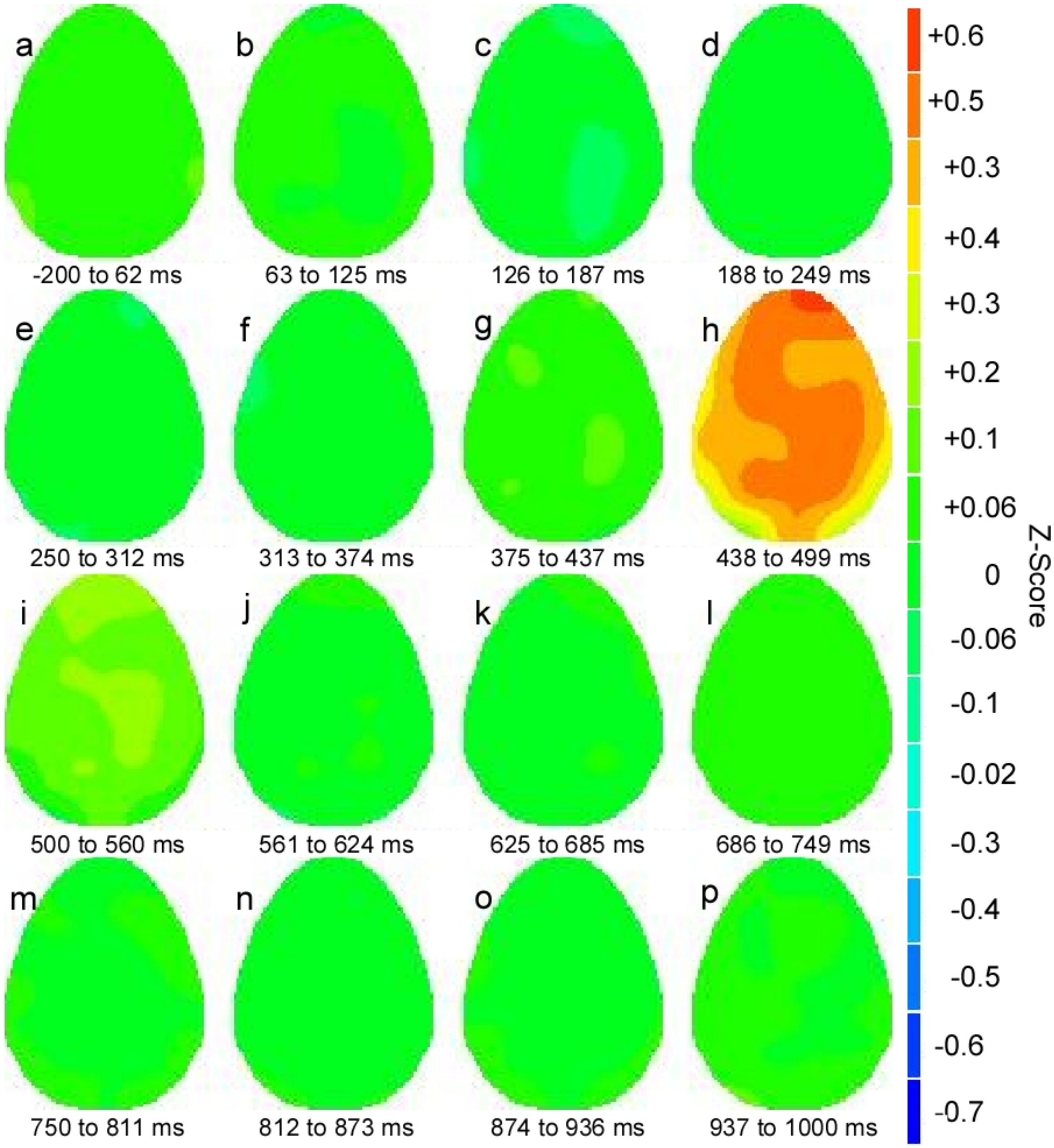


*Figure 6.* Z-score distribution between the CG and LI-1 when listening to semantically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ .6 µV) and blue indicates areas of greatest negativity (≤ -.7 µV).

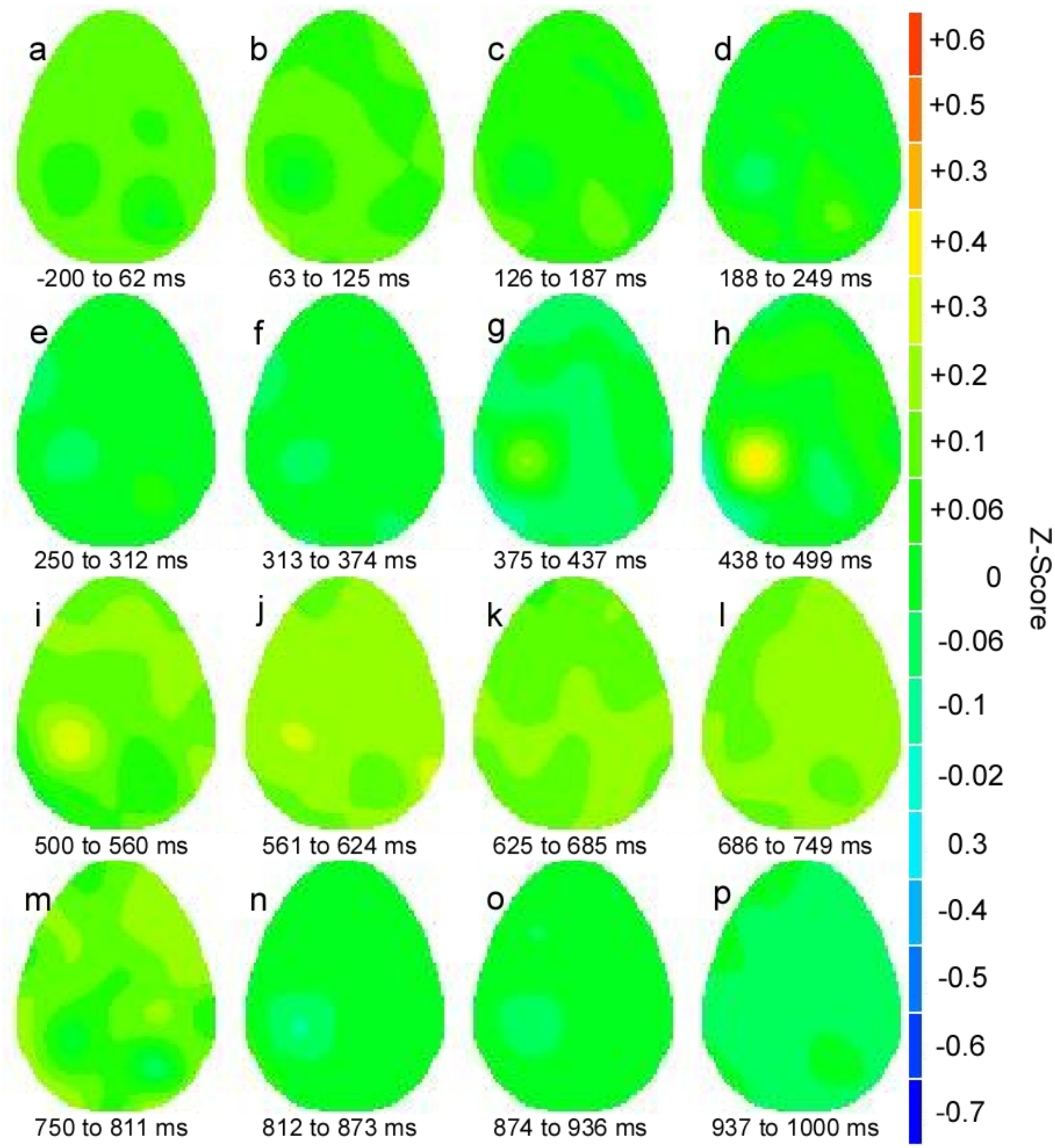


*Figure 7.* Z-score distribution between the CG and LI-2 when listening to linguistically correct sentences. Orange/red indicates areas of greatest positivity (≥ .6 μV) and blue indicates areas of greatest negativity (≤ -.7 μV).

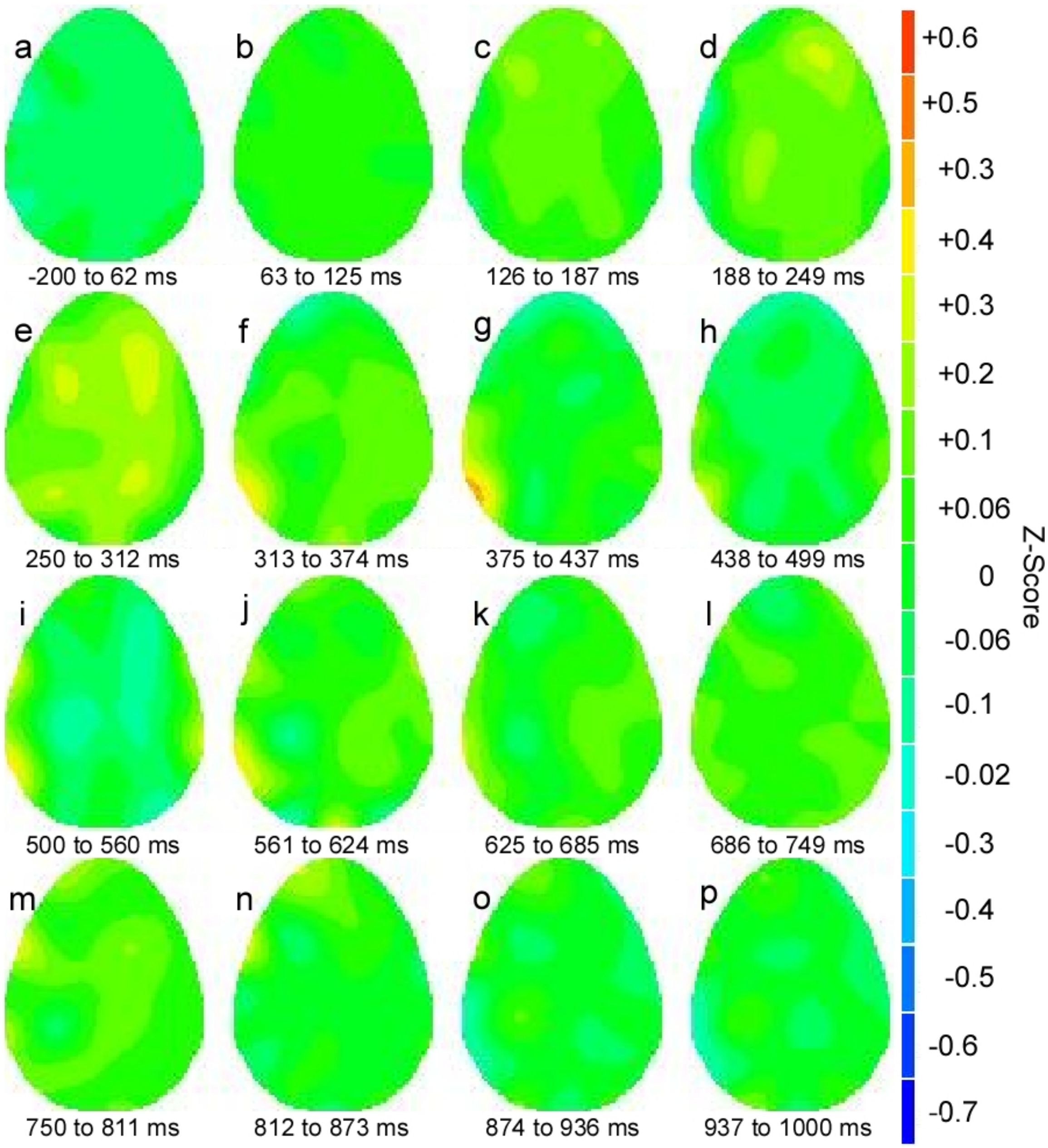


*Figure 8.* Z-score distribution between the CG and LI-2 when listening to syntactically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ .6 µV) and blue indicates areas of greatest negativity (≤ -.7 µV).

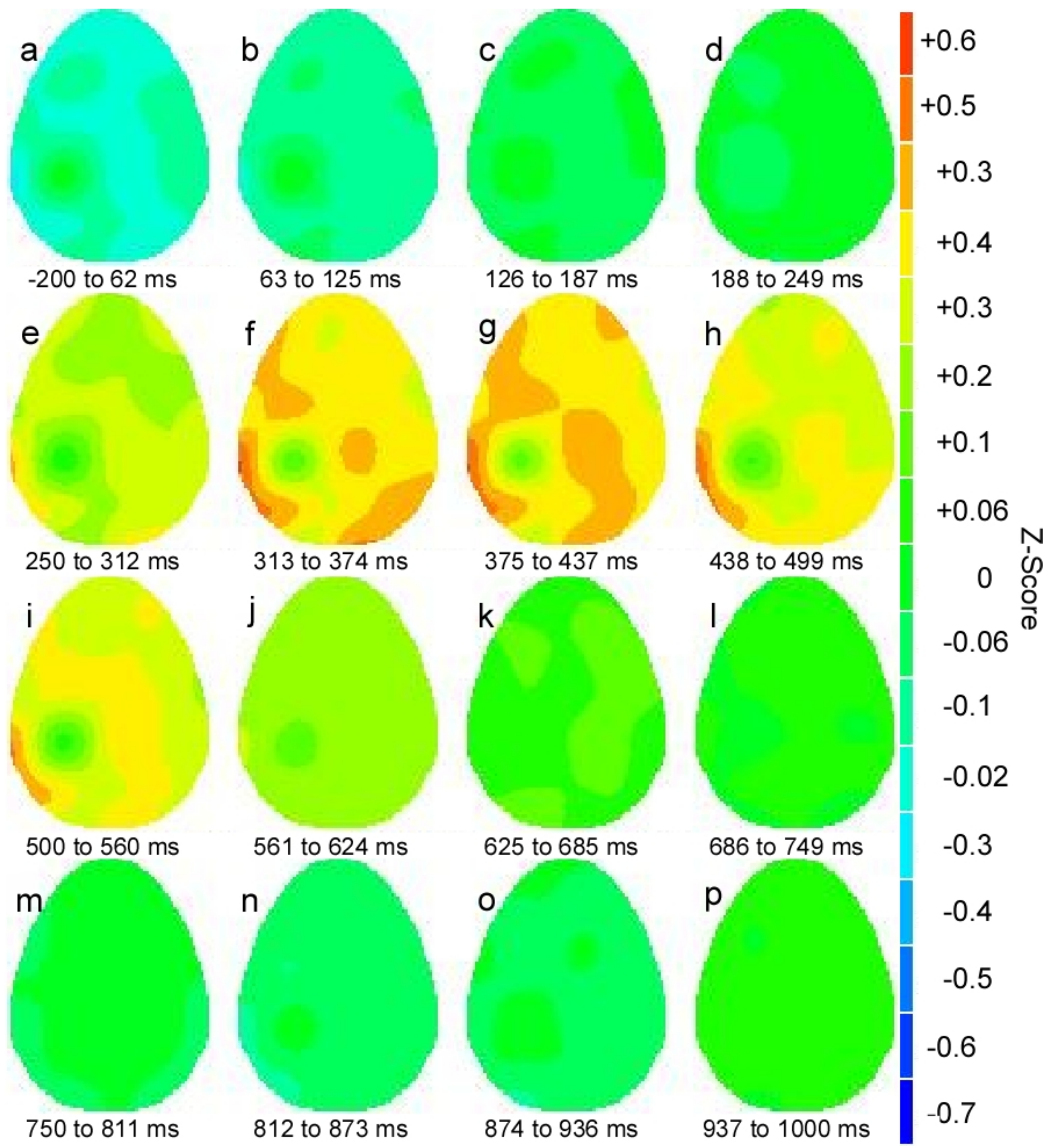


*Figure 9.* Z-score distribution between the CG and LI-2 when listening to syntactically incorrect sentences. Orange/red indicates areas of greatest positivity (≥ .6 µV) and blue indicates areas of greatest negativity (≤ -.7 µV).

larger, more focused difference is seen over the left posterior temporal region between 375 and 437 ms (Figure 8g). Finally, late processing differences occur over the left posterior parietal regions from 750 to 1000 ms.

Figure 9 shows the z-score distribution between the CG and LI-2 for semantically incorrect sentences. Early processing differences can be seen until approximately 125 ms (Figure 9a-b) primarily over the frontal and mid-occipital regions. Considerable processing is observed from about 250 to 312 ms (Figure 9e) over the left posterior temporal region spreading to a maximum between 375 to 437 ms (Figure 9g) and continuing to diminish out to about 560 ms (Figure 9i) over the left posterior temporal and left anterior parietal areas.

**Differences between the CG, LI-1, and LI-2.** Differences in processing may be seen between LI-1 and LI-2. In comparing Figure 4 and Figure 7, it is observed that stronger processing is seen over the left temporal area for LI-1 (Figure 4h) between 438 and 499 ms than for LI-2 (Figure 7h). For both participants, processing is seen over the left central parietal region. However, unlike LI-1, LI-2 does not have additional processing in surrounding areas in this time frame. In the time frame between 500 and 560 ms, a strong temporal processing is seen for LI-1 (Figure 4i) with the spread of activity occurring towards the mid- temporal and mid- frontal areas. Similar to Figure 7h, Figure 7i shows continued processing over the left central and parietal regions for LI-2.

There is little difference in processing for the syntactically incorrect sentences between the CG and LI-1 (Figure 5). However, this is not the case for LI-2, where processing over the left posterior parietal region is seen between 313 and 437 ms (Figures 8f-g).

In the semantically incorrect sentence comparison between LI-1 (Figure 6) and LI-2 (Figure 9), LI-1 shows a primary difference in processing activity between 438 and 499 ms

(Figure 6h). LI-2 is showing strong processing over the left posterior parietal regions between 313 and 499 ms (Figure 9f-h), with some differences seen over the left anterior and right occipital regions.

**N400, P600 and ELAN Comparison**

Table 4 shows the descriptive statistics for the linguistically correct sentences presented to the CG. The major components of the N400, P600, and ELAN are within published norms for this age group (Cummings & Ceponine, 2010; Hahne et al., 2004; Henderson, Baseler, Clarke, Watson, & Snowling, 2011; Neville et al., 1993; Sabisch et al., 2006a). For values of the ELAN, and as noted in Table 4, the waveform would not be expected in the presence of linguistically correct sentences (Friederici, 2004).

Tables 5 and 6 show the descriptive statistics for the syntactically incorrect and semantically incorrect sentences for the CG. Unlike for the linguistically correct sentences, the ELAN waveform is present. Again, the descriptive statistics agree with other studies using similar age groups in a normal population (Cummings & Ceponine, 2010; Hahne et al., 2004; Henderson et al., 2011; Neville et al., 1993; Sabisch et al., 2006a).

Table 7 shows the descriptive statistics for LI-1 and LI-2 for the N400. As expected, and illustrated by LI-1, the amplitude decreases and latency increases going from linguistically correct sentences, to syntactically incorrect sentences, and finally to semantically incorrect sentences. The N400 is typically elicited by semantically incongruent stimuli and precedes the P600 in latency, while the P600 is elicited by syntactical errors (Friederici, 2004; McPherson & Salamat, 2004). This suggests that semantic stimuli are processed before syntactic stimuli. The results in Table 7 are consistent with this notion. In LI-2, the N400 was only seen for the syntactically incorrect sentences.

Table 7 also shows the descriptive statistics for the participants with LI for the P600 and ELAN. The P600 is present for all three conditions in LI-1; however, it is only seen in the syntactically incorrect sentences for LI-2. The ELAN is only present in syntactically incorrect and semantically incorrect sentences for LI-1.

## Discussion

This study examined the ERPs of two children with LI and five typically developing children while listening to linguistically correct, syntactically incorrect, and semantically

Table 4

*Linguistically Correct Sentences Presented to the CG*

| Measure | *M* | *SD* | Minimum | Maximum |
|---|---|---|---|---|
| N400 Amplitude | -3.38 | 1.32 | -4.90 | -2.00 |
| N400 Latency | 398.25 | 70.41 | 324.80 | 493.60 |
| P600 Amplitude | 5.36 | 3.44 | 1.90 | 9.20 |
| P600 Latency | 547.52 | 98.47 | 392.40 | 641.20 |
| ELAN Amplitude | -15.50 | | -15.50 | -15.50 |
| ELAN Latency | 220.00 | | 220.00 | 220.00 |

Table 5

*Syntactically Incorrect Sentences Presented to the CG*

| Measure | *M* | *SD* | Minimum | Maximum |
|---|---|---|---|---|
| N400 Amplitude | -6.22 | 4.44 | -13.40 | -2.50 |
| N400 Latency | 400.88 | 91.98 | 288.80 | 524.00 |
| P600 Amplitude | 8.28 | 2.61 | 4.70 | 11.00 |
| P600 Latency | 659.52 | 111.37 | 478.00 | 778.80 |
| ELAN Amplitude | -3.10 | 0.99 | -3.80 | -2.40 |
| ELAN Latency | 182.80 | 30.26 | 161.40 | 204.20 |

Table 6

*Semantically Incorrect Sentences Presented to the CG*

| Measure | *M* | *SD* | Minimum | Maximum |
|---|---|---|---|---|
| N400 Amplitude | -3.70 | 1.27 | -5.20 | -2.30 |
| N400 Latency | 412.60 | 37.89 | 360.80 | 448.60 |
| P600 Amplitude | 2.25 | 1.57 | 1.00 | 4.50 |
| P600 Latency | 590.55 | 65.97 | 506.00 | 667.20 |
| ELAN Amplitude | -3.47 | 1.63 | -5.30 | -2.20 |
| ELAN Latency | 203.13 | 33.87 | 164.80 | 229.00 |

Table 7

*N400, P600 and ELAN for LI Participants*

| Case Study | Code | N400 Maximum Amplitude | N400 Maximum Latency | P600 Amplitude | P600 Latency | ELAN Amplitude | ELAN Latency |
|---|---|---|---|---|---|---|---|
| 1 | 1 | -25.0 | 348.4 | 27.8 | 640.0 | | |
| | 2 | -17.3 | 519.6 | -10.1 | 614.2 | -10.5 | 252.8 |
| | 3 | -9.1 | 535.4 | 8.9 | 668.2 | -29.9 | 255.0 |
| 2 | 1 | | | | | | |
| | 2 | -5.7 | 412.6 | 8.7 | 678.4 | | |
| | 3 | | | | | | |

*Note:* Code 1 = linguistically correct sentences, Code 2 = syntactically incorrect sentences, Code 3 = semantically incorrect sentences.

incorrect sentences. The results gathered illustrate how children with LI process language differently than typically developing peers. Specifically, the N400, P600, and ELAN were analyzed in each condition across participants and the results were compared to determine differences between the two groups.

**Discussion of Brain Maps**

Figure 1 shows the scalp distribution for the CG when listening to linguistically correct sentences. Early processing is seen primarily over the left parietal occipital region from 62 to 125 ms. During this same time frame, frontal temporal processing is also observed. Activation seen over these regions is consistent with another study by Newman, Pancheva, Ozawa, Neville, and Ullman (2001) that had similar findings concerning linguistically correct sentences. Newman et al. (2001) stated that activation of the superior temporal gyrus as well as temporal parietal and inferior frontal regions have been consistently revealed in conditions with linguistically correct stimuli. The frontal region activation observed in the current study is also consistent with statements made by Hickok and Peoppel (2007) who state that speech perception tasks involve some degree of executive control and working memory which may explain frontal lobe activations.

Figure 2 shows the scalp distribution for the CG when listening to syntactically incorrect sentences. Activation of the left frontal region is observed at approximately 375 ms and again at approximately 812 ms. The activation of this region in the current study is similar to the results of a study by Newman et al. (2001) who included typical adult participants. The effects Newman et al. (2001) found in relation to syntactic errors was primarily in the pre-frontal regions, with activation also seen over the superior frontal gyrus. These authors state that the superior frontal gyrus has traditionally been identified as a major substrate of syntactic processing (Newman et al., 2001).

Figure 3 shows the scalp distribution for the CG when listening to semantically incorrect sentences. Activation is seen over the left posterior temporal region at approximately 60 ms and then over the left anterior temporal region at approximately 874 ms. This area of activation is also consistent with Newman et al. (2001). When participants were presented with semantically incongruent stimuli, results showed enhanced activity over the posterior temporal and temporal parietal lobes. Thus, the temporal lobe is known to be involved in semantic processes (Newman et al., 2001). The N400 is elicited from semantically incongruent stimuli and, when presented auditorily, will typically elicit an N400 lateralized to the left hemisphere (Holcomb & Neville, 1990). Figure 3 displays areas of activity consistent with this notion.

Although the areas of activation for the CG in the current study are consistent with other findings, other studies have used typical adult participants instead of children. This suggests that, at least by 8 years of age, typically developing children may process linguistic information similar to adults in regards to the areas of the brain that are activated during the processing of linguistic stimuli.

The CG, LI-1, and LI-2 display differences in the time of processing when presented with semantically incorrect sentences. Early processing is seen in the CG (Figure 3) at approximately 60 ms. LI-1 and LI-2 take a longer period of time to begin processing the semantically incorrect sentences and processing does not appear to begin until about 438 ms in LI-1 (Figure 6), and 125 ms in LI-2 (Figure 9). We see this same trend of later processing in the participants with LI in distributions obtained by linguistically correct sentences (Figures 1, 4, and 7). The results from the current study are consistent with the results found by Montgomery (2006) that support the notion that children with LI exhibit slower real-time language processing relative to same-age peers.

**Discussion of the N400**

Table 7 for LI-1 displays a larger amplitude in the N400 than the CG (Table 6) when listening to semantically incorrect sentences. These results are similar to those reported by

Neville et al. (1993) that also found children with LI to have larger N400 amplitudes than a control group when presented with semantically incongruent stimuli. The larger N400 amplitude noted in LI-1, suggests that LI-1 required compensatory strategy and increased effort to process the semantic error (McPherson & Salamat, 2004; Neville et al., 1993).

LI-2 displayed different results than LI-1. When presented with semantically incorrect sentences, LI-2 did not display an N400. These results are consistent with a study completed by Sabisch et al. (2006b) who also found that the group with LI did not demonstrate an N400. This suggests that LI-2 had difficulty integrating semantic meaning (Sabisch et al., 2006b). LI-2 also displays an absence of the N400 for the linguistically correct sentences (Table 7). The absence of the N400 for the linguistically correct sentences and the semantically incorrect sentences suggests that LI-2 is not recognizing the difference between two linguistically correct sentences or between a linguistically correct sentence and a semantically incorrect sentence.

**Discussion of the P600**

Tables 4, 5, and 6 show that the amplitude of the P600 for the CG is higher when the CG was presented with syntactically incorrect sentences than when presented with linguistically correct or semantically incorrect sentences. The P600 is a wave observed in the presence of outright syntactic violations (Friederici, 2004). This suggests that the CG had no difficulty in detecting this syntactic error.  When analyzing the results from LI-2 (Table 7), we see that the P600 is only present when LI-2 was presented with syntactically incorrect sentences. This suggests that LI-2 is also detecting syntactical errors. When analyzing brain activity and its distribution from the current study, the conclusion that both of the participants with LI are detecting the syntactical error may be supported. LI-1 (Figure 6) and LI-2 (Figure 9) show more differences in activity from the CG when presented with semantically incorrect sentences than with syntactically incorrect sentences (Figures 5 and 8). This suggests greater difficulty in processing semantic errors than syntactic errors for the participants with LI. This is consistent with the findings of Sabisch, Hahne, Glass, Von Suchodeltz, and Friederici (2009), who also used children with LI and analyzed their P600. Sabisch et al. (2009) concluded that the P600 might be intact in children with LI.

**Discussion of the ELAN**

Table 7 shows the results for the ELAN in participants LI-1 and LI-2. Similar to the CG, LI-1 does not display the ELAN for linguistically correct sentences, but does display the ELAN for syntactically and semantically incorrect sentences. Although the results for the CG and LI-1 are similar, there is a difference in the ELAN for the CG and LI-1. The difference between the CG and LI-1 is that LI-1 has a significantly larger ELAN amplitude than the CG. A larger amplitude suggests that LI-1 required a greater amount of effort to process the syntactic and semantic errors than the CG (McPherson & Salamat, 2004).

LI-2 did not display the ELAN for any of the three sentence types. The absence of the ELAN for any of the three conditions may indicate that LI-2 has not developed this ERP at this stage of linguistic processing development. This is consistent with findings by Hahne et al. (2004) who found that the ELAN was not present in children between the ages of six and ten.

**Conclusions**

Results from the present study are consistent with other studies that show the brain mapping in typically developing children to be similar to adult processing. The present study showed that the brain mapping in the CG is similar to the findings of Newman et al. (2001) and Hickok and Poeppel (2007) who used adult participants. This result suggests that, at least by eight years of age, typically developing children may process linguistic information similar to adults in regards to the areas of the brain that are activated during the processing of linguistic stimuli (Hickok & Peoppel, 2007; Newman et al., 2001). This observation is consistent with Hahne et al. (2004) who reported that the neurophysiological basis for semantic processes during auditory sentence comprehension does not change dramatically between early childhood and adulthood.

The brain mapping results from the present study also show that children with LI may process linguistic information more slowly than typically developing children when listening to the three sentence types. For example, in the present study, LI-1 and LI-2 displayed similar brain areas of activation as the CG for linguistically correct and semantically incorrect sentences. However, these areas were activated at a later time when compared to the CG and are consistent with the behavioral findings from Montgomery (2006) that reported children with LI exhibit slower real-time processing than typically developing children.

Brain mapping results from the present study may also indicate that in some conditions, children with LI may require more effort than typically developing children in processing linguistic information. This is illustrated by LI-1 who showed a larger N400 amplitude when processing semantically incorrect sentences. Another example of this is seen in the ELAN for LI-1 when presented with syntactically incorrect sentences. LI-1 displays a larger ELAN and N400 amplitude indicating that LI-1 required more effort to process the semantic and syntactic errors (McPherson & Salamat, 2004).

Although the current study has found neurophysiological differences between typically developing children and children with LI, some results from the current study suggest that the participants with LI and the CG participants may have similarities. For example, when comparing results for the P600, the current study found that the participants with LI, as well as the CG, displayed the P600 when presented with syntactically incorrect sentences. This suggests that syntactical processing is intact in children with LI as well as in typically developing children. This is consistent with the findings of Sabisch (2009), who also noted that the P600 is intact in children with LI. LI-1 also showed some similarities to the CG in regards to the ELAN. Similar to the CG, the ELAN was only elicited in LI-1 when she was presented with syntactically and semantically incorrect sentences.

Because of the processing differences seen between LI-1 and LI-2, which were considered somewhat homogeneous from their clinical evaluations, it can be concluded that children with the same diagnosis, such as LI, may also display different neurophysiological findings from each other. For semantic errors, LI-1 displayed a larger N400 amplitude than the CG, while LI-2 did not display the N400. For syntactic errors, LI-1 displayed a larger ELAN amplitude than the CG, while LI-2 did not display the ELAN. The variability of the N400 and the ELAN between LI-1 and LI-2 in the current study and in other studies suggests heterogeneity in children with LI, even in the presence of similar tasks. Hence, the diagnosis of LI does not mean it is homogeneous across children with LI of equal age, at least according to the results of the present study and our understanding from other similar studies. Bishop (2007) also noted differences between participants with LI and concluded that research should move from a focus on group analysis to a focus on individual differences.

Results from the current study may also indicate that the ELAN may not be fully mature at eight years of age. The P600 and the ELAN are both associated with syntactic processing. As stated previously, LI-1 and LI-2 displayed a P600 when listening to syntactically incorrect sentences, indicating no difficulty in detecting the syntactic error. Yet, results from the current study also showed that LI-2 did not demonstrate the ELAN in the presence of syntactical errors.

These results in LI-2 lead us to question why the P600 was elicited and not the ELAN in the presence of syntactical errors for LI-2. Hahne et al. (2004) reported in their study of typically developing children between the ages of 6 and 13 that an ELAN for syntactic violations was not observed in children between the ages of six and ten years, and was only comparable to an adult pattern in the group of children who were 13 years of age. Hahne et al. (2004) indicated that higher automatic structure building processes reflected in the ELAN gradually develop toward adult-like processing during the later years of childhood, reaching adult-like maturity at about 13 years (Hahne et al., 2004).

**Recommendations for Future Research**

The findings of the present study indicate a need for future research to better understand the role of the N400 in semantic processing in children with LI. The results of the present study are consistent with other studies in the observation that the N400 is sometimes present and sometimes not present in children with LI. It would be of interest to investigate what situations cause the N400 to be elicited or absent in children with LI.

There is limited research involving young participants, both typically developing and those with LI, concerning cortical activity seen in semantic and syntactic processing. More research regarding this would be beneficial in further understanding how the areas activated in children might be the same or different from adult participants. Further research with older participants with LI would also be valuable in order to determine the cognitive development of semantic and syntactic processing in children with LI.

Another point of interest for future studies would be to look at the behavioral responses to the children in the current study. It may be insightful to investigate whether or not participants' behavioral responses (judging whether the sentence was correct or incorrect), had any correlation with their brain maps and ERP results.

There is much to learn concerning the language processing of typically developing children and children with LI by using ERPs. Electrophysiological measures make it possible to study the neurophysiological activity that occurs during language processing in children with LI. This type of research will be useful in providing more information to better understand the neurological basis for language impairments. This information can also help researchers and clinicians develop more appropriate therapy techniques for children with LI.

**References**

Bishop, D. V., & McArthur, G. M. (2004). Immature cortical responses to auditory stimuli in specific language impairment: Evidence from ERPs to rapid tone sequences. *Developmental Science, 7*(4), F11-18. doi: 10.1111/j.1467-7687.2004.00356.x

Bishop, D. V., & McArthur, G. M. (2005). Individual differences in auditory processing in specific language impairment: A follow-up study using event-related potentials and behavioural thresholds. *Cortex, 41*(3), 327-341. doi: 10.1016/S0010-9452(08)70270-3

Bishop, D. V., & McArthur, G. M. (2007). Atypical long-latency auditory event-related potentials in a subset of children with specific language impairment. *Developmental Science, 10*(5), 576-587. doi: 10.1111/j.1467-7687.2007.00620.x

Canseco-Gonzalez, E. (2000). Using the recording of event-related brain potentials in the study of sentence processing. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 229-266). San Diego: Academic Press. doi: 10.1016/B978-012304260-6/50014-1

Carrow-Woolfolk, E., & American Guidance Service. (1999). *CASL: Comprehensive assessment of spoken language.* Circle Pines, MN: American Guidance Services.

Compumedics Neuroscan (2008). CURRY 6 [computer software]. North Carolina: Compumedics USA.

Compumedics Neuroscan (2008). NeuroScan 4.5 [computer software]. North Carolina: Compumedics USA.

Compumedics Neuroscan (2008). Stim 2 [computer software]. North Carolina: Compumedics USA.

Cummings, A., & Ceponiene, R. (2010). Verbal and nonverbal semantic processing in children with developmental language impairment. *Neuropsychologia, 48*(1), 77-85. doi: 10.1016/j.neuropsychologia.2009.08.012

Friederici, A. D. (2004). Event-related brain potential studies in language. *Current Neurology and Neuroscience Reports, 4*(6), 466-470. doi: 10.1007/s11910-004-0070-0

Friederici, A. D. (2006). The neural basis of language development and its impairment. *Neuron, 52*(6), 941-952. doi: 10.1016/j.neuron.2006.12.002

Friedrich, M., & Friederici, A. D. (2006). Early N400 development and later language acquisition. *Psychophysiology, 43*(1), 1-12. doi: 10.1111/j.1469-8986.2006.00381.x

Hahne, A., Eckstein, K., & Friederici, A. D. (2004). Brain signatures of syntactic and semantic processes during children's language development. *Journal of Cognitive Neuroscience, 16*(7), 1302-1318. doi: 10.1162/0898929041920504

Henderson, L. M., Baseler, H. A., Clarke, P. J., Watson, S., & Snowling, M. J. (2011). The N400 effect in children: Relationships with comprehension, vocabulary and decoding. *Brain and Language, 117*(2), 88-99. doi: 10.1016/j.bandl.2010.12.003

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*(5), 393-402. doi: 10.1038/nrn2113

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes, 5*(4), 281-312. doi: 10.1080/01690969008407065

Houghton Mifflin Company. (1990). *Houghton Mifflin English: Teacher's Edition.* Boston: Houghton Mifflin.

Houghton Mifflin Company. (1995). *Houghton Mifflin English: Teacher's Edition.* Boston: Houghton Mifflin.

Jurcak, V., Tsuzuki, D., & Ippeita, D. (2007). 10/20, 10/10, and 10/5 systems revisited: Their validity as relative head-surface-based positioning systems. *Neuroimage, 34*(4), 1600-1611. doi: 10.1016/j.neuroimage.2006.09.024

Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics, 16*(1), 43-58. doi: 10.1016/S0911-6044(02)00008-8

Kutas, M., & Hillyard, S. A. (1980a). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology, 11*(2), 99-116. doi: 10.1016/0301-0511(80)90046-0

Kutas, M., & Hillyard, S. A. (1980b). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203-205. doi: 10.1126/science.7350657

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory and Cognition, 11*(5), 539-550. doi: 10.3758/BF03196991

McPherson, D. L., & Salamat, M. T. (2004). Interactions among variables in the P300 response to a continuous performance task in normal and ADHD adults. *Journal of the American Academy of Audiology, 15*(10), 666-677. doi: 10.3766/jaaa.15.10.2

Mills, D. L., & Neville, H. J. (1997). Electrophysiological studies of language and language impairment. *Seminars in Pediatric Neurology, 4*(2), 125-134. doi: 10.1016/S1071-9091(97)80029-0

Montgomery, J. W. (2006). Real-time language processing in school-age children with specific language impairment. *International Journal of Language and Communication Disorders, 41*(3), 275-291. doi: 10.1080/13682820500227987

Montgomery, J. W., & Evans, J. L. (2009). Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech Language and Hearing Research, 52*(2), 269-288. doi: 10.1044/1092-4388(2008/07-0116)

Neville, H. J., Coffey, S. A., Holcomb, P. J., & Tallal, P. (1993). The neurobiology of sensory and language processing in language impaired children. *Journal of Cognitive Neuroscience, 5*(2), 235-253. doi: 10.1162/jocn.1993.5.2.235

Newman, A. J., Pancheva, R., Ozawa, K., Neville, H. J., & Ullman, M. T. (2001). An event-related fMRI study of syntactic and semantic violations. *Journal of Psycholinguistic Research, 30*(3), 339-364.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicted by syntactic anomaly. *Journal of Memory and Language, 31*, 785-806. doi: 10.1016/0749-596X(92)90039-Z

Picton, T. W., & Stuss, D. T. (1984). Event-related potentials in the study of speech and language: A critical review. In D. Caplan, R. L. Andre & A. Smith (Eds.), *Biological perspectives on language* (pp. 303-360). Cambridge: The MIT Press.

Polich, J. (1985). Semantic categorization and event-related potentials. *Brain and Language, 26*(2), 304-321. doi: 10.1016/0093-934X(85)90045-8

Sabisch, B., Hahne, A., Glass, E., von Suchodoletz, W., & Friederici, A. D. (2006a). Auditory language comprehension in children with developmental dyslexia: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 18*(10), 1676-1695. doi: 10.1162/jocn.2006.18.10.1676

Sabisch, B., Hahne, A., Glass, E., Von Suchodoletz, W., & Friederici, A. D. (2006b). Lexical-semantic processes in children with specific language impairment. *Neuroreport, 17*(14), 1511-1514. doi: 10.1097/01.wnr.0000236850.61306.91

Sabisch, B., Hahne, C. A., Glass, E., von Suchodoletz, W., & Friederici, A. D. (2009). Children with specific language impairment: The role of prosodic processes in explaining difficulties in processing syntactic information. *Brain Research, 1261*, 37-44. doi: 10.1016/j.brainres.2009.01.012

Semel, E. M., Wiig, E. H., & Secord, W. (2004). *CELF-4: Clinical evaluation of language fundamentals screening test.* San Antonio, TX: Psych Corp.

Weber-Fox, C., Leonard, L. B., Wray, A. H., & Tomblin, J. B. (2010). Electrophysiological correlates of rapid auditory and linguistic processing in adolescents with specific language impairment. *Brain Language. 115*(3), 162-181. doi: 10.1016/j.bandl.2010.09.001

Wechsler, D., Pearson Education, Inc., & Psychological Corporation (2003). *WISC-IV: Wechsler intelligence Scale for Children.*San Antonio, TX: Pearson.

## Appendix A

## Annotated Bibliography

Bishop, D. V., & McArthur, G. M. (2004). Immature cortical responses to auditory stimuli in specific language impairment: Evidence from ERPs to rapid tone sequences. *Developmental Science, 7*(4), F11-18. doi: 10.1111/j.1467-7687.2004.00356.x

*Objective:* This study considered the auditory ERP responses of children with language impairment (LI) and controls to auditory stimuli. This study tested two hypotheses. First, Bishop and McArthur (2004) predicted that distinctive brain responses to two closely separated auditory stimuli would become apparent with age in typically developing participants. Second, they predicted that participants with LI would show immature responses to tone pair stimuli. In other words, ERPs of the children with LI would resemble those of younger typically developing children. *Design:* Participants were either presented with the single tone condition or with four tone-pair conditions. In the tone-pair conditions, a pure tone was followed by the same tone after an inter-stimulus interval (ISI). The four conditions differed only in length of ISI. The intraclass correlation (ICC) was computed for each participant between the ERP to a single tone and the ERP to the tone pair. ICC takes into account differences in amplitude as well as shape between two waveforms. *Study Sample:* Participants included 16 children with LI and 16 age matched controls. The participants used were 10 to 19 years of age. *Results:* When a single tone was presented, the classical components of an ERP were seen. An initial positivity around 80 ms (P1) followed by a negativity around 120 ms (N1), a positivity at around 160 ms (P2) and a second negative peak at around 240 ms (N2) were seen. When a second tone occurred 20 to 50 ms after the initial tone, responses to the two tones merged, the P2 response to the first tone was substantially diminished, and there was a larger N2. When the second tone occurred 150 ms after the initial tone, a separate brain response was visible. The two groups differed significantly only at the 50 ms ISI. ERPs of older participants with LI were more similar to those of younger typically developing children than their own age peers. *Conclusions:* These results suggest that the temporal resolution of the brain improves with age. At 50 ms ISI, integration of responses was seen for younger participants, but older participants showed a separate response to the two tones. After testing the first hypothesis, Bishop and McArthur (2004) found that participants below 14 years of age showed little differentiation in response to single tones vs. tone pairs. Older participants showed a distinctive response to the second tone. After testing the second hypothesis, Bishop and McArthur (2004) found that older participants with LI bore a closer resemblance to young controls than to age-matched controls in their response profile when they had high ICCs in the 50 ms ISI condition. *Relevance to Current Work:* This study discusses the immature auditory processing in LI. This is relevant to the current work in that it discusses the deficits that children with LI may be experiencing. Bishop and McArthur (2004) also discuss the auditory temporal deficit hypothesis of LI. This hypothesis states that it is not a particular aspect of auditory perception that is affected, but the overall course of development of central auditory processing.

Bishop, D. V., & McArthur, G. M. (2005). Individual differences in auditory processing in specific language impairment: A follow-up study using event-related potentials and behavioural thresholds. *Cortex, 41*(3), 327-341. doi: 10.1016/S0010-9452(08)70270-3

*Objective:* Bishop and McArthur (2005) wanted to re-test individuals who had poor frequency discrimination thresholds after a period of 18 months passed. They did this in order to see if the results were indicative of the maturational hypothesis. The maturational hypothesis states that the deficits seen in children with language impairment (LI) reflect delayed maturation of cortical development, rather than a more permanent abnormality. Another objective was to investigate if waveforms of individuals with LI deviate from controls in their age range. *Design:* The study included a frequency discrimination task. In this task, two tones were presented to participants as the mean interval between the start of each tone was varied twice. The first tone was played and the second tone followed. The second tone was the same except for having a higher frequency. The participants were then asked to identify which interval, the first or second, contained the higher tone. *Study Sample:* Participants involved in this study included 24 individuals. This included 11 individuals with LI and 13 control participants. The average age of the participants was 15 years of age. The participants with LI had a deficit in frequency discrimination. *Results:* There was a high correlation between the frequency discrimination seen on the two occasions for the 24 participants. The thresholds for the LI group with poor frequency discrimination improved with time and the control group was more stable. This is characteristic of the maturational hypothesis. ERPs in the range from 100 to 228 ms post stimulus were analyzed for each individual. Bishop and McArthur (2005) found the waveforms of the participants that had LI to be deviant from the control group in that the intraclass correlation (ICC) for each was significantly lower than the transformed ICC values of the control group. ICC takes into account differences in amplitude as well as shape between two waveforms. The LI group showed more immature ERPs than the control group. However, the results did not reach statistical significance. *Conclusions:* The data shown when comparing the LI group with the younger typical kids were compatible with the idea that auditory skills show a maturational lag in children with LI. In general, differences in waveform shape rather than differences in amplitude were largely responsible for the ICC difference between individuals with LI and the control grand mean. *Relevance to Current Work:* This article discusses children with LI and that their deficit in processing language may be attributed to a deficit in auditory processing. The rate at which words are typically presented may be difficult for a child with LI to interpret and slower rates may be easier for them. As children with LI mature, their auditory cortex matures as well. Bishop and McArthur (2005) also proposed that children with LI will catch up with their peers at some point, but they will continue to be behind in language processing because of the deficit in their early years. Most studies have found ERP waves to be different in amplitude rather than latency. This is relevant to the current work in understanding the deficits children with LI may experience when processing language.

Bishop, D. V., Hardiman, M., Uwer, R., & Von Suchodoletz, W. (2007). Atypical long-latency auditory event-related potentials in a subset of children with specific language impairment. *Developmental Science, 10*(5), 576-587. doi: 10.1111/j.1467-7687.2007.00620.x

*Objective:* The authors of this study sought to test the ability of children with language impairment (LI) against their age matched controls to discriminate the standard deviant stimuli used in an ERP session. *Design:* The children were played pairs of stimuli and asked to judge if they were the same or different. Instead of measuring the latency and amplitude of peaks, Bishop and McArthur (2007) used the intraclass correlation (ICC) to provide a global measure of similarity between the waveform of an individual child and the grand average of a typically developing group of the same age. ICC takes into account differences in amplitude as well as shape between two waveforms. *Study Sample:* Children with LI and the typically developing sample ranged in age from five to ten years. *Results:* There were significant differences in ICC values, and there was a substantial overlap between groups. The ICC has been proposed as a useful statistic for evaluating heterogeneity because it allows one to compare an individual's auditory ERP with the grand average waveform from a typically developing reference group. The waveforms of children with LI showed abnormalities for frontal, central, and temporal electrodes on the right side of the head, with a trend for smaller differences at the midline. A substantial proportion of children with LI had age-appropriate waveforms in this time interval. *Conclusions:* This study suggests that only a subset of children with LI have atypical ERPs. This study confirms suggestions that children with LI are hetergeneous, with some children with LI showing normal auditory ERPs and other showing atypical ERPs. In this study, some children with LI were more likely than controls to have atypical waveforms, but this was not the case for all children with LI. *Relevance to Current Work:* This article discusses children with LI and explains one way in which these children are different from their typical counterparts and how they may be the same. Because of the different results found when analyzing children with LI, the authors of this article state that we need to move away from group analyses and develop methods for identifying abnormalities of ERPs in individual children.

Byrne, J., Connolly, J., MacLean, S., Dooley, J., Gordon, K., & Beattie, T. (1999). Brain activity and language assessment using event-related potentials: Development of a clinical protocol. *Developmental Medicine and Child Neurology*, *41,* 740-747. doi:10.1017/s0012162299001504

*Objective:* The purpose of this study was to test the validity of a new computerized task to assess children's receptive vocabulary using event-related potentials (ERPs). The main goal of this study was to examine ERP components of typically developing children. *Design:* Typical children were presented with images and a corresponding word. They were then asked to indicate whether or not the word was congruent with the picture presented. *Study Sample*: A total of 56 children with normal development participated in this study. The participants ranged from 5 to 12 years of age. These participants were also divided into four different age groups. *Results:* The N400 was scored and averaged in this study. The N400 amplitude was found to be significantly higher to the incongruent picture–word pair than to the congruent picture–word pair. This effect was found for each of the four age groups. *Conclusions:* This task accurately estimated current receptive vocabulary in typically developing children that participated in this study. However, authors suggest that a broader assessment protocol should be studied for other populations other than typically developing children. *Relevance to the Current Work:* This study analyzes ERPs in typical children and explains how they may be elicited.

Canseco-Gonzalez, E. (2000). Using the recording of event-related brain potentials in the study of sentence processing. In Y. Grodzinsky, L. Shapiro, & D. Swinney (Eds.), *Language and the brain: Representation and processing* (pp. 229-266). San Diego: Academic Press. doi: 10.1016/B978-012304260-6/50014-1

*Objective:* This chapter gives a review of ERPs in speech and language. Canseco-Gonzalez (2000) describes event-related potentials (ERPs) and how they are useful in understanding the way that sentences are processed by the brain. The author discusses semantic processing and how this is related to the N400. The author also discusses other components of processing language such as the P600 and the ELAN. The author states that the ELAN is observed with outright syntactic violations or word category violations. The author also states that it is distinct from the N400 in that it has a more frontal distribution and a smaller amplitude than the N400. *Relevance to the Current Work:* This chapter describes ERPs in detail and describes how different components can be elicted. These same components will be used in the current work.

Carrow-Woolfolk, E., & American Guidance Service. (1999). *CASL: Comprehensive assessment of spoken language.* Circle Pines, MN: American Guidance Services.

*Objective:* The CASL was designed to test children's language abilities. *Relevance to the current work*: The CASL was used in the current study to test participant's language abilities.

Ceponiene, R., Cummings, A., Wulfeck, B., Ballantyne, A., & Townsend, J. (2009). Spectral vs. temporal auditory processing in specific language impairment: a developmental ERP study. *Brain Language, 110*(3), 107-120. doi: 10.1016/j.bandl.2009.04.003

*Objective:* This study examined event-related potential (ERP) meaures of auditory processing in typically developing children and children with language impairment (LI). *Design:* Three consonant vowel syllables, /ba/, /da/, and /ga/, were used in the study. During a behavioral syllable discrimination task, children listened to a total of 180 syllable pairs. The children pressed a happy-face button if they perceived two syllables to be the same, and a sad face button if they heard them as different. During the task in which ERPs were elicted, participants listened to the stimuli while they watched soundless cartoons on a computer monitor and were asked to ignore the sounds. *Study Sample:* Fifty three children took part in this study. Twenty five of the participants had LI with an average age of 12 years and twenty five of the participants were typically developing with an average age of 12 years as well. *Results:* Overall, the typical participants were more accurate, but not significantly faster than the children with LI. The typical children performed similarly on both types of trials, whereas the children with LI performed better on trials where the two syllables were the same than if they were different. Reaction times did not differ in the groups. There was no significant effect or interaction involving age. Results also indicated that reaction times decreased with age. *Conclusions:* Results suggest a deficit in acoustic feature integration at higher levels of auditory processing. The children with LI did not discriminate syllables as well as typically developing children regardless of the duration between sounds. *Relevance to Current Work:* This study discusses a deficit seen in children with LI. Authors also elicited ERP waveforms while the participants listened to the stimuli. This is similar to the current study.

Compumedics Neuroscan (2008). CURRY 6 [computer software]. North Carolina: Compumedics USA.

*Objective:* CURRY 6 software was designed to overlay temporal electrophysiological data onto brain images and reconstruct sources of electrical activity. *Relevance to the current work*:

CURRY 6 computer software was used in the current study during data collection.

Compumedics Neuroscan (2008). NeuroScan 4.5 [computer software]. North Carolina: Compumedics USA.

*Objective*: NeuroScan 4.5 software records EEG data as they are collected and has built-in analysis capabilities to filter and edit data after collection. *Relevance to the current work*: NeuroScan 4.5 computer software was used in the current study during EEG data collection. EEG data were streamed onto a computer using the software.

Compumedics Neuroscan (2008). Stim 2 [computer software]. North Carolina: Compumedics USA.

*Objective*: Stim 2 software was designed to stream auditory stimuli from the computer to the participant. *Relevance to the current work*: Stim 2 computer software was used in the current study during stimulus presentation.

Cummings, A., & Ceponiene, R. (2010). Verbal and nonverbal semantic processing in children with developmental language impairment. *Neuropsychologia, 48*(1), 77-85. doi: 10.1016/j.neuropsychologia.2009.08.012

*Objective:* The purpose of this study was to examine, with behavioral and electrophysiological measures, whether children with language impairment (LI) show verbal semantic integration deficits at a single-item level.  If found, Cummings and Ceponiene (2010) wanted to know whether such an impairment extends to the non-verbal domain. *Design:* This study employed a picture-sound and a picture-word matching design to assess electrophysiological brain activity related to semantic integration. The participants' task was to press a button marked by a smiley face as quickly as possible if they thought the picture and auditory stimulus matched, and to press a button marked by the sad face if they thought that the stimuli mismatched. Behavioral accuracy and reaction time measures were both analyzed in the results of this study. *Study Sample*: Sixteen children with LI, ages 7 to 15 years, and 16 age matched typically developing controls (TD), ages 7 to 15 years, participated in the experiment. *Results:* Overall, participants responded more accurately to environmental sounds than to words. In the picture-environmental sound trials, behavioral performance and the brain's response to semantic incongruency (the N400) of the children with LI were comparable to those of their typically developing peers. In the picture-word trials, children with LI tended to be less accurate than their controls and their N400 effect was significantly delayed in latency. *Conclusions:* The main finding was delayed processing of picture-word trials in the LI group. This finding suggests that children with LI have a semantic integration deficit, somewhat specific to the verbal domain. This is consistent with the storage deficit hypothesis of LI. This hypothesis suggests that there is a weakened or less efficient connection with the language networks of children with LI. *Relevance to the Current Work:* This study describes very well the characteristics of LI children as well as the semantic and syntactic deficits they have. This specific analysis of the N400 is important to the current work.

Davids, N., Segers, E., Vanden Brink, D., Mitterer, H., van Balkom, H., Hagoort, P., & Verhoeven, L. (2011). The nature of auditory discrimination problems in children with specific language impairment: An MMN study. *Neuropsychologia, 49*(1), 19-28. doi: 10.1016/j.neuropsychologia.2010.11.001

*Objective:* This was designed to shed more light on the nature of the auditory discrimination difficulties seen in individuals with language impairment (LI). The main question was whether discrimination deficits of children with LI are primarily phonological in nature, or if they coincide with non-speech processing difficulties. *Design:* In the first experiment, after listening to each stimulus, the participant was required to point to the picture that belonged to the presented stimulus. In the second experiment, participants were instructed to watch a movie and listen to auditory stimuli. The mis-matched negativity (MMN) was then recorded for each participant. *Study Sample:* Twenty five children with LI participated in this study. The control group matched on gender and consisted of 25 children with typical speech and language development. *Results:* On both the linguistic identification and discrimination tasks, the LI group performed significantly below the control group. *Conclusions:* While these results indicate that children with LI have a linguistic discrimination deficit, researchers were unable to discern whether these discrimination difficulties extend to non-speech information. Because the behavioral non-linguistic discrimination task was too difficult for these young children, the nature of auditory discrimination problems was further studied by the MMN paradigm. *Relevance to Current Work:* This study is helpful in that it gives more information about the deficits in children with LI.

Evans, J. L., Selinger, C., & Pollak, S. D. (2011). P300 as a measure of processing capacity in auditory and visual domains in specific language impairment. *Brain Research, 1389*, 93-102. doi: 10.1016/j.brainres.2011.02.010

*Objective:* The authors of this study sought to test processing speed and working memory in children with language impairment (LI). The authors hypothesized that if LI is primarily a speed of processing deficit, then results would show a slower behavioral reaction time as well as slower ERP latency in LI children. If the children with LI reflected limited processing capacity, researchers expected to see differences in behavioral accuracy and ERP amplitude for LI and for controls with no difference in latencies. Authors also sought to investigate if the cognitive processing deficits in LI are specific to the linguistic domain. *Design:* In the auditory condition, children heard a series of words. In the visual condition they saw a series of human faces with neutral affect. Children were asked to press a button on a button-box as soon as they heard or saw a target word or face that matched a word or face they had heard or seen one or two items back in the sequence. *Study Sample:* A total of 20 adolescents participated in the study. Ten of these had LI and ten were typically developing children. *Results:* Performance was significantly better in the auditory modalities when compared to the visual modalities for both groups. Results also showed that reaction times for the LI group were no slower than the age matched group. Both groups did respond more quickly in the visual modality. ERP amplitudes for the LI group were lower in the high memory load condition. ERP latencies did not differ between groups or across conditions, suggesting that neither group status nor condition affected processing speed. *Conclusions:* The results of this experiment suggest that processing speed and working memory are both deficits in children with LI and that these processing deficits may operate slightly differently in the auditory and visual modalities. Although LI is thought to be a disorder primarily of language processing, the present data suggest deficits in auditory as well as visual domains. *Relevance to Current Work*: This article discusses how children with LI differ from their typically developing counterparts in their working memory abilities.

Friederici, A. D. (2004). Event-related brain potential studies in language. *Current Neurology and Neuroscience Reports, 4*(6), 466-470. doi: 10.1007/s11910-004-0070-0

*Objective:* This article is a review of the four relevant language-related components in event-related brain potentials. *Conclusions:* Event-related brain potential studies involving both healthy participants and patients with specific brain lesions allow conclusions to be drawn with respect to the language-brain relationship. *Relevance to the Current Work:* This article discusses the ELAN, P600 and N400 ERP's in semantic and syntactic processing of language. This article is helpful in understanding the use for all three of these components when studying language processing. This article also discusses the temporal aspect of ERPs which is relevant to the current work.

Friederici, A. D. (2006). The neural basis of language development and its impairment. *Neuron, 52*(6), 941-952. doi: 10.1016/j.neuron.2006.12.002

*Objective:* This article is a review that discusses the development of language processes in typically developing individuals as well as in individuals with deficits such as language impairment (LI) and autism. The article consists of two parts. The first part discusses the neural correlates of normal language development using adult data as the reference model, and the second part covers the available neurophysiological and neuroanatomical studies on LI. *Results:* According to this review, LI is defined as a developmental disorder that selectively affects the domain of language processing. Children with LI perform below their age on language tasks requiring the processing of phonological, semantic, or syntactic information. Children with LI perform below their age despite normal intelligence, and adequate learning environment, and the absence of hearing problems. This article also discusses the different views on the underlying deficit of LI. Authors discuss a deficit in grammar, temporal auditory processing, reduced capacity in processing, and the procedural memory system. In discussing semantic processing, children with LI do not typically show an N400 when compared to their normally developing counterparts. *Conclusions:* The absence of the N400 effect in LI children may reflect insufficient lexical-semantic representations that prohibit the normal detection of the semantic mismatch. The authors of this review concluded that impaired language development is associated with abnormalities in the neurophysiological patterns of different aspects of language processing and with abnormalities in the structures of areas known to support language processes in the healthy adult brain. *Relevance to Current Work:* The discussion about children with LI is of most relevance to the current work and information regarding ERPs in children with LI was used in the current study.

Friedrich, M., Weber, C., & Friederici, A. D. (2004). Electrophysiological evidence for delayed mismatch response in infants at-risk for specific language impairment. *Psychophysiology, 41*(5), 772-782. doi: 10.1111/j.1469-8986.2004.00202.x

*Objective*: The authors of this article investigated whether infants with a family history of language impairment (LI) were slower in their processing of speech stimuli than infants without such a history. This study investigated whether delayed auditory processing typically found in children with LI can already be observed in the event-related potentials (ERPs) of two month old infants. *Design:* A frequently occurring standard long syllable /ba:/ with a duration of 341 ms was occasionally replaced by a deviant short syllable /ba/ with a duration of 202 ms, and a standard short syllable /ba/ was replaced by a deviant long syllable /ba:/. The short syllable /ba/ was infant-directed and was spoken by a young mother who was a native speaker of standard German. *Study Sample:* Infants with and without a family history of LI were tested in this study. *Results:* For the long syllable, a positive mismatch response occurred in the difference wave between deviant and standard stimuli. Its amplitude was higher in infants during quiet sleep than in awake infants, although its peak latency remained unaffected by alertness. Awake infants showed an adult like mismatch negativity preceding the positivity. *Conclusions:* Risk for LI was reflected in the latency of the positive mismatch response, which was delayed in infants with risk compared to infants without risk. This latency difference suggests that two month old infants at risk for LI are already affected in processing an auditory stimulus change of duration. *Relevance to Current Work:* This study discusses that we can see deficits that are typical of children with LI early in a child's development.

Friedrich, M., & Friederici, A. D. (2006). Early N400 development and later language acquisition. *Psychophysiology, 43*(1), 1-12. doi: 10.1111/j.1469-8986.2006.00381.x

*Objective:* This study was a longitudinal study that involved testing of children at 19 months and then again at 30 months. The authors of this study sought to investigate whether the occurrence of an N400 at 19 months is associated with the child's language skills later on in development. The N400 indicates semantic processing routines in both adults and children. The amplitude of the N400 indicates the effort for integrating a potentially meaningful stimulus into the current semantic context. The authors hypothesized that if children had poor language skills later on, and were also at risk for the development of language impairment (LI), they were more likely to have been delayed in their early lexical-semantic development. If these children lacked the phonological lexical priming effect and the N400, this would be reason to say that they were already impaired in their early development. *Design:* During the EEG recordings, children were first presented with a picture of an object and after a 900 ms interval, an indefinite article with a word length of about 700 ms was acoustically presented to refer to the pictured object. After another pause, the article was followed by a word or nonsense word. *Study Sample:* There were a total of 40 children who entered the final analyses. *Results:* Results showed that children with later age-adequate expressive language skills already had an N400 when they were tested at 19 months. In contrast, children that experienced poor expressive language skills who also had an enhanced risk for the development of LI, did not show an N400 at the age of 19 months. *Conclusions:* The results of this study imply that children who have deficits in their expressive language at the age of 30 months are already impaired in their semantic development about one year earlier. *Relevance to Current Study:* This article discusses the critical mass hypothesis which states that after the lexicon in a child exceeds a particular size, a qualitative shift can be observed in further lexical and morphosyntactic development. According to the critical mass hypothesis, the slower acquisition of language-related skills and even the development of LI should be associated with weaker early lexical-semantic abilities. This article also discusses the deficits that children with LI may have at an earlier age. The deficits seen here can be found with the non-existent N400 during the task.

Hahne, A., Eckstein, K., & Friederici, A. D. (2004). Brain signatures of syntactic and semantic processes during children's language development. *Journal of Cognitive Neuroscience, 16*(7), 1302-1318. doi: 10.1162/0898929041920504

*Objective:* This study sought to investigate developmental changes in the neurophysiological markers of semantic and syntactic processes of 6 to 13 year olds. The study used three ERP components that reflect semantic and syntactic processes in adults. Authors included the N400, the ELAN and the P600 in their analysis. *Design:* Authors used correct, semantically incorrect, and syntactically incorrect sentences that were auditorily presented to the participants. The participants were then asked to judge its correctness by pressing the smiley face or frowny face. *Study Sample:* Children ranging from 6 to 13 years of age participated in the experiment and were assigned to five age groups. Their results were also compared to the data collected from adults. *Results:* For semantic violations, adults demonstrated an N400, as did children, but the latency decreased with age. For syntactic violations, adults displayed an early left anterior negativity (ELAN) and a late centro-parietal positivity (P600). The ELAN was not present in children between the ages of six and ten. The ELAN was only comparable to an adult pattern in the group of children 13 years of age. *Conclusions:* These results indicate that the neurophysiological basis for semantic processes during auditory sentence comprehension does not change dramatically between early childhood and adulthood. Syntactic processes for sentences appear to differ between early and late childhood, at least with respect to those processes reflected in the ELAN component. As there is evidence that the ELAN reflects highly automatic structure building processes, the authors conclude that these processes are not yet established at age 7 years, but gradually develop toward adult-like processing during late childhood. *Relevance to Current Work:* The current study will also include electrophysiological measures such as the N400, ELAN, and P600 in children.

Henderson, L. M., Baseler, H. A., Clarke, P. J., Watson, S., & Snowling, M. J. (2011). The N400 effect in children: Relationships with comprehension, vocabulary and decoding. *Brain and Language, 117*(2), 88-99. doi: 10.1016/j.bandl.2010.12.003

*Objective:* Authors of this study sought to provide evidence of the N400 effect in school-aged children. The second objective was to provide neurophysiological support for the importance of access to word meaning to language comprehension in children. Authors also sought to provide further information on the extent to which event related potential (ERP) indicators of vocabulary knowledge are predictive of behavioral performance for the same items. *Design:* In the semantic tasks, participants saw a series of two pictures (picture–picture) or a series of two words (word–word) and were asked to decide if they were semantically related. In the phonological task they heard two words (e.g., bear–bare) and were asked to decide if they sounded the same. *Study Sample:* Eighteen children aged 8 to 10 years were recruited for this study from six primary schools in York, UK. *Results:* The peak amplitudes of the N400 were significantly greater for the semantically incongruent condition than the congruent condition and the N400 congruency effect was particularly prominent in frontal regions. *Conclusions:* The present findings highlight the issue that behavioral and neurophysiological methodologies likely tap different processes but are also related. *Relevance to the Current Work:* In the introduction to this study, the authors discuss the N400 effect and what the N400 peaks indicate. This is relevant to the current study when describing how the N400 is elicited and its use in analyzing language processing.

Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience, 8*(5), 393-402. doi: 10.1038/nrn2113

*Objective:* This article outlines a dual-stream model of speech processing that remedies the fact that neuroanatomy of speech has been difficult to characterize. *Relevance to the Current Work:* This article discusses semantic and syntactic processing by the brain and what areas of the brain studies have seen activity in during this processing. The current work is also searching to answer this question in participants.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes, 5*(4), 281-312. doi: 10.1080/01690969008407065

*Objective:* This study sought to compare and contrast semantic priming in the visual and auditory modalities using event-related potentials (ERPs) and behavioral measures. *Design:* Participants completed two lexical decision tasks where stimuli were word pairs consisting of a prime word followed by equal numbers of words semantically related to the primes, words unrelated to the primes, pseudowords, and nonwords. Participants performed each task visually and then auditorily. *Study Sample:* Participants were 16 adults between the ages of 20 and 32 years. All participants were right handed native speakers of English with normal visual and auditory acuity. *Results:* Participants made slower responses, made more errors, and their ERPs had larger negative components such as the N400 to unrelated words than related words in both modalities. However, the ERP priming effect began earlier, was larger in size, and lasted longer in the auditory modality than the visual modality. The N400 distribution also differed in the two modalities. *Conclusions:* The results suggest that there may be overlap in the priming processes that occur in each modality but that these processes are not identical. The results also demonstrate that the N400 component may be specifically responsive to language or potential language events. *Relevance to Current Work:* The current work is also researching the N400 and semantic errors.

Houghton Mifflin Company. (1990). *Houghton Mifflin English: Teacher's Edition.* Boston: Houghton Mifflin.

*Relevance to Current Work:* This book was used to obtain stimuli for the current work.

Houghton Mifflin Company. (1995). *Houghton Mifflin English: Teacher's Edition.* Boston: Houghton Mifflin.

*Relevance to Current Work:* This book was used to obtain stimuli for the current work.

Jurcak, V., Tsuzuki, D., & Ippeita, D. (2007). 10/20, 10/10, and 10/5 systems revisited: Their validity as relative head-surface-based positioning systems. *Neuroimage, 34*(4), 1600-1611. doi: 10.1016/j.neuroimage.2006.09.024

*Objective:* The aim of this study was to evaluate the effectiveness of 10/20-derived systems in head-surface-based positioning systems. This study presents a referential framework for establishing the effective spatial resolutions of 10/20, 10/10, and 10/5 systems as relative head-surface-based positioning systems. *Design:* Authors sought to test the 10/20 systems in order to show that it could be a standardized method when conducting research. *Study Sample:* The MRI data sets were analyzed in 17 adults aged 22 to 51 years of age. *Results/Conclusions:* In studying the 10/20 systems, it has gained importance as a standard method for setting landmarks over the scalp when conducting research. *Relevance to the Current Work:* The current work is using the placement of electrodes, showing why this article is important.

Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics, 16*(1), 43-58. doi: 10.1016/S0911-6044(02)00008-8

*Objective:* This article discusses three event related potential (ERP) components. Authors discuss the N400, the P600 and the ELAN. Kotz and Friederici (2003) also discuss how these components may be affected when used in studies containing individuals with pathological differences. *Design:* In studying structural deficits, ERPs were recorded from patients with temporo-parietal lesions. As they investigated functional deficits, the authors of this study used an auditory word pair to investigate lexical–semantic integration processes in aphasic patients. *Study Sample:* To test structural deficits, authors involved patients with temporo-parietal lesions. To test functional deficits, authors used three different patient groups. Authors included patients with left hemisphere lesions diagnosed as Broca's aphasics, patients with left hemisphere lesions diagnosed as Wernicke's aphasics, and patients with right hemisphere lesions. *Results:* In the analysis for functional deficits, a statistically reliable N400 was found in the Broca's patient group for semantically related targets. In the Wernicke patient group the N400 was also present, but clearly reduced compared to normal controls. *Conclusions:* In testing structural deficits, it appears that anterior and posterior parts of the temporal lobe are engaged in the processing of lexical–semantic information as reflected in the N400 component. Furthermore, it is apparent that the modulation of the N400 varied mainly as a function of amplitude and latency. This might imply that other cognitive processes come into play in order to process lexical– semantic information when a patient suffers from a temporal lobe lesion. The authors also concluded that patients with clear comprehension deficits show a reduction of the N400 effect indicating a reduction in their ability to match words for their semantic similarity. *Relevance to Current Work:* This article defines the three ERPs to be used in the current work. It discusses the components of an ERP (latency, amplitude and topography) and how they relate to brain function.

Kutas, M., & Hillyard, S. A. (1980a). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology, 11*(2), 99-116. doi: 10.1016/0301-0511(80)90046-0

*Objective:* Previous studies have shown that a late positivity and the P400 are typically elicited with incongruous or unexpected stimuli. This study sought to investigate whether both types of waveforms could be elicited in the same series of sentences, and what would happen when a word was both semantically and physically deviant. *Design:* ERPs were recorded from young adult participants as they silently read 160 different sentences that were presented one word at a time. The sentences either ended normally or were completed by unexpected words that were either semantically inappropriate, physically deviant, or both. *Study Sample:* Participants included 14 young adults that ranged from 19 to 35 years of age. *Results:* Each of the two types of deviations were associated with distinctly different ERP components. The N400 was present for semantic deviations and a late positive complex was observed for physical deviations. Results also show that the two ERP effects may be elicited concurrently by the same word when it exhibits both types of deviations. The amplitude of the N400 wave to semantic incongruity was essentially the same whether or not the word was physically deviant and the late positivity ERP was not affected by the semantic incongruity. *Conclusions:* The results of this study confirmed the results of a previous study done by the same authors. They found that semantically and physically deviant words in a silent reading task are associated with distinctly different ERP components. Authors also found that both ERP effects can be elicited at the same time. *Relevance to Current Work:* The current work specifically investigates the N400 and semantic deviations in sentences.

Kutas, M., & Hillyard, S. A. (1980b). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*(4427), 203-205. doi: 10.1126/science.7350657

*Objective:* The authors of this study sought to evaluate ERPs in sentence reading tasks. Kutas and Hillyard (1980b) specifically wanted to evaluate effects of semantically inappropriate sentences. *Design:* Participants were presented sentences where the sentence ended in a semantically inappropriate, but syntactically correct, word. They were either of moderate or strong semantic incongruity. The participants were also presented with sentences where the last word of the sentence was physically larger than the other words. *Results:* Words that were physically larger than normal elicited a late positive series of potentials, whereas semantically inappropriate words elicited a late negative wave, or the N400. *Conclusions:* The N400 that was found during this study may be an electrophysiological sign of the processing of semantically anomalous information. *Relevance to Current Work:* This article specifically discusses the N400 and its importance in semantic processing which is important to the current work.

Kutas, M., & Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory and Cognition, 11*(5), 539-550. doi: 10.3758/BF03196991

*Objective:* This study was conducted in order to investigate whether the N400 effect is specific to semantically deviant words or if it is elicited by a broader class of unexpected words. Authors specifically analyzed words that were syntactically incorrect. Another experimental goal was to determine whether the N400 could be elicited in a more natural reading situation. *Design:* Words were displayed on a computer screen and participants were asked to read the sentences one word at a time. Participants were then asked to answer multiple choice questions about the text at the end of the session. The stimuli included semantically inappropriate sentences where the error was made at the beginning, middle, or end of the sentence as well as grammatical errors. *Study*

*Sample:* Seventeen young adults ranging from 18 to 33 years of age took part in this study. *Results:* The authors found that the semantically inappropriate words elicited a large N400 component and the grammatical errors were associated with smaller and less consistent components. *Conclusions:* The results of these findings add to the evidence that the N400 is more closely related to semantic processing than grammatical processing. *Relevance to Current Work:* This article has an explanation of the N400 that will help the current study in explaining how that relates to language processing.

McPherson, D. L., & Salamat, M. T. (2004). Interactions among variables in the P300 response to a continuous performance task in normal and ADHD adults. *Journal of the American Academy of Audiology, 15*(10), 666-677. doi: 10.3766/jaaa.15.10.2

*Objective:* This study sought to investigate the effect of variable interstimulus intervals (ISIs) in a group of normal adults and those with attention deficit hyperactivity disorder (ADHD) on behavioral reaction time and the auditory P300 event-related potential (ERP). *Design:* As participants were seated in a recliner chair, auditory ERPs were obtained. Four tones and three ISIs were randomly presented with no condition occurring in succession. The participants were asked to respond by pushing a button in response to common tones and withholding the response for rare tones. The number of hits, misses, correct rejections, and false alarms were recorded for each ISI. *Study Sample:* This study involved 20 normal participants. They were aged 17 to 25 years of age with no history of ADHD. It also involved a group of 11 participants that ranged in age from 19 to 31 years of age that had a diagnosis of ADHD. *Results:* All participants in the normal group showed good reproducibility and identifiable waveform morphology for the P300. There was greater variability in the morphology of the waveforms for the ADHD group. Significant differences between the normal group and the group with ADHD were seen for the latency of the P300 at each of the three ISIs. Significant differences were seen for the amplitude of the P300 in some conditions. *Conclusions:* Authors concluded that there must be a processing lag that occurs between the brain recognizing that there is a difference between the stimuli and actually physically detecting the task. *Relevance to Current Work:* This work is helpful in understanding what the different components of the ERP help us understand. For example, this article describes latency and amplitude and what these components can tell us.

Mills, D. L., & Neville, H. J. (1997). Electrophysiological studies of language and language impairment. *Seminars in Pediatric Neurology, 4*(2), 125-134. doi: 10.1016/S1071-9091(97)80029-0

*Objective:* This study analyzes the developmental changes in neural systems that are linked to the attainment of specific language milestones during the first four years of life. Authors studied changes in the organization of language-relevant brain systems in children as children go through different ages. Mills and Neville (1997) also examined the event related potential (ERP) patterns of late talkers to see if they might be predictive of language performance later in age. *Design:* The children sat on their parent's lap as they listened to a series of words presented through a speaker. The words included words they understood, words they did not understand, and backwards words, all in English. *Study Sample:* Typical children and children with language impairment (LI) were involved in this study. Authors also included participants that were described as being late talkers. *Results:* Atypical patterns of brain activity were observed in subsets of children with LI for both sensory and language processing. However, it was not the same groups of children who displayed abnormalities across the different tasks. *Conclusions:* This study suggests that the organization of neural systems important in language acquisition display dramatic changes during development. Some of these are linked to the attainment of language milestones and appear to be independent of chronological age. Authors also found that using event related potentials is a suitable way to study the neurobiology of language and LI. *Relevance to the Current Work:* This article discusses some of the findings that have been discovered concerning children with LI.

Montgomery, J. W. (2006). Real-time language processing in school-age children with specific language impairment. *International Journal of Language and Communication Disorders, 41*(3), 275-291. doi: 10.1080/13682820500227987

*Objective:* This study was designed to explore the hypothesis that children with language impairment (LI) possess inefficient linguistic processing operations. Montgomery (2006) argues that children with LI are slower to access and integrate the linguistic properties of incoming words into a sentence. Montgomery (2006) wanted to examine whether the real-time language processing limitation of children with LI is attributable to inefficient acoustic-phonetic processing, slower higher-order linguistic processing, or to both poor sensory and linguistic processing. *Design:* Children were told to listen to lists of words or short stories and to push a response pad as soon as they heard the target word in the list or the story. In both tasks, children made a timed response immediately upon recognizing the target. *Study Sample:* This study involved 16 children with LI, 16 age matched children, and 16 younger typically developing children matched for receptive syntax knowledge. *Results:* Children with LI and chronologically aged matched children showed comparable reaction time in the isolated lexical processing task and both were faster than younger children. In the sentence-processing task, children with LI were slower at lexical processing than typical age matched and younger children, with typical age matched children demonstrating the fastest processing. *Conclusions:* The real time language processing of children with LI appears to be attributable to the inefficient higher-order linguistic processing operations and not to inferior acoustic-phonetic processing. The slower language processing of children with LI relative to young, language-matched children suggests that the language mechanism of children with LI operates more slowly than what might otherwise be predicted by their linguistic competence. *Relevance to the Current Work:* This article discusses the revised cohort theory which discusses the reasons why children with LI might be slower to process spoken language as well as other theories of language processing.

Montgomery, J. W., & Evans, J. L. (2009). Complex sentence comprehension and working memory in children with specific language impairment. *Journal of Speech Language and Hearing Research, 52*(2), 269-288. doi: 10.1044/1092-4388(2008/07-0116)

*Objective:* It is unclear to what extent complex sentence comprehension problems relate to children with LI's working memory limitations. This study performed experiments in order to find the association of two core components or mechanisms of working memory and the effects it has on the comprehension of complex sentences in children with LI. *Design:* Under the phonological short term memory (PSTM) task, children participated in a non-word repetition task. The children also listened to a sentence and then answered a yes or no question about the sentence. Participants were also asked to state what the last word of the sentence was. The sentence comprehension task involved sentences, complex sentences and simple sentences. *Study Sample:* This study involved 24 children with LI who were between the ages of 6 and 12 years. Authors also used 18 typically developing children that were matched in age and 16 young typically developing children that were matched on receptive language skills. *Results:* The LI group's performance on the non-word repetition task was compared to the age-matched (CA) group and showed that the LI group repeated significantly fewer non-words than the CA children. For sentence comprehension accuracy, no group difference occurred. For percentage of words recalled, the LI group recalled significantly fewer words than the CA group. *Conclusions:* The findings from this study indicate that the poor comprehension of complex grammar by children with LI is significantly associated with a limitation in working memory. *Relevance to Current Work:* This article discusses the effects that working memory has on comprehension by children with LI. Authors also discuss the fact that children with LI have a smaller supply of attentional resources that limit their ability to store as much verbal material while maintaining accurate comprehension.

Neville, H. J., Coffey, S. A., Holcomb, P. J., & Tallal, P. (1993). The neurobiology of sensory and language processing in language impaired children. *Journal of Cognitive Neuroscience, 5*(2), 235-253. doi: 10.1162/jocn.1993.5.2.235

*Objective:* This study tested specific hypotheses about the organization of language-relevant brain systems in both normal and language impaired children. Authors also assessed the effects of rate of stimulus presentation on the amplitude and latency of event related potentials (ERPs). *Design:* Participants read a series of sentences ending with an appropriate or anomalous final word and ERPs were recorded. Authors then examined the effects of context on the N400 to sentence final words and the comparison of ERPs to different categories of words within sentences. *Study Sample:* Participants consisted of 34 people between the ages of eight and ten years. Participants also included children with a reading disability (RD). *Results:* In behavioral analysis, language impaired (LI) children were less accurate than the control children in deciding whether a tone was or was not a target. The ERPs to the standard tones were of similar latency and morphology in the LI and control groups and were characterized by a negative peak around 140 ms. There was not enough variability of the normal participant's scores to permit a correlation with ERPs. Children with LI did not differ in the speed or accuracy of responding to the target from the control group. LI participants were less accurate in judging whether or not the sentence made sense. The N400 response was significantly larger in the LI than control children. *Conclusions:* These results imply that a single factor account of the deficits in LI and of RD children is not adequate. Multiple aspects of processing were affected in the RD group. The results suggest that specific aspects of sensory and language processing were abnormal in this group as a whole, while other aspects were present only in some participants of the sample. *Relevance to Current Work:* This article suggests that using ERP with behavioral measures is the best way to approach these kinds of studies. This article is helpful in that it describes theory of auditory sensory processing deficits in children with LI.

Newman, A. J., Pancheva, R., Ozawa, K., Neville, H. J., & Ullman, M. T. (2001). An event-related fMRI study of syntactic and semantic violations. *Journal of Psycholinguistic Research, 30*(3), 339-364.

*Objective:* This study used event-related functional magnetic resonance imaging to identify brain regions involved in syntactic and semantic processing. *Design:* Adult males read well-formed sentences randomly inter-mixed with sentences which either contained violations of syntactic structure or semantic errors. *Study Sample:* This study involved adults as participants to research event-related functional magnetic resonance imaging. *Results:* Reading incorrect sentences yielded distinct patterns of activation for the two violation types. *Conclusions:* The results of this study demonstrate that syntactic and semantic processing result in patterns of activation including temporal and parietal regions. *Relevance to the Current Work:* The current work will be analyzing these same areas of activation with semantic and syntactic errors in children.

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*, 785-806. doi: 10.1016/0749-596X(92)90039-Z

*Objective:* This study sought to investigate the event related potential (ERP) responses to syntactic errors in the analysis of a sentence. First, Osterhout and Holcomb (1992) wanted to see if there is an ERP response to words that is not attached to the computed syntactic structure of the sentence. Authors specifically analyzed the garden path effect. Second, they wanted to know if this response is distinct from the N400 component. *Design:* Participants were instructed to read each sentence carefully and then judge whether or not the sentence was acceptable or unacceptable. *Study Sample:* Fifteen undergraduate students ranging in age from 18 to 25 years participated in this study. *Results:* The authors found that words which were inconsistent with the preferred sentence structure elicited a brain potential (P600) quite distinct from the potential previously observed following contextually inappropriate words (N400). Final words in sentences typically judged to be unacceptable elicited an N400-like effect. *Conclusions:* The results found in this study suggest that ERPs are sensitive to syntactic anomaly. *Relevance to Current Work:* This article discusses how ERPs are helpful in studying language processing and the different components that can be measured when they are used. This article discusses the N400 and how it can relate to context and word priming. This article also discusses the P600 and what is meant by reanalysis of the syntactic structure.

Picton, T. W., & Stuss, D. T. (1984). Event-related potentials in the study of speech and language: A critical review. In D. Caplan, R. L. Andre & A. Smith (Eds.), *Biological perspectives on language* (pp. 303-360). Cambridge: The MIT Press.

*Objective:* This chapter is a critical review of many studies and the findings we have concerning event-related potentials (ERPs). Picton and Stuss describe ERPs and why they are important in the processing of language. The authors specifically take time to describe why we use ERPs in research and what they are useful for when analyzing language. Two different reasons for studying the event-related potentials of individuals with language disorders were specifically discussed. The first is to describe the underlying pathology using neurophysiological measures and the second is to understand the neurophysiology using different types of pathology as experimental tools. ERPs in individuals with language impairment can help in understanding the physiology of the impairment. Authors also summarize early studies that involve ERPs.

*Relevance to the Current Work:* This chapter is relevant to the current work in that ERPs are used to analyze different components of language.

Polich, J. (1985). Semantic categorization and event-related potentials. *Brain and Language, 26*(2), 304-321. doi: 10.1016/0093-934X(85)90045-8

*Objective:* This study sought to examine the N400 component of event-related potentials (ERPs). *Design:* Subjects were presented with a series of words belonging to the same category and a series of declarative sentences. In the presented words, half of the word series ended with a semantically unrelated word, and half of the sentences ended with a semantically appropriate word. Subjects were asked to indicate whether the word series or sentences ended appropriately or not. *Study Sample:* Ten subjects took part in this study. All spoke English as their native language. *Results:* Word series and sentences with semantically incongruous endings produced a negative component at 400 ms followed by a positive going wave for both the reading and the decision tasks. *Conclusions:* It is reasonable to conclude that the negative potentials observed for the odd-ending word series and the incongruous sentences are instances of the N400 component. *Relevance to Current Work:* This study is relevant to the current work in that it discusses the N400 component and how it can be elicited with semantically incongruent stimuli.

Sabisch, B., Hahne, A., Glass, E., Von Suchodoletz, W., & Friederici, A. D. (2006a). Auditory language comprehension in children with developmental dyslexia: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 18*(10), 1676-1695. doi: 10.1162/jocn.2006.18.10.1676

*Objective:* This study sought to investigate whether children with dyslexia are different from normally developing control children in the processing of prosodic information and in the processing of syntactic information. The researchers tested the ERP response to lexical-semantic anomalies. *Design:* In the ERP experiment, the children were instructed to listen carefully to the sentences presented. Children were then told to press a button to indicate if the sentences were correct or not. *Study Sample:* The study involved 16 children with developmental dyslexia and 16 control children. The children tested ranged in age from 9 years to 12 years. The children involved were German speaking. *Results:* Results show that the children with dyslexia performed worse in the detection task than the unimpaired control group. This suggests that children with developmental dyslexia are deficient in the processing of segmental phonological information. For the syntactic violation, an ELAN followed by a P600 occurred in the control children. For the children with dyslexia, the P600 was similar but the ELAN had differences in that it was delayed 300 ms. *Conclusions:* Because children with developmental dyslexia detected the semantic violation more often than the syntactic violation, it is suggested that the processing of semantic information is relatively intact. The N400 that was elicited was similar in both groups which showed that semantic processing was similar in both groups. The findings strengthen the view that developmental dyslexia is associated with a phonological deficit that might hamper the acquisition of automatic syntactic processes. *Relevance to Current Work:* This study describes a study in which sentences containing semantic and syntactic violations were presented to participants. This particular study involved children with dyslexia and a matched control group of typical children.

Sabisch, B., Hahne, A., Glass, E., Von Suchodoletz, W., & Friederici, A. D. (2006b). Lexical-semantic processes in children with specific language impairment. *Neuroreport, 17*(14), 1511-1514. doi: 10.1097/01.wnr.0000236850.61306.91

*Objective:* There were two purposes of this study. The first was to research lexical-semantic processes indicated by the N400 component in language impaired (LI) children compared to typical children. The second purpose of the study was to evaluate whether the peak amplitude of the N400 predicts verbal short-term memory capacity and use of word knowledge. *Design:* Two different types of sentences were used. One sentence was correct and the other had a semantic violation. The children were asked to judge the correctness of the sentence by pressing one of two buttons. *Study Sample:* Sixteen children with LI and 16 control children took part in this study. *Results:* LI children performed worse than the control children because they classified semantically incorrect sentences as correct more often. The control children exhibited a N400 component with semantically incorrect sentences. The LI children did not show a N400 effect. The correlation analysis showed that larger amplitudes of the N400 effect were associated with better verbal short-term working memory abilities. Authors also found that larger amplitudes of the N400 effect were associated with better use of word knowledge. *Conclusions:* Difficulties in lexical integration are associated with larger N400 amplitudes. The absence of the N400 suggests a weaker lexical-semantic representation of the verbs and their selectional restrictions or difficulties in lexical-semantic integration processes. Smaller amplitudes of the N400 were also associated with poorer verbal short-term working memory capacity and poor vocabulary across groups of children. *Relevance to Current Work:* This article is relevant in that it discusses the role of the N400 in semantic processing. The current work is using children with LI and analyzing the N400.

Sabisch, B., Hahne, C. A., Glass, E., Von Suchodoletz, W., & Friederici, A. D. (2009). Children with specific language impairment: The role of prosodic processes in explaining difficulties in processing syntactic information. *Brain Research, 1261*, 37-44. doi: 10.1016/j.brainres.2009.01.012

*Objective:* The purpose of this study was to test whether children with language impairment (LI) differ from typically developing children in the processing of syntactic information using the ELAN and the P600 for analysis. *Design:* The processing of correct sentences was contrasted with that of sentences containing a word category violation and an incongruous continuation of the prosodic contour. Participants had to indicate whether or not the sentence was correct using a smiley face or a frowny face button. *Study Sample*: In this particular study, 16 children with LI and 16 normally developing children were used in order to gain results. They all spoke German. *Results:* The control children performed better than children with LI across all conditions. ERPs evoked by the violation condition showed a combined pattern of an early bilateral anterior negativity sustaining into a late negativity over anterior electrode sites for the typical children. Only a late left lateralized anterior negativity and a broadly distributed positivity were observed in the children with LI. *Conclusions:* The late left anterior negativity for children with LI suggests that their comprehension processes are not as early as in age-matched controls and do not show the same level of automaticity. Functionally, it could be assumed that the late left anterior negativity observed for the children with LI reflected delayed syntactic processes or phrase structure building. The right anterior negativity which has been shown to reflect prosodic processing was not present in children with LI. This suggests that they might not rely on prosodic information in the way typical controls do. The similarities in the distribution and latency of the P600 suggest that these processes might be intact in children with LI. *Relevance to the Current Work:* This study discusses the differences in children with LI compared to their typical counterparts. The current study is analyzing the semantic and syntactic elements of a sentence and asking participants to indicate correct from incorrect sentences.

Semel, E. M., Wiig, E. H., & Secord, W. (2004). *CELF-4: Clinical evaluation of language fundamentals screening test.* San Antonio, TX: Psych Corp.

*Objective:* The CELF-4 was designed to test children language abilities. *Relevance to the current work*: The CELF-4 was used in the current study to test participant's language abilities.

Weber-Fox, C., Leonard, L. B., Wray, A. H., & Tomblin, J. B. (2010). Electrophysiological correlates of rapid auditory and linguistic processing in adolescents with specific language impairment. *Brain Language. 115*(3), 162-181. doi: 10.1016/j.bandl.2010.09.001

*Objective:* The authors of this study sought to test participant's neural activity elicited by a non-linguistic rapid auditory processing task. *Design:* Each individual participated in two experiments. For the rapid auditory processing task, participants were instructed to listen to the tones presented through headphones and to press a response key as rapidly as possible each time they heard the higher tone. For the sentence processing task, participants were instructed to listen to each of the sentences and judge whether the sentence was a good English sentence and made sense. Participants were to indicate this by pressing a yes or no button. *Study Sample:* Participants include 30 adolescents between the ages of 14 and 18 years. They were split into two groups which consisted of those with language impairment (LI) and those with normal language development. *Results:* Reaction times and accuracy in sentence judgment were taken into account for behavioral measures of this study. Many adolescents with LI displayed reduced behavioral accuracy for detecting verb-agreement violations and semantic anomalies, along with less robust P600s elicited by verb-agreement violations. *Conclusions:* The ERP's of this current study provide evidence that neural processes are weak in adolescents with LI when encountering verb-agreement violations. These findings indicate that when challenged to a greater extent, the semantic processing system in adolescents with LI is vulnerable and functions less effectively compared to peers with normal language development. *Relevance to Current Work:* This article discusses cognitive processes in adolescence with LI.

Wechsler, D., Pearson Education, Inc., & Psychological Corporation (2003). *WISC-IV: Wechsler intelligence Scale for Children.*San Antonio, TX: Pearson.

*Objective:* The WISC-IV was designed to test non-verbal intelligence in children from 6 to 16 years of age. *Relevance to the current work*: One participant in the study was administered the WISC-IV.

# Appendix B

## Stimuli

### A. Correct Sentences

1. The mother smiles.
2. A boy looks.
3. A baby laughs.
4. The wind blows.
5. The boats sail.
6. The dog digs.
7. The whale swims.
8. Two children run.
9. One girl swings.
10. They run.
11. The kite flies.
12. The ballerina dances.
13. They sing.
14. The teacher reads.
15. The girls cheer.
16. The rollercoaster shakes.
17. The class sits.
18. The bus driver waits.
19. My sister plays.
20. The nurse helps.
21. The author writes.
22. I wonder what he thinks.
23. Trees and flowers grow.
24. The truck driver waves.
25. The people leave.
26. The bread bakes.
27. The duck quacks.
28. The washing machine washes.
29. Sally likes to walk.
30. The figure skater ice skates.
31. The lion escapes.
32. The ranger hikes.
33. The athlete drinks.
34. Charlie paints.
35. The girl laughed.
36. The train moved.
37. My friend smiled.
38. The balloon popped.
39. The horse kicked.
40. The plane flew.

41. The doorbell rang.
42. Uncle Ed ran.
43. Santa Claus came.
44. The guests left.
45. The librarian whispered.
46. We started.
47. The runner rested.
48. The patient coughed.
49. The little boy fell.
50. The mailman drove.
51. Andy threw.
52. Jeff swung.
53. The tiger slept.
54. We watched.
55. The star twinkled.
56. The worm crawled.
57. The ball bounced.
58. The student learned.
59. The car turned.
60. The hippo splashed.
61. The horn honked.
62. The kitten meowed.
63. The water boiled.
64. The woman sang.
65. The artist drew.
66. The dolphin swam.
67. The ship sunk.
68. The cowboy rode.
69. The sleeves covered both hands.
70. The coat had two big pockets.
71. She found a key in one pocket.
72. The key will open many doors.
73. Dennis saw three blue belts.
74. Kerry wore a striped skirt.
75. Baby dogs are called puppies.
76. Some animals like to eat berries.
77. One child hopped on both feet.
78. A cat chased three mice.
79. The bus passed some geese.
80. A baby was playing with a toy mouse.
81. He fell and hit his two front teeth.
82. Grandma picked corn.
83. My father drives a truck.
84. His truck has sixteen wheels.
85. Dad drives the truck to a dock.
86. They drove to a store.

87. Uncle Henry is a cook.
88. He works at a school.
89. Mr. Lee ate three beans.
90. My cousins own a huge pool.
91. My sister is having a party.
92. Two boys are swimming in the water.
93. Many foods come from plants.
94. A king lived in a huge castle.
95. The queen showed the guests each room.
96. Food was served on long tables.
97. The children played in a box.
98. Some horses waited by a gate.
99. The tree had many branches.
100. Some people build houses.
101. Farmers grow fruit and vegetables.
102. Drivers take packages to cities.

**B. Semantic Errors**

1. The block smiles.
2. A mountain sees.
3. A bottle laughs.
4. The wind jumps.
5. The boats run.
6. The tree digs.
7. The rock swims.
8. Two thumbs run.
9. The sky swings.
10. The papers run.
11. The kite kisses.
12. The door dances.
13. Sticks sing.
14. The fish reads.
15. The grass cheers.
16. The rollercoaster swims.
17. The lightning sits.
18. The light waits.
19. My kitchen plays.
20. The chalk helps.
21. The shirt writes.
22. I wonder what he walks.
23. Trees and flowers quack.
24. The truck driver flies.
25. The ground leaves.
26. The bread jumps.
27. The duck drives.
28. The washing machine giggles.
29. The boat walks.
30. The sock ice skates.
31. The window escapes.
32. The pen hikes.
33. The ear drinks.
34. The fan paints.
35. The shoe laughed.
36. The train eats.
37. My foot smiled.
38. The balloon ate.
39. The pencil kicked.
40. The plane cried.
41. The doorbell danced.
42. The picture ran.
43. The nose came.
44. The finger left.

45. The cup whispered.
46. We cracked.
47. The clock rested.
48. The toe coughed.
49. The little cloud fell.
50. The dog drove.
51. The phone threw.
52. The dirt swung.
53. The tiger barked.
54. We twinkled.
55. The star swallowed.
56. The worm mooed.
57. The waterfall bounced.
58. The soap learned.
59. The house turned.
60. The hippo meowed.
61. The horn winked.
62. The kitten oinked.
63. The water yelled.
64. The can sang.
65. The garbage drew.
66. The dolphin jogged.
67. The ship walked.
68. The tooth rode.
69. The sleeves covered both moons.
70. The coat had two big legs.
71. She found a key in one ear.
72. The key will open many hangers.
73. Dennis saw three blue hugs.
74. Kerry wore a striped banana.
75. Baby dogs are called worms
76. The animals like to eat pianos.
77. One child hopped on both eyes.
78. A cat chased three pickles.
79. The bus passed some earthquakes.
80. A baby was playing with a toy word.
81. He fell and hit his two front apples.
82. Grandma picked robots.
83. My father drives a hair.
84. His truck has sixteen fingers.
85. Dad drives the truck to a duck.
86. They drove to a grape.
87. Uncle Henry is a steak.
88. He works at a cloud.
89. Mr. Lee ate three fires.
90. My cousins own a huge leg.

91. My sister is having a party.
92. Two boys are swimming in the peanut butter.
93. Many foods come from stars.
94. A king lived in a huge hotdog.
95. The queen showed the guests each sneeze.
96. Food was served on long ceilings.
97. The children played in a marshmallow.
98. Some horses waited by a smile.
99. The tree had many chickens.
100. Some people build oranges.
101. Farmers grow fruit and monkeys.
102. Drivers take packages to ants.

**C. Syntactic Errors**

1. The mother smile.
2. A boy look.
3. A baby laugh.
4. The wind blow.
5. The boats sails.
6. The dog dig.
7. The whale swim.
8. Two children runs.
9. One girl swing.
10. They runs.
11. The kite fly.
12. The ballerina dance.
13. They sings.
14. The teacher read.
15. The girls cheers.
16. The rollercoaster shake.
17. The class sit.
18. The bus driver wait.
19. My sister play.
20. The nurse help.
21. The author write.
22. I wonder what he think.
23. Trees and flowers grows.
24. The truck driver wave.
25. The people leaves.
26. The bread bake.
27. The duck quack.
28. The washing machine wash.
29. Sally likes to walks.
30. The figure skater ice skate.
31. The lion escape.
32. The ranger hike.
33. The athlete drink.
34. Charlie paint.
35. The girl laugh.
36. The train move.
37. My friend smile.
38. The balloon pop.
39. The horse kick.
40. The plane flied.
41. The doorbell ringed.
42. Uncle Ed runned.
43. Santa Claus comed.
44. The guests leaved.

45. The librarian whisper.
46. We starts.
47. The runner rest.
48. The patient cough.
49. The little boy falled.
50. The mailman drived.
51. Andy throwed.
52. Jeff swinged.
53. The tiger sleeped.
54. We watches.
55. The star twinkle.
56. The worm crawl.
57. The ball bounce.
58. The student learn.
59. The car turn.
60. The hippo splash.
61. The horn honk.
62. The kitten meow.
63. The water boil.
64. The woman singed.
65. The artist drawed.
66. The dolphin swimed.
67. The ship sinked.
68. The cowboy rided.
69. The sleeves covered both hand.
70. The coat had two big pocket.
71. She found keys in one pockets.
72. The key will open many door.
73. Dennis saw three blue belt.
74. Kerry wore a striped skirts.
75. Baby dogs are called puppy.
76. The animals like to eat berry.
77. One child hopped on both feets.
78. A cat chased three mouses.
79. The bus passes some gooses.
80. A baby was playing with a toy mouses.
81. He fell and hit his two front tooths.
82. Grandma picked corns.
83. My father drives a trucks.
84. His truck has sixteen wheel.
85. Dad drives the truck to a docks.
86. They drove to a stores.
87. Uncle Henry is a cooks.
88. He works at a schools.
89. Mr. Lee ate three bean.
90. My cousins own a huge pools.

91. My sister is having a parties.
92. Two boys are swimming in the waters.
93. Many foods come from plant.
94. A king lived in a huge castles.
95. The king showed the guests each rooms.
96. Food was served on long table.
97. The children played in a boxes.
98. Some horses waited by a gates.
99. The tree had many branch.
100. Some people build house.
101. Farmers grow fruit and vegetable.
102. Drivers take packages to city.

# Appendix C

## Informed Consent

## BYU Research Opportunity

I would like to invite you to consider involving your child in a research project in the Communication Disorders Department at Brigham Young University. This research is designed to examine the processing of language by the brain in children with language impairment using measures to record brain waves. Participation in this study will help teachers and scientists better understand the brain's ability to process language. This research project will be conducted by Hillary Benton, a graduate student in the communications disorders program at Brigham Young University. She will be supervised by Dr. David McPherson, professor in the communications disorders program at Brigham Young University.

If your child is involved in this research, he/she will receive a full hearing screening as well as $30.00 compensation. All information from the hearing screening will be available to you.

The study will be conducted in room 111 of the John Taylor Building on the campus of Brigham Young University. Testing at Brigham Young University, including orientation and testing, requires one 2-3 hour session. Your child may ask for a break at any time during testing. Basic hearing tests will be administered during the first half-hour of the session.

Surface electrodes (metal discs about the size of a dime) will be used to record electrical activity of your child's brain. These discs will be applied to the surface of the skin with a cream or gel and are easily removed with water. Blunt needles will be used as a part of this study to help apply the electrode gel. These "needles" do not have the capability of puncturing the skin; they are simply syringe-like applicators. Your child may feel uncomfortable using the cap and having gel on his or her face and head. If your child is uncomfortable, he or she will be assured that they will only have the electrodes on for a short period of time. If your child has a negative reaction to the electrodes, the electrodes and gel will be removed. The gel is easily removed with warm, but not hot water. Discomfort from the electrode cap immediately dissipates upon removal of the cap. This is similar to a "sports cap" that adds slight pressure to the scalp.

Your child will wear the electrode cap while he/she listens to 306 sentences, during which time the electrical activity of his/her brain will be recorded on a computer. Your child will be asked to give responses during the hearing test and the sentence presentation.

If you are interested in being involved in this study, or have any questions about procedures or compensation, please contact Hillary Benton at hillary.benton@outlook.com or 801-698-9722.

Thank you for your consideration, your participation would be greatly appreciated.

Hillary Benton,

**Parental Permission for a Minor**

**Introduction**

This research is designed to examine the processing of language by the brain in children with language impairment using measures to record brain waves. Participation in this study will help teachers and scientists better understand the brain's ability to process language.

This research project will be conducted by Hillary Benton, a graduate student in the communications disorders program at Brigham Young University. She will be supervised by Dr. David McPherson, professor in the communications disorders program at Brigham Young University.

**Procedures**

Your child has been invited to participate in a research study conducted by Dr. David L. McPherson and / or such assistants as may be selected by him.

The study will be conducted in room 111 of the John Taylor Building on the campus of Brigham Young University. Testing at Brigham Young University, including orientation and testing, requires one 2-3 hour session. Your child may ask for a break at any time during testing. Basic hearing tests will be administered during the first half-hour of the session.

Surface electrodes (metal discs about the size of a dime) will be used to record electrical activity of your child's brain. These discs will be applied to the surface of the skin with a cream or gel and are easily removed with water. Blunt needles will be used as a part of this study to help apply the electrode gel. They will *never* be used to puncture the skin. Your child may feel uncomfortable using the cap and having gel on his or her face and head. If your child is uncomfortable, he or she will be assured that they will only have the electrodes on for a short period of time. If your child has a negative reaction to the electrodes, the electrodes and gel will be removed. The gel is easily removed with warm, but not hot water. Discomfort from the electrode cap immediately dissipates upon removal of the cap. This is similar to a "sports cap" that adds slight pressure to the scalp.

Language processing will be measured using an electrode cap, which simply measures the electrical activity of your child's brain and *does not* emit electricity, and no electrical impulses will be applied to the brain. These measurements of the electrical activity are similar to what is known as an "EEG" or brain wave test. These measurements are of normal, continuous electrical activity in the brain.

Your child will wear the electrode cap while he/she listens to 306 sentences, during which time the electrical activity of his/her brain will be recorded on a computer. Your child will be asked to give responses during the hearing test and the sentence presentation.

The procedures used to record the responses of the brain are standardized and have been used without incident in many previous investigations. The combination of sentences presented is experimental, but the recording procedure is not.

**Risks**

There are very few potential risks from this procedure, and these risks are minimal. The risks of this study include possible allergic reactions to the conductive gel or to the skin prepping gel. Allergic reactions to the gel are extremely rare. There is also a possibility for an allergic reaction to the electrodes. If any of these reactions occur, a rash would appear. Treatment would include removing the electrodes and gel and exposing the site to air, resulting in alleviation of the irritation. If there is an allergic reaction, testing procedures would be discontinued. Another unlikely risk is a small abrasion on the scalp when the blunt needle is used to place electrode gel. Treatment would also include removing the electrode and gel, exposing the site to air and testing procedures would be discontinued.

There are no other known risks with this procedure. It is understood that participation in this study is voluntary and the participant may withdraw during any part of the testing without any negative consequences now or in the future.

**Confidentiality**

Participation in this study is voluntary and your child has the right to refuse to participate or withdraw at any time. All information obtained from testing is strictly confidential and is protected under the laws governing privacy. No information specifically pertaining to your child, other than reporting of test results without identifying information may be released without your signature. All identifying references will be removed and replaced by control numbers which will identify any disclosed or published data. Data collected in this study will be stored in a secured area accessible only to personnel associated with the study.

**Benefits**

Your child will benefit from receiving a hearing, otoscopy and tympanometry screening. You will also benefit from receiving these results free of charge to you.

Researchers and clinicians will also benefit from the information obtained during this study. It is important for us to continue to understand the way that language is processed.

**Compensation**

Your child will receive $30 for participating in this study. However, if your child does not complete the entire study, they will be prorated for the tasks they have completed.

**Questions about the Research**

Please direct any further questions about the study to Hillary Benton at hillary.benton@outlook.com or 801-698-9722. You may also contact David McPherson at david_mcpherson@byu.edu or 801-422-6458.

Questions about your child's rights as a study participant or to submit comment or complaints about the study should be directed to the IRB Administrator, Brigham Young University, A-285 ASB, Provo, UT 84602. Call (801) 422-1461 or send emails to irb@byu.edu.

You have been given a copy of this consent form to keep.

**Participation**

Participation in this research study is voluntary. You are free to decline to have your child participate in this research study. You may withdraw you child's participation at any point without penalty.

Child's Name: ______________________________

Parent Name: _______________ Signature: _________________ Date: ______

**Research Participant Consent**

**What is this research about?**

We want to tell you about a research study we are doing. A research study is a special way to find the answers to questions. We are trying to learn more about how children with language impairment understand the language they hear.

If you decide you want to be in this study, this is what will happen. You will come to the Brigham Young University Speech and Language Clinic. While you are there, you will first get your hearing checked. You will also wear a silly hat that has connections attached to the computer. The hat looks like a shower cap with holes. In the holes, the clinician will put some clear gel. When the gel is on your head, it may tickle for a moment. It might also feel gooey. If you don't like the feel of the gel and cap, you can ask the clinician to take it off at any time. You will hear some sentences through ear probes. You will press a button to tell the researcher if the sentence you heard was "good" or "bad". If you get tired, you can ask for a rest.

**Can anything bad happen to me?**

The cap and gel we put on your head may feel a little uncomfortable. However, you will only need to wear this for a short time, and you can take any breaks you may need.

**Can anything good happen to me?**

We don't know if being in this study will help you. But we hope to learn something that will help other people someday. You will get to have your hearing checked if you want to do the study. You will also receive money for being in this study. You will receive $30.00 at the end of the study. If you do not finish the entire study, you will be given some of the money for the activities you finished.

**Do I have other choices?**

You do not have to do any part of this study. If you change your mind, you can quit the study at any time.

**Will anyone know I am in the study?**

We won't tell anyone you took part in this study. When we are done with the study, we will write a report about what we learned. We won't use your name in the report.

**What happens if I get hurt?**

Your parents have given permission for you to be involved in this study. If anything happens to you, your parents have been given information about what to do.

**What if I do not want to do this?**

You don't have to be in this study. It's up to you. If you say yes now, but change your mind later, that's okay too. All you have to do is tell us.

You will receive $30 for being in this research study. Before you say yes to be in this study; be sure to ask Hillary to tell you more about anything that you don't understand.

If you want to be in this study, please sign and print your name.

□ Yes, I will be in this research study. □ No, I don't want to do this

Name (Printed): ___________________ Signature: ____________ Date: ___________