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The P600 Event-Related Potential Across Ages and Ear Conditions

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The P600 Event-Related Potential Across Ages and Ear Conditions

Kyla Lewis Tree

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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Studying language development through event-related potentials provides specific information regarding how the brain processes specific aspects of language over time. In this study, the P600 component, a positive wave occurring approximately 600 ms post-stimulus and known for detecting syntactic errors, was specifically analyzed. Thirty children between the ages of 5 and 12 years listened to linguistically correct, syntactically incorrect, and semantically incorrect sentences in three ear conditions: monaurally to the right ear, monaurally to the left ear, and binaurally. The participants were instructed to judge the sentences to be correct or incorrect. Comparisons were then made of the latency and amplitude of the P600 between the age groups, sentence types, and ear conditions.

The results of this study indicate that younger children exhibit later latencies and higher amplitudes than do adults. The study also suggests that syntactic processing becomes fully established around the age of 8 to 9 years. In reference to ear condition, this study found that ear condition may be a factor in a child's ability to recognize syntax. This was the first study that investigated developmental ERPs and ear condition. Therefore, this finding is a result of interest that needs to be further explored in future studies. The current study also suggests that the right ear advantage (REA) phenomenon may exist neurologically in older ages with monotic sentences. This is another area that would benefit from additional research as this phenomenon has not been previously described.

Keywords: P600, event-related potentials, right ear advantage, language development, syntax

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BRIGHAM YOUNG UNIVERSITY

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The dissertation of Kyla Lewis Tree is acceptable in its final form including (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory and ready for submission.

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Introduction

Research has shown that by approximately 3 years of age children have typically gained a basic understanding of the phonological, morphosyntactic, and semantic regularities of their language. Despite this basic comprehension at an early age, however, it is not until several years later that a child's parsing system matches that of an adult (Hahne, Eckstein, & Friederici, 2004). This is true neurologically as well. According to an event-related potential (ERP) study by Friederici (1983), a child's syntactic language abilities may not become adult-like neurologically until after 11 years of age. In 2004, Hahne et al. reported that a child's syntactic language abilities may not match that of an adult neurologically until 13 years of age.

More recently, language development has been studied through a variety of neurophysiological techniques. One approach that is commonly used is ERPs. According to Featherston, Gross, Munte, and Clahsen (2000), ERPs are small changes in brain electrical activity produced by neurons in the brain. These changes are elicited by sensory, motor, or cognitive processes (Hahne & Friederici, 1999). Studying language development through ERPs provides specific information regarding how the brain processes certain aspects of language over time. Three ERPs that are strongly associated with language processing are the N400, the early left anterior negativity (ELAN), and the P600 (Friederici, 1997).

Previous studies have shown ERPs to be a viable method in investigating language processing in adults (McPherson, Ballachanda, & Kaf, 2007). However, there is limited information on language processing in children; especially during the critical stages of language development. Even when children have been participants in ERP studies, the age range is often small, contains gaps, or does not include very young children. While any information regarding neurological development in children is helpful, a more complete age range is needed.

The purpose of this study was to provide greater insight into childhood language development by observing ERPs in children aged 5;0 and 12;5 years (years;months). More specifically, the study observed the P600, which is typically responsible for detecting syntactic errors, ambiguous syntactic structures, or difficult syntactic structures (van Herten, Kolk, & Chwilla, 2005). In addition, this study tested for ear advantage, a phenomena that has not been tested using ERP developmental studies in the past.

Review of Literature

Event-Related Potentials and Measurement

Early studies of language processing primarily focused on the relationship of language behaviors to brain lesions. However, with the advancement of new methods of brain imaging during the past three decades, greater insight into language processing has been achieved. For example, two brain imaging technologies, magnetic resonance imaging and positron emission tomography, can show scientists which part of the brain is active when language is being processed. This has allowed scientists to study specifically which regions and structures of the brain are responsible for targeted language tasks. Magnetic resonance imaging and positron emission tomography are limited, however, in that they do not provide a break-down of how language is processed over time. Due to this limitation, other approaches have been used to study language processing. These approaches include electroencephalography (EEG) and magnetoencephalography (MEG). EEG and MEG measure the electrical activity of the brain in response to sensory, motor, or cognitive processes over time. Viewing the brain's response at a single event or stimulus is known as an ERP (Friederici, 2004).

When analyzing linguistic cognitive processing, there are typically four features of ERPs that are observed: (a) latency, or time in ms relative to the onset of a stimulus; (b) polarity, positive (P) or negative (N); (c) amplitude, or displacement of the ERP; and (d) topographic location, or scalp distribution (Friederici, 1997). ERPs are measured by placing electrodes on the scalp, which are capable of showing concurrent postsynaptic activity from various neuronal populations in the brain. Several samples are electronically averaged to help distinguish ERP features from EEG background activity produced by the brain (Friederici; Kutas & Hillyard, 1983; Picton & Stuss, 1984). The outcome is a waveform with peaks and troughs, also termed components. When categorizing the components, the two features of polarity and latency are marked (Coulson, King, & Kutas, 1998). For example, P600 represents a positive polarity with a 600 ms post-stimulus response.

There are three long latency ERPs strongly associated with language processing, the N400, the ELAN, and the P600. In efforts to incorporate the temporal and neurotopological aspects of these three ERP components, Friederici (1997) proposed three processing phases. In the first phase, an analysis is performed of the syntactic structure. This phase is reflected by the ELAN. In the second phase, a lexical-semantic process is performed. This phase is reflected by the N400. In the third and final phase, lexical-syntactic information is processed and a reanalysis then occurs. This third phase is reflected in the P600.

The ELAN. The ELAN is a negative wave that reaches maximum amplitude 200 to 400 ms post-stimulus (Friederici, 1997). The ELAN is most commonly elicited when a syntactic violation occurs. An example of a syntactic violation is *Max's of proof the theorem…* (Friederici, 2004). The correct syntax is *Max's proof of the theorem...* The topography of the ELAN varies between studies; however, the general scalp distribution of the ELAN occurs over the left frontal lobe (van Herten et al., 2005).

The N400. The N400 is a negative wave that reaches maximum amplitude at approximately 400 ms post-stimulus. The N400 most commonly occurs when associated with semantic violations. An example of a semantic violation would be *he ate a bridge*. Since bridges are often made of metal or wood, it is improbable that a person could eat one. Therefore, this sentence is classified as not making sense. Semantic violations are not the only means of eliciting the N400. If a sentence includes a word that is less predictable, this could also cause the N400 to be elicited. For example, *he ate a bug*. Eating a bug is possible, but not expected or predicted. According to van Herten et al. (2005), the greater the unpredictability of a word, the greater the amplitude of the N400. The N400's topographic spread of activity is typically distributed over both the right and left hemispheres. However, when words are presented visually, a greater portion of the right hemisphere is activated. When words are presented auditorily, the distribution is more symmetric, sometimes using a greater portion of the left hemisphere (Friederici, 2004).

The P600. The P600 is a positive wave that has a late centro-parietal distribution reaching maximum amplitude between 500 and 800 ms post-stimulus. The P600 follows the ELAN and makes a second parsing of a sentence for syntactic errors. More specifically, the P600 is associated and elicited by obvious syntactic violations, ambiguous syntactic structures, or difficult syntactic structures (van Herten et al., 2005). An example of an obvious syntactic violation is *the car droves down the street*. An example of an ambiguous syntactic structure is, *the woman persuaded to answer the door* (van Herten et al., 2005). These types of sentences with non-preferred syntactic structure are called garden-path sentences. An example of a difficult syntactic structure is *Emily wondered who the performer in the concert had imitated for the audience's amusement* (van Herten et al., 2005). Due to the complexity of the "who" sentence, a person may have difficulty assigning the proper syntactic structure to the sentence. Therefore, a reanalysis may take place, which would elicit the P600.

Variations of the P600

Limited research is available regarding the P600 in children and its changes during neurological maturation. The P600 is a multi-modality response and therefore it is possible to examine both visual and auditory modalities. Also, the P600 is a member of the P300 family and the specificity of the P600 to syntactic processing permits measurement of the P600 in children.

Auditory versus visual modalities. Over the years, studies have been carried out that examined different effects of auditory and visual modalities on the ERP. In 1993, Osterhout and Holcomb reported a slight difference in topographic distribution of the P600 between the auditory and visual modalities. When using an auditory modality versus a visual modality, they found neurological activity to be more widely distributed over the right hemisphere. Osterhout and Holcomb (1993) also reported a greater constriction of neurological activity in the posterior portion of the brain when using an auditory modality versus a visual modality. Hagoort and Brown (2000) also reported similar findings to those of Osterhout and Holcomb (1993).

In 1993, Osterhout and Holcomb reported a significant difference in latency of the P600 when comparing the two modalities. They found that the latency of the P600 occurs earlier when using an auditory modality than when using a visual modality. In 1998, Patel, Gibson, Ratner, Besson, and Holcomb reported similar results as Osterhout and Holcomb (1993) in relation to the latency of the P600. Friederici, Pfeifer, and Hahne (1993), however, reported different findings than those of Patel et al. (1998) and Osterhout and Holcomb (1993). Friederici et al. (1993) did not find a significant difference in the latency of the P600 between auditory and visual modalities. In 2000, Hagoort and Brown’s study supported Friederici et al.’s (1983) study by reporting similar measures of latency of the P600 when using either an auditory or visual modality.

The P300 family. It has been suggested that the P600 should be identified as a member of the P300 family, or more specifically, it should be identified as identical to the P300b component. The P300b is known to detect unexpected stimuli. Many researchers believe that the unexpectedness of the syntactic error is actually what elicits the P600, not the actual syntactic error. In Coulson, King, and Kutas's (1998) study, they reported the P300 and the P600 family to have similar centro-parietal scalp distributions.

Frisch, Kotz, Cramon, and Friederici (2003), however, state that the P600 is separate from the P300 family. Earlier research has shown that the P300 is generated by the thalamic region and in the posterior lobe while no generator is known for the P600. Kotz et al. (2003) looked at aphasic patients and noted that some of the aphasic patients had lesions in the basal ganglia while others had more diffuse damage. Although, the P300 was present in both groups of patients, the P600 was not. The P600 was found only in the aphasic group that did not display lesions in the basal ganglia. These findings indicate that the basal ganglia plays an important role in the generation of the P600, therefore, strongly suggesting a dissociation between the P600 and P300.

Specificity of the P600. The P600 is typically associated with syntactic anomalies. However, in a few studies, the P600 has also been found in sentences with semantic anomalies. In a study performed by Kolk, Chwilla, van Herten, and Oor (2003), a P600 was observed when sentences with semantic reversal anomalies were presented to Dutch participants. van Herten et al. (2005) proposed an explanation to the outcome with two hypotheses. The first hypothesis, the *plausibility heuristic hypothesis,* states that the reader interprets a sentence in a way that is most plausible. For example, rather than reading *the man bit the dog*, they would read the sentence as *the dog bit the man*. While it is plausible for the man to bite the dog, it is not as likely. The second hypothesis, the *syntactic prediction hypothesis*, states that from the plausible interpretation, a syntactic prediction is then formed. van Herten et al. proposed when the predicted syntax and the observed syntax are different, the P600 is elicited due to the mismatch.

van Herten et al. (2005) tested the syntactic prediction hypothesis. They manipulated the singular and plural forms of the subject and verb in each sentence to be mismatched or matched correctly. If the subject and verb were mismatched, they would expect to see the P600. However, if the subject and verb were matched correctly, then they would not expect to see the P600. The results of the study showed the P600 being present in both situations, therefore, the presence of the P600 was associated with semantics thus discounting the syntactic prediction hypothesis.

Additional studies were reported by Kuperberg, Sitnikova, Caplan, and Holcomb (2003) as well as Hoeks, Stowe, and Doedens (2004) in which the P600 was present when semantic violations were presented. Both studies reported that as a reader encounters an unexpected sentence one of two things may occur. First, the reader can accept the unexpected event as real. Second, the reader can re-attend to the unexpected event and question if they had read the sentence correctly. Kuperberg et al. (2003) and Hoeks et al. (2004) reported that the reprocessing reevaluates whether or not the participant processed the sentence correctly.

In 1998, Coulson et al. reported that the P600 is sensitive to the prediction of syntax. Later, Kuperberg et al. (2003) and Hoeks et al. (2004) investigated that the discrepancy between the predicted sentence and the unpredicted sentence triggered the P600. This idea broadened the role of the P600 in the analysis of language processing. Therefore, in addition to syntax, the P600 is also thought to be effected by “the monitoring process that checks upon the veridicality of one’s analysis” (van Herten et al., 2005, p. 254).

Syntactic processing in children. Hahne et al. (2004) looked at developmental aspects of language comprehension using ERPs in children aged 6, 7, 8, 10, and 13 years. The participants listened to passive sentences that were correct, syntactically incorrect, and semantically incorrect. Their results were then compared to adult models. The P600 was present in all ages from 6 to 13 years with latency decreasing with age. At age 13 years, the P600 resembled the adult model with a P600 latency occurring at approximately 400 ms. At 8 and 10 years of age, the P600 latency occurred at approximately 600 ms. At 7 years of age, a P600 between 400 and 1500 ms was found. At age 6 years, a late positivity between 1250 and 1500 ms was found.

Hahne et al. (2004) also reported that children exhibit a decreasing rate in error as age increased. The mean percent of errors that children aged 10 and 13 years produced was less than five percent. The mean percent of errors that children aged 7 and 8 years produced was less than 10 percent. The mean percent of errors that children aged 6 years produced was 20 percent, twice as high as the mean for 7-year-old children. This data suggests that children between the ages of 6 and 13 years still have some level of syntactic difficulty processing sentences.

Friederici (1983) studied children between the ages of 8 and 12 years. The study found that children do not independently process function words in sentences until after about the age of 9 or 10 years. Friederici also found that children do not display an adult-like P600 latency until after 11 years of age.

Atchley et al. (2006) also studied syntactic processing. They tested children between the ages of 8 and 13 years. The children listened to sentences that were correct, syntactically incorrect, or semantically incorrect. The syntactic error was either a verb drop violation or an agreement violation. For the verb drop violations, Atchley et al. in the same study found the location, latency, and amplitude of the children’s P600 component to resemble that of the adult model. For the agreement violations, Atchley et al. also noted a greater delay in latency for the P600 component (623–673 ms and 674–724 ms) in children than what has been previously reported in adults (623–673 ms). For the agreement violation, Atchley et al. found the children's P600 component to have slightly greater amplitude than in the adult's P600 component.

In 2001, a subsequent study by Friederici and Hahne compared the latency and amplitude of the P600 in children versus adults. Their study was performed with German-speaking children. Despite the difference in language spoken between the two groups of children, Friederici and Hahne (2001) reported similar findings as Atchley et al. (2006). Friederici and Hahne (2001) found the P600 component of German-speaking children displayed a greater delay in latency and exhibited greater amplitude of the P600 than that of the adult model.

Present Study

The current study evaluates the electrophysiological response of the P600. The P600 is elicited by syntactic and semantic errors presented to typically developing children aged 5;0 to 12;5. The comparison of the P600 components regarding latency and amplitude will increase our understanding of the development of cognitive language processing in children. The current study also evaluated the latency and amplitude of the P600 in terms of ear condition and hemispheric asymmetries.

Method

Participants

The participants consisted of normally developing children between the ages of 5;0 and 12;5. The participants were divided into five groups. The groups consisted of ages 5;0-6;5 (Group 1), 6;6-7;11 (Group 2), 8;0-9;5 (Group 3), 9;6-10;11 (Group 4), and 11;0-12;5 (Group 5). Six participants were tested in each of the five age groups, totaling 30 children who participated in the study. Each participant met the following criteria:

1. No reported known history of neuropsychiatric disorders.
2. Normal hearing as demonstrated with pure tone thresholds of ≤ 25 dB HL at 250, 500, 1000, 2000, 4000, and 8000 Hz (Hanks & Rose, 1993; Northern, 1991).
3. No evidence of language delay or disorder as determined by a standard score of at least 85 on the Comprehensive Assessment of Spoken Language (CASL).
4. No evidence of a cognitive impairment as determined by a standard score of at least 85 on the Universal Nonverbal Intelligence Test (UNIT).

Instrumentation

An electrode cap (Electrocap International) was used to place silver-silver chloride electrodes over the scalp at 32 electrode positions according to the 10-20 International System (Jasper, 1958). Electrode impedances were kept below 5000 ohms. Eye movements were monitored by placing electrodes on the outer cantha of one eye and above the supra-orbital foramen of the opposite eye. During post-hoc averaging, trials containing eye movement were rejected.

Hearing screenings were performed using a Grason-Stadler model GSI-61 audiometer. A NeuroScan computer using Scan 4.0 software was used to collect the event related potentials. The raw electrical potentials were filtered between DC and 300 Hz. A 1900 ms sample was taken from the onset of the last word of each sentence. Sentences were presented through a forced choice procedure in which a participant’s response would trigger the presentation of the next sentence. The GSI-61 audiometer was used to present stimuli through 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 and with all electronic equipment operating.

A female native English speaker recorded the stimulus sentences. Stimuli were digitally recorded in a sound-isolated chamber using a low impedance dynamic microphone (DPA 4011). The microphone was positioned approximately 6 inches from the speaker's mouth. An A/D converter (Mini-me) by Apogee Systems was used to convert the stimuli. All recordings were made at 44.1 kHz with 24-bit quantization. The sentences were then down-sampled with Adobe Audition Software to 16-bit quantization to interface with NeuroScan software. Sentences were also segmented with Adobe Audition. Selections were cut at a zero crossing and ramped over the initial and ending 25 ms. 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, taking care to not adjust above peak recording levels. Two participants then listened to the sentences and digitally edited four tokens to eliminate noise artifacts.

Stimuli

Sentences were presented to the participants in three ear conditions: monaurally to the right ear, monaurally to the left ear, and binaurally. The sentences were presented through insert phones (ER3-A) at 65 dB HL in a sound-attenuated chamber through the GSI-61 audiometer. Sentences were taken from the Houghton Mifflin English Textbook Level 2. Sentences were determined to be at the comprehension level of a typically developing 5-year-old. One hundred and two sentences were used to create the stimuli. Three versions of each sentence were created, totaling 306 sentences. One version of the sentences was correct, another version contained a syntactic error, and the third version contained a semantic error. Syntactic errors included one of the following: a plural noun syntactic error, a past tense *–ed* verb syntactic error, a past tense irregular verb syntactic error, or a third person verb syntactic error. These syntactic errors were chosen since the morphemes are used appropriately by a typically developing 5-year-old (Brown, 1973). The errors were relative to the participants’ regional dialect. All syntactic and semantic errors occurred in the final word of the sentence. Three randomized versions were constructed from the 306 sentences. Each version contained approximately 50 linguistically correct sentences, 50 syntactically incorrect sentences, and 50 semantically incorrect sentences. The correct and incorrect versions of the same sentence never occurred consecutively. Each participant listened to a different version in each of the three conditions. Conditions were randomized between participants. Each participant listened to a total of 450 sentences. Each participant was given a five minute training period using practice examples to ensure they understood the directions. After listening to each sentence, participants pushed a smiling face button if they thought the sentence was correct and a frowning face button if they thought the sentence was incorrect. After the first and second presentation of sentences, the participants were offered a five-minute break. Examples of the sentences are listed below (see Appendix C for the complete set):

No syntactic errors.

1. The sleeves covered both hands.
2. The girl laughed.
3. The plane flew.
4. The mother smiles.

Four examples of semantic error.

1. The sleeves covered both *moons*.
2. The shoe *laughed*.
3. The plane *cried*.
4. The block *smiles*.

Four examples of 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. The mother *smile* (third person verb error).

Analysis

The auditory evoked potential waveforms obtained for each participant were averaged for the linguistically correct and deviant conditions (syntactically and semantically incorrect). 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. Next, 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 P600 latency and amplitude for each age group in all ear and sentence conditions. Grand average waveforms were also created for each group in all ear and sentence conditions. Finally, percentage of participants who demonstrated identifiable P600s was determined for each age group.

Results

The following results were derived from children across the five different age groups. The mean ages were 5;11 (Group 1), 7;2 (Group 2), 8;8 (Group 3), 10;0 (Group 4), and 11;7 (Group 5).

Descriptive Statistics for Group 1

The descriptive statistics for the youngest age group, 5;2-6;5, are displayed in Table 1. The latency for the binaural stimulation for the syntactically incorrect sentences is 724.72 ms and the latency for the binaural stimulation for the semantically incorrect sentences is 715.20 ms. The two latencies are similar, being less than 10 ms apart. The latency for the binaural stimulation for the syntactically incorrect sentences is 670.80 ms and the latency for the binaural stimulation for the semantically incorrect sentences is 674.73 ms. These two latencies are also similar to each other, being less than 4 ms apart. The latency for the right ear stimulation for the linguistically correct sentences is 613.60 ms and the latency for the right ear stimulation for the syntactically incorrect sentences is 687.45 ms. The difference between the two latencies is greater than one standard deviation.

Descriptive Statistics for Group 2

Table 2 displays the descriptive statistics for Group 2, ages 6;8-7;11. The data from the syntactically incorrect sentences in Table 2 shows that the average latencies for the right ear (693.10 ms) and binaural stimulations (694.47 ms) are similar, being less than 2 ms apart. The latency for the right ear stimulation for the syntactically incorrect sentences is 693.10 ms and the latency for the right ear stimulation for the semantically incorrect sentences is 692.20 ms. The two latencies are similar to each other, being less than 2 ms apart. The latency for the left ear stimulation for the linguistically correct sentences is 732.95 ms and the latency for the left

Table 1

Descriptive Statistics for the P600 in Participants 5;2 to 6;5 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=6)				
Latency (ms)	657.67	80.44	544.60	775.60
Amplitude (µV)	5.31	4.57	-1.73	11.36
Right Ear (n=4)				
Latency (ms)	613.60	50.49	566.00	677.20
Amplitude (µV)	-0.15	8.02	-9.34	6.69
Binaural Ear (n=3)				
Latency (ms)	641.53	32.69	613.00	677.20
Amplitude (µV)	9.89	7.43	3.62	18.10
Syntactic Error				
Left Ear (n=5)				
Latency (ms)	724.72	58.48	645.20	792.80
Amplitude (µV)	5.30	5.55	-2.14	12.79
Right Ear (n=4)				
Latency (ms)	687.45	70.62	608.80	780.00
Amplitude (µV)	3.06	5.98	-3.14	9.03
Binaural Ear (n=4)				
Latency (ms)	670.80	77.95	568.20	756.40
Amplitude (µV)	3.85	3.09	2.02	8.47
Semantic Error				
Left Ear (n=4)				
Latency (ms)	715.20	31.07	688.00	750.00
Amplitude (µV)	7.55	4.15	2.02	11.92
Right Ear (n=3)				
Latency (ms)	662.07	99.76	576.00	771.40
Amplitude (µV)	5.72	4.74	2.16	11.10
Binaural Ear (n=3)				
Latency (ms)	674.73	78.61	584.00	722.20
Amplitude (µV)	7.70	6.90	0.36	14.05

Table 2

Descriptive Statistics for the P600 in Participants 6;8 to 7;11 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=4)				
Latency (ms)	732.95	59.73	668.60	803.40
Amplitude (µV)	14.45	13.60	3.97	34.33
Right Ear (n=4)				
Latency (ms)	651.05	42.82	608.80	705.00
Amplitude (µV)	11.87	5.87	7.86	20.46
Binaural Ear (n=4)				
Latency (ms)	644.10	73.41	581.00	750.00
Amplitude (µV)	7.78	4.30	5.00	14.12
Syntactic Error				
Left Ear (n=5)				
Latency (ms)	671.08	85.12	576.60	788.60
Amplitude (µV)	8.67	5.98	2.14	17.49
Right Ear (n=4)				
Latency (ms)	693.10	88.65	593.00	805.60
Amplitude (µV)	2.34	6.95	-2.37	12.66
Binaural Ear (n=6)				
Latency (ms)	694.47	87.59	570.80	816.40
Amplitude (µV)	8.58	7.21	3.08	22.58
Semantic Error				
Left Ear (n=3)				
Latency (ms)	631.07	64.99	576.60	703.00
Amplitude (µV)	7.50	3.54	5.13	11.56
Right Ear (n=5)				
Latency (ms)	692.20	72.61	608.80	769.20
Amplitude (µV)	7.15	4.84	.59	11.98
Binaural Ear (n=6)				
Latency (ms)	712.20	68.98	600.20	795.00
Amplitude (µV)	5.11	6.12	-2.58	11.53

ear stimulation for the semantically incorrect sentences is 631.07 ms. The difference between these two latencies is greater than one standard deviation.

Descriptive Statistics for Group 3

The descriptive statistics for Group 3, ages 8;3-9;3, are displayed in Table 3. For the syntactically incorrect condition, the left ear (750.73 ms) and right ear (620.60 ms) latencies are greater than one standard deviation. The latency for left ear stimulation for the syntactically incorrect sentences is 750.73 ms and the latency for left ear stimulation for the semantically incorrect sentences is 682.15 ms. The difference between these two latencies are greater than one standard deviation. In contrast, for the semantically incorrect condition, the left ear (682.15 ms) and right ear (688.50 ms) latencies are similar, being less than 7 ms apart.

Descriptive Statistics for Group 4

Table 4 shows the descriptive statistics for Group 4, ages 9;6-10;6. The data from the semantically incorrect sentences in Table 4 shows that the average latencies for the right ear stimulation (702.32 ms) and binaural stimulation (705.40 ms) are similar. The two latencies are less than 4 ms apart. In addition, the binaural stimulation of the syntactically incorrect sentences (705.56 ms) and the binaural stimulation of the semantically incorrect sentences (705.40 ms) are also similar. The difference between these two latencies is less than 1 ms.

Descriptive Statistics for Group 5

The descriptive statistics for the oldest age group, ages 11;0-12;5, are displayed in Table 5. The data from the linguistically correct sentences in Table 5 shows that the average latency for the left (702.90 ms) and right ear (622.33 ms) stimulations are greater than one standard deviation. The mean latencies for the left ear (676.13 ms) and right ear (672.90 ms) stimulations of the syntactically incorrect sentences, however, are similar. The difference between these two

Table 3

Descriptive Statistics for the P600 in Participants 8;3 to 9;3 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=4)				
Latency (ms)	639.30	133.86	512.60	771.40
Amplitude (µV)	6.17	6.34	0.36	14.39
Right Ear (n=4)				
Latency (ms)	648.35	66.11	591.60	715.80
Amplitude (µV)	4.91	4.95	0.46	9.52
Binaural Ear (n=4)				
Latency (ms)	683.65	57.36	608.80	728.60
Amplitude (µV)	2.96	5.20	-2.37	9.17
Syntactic Error				
Left Ear (n=3)				
Latency (ms)	750.73	50.17	707.20	805.60
Amplitude (µV)	6.19	4.72	2.68	11.56
Right Ear (n=4)				
Latency (ms)	620.60	100.60	548.80	767.20
Amplitude (µV)	4.39	4.77	-.01	10.05
Binaural Ear (n=4)				
Latency (ms)	646.25	79.97	538.20	715.80
Amplitude (µV)	5.35	3.64	1.59	8.96
Semantic Error				
Left Ear (n=4)				
Latency (ms)	682.15	56.16	613.60	741.40
Amplitude (µV)	4.64	3.88	2.07	10.33
Right Ear (n=4)				
Latency (ms)	688.50	37.17	662.2	743.60
Amplitude (µV)	6.57	4.51	1.21	11.83
Binaural Ear (n=5)				
Latency (ms)	702.88	56.46	628.00	773.60
Amplitude (µV)	4.81	4.01	1.12	11.62

Table 4

Descriptive Statistics for the P600 in Participants 9;6 to 10;6 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=3)				
Latency (ms)	633.60	38.30	591.60	666.60
Amplitude (µV)	3.74	6.28	-2.94	9.53
Right Ear (n=5)				
Latency (ms)	647.12	55.02	583.20	728.60
Amplitude (µV)	7.66	3.87	2.84	13.47
Binaural Ear (n=5)				
Latency (ms)	660.12	137.48	519.00	806.20
Amplitude (µV)	6.26	1.35	4.95	8.43
Syntactic Error				
Left Ear (n=6)				
Latency (ms)	674.33	123.84	508.20	847.60
Amplitude (µV)	5.85	4.00	1.12	11.73
Right Ear (n=4)				
Latency (ms)	669.25	66.20	602.40	750.00
Amplitude (µV)	6.13	2.45	2.75	8.52
Binaural Ear (n=5)				
Latency (ms)	705.56	71.75	643.00	810.20
Amplitude (µV)	6.87	7.68	-1.00	15.11
Semantic Error				
Left Ear (n=5)				
Latency (ms)	689.32	59.94	634.40	775.60
Amplitude (µV)	9.10	8.15	-0.98	18.22
Right Ear (n=5)				
Latency (ms)	702.32	73.67	604.60	798.20
Amplitude (µV)	6.89	6.22	-0.69	15.63
Binaural Ear (n=4)				
Latency (ms)	705.40	84.72	606.60	794.20
Amplitude (µV)	6.85	7.62	-2.15	15.13

Table 5

Descriptive Statistics for the P600 in Participants 11;0 to 12;5 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=2)				
Latency (ms)	702.90	57.56	662.20	743.60
Amplitude (µV)	4.96	1.31	4.03	5.89
Right Ear (n=3)				
Latency (ms)	622.33	52.28	563.80	644.40
Amplitude (µV)	3.18	2.96	0.02	5.90
Binaural Ear (n=4)				
Latency (ms)	667.25	76.96	602.20	762.80
Amplitude (µV)	2.73	3.34	-2.12	5.08
Syntactic Error				
Left Ear (n=6)				
Latency (ms)	647.20	104.63	536.40	798.20
Amplitude (µV)	3.74	3.15	-0.98	7.17
Right Ear (n=6)				
Latency (ms)	640.83	66.28	531.80	696.60
Amplitude (µV)	3.05	2.34	-0.78	5.63
Binaural Ear (n=3)				
Latency (ms)	597.20	78.85	506.20	645.20
Amplitude (µV)	1.45	1.21	0.14	2.53
Semantic Error				
Left Ear (n=3)				
Latency (ms)	676.13	80.25	629.40	768.80
Amplitude (µV)	3.33	3.33	-0.46	5.83
Right Ear (n=4)				
Latency (ms)	672.90	64.22	638.80	769.20
Amplitude (µV)	3.88	4.10	1.21	9.98
Binaural Ear (n=2)				
Latency (ms)	691.70	105.08	617.40	766.00
Amplitude (µV)	15.26	4.92	11.78	18.74

latencies is less than 4 ms. The latencies between the left (647.20 ms) and right ear (640.83 ms) stimulations of the semantically incorrect sentences are also similar. The difference between these two latencies is less than 7 ms.

Developmental Waveforms of the P600 ERP

Figure 1 represents the ERP waveforms for all age groups. In each age group, the waveforms are displayed for all three sentence conditions: linguistically correct, syntactically incorrect, and semantically incorrect. Within each sentence condition, waveforms are displayed for the right ear, left ear, and binaural presentations. The arrows indicate the peak amplitude of the P600 ERP.

In Group 1, the P600 is present in the linguistically correct condition in the left ear stimulation and in the syntactically incorrect condition in the right ear stimulation. In Group 2, the P600 is present in all three sentence conditions. In the linguistically correct and syntactically incorrect condition, the P600 is present in both the left and right ear stimulation. However, the P600 is present in the right ear and binaural stimulation for the semantically incorrect sentence condition. In Group 3, the P600 is present in the right ear and binaural stimulation for the syntactically incorrect condition and in the left ear stimulation for the semantically incorrect condition. In Group 4, the P600 is present in the right and left ear stimulation in the syntactically incorrect condition. In Group 5, the P600 is seen in the right and left ear stimulation in the linguistically correct condition and in the left ear stimulation for the syntactically incorrect condition.

Percent of Identifiable P600 Component

In Table 6, the percentage of the identifiable P600 component is shown for each of the three stimuli conditions across the age groups. In the correct condition, the lowest percentage

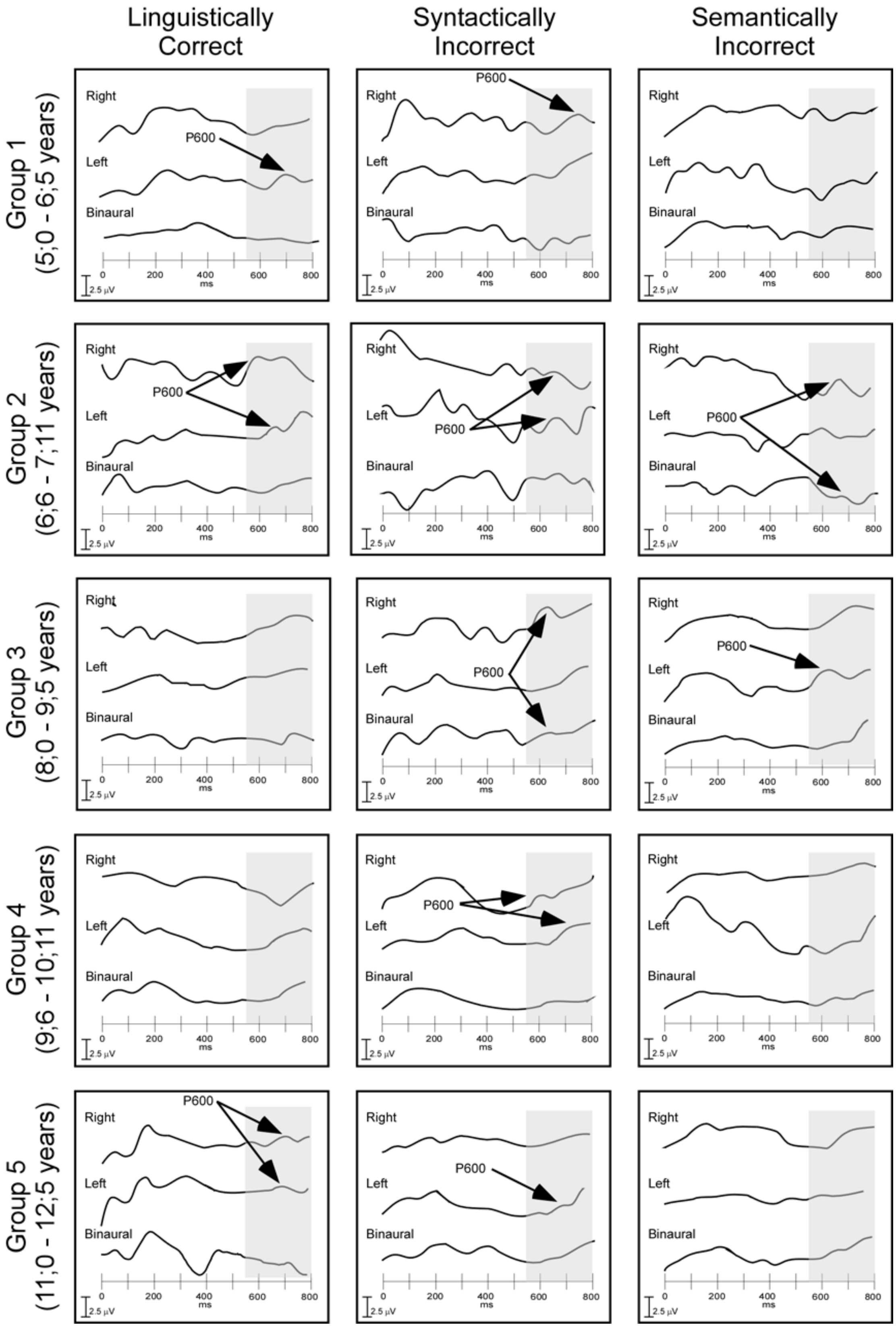

Figure 1. Developmental ERP waveforms of the P600 across all conditions

Table 6

Percent of Identifiable P600 Component for the Three Stimulus Conditions Across Age Groups

Age	Correct	Syntactic Error	Semantic Error
5;2-6;5	83.3	75.0	58.3
6;8-7;11	66.7	75.0	66.7
8;3-9;3	66.7	58.3	66.7
9;6-10;6	66.7	83.3	83.3
11;0-12;5	41.7	100.0	58.3

present was found in the oldest age group (11;1 to 12;5). In the semantic error stimuli, the lowest percentage present was found in both the oldest and the youngest age group (5;2 to 6;5). In the syntactic error stimuli, the highest percentage was found in the oldest age group.

Discussion and Conclusion

Discussion

Comparison of average latencies and amplitudes. The average latency for binaural stimulation from the syntactically incorrect sentences from Table 1 is 670.80 ms. This latency is not in agreement with Hahne and Friederici’s study from 1999 who found that 6-year-old children displayed a P600 latency between 750 and 1000 ms. However, it is consistent with Friederici and Hahne’s later study from 2001. In the 2001 study they found that 6- and 7-year-old children displayed a P600 latency between 350 and 1300 ms. Hahne et al. in 2004 reported a latency between 1250 and 1500 ms for 6-year-old children. These differences may be attributed to differences in the interpretation of the identification of the P600 or differences in the tagging of the initialization of latency within a sentence (e.g., beginning of the sentence, beginning of the key word, etc.). In the present study, the latency was tagged at the end of the key word. The differences in reported latencies may also be attributed to the lack of testing of 5-year-old children.

The average latency for binaural stimulation using syntactically incorrect sentences from Table 2 is 694.47 ms. This latency differs from previous research reported by Friederici and Hahne (1999) who found that 7-year-old children displayed a P600 latency between 750 and 1000 ms. However, in 2001, Friederici and Hahne published a study consistent with the present study. They reported P600 latencies between 350 and 1300 ms for 6- and 7-year-old children. Similarly, in 2004, Hahne et al. reported that 7-year-old children displayed a P600 latency between 400 and 1500 ms, which is also consistent with the present study.

The average latencies for the binaural stimulation from the syntactically incorrect sentences from Table 3 is 646.25 ms. This latency is consistent with research from Atchley et al. (2006), who found that the P600 latency of a child would occur between 623 and 724 ms. It is also consistent with research from Hahne et al. (2004), who found that 8-year-old children displayed a P600 latency of approximately 600 ms.

The average latency for the binaural stimulation from the syntactically incorrect sentences from Table 4 is 705.56 ms. This latency is consistent with research from Atchley et al. (2006), who found that the latency of the P600 of a child would occur between 623 and 724 ms. This is also consistent with research from Hahne et al. (2004), who found that 10-year-old children displayed a P600 latency of approximately 600 ms.

The average latency for the binaural stimulation from the syntactically incorrect sentences from Table 5 is 597.20 ms. This latency is not in agreement with research from Atchley et al. (2006) for children or adults. Atchley et al. reported the latency of the P600 in children to occur between 623 and 724 ms and the latency of adults to occur between 623 and 673 ms: essentially, non-significant latency differences.

The average latencies for the binaural stimulations from the syntactically incorrect sentences in Tables 1-4 are consistent with the results from Friederici and Hahne (2001), Atchley et al. (2006), and Hahne et al. (2004). The consistency of findings in previous studies corroborates the present study's results. The average latency for the binaural stimulation from the syntactically incorrect sentences in Table 5 is not in agreement with previous research. There is only one study at this time that has stated specific latencies in 11- and 12-year-old children. Therefore, further research including 11- and 12-year-old children would be beneficial.

The earliest averaged latency for binaural stimulation of the syntactically incorrect sentences from the five groups of participants is from Group 5, the oldest age group. This is consistent with previous research from Friederici and Hahne (2001), that reported that the P600 typically has an earlier latency in adults than in younger children. Atchley et al. (2006) also found an earlier latency in adults than in children when an agreement violation sentence was presented. The shorter latency found in adults implies a quicker processing of the information.

The average amplitudes for the binaural stimulations from the syntactically incorrect sentences from Tables 1-5 are as follows: 3.85µV (Group 1), 8.58 µV (Group2), 5.35 µV (Group 3), 6.87µV (Group 4), and 1.45 µV (Group 5). The smallest average amplitude from the five groups of participants is Group 5, the oldest age group. This is consistent with previous research from Friederici and Hahne (2001) and Atchley et al. (2006), who reported that the P600 typically has smaller amplitudes in adults than in children. The smaller amplitude suggests fewer demands when processing the information.

Ear condition comparisons. The difference in ear condition (right ear, left ear, or binaural) does not appear to have a large influence on the latency or amplitude of the P600. It was noted, however, that when comparing the three ear conditions, the right ear either had the shortest or medial latency, never demonstrating the longest latency. For example, in Group 1, the latency for the right ear stimulation in the linguistically correct condition was 613.60 ms, while the latency for the left ear stimulation was 657.60 ms and the latency for the binaural stimulation was 641.53 ms. In this situation, the latency for the right ear stimulation was the shortest latency when compared to the other ear conditions.

It was also noted that when comparing the mean latencies for the right ear, left ear, and binaural stimulations, the right ear and binaural stimulations were closer in latency than the right and left ear stimulations or the left ear and binaural stimulations 53% of the time (8/15). This may be due to Right Ear Advantage (REA). REA occurs when language is processed slightly quicker for information presented to the right ear versus the left ear. The left hemisphere of the brain is typically responsible for language functions, such as processing semantic and syntactic information. When information is presented to the right ear, the auditory information is directly transmitted contralaterally to the left hemisphere to be processed. However, when information is presented to the left ear, interhemispheric processing must occur. First, the information must decussate over to the right hemisphere and then pass through the corpus callosum in order to reach the left hemisphere (Bellis, 2003, p. 57). Behaviorally, REA is typically only seen in very young children when listening to monotic sentences. The results of the study indicate that the phenomenon may occur through 9 or 10 years of age. This may possibly be due to the greater demands on processing seen in utilization of more complex sentence material.

Developmental ERP waveforms of the P600. Figure 1 displayed the P600 waveform across the five age groups for each of the three stimuli conditions for each of the three ear conditions. In the linguistically correct condition, the participants in Groups 1 and 2 incorrectly recognized a syntactic error. This is shown by the presence of the P600 in the linguistically correct column for these two age groups. In Groups 3 and 4, the P600 is absent. This suggests a development of the brain’s ability to recognize syntactic errors over time. In Group 5, the P600 is present again. Its presence here may not necessarily be due to the recognition of a syntactic error, but instead, due to higher syntactic processing (Hahne et al., 2004). In the syntactically incorrect condition, the P600 is present for all age groups. This indicates that all ages were able to correctly recognize the syntactic errors presented. In the semantically incorrect condition, the P600 is present in the younger age groups, but absent in the older age groups, thus showing the development of the brain’s ability to recognize syntactic errors in late childhood years. Although this has not been shown for the P600 in previous studies, research has reported that semantic processes are not established until after age 8 or 9 years (Holcomb, Coffey, & Neville, 1992). The presence of the P600 in the younger ages may relate to previous research, which states that the P600 may represent not only syntax, but semantics as well (Hoeks et al., 2004; Kolk et al., 2003; Kuperberg et al., 2003).

The participants in age Groups 2 and 3 had difficulty correctly distinguishing the P600. In both age groups, the P600 is present in the syntactically incorrect condition. However, the P600 is also present in the semantically incorrect condition. The participants were uncertain whether the semantic errors were syntactic or semantic. In Groups 4 and 5, the participants were able to correctly recognize the errors. This is shown by the presence of the P600 in the syntactically incorrect condition, but absent in the semantically incorrect condition. This may indicate a development of the brain's ability to distinguish syntactic errors from semantic errors by age 9 or 10. In Figure 1, an inconsistency occurs between the three ear conditions: right ear, left ear, and binaurally. Previous research suggests that since the sentences were presented monaurally, the P600 should be present in all three ear conditions in the syntactically incorrect condition (Bellis, 2003, p. 57). However, in Figure 1, there are inconsistent placements of the P600 among each ear condition throughout each age group. For example, in Group 1, the P600 is present in the linguistically correct condition in the left ear. In the same age group, the P600 is present in the syntactically incorrect condition in the right ear. Another example can be seen by observing the P600 waveforms in Groups 2 and 3. In Group 2, the P600 is present in the right and left ears, but not binaurally. Yet, in Group 3, the P600 is present in the right ear and binaurally, but not in the left ear.

In Figure 1, inconsistencies exist concerning when the P600 becomes established or adult-like. As mentioned, in the syntactically incorrect condition, the P600 exists in all five age groups. However, within each age group, the P600 is only present in some of the ear conditions. This provides evidence that the brain is able to recognize syntactic errors in ages as young as 5;2; but they may only be able to do so in certain ear conditions. This observation has resulted in an area of interest that needs further exploration in future studies.

Identification of the P600 component across the age groups. Table 6 shows the variability of the P600 for the three sentence conditions. In the correct stimuli condition, the presence of the P600 decreased as age increased by approximately 42% from the youngest age group to the oldest age group. Although the P600 is not typically present in a correct stimulus group, the P600 may be present if a higher level of syntactic processing is needed to evaluate a sentence (Hahne et al., 2004). This would suggest that the sentences used in the current study required a higher syntactic processing. The older age groups may have had the lowest percentage of identifiable P600s because their ability to evaluate syntax may be more developed.

According to Table 6 under the syntactic stimuli condition, the highest percentage of identifying the P600 component was found in the oldest age group. For the current study, this high percentage is interpreted as the older children having more advanced linguistic skills.

The P600 is also typically absent in the presence of a semantic error. However, the presence of the P600 in a semantic error may be due to the inability of the individual to distinguish the syntactic error from a semantic error. For the semantic error stimuli, Table 6 displays the lowest percentage of identifiable P600 components present in the youngest age group and the oldest age group. The P600 component may be seen as less identifiable to the youngest age group because the children may not have limited skills to recognize or distinguish syntactic or semantic errors. In fact, the sentence may actually appear correct to the child (Hahne et al., 2004). The P600 component may also be seen as less identifiable to the oldest age group because they have a greater linguistic ability to recognize the difference between a syntactic and semantic error.

Conclusion

The results of the current study affirm previous research of the P600 in that younger children exhibit later latencies and higher amplitudes than do adults. The difference is small, but a difference does exist. In addition, the current study also suggests that the age by which syntactic processing becomes fully established is 8 or 9 years. While younger ages, such as 5 or 6 years, may still be able to distinguish certain items of syntax, a more adult-like knowledge of syntax is not expected until a few years later. This research further suggests that ear condition may be a factor in a child’s ability to recognize syntax. This was the first study that associated developmental ERPs and ear condition. Therefore, this finding is a result of interest that needs to be further explored in future studies. The current study also noted that the REA phenomena may exist neurologically in older ages with monotic sentences. This is another area that would benefit from future research due to the new findings. The current study found contrasting data concerning the mean latency of 5- and 6-year-old children. A previous article agreed while two others reported contrasting data. This may be due to a transitional developmental period or the possibility of population bias such as regionalization of language learning skills. Further research into this area would provide insight into the neurophysiological basis of language processing during a dynamic developmental age. Contrasting data was also found concerning the mean latency of 11- and 12-year-old children. Only one study at this time has reported specific P600 latencies in 11- and 12-year-old children. Therefore, further research including 11- and 12-year-old children would also be beneficial.

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Appendix A

Parental Informed Consent for Child to Act as a Human Research Subject

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Name of Participant:____________________________ Date of Birth:_________________

Purpose of Study

This research is designed to examine the syntactic processing of language by the brain in children using electrophysiological measures known as event-related potentials. Participation in this study will help teachers and scientists better understand the brain's ability to process language.

Procedures

Your child has been asked 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 at your child's school and in room 111 of the John Taylor Building on the campus of Brigham Young University. The testing at the school will consist of two sessions. One session will test your child's IQ and the second session will test your child's language. Each session at the school will take approximately 1 hour. 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 my 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 648 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, standardized language test, and the electrophysiological recording.

The procedures used to record the electrophysiological 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.

Benefits

Benefits from participating in this study include an assessment of hearing, language and IQ. I will be notified if any clinical deficits are found in these areas. I also understand that there may be no direct benefit to me or my child. However, the information obtained will help to further the understanding of language processing, which will be beneficial to professionals involved in treating speech and hearing disorders.

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.

Other Considerations

There are no charges incurred by you or your child for participation in this study. There is no treatment or intervention involved in this study.

The procedures listed above have been explained to me and my child by: ___________________ in a satisfactory manner and any questions relating to such risks have been answered. If there are any further questions or concerns regarding this study, I may ask any of the investigators or contact David McPherson, Ph.D., Audiology and Speech-Language Pathology, 129 Taylor Building, Provo, Utah 84602; phone (801) 422-6458; email: david_mcpherson@byu.edu.

If there are any questions regarding my rights as a participant in this research project, we may contact Renea Beckstrand, PhD, Chair of Institutional Review Board, 422 SWKT, Brigham Young University, Provo, Utah 84602; phone (801) 422-3873; email: renea_beckstrand@byu.edu.

I give permission for my child to participate in the study explained above.

____________________________ _____________

Signature of Parent/Guardian Date

____________________________ _____________

Signature of Witness Date

Appendix B

Child Informed Consent to Act as a Human Research Subject

David L. McPherson, Ph.D.
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This study is to look at how the brain processes words that we hear. Being part of this study will help teachers and scientists better understand how the brain reacts to speech. What we learn will be useful to people who help children with speech problems. My parents have agreed that I can help with this research.

I will be pulled out of class twice for testing. During this time, if I get tired I can ask for a break from testing. I will visit BYU one time. During my visit, my hearing will be checked. Also, I will 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 sticky, clear gel. When the gel is put on my head, it may tickle for a moment. It may also feel gooey. If I don’t like the feel of the gel and cap, I can ask the clinician to take it off at any time. I will hear some sentences through the ear probes. I will press a button to tell the researcher if the sentence I heard was “good” or “bad.” If I get tired, I can ask for a rest.

I understand that I do not have to do any part of this study. If I change my mind, I can quit the study at any time.

I would like to be part of this study.

______________________________	_______________
Signature of Participant	Date
______________________________	_______________
Signature of Witness	Date

Appendix C

Stimulus Sentences

A. Correct Sentences

Houghton Mifflin English: Teacher's Edition, Level 2. (1995). Boston. Houghton Mifflin Company. (pp. 95–187)

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

Houghton Mifflin English: Teacher's Edition, Level 2. (1995). Boston. Houghton Mifflin Company. (p. 95–187)

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 docks.
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 parties.
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 king 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

Houghton Mifflin English: Teacher's Edition, Level 3. (1990). Boston. Houghton Mifflin Company. (pp. 26, 74–89)

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.
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78. A cat chased three mouses.
79. The bus passes some gooses.
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81. He fell and hit his two front tooths.

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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.