2010-06-23

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Melissa Crandall
Brigham Young University - Provo

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The ELAN Event-Related Potential in

Children 5 to 12 Years of Age

Melissa Crandall

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

Master of Science

David L. McPherson, Chair
Shawn L. Nissen
Ron W. Channell

Department of Communication Disorders

Brigham Young University

August 2010

ABSTRACT

The ELAN Event-Related Potential in Children 5 to 12 Years of Age Across Ear Conditions

Melissa Crandall

Department of Communication Disorders

Master of Science

The examination of Event Related Potentials during language processing tasks provides valuable information of how the brain processes language over time. In the current study, the development of the early left anterior negativity (ELAN) was analyzed in young children. Previous research has described the ELAN as a negative waveform elicited during syntactic processing between 200 and 500 ms post linguistic stimuli. Thirty children from 5 to 12 years of age listened to sentences that were linguistically correct, syntactically incorrect, or semantically incorrect. Sentences were presented for right monaural, left monaural, and binaural ear conditions to determine possible differences related to right ear advantage (REA).

An ELAN-like component in regards to latency and amplitude was observed in children 8 years of age and older; however, comparison between linguistic conditions suggest that the ability to differentiate between linguistically correct, syntactically incorrect, and semantically incorrect stimuli is not established until 12 years of age. Results suggest that adult-like syntactic processing of morphosyntactic errors is not established until after 12 years of age. Comparison between ear conditions suggests that the REA effect may exist in older children, a finding that has not been reflected in previous behavioral research.

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

ACKNOWLEDGMENTS

I would like to thank all those who supported me and made the completing of this project a reality. I am very thankful for the encouragement, insight and time that Dr. McPherson is always willing to provide. I would like to also thank Dr. Nissen and Dr. Channell for their input and support. This project would have been impossible without the support from Laurie Madsen and Kyla Tree. Thanks for helping me to stay motivated. I would like to express my thanks and love to the clinic staff and my clinic mentors who always encouraged me and taught with patience, love, and through example. Lastly, I will always be grateful for loving parents who have always supported and believed in me no matter what.

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Introduction

Behavioral and electrophysiological research of language processing has promoted a greater understanding of language development in children. Although behavioral studies of language in children have established language developmental norms for children, only in the past decade has the neurophysiologic basis for language processing been investigated. The use of event related potentials (ERPs) have allowed for the expansion of understanding of language development (Friederici, 2004).

ERPs are electroencephalographic measurements of neural activity time-locked to a critical stimulus event. These measures are commonly used when studying language processing due to their ability to observe language events as they occur in real time (Friederici, 2004). Three ERP components have been established as specific language processing components in adult populations. These components are the N400, the P600, and the early left anterior negativity (ELAN). The current study is directed at investigating the ELAN in young children.

Current electrophysiological research involving language development has discovered subtle differences in child language processing that has not been observed in behavioral data, allowing for a more complete picture of the development of language to adult-like processing. For example, a recent ERP study found that children may not develop adult-like syntactic processing until after 13 years of age (Hahne, Eckstein, & Friederici, 2004). Studies have shown that ERP data provides valuable information concerning language processing; however, only few studies have investigated the development of language processing in young children.

The purpose of the present study was to provide a more detailed account of language processing development in children from 5;0 to 12;5 years (years;months) of age utilizing electrophysiological measures. Specifically, the processing of linguistically correct, syntactically incorrect, and semantically incorrect sentences were investigated in relation to the ELAN. This

ERP component has been associated with the detection of syntactic errors in adult populations (Friederici, 2004). Additionally, this study investigated electrophysiological findings in relation to a possible Right Ear Advantage (REA), a phenomenon that has been observed behaviorally in very young children.

Review of Literature

ERPs are electroencephalographic measurements of neural activity, time-locked to a critical stimulus event. These measures are especially useful when studying language processing due to the ability to observe language events as they occur in real time (Friederici, 2004). Several ERP components have been established as specific language processing components in adult populations. These components are the ELAN, the N400, and the P600. The research investigating each ERP component relating to language processing in adult and child populations are reviewed.

ERPs and ERP Measurement

Our understanding of the nature of language processing has expanded in recent history through electrophysiological research. Early studies investigating the physiology of language processing relied on the study of the correlation between language deficits and brain lesions. Brain imaging techniques, including functional magnetic resonance imaging (fMRI) and positive emission tomography (PET) localize metabolic changes with high spatial resolution. These techniques have allowed researchers to identify areas within the brain that are active during language processing tasks; however, they are limited in their ability to demonstrate the complexity of language processing over time (Canseco-Gonzalez, 2000; Friederici, 2004; Kutas & Federmeier, 2000).

Methods that demonstrate the activity of the brain over time include electroencephalography (EEG) and magnetoencephalography (MEG). Both methods measure postsynaptic neural activity over time. These measures, in addition to ERPs, are commonly used when studying language processing due to the ability to observe language events as they occur in real time (Friederici, 1997, 2004; Kotz & Friederici, 2003). Unlike other brain imaging techniques, ERP data does not provide the same level of spatial resolution that would allow for definite localization of generating neurostructures (Friederici, 1997). Language is a complex system consisting of various levels of processing; nonetheless, ERPs demonstrate a system that allows for rapid and effective computation required for the study of the electrophysiology of language processing (Canseco-Gonzalez, 2000).

ERP measurements are made at the level of the scalp, which creates difficulty in accurately analyzing data due to the wealth of energy that is produced by the brain at any given time. Averaging procedures are necessary to control for brain activity not involved with the stimulus activation. Recordings of electrical energy for a specific event are obtained repeatedly and mathematically averaged together. During the averaging processes, observed random electrical activity is considered background activity and is averaged to near zero while ERPs elicited by the language stimuli will in theory remain constant. This allows the researcher to observe various ERP components in relation to language processing (Canseco-Gonzalez, 2000; Picton & Stuss, 1984).

For the past 30 years, researchers have utilized ERP data for the study of different cognitive processes in regards to language. It is assumed that different cognitive processes are reflected by specific brain activity patterns. Under this assumption, researchers have attempted to observe ERP patterns associated with specific linguistic processes. Recently, this area of research has been investigated by observing ERPs associated with linguistic errors, including semantic, phonological, and syntactic errors (Canseco-Gonzalez, 2000). Three different linguistically related ERP components have been consistently identified in the research: (a) the N400 is a broadly distributed negativity occurring approximately 400 ms after critical stimuli; (b) the P600 is a centroparietal positivity occurring approximately 600 ms after stimulus presentation, and (c) the ELAN and LAN are early left anterior negativity that occurs between 100 and 500 ms after critical stimuli presentation (Friederici, 2004).

ERPs display different dimensions or components including latency, amplitude, scalp distribution, and polarity. The latency is measured in milliseconds and reflects the timing of cognitive processing. Amplitude indicates the ease in which the brain integrates and processes stimuli. Information concerning scalp distribution allows researchers to differentiate between various cognitive processes by observing changes in activated structures. As discussed, ERP data is collected at the level of the scalp; therefore, a thorough picture of electrical brain processing cannot be provided by ERP data alone. For example, with only ERP data it is difficult to identify the source of energy generation for specific stimuli processing (Picton & Stuss, 1984). Analysis of each ERP component may allow researchers to more specifically identify areas of deficits in regards to language processing; however, a combination of ERPs with tests of higher spatial resolution such as fMRI would allow for a more comprehensive depiction of language cognitive processing (Friederici, 1997).

A Temporal Model of Language Processing

Friederici (1997) has proposed a model of language comprehension in three phases, which integrates the three main linguistic ERP components (i.e., N400, P600, and ELAN). The first phase of language analysis involves building an initial syntactic structure using incoming auditory or visual information. This first stage is reflected by the ELAN (between 200 and 400 ms). During the second phase, lexical semantic processing takes place and is reflected by the N400 (between 300 and 600ms). In the final phase, lexical-semantic and structural information are integrated and reanalysis occurs if a discrepancy is observed during processing. This stage is reflected by the P600, which peaks between 500 and 800 ms (Friederici, 1997).

Friederici (2004) later expanded her language processing model to specifically address syntactic processing. During the initial phase (reflected by the ELAN) phrase structure is constructed based on word category information. After phrase structure is assembled, the relations between phrases are identified and grammatical roles are formed. The final syntactic phase involves integration of language components of the incoming stimuli. Structural, lexical-semantic, and grammatical information are utilized to achieve comprehension. The integration of both syntactic information and semantic information is reflected in the P600 (Friederici, 2004).

Electrophysiology of Semantic Processing

The N400 is a negative waveform that peaks at approximately 400 ms after onset of critical stimulus and has been found to be correlated with lexical-semantic processing. The N400 effect has been observed in both adult and child populations (Friederici, 2004).

MEG studies suggest that the N400 is generated in the superior temporal sulcus and frontal areas (Fredierici, 2004). A study completed by Halgren et al. (2002) used MEG during oral reading of semantically correct and incorrect sentences. Semantically incorrect sentences elicited a large effect over the left hemisphere, which peaked around 450 ms. At the peak of the N400, activity in the left hemisphere was observed to be wide-spread and included anterior temporal, perisylvian, orbital, frontopolar, and dorsolateral prefrontal cortices. In addition, activation was also observed within the right hemisphere, including orbital and right anterior temporal cortical activation. Activity seemed to originate in or near the left superior temporal sulcus. Similar results have been reported from fMRI studies (Halgren et al., 2002).

Initial studies completed by Kutas and Hillyard (1980a, 1980b, 1980c) demonstrated the relationship between lexical-semantic processing and the N400. These studies presented visual stimuli of semantically deviant sentences. In one study, subjects were required to silently read seven-word sentences, each with semantic errors categorized as a (a) moderate error (e.g. *He* *took a sip from the waterfall*), (b) strong error (e.g. *He took a sip from the transmitter*), or (c) appropriate sentence with physical deviations. The researchers observed a negative component beginning about 250 ms and peaking around 400 ms (N400) for both moderate and strong errors with a substantially larger N400 component for stronger errors. A positivity (later described as the P300) was elicited by target words with physical deviations but was not observed during stimuli with only semantic errors. The P300 was observed to be elicited by surprising events related to the task but independent from language processing (Friederici, 1997). The results suggest that the N400 may be an indicator of cognitive reprocessing of semantic inconsistencies within a sentence (Kutas & Hillyard, 1980c).

These studies assisted in establishing the lexical-semantic role of the N400. Kutas and Hillyard (1983) further investigated this role using sentences with grammatical errors that had little to no effect on the meaning of the sentences in addition to sentences with semantic errors. As expected, a large N400 was observed only with semantically incorrect stimuli. Smaller, differently distributed and less consistent negativities were observed during syntactic tasks. It was concluded from these results that the N400 is exclusively related to semantic processing rather than to syntactic processing. Another study investigated the effect of unexpected words which were either semantically inappropriate, physically deviant, or both. The ERPs evoked from these stimuli produced several different components. An N400 was observed for semantically inappropriate words while a late positivity was observed for physical deviations. Positive components were not observed during semantic tasks. Both distinct ERPs were observed when deviations were presented simultaneously (Kutas & Hillyard, 1980a).

The N400 has not only been observed in sentence contexts but has also been elicited in response to word paring tasks. A semantic priming effect is demonstrated when a target word is recognized faster when proceeded by a semantically related word or prime. The relationship between semantic priming and the N400 was observed when a prime word was followed by either a semantically related word, a phonologically related word (rhyme), or a semantically unrelated word. The N400 was smaller with semantically primed words, intermediate with phonologically primed words, and largest with unrelated words (Osterhout & Holcomb, 1995).

The N400 in relation to semantic priming has been investigated using various modalities. One study observed the effects of semantic priming in both visual and auditory modalities. Word pairs were presented which consisted of a prime word followed by either a semantically related word or a semantically inappropriate word. A larger N400 was observed for semantically inappropriate words in both visual and auditory modalities. An auditory presentation elicited an earlier N400 in addition to an increase in the component's duration (Holcomb & Neville, 1990). It is concluded that the N400 reflects, through observations of latency and amplitude, the degree to which a target word is semantically primed.

Topography of the N400 has been shown to be sensitive to stimuli modality. When presented with visual stimuli, the N400 often demonstrates increased distribution over the right hemisphere. In regards to auditory stimuli, the N400 appears to be earlier and more prolonged with an increased distribution over the left hemisphere (Friederici, 2004). Hagoort, Brown, and Swaab (1996) observed a reduced and even absent N400 effect in patients with lesions in Wernicke's area while those classified with Broca's Aphasia demonstrated a N400 effect. These results emphasize that information collected from ERP studies may be utilized for language diagnostic purposes (Friederici, 1997).

As demonstrated in previous studies, the amplitude of the N400 varies according to context. In the absence of context (word pair tasks) the amplitude of the N400 increases. The greater predictability or frequency of a word will reduce the amplitude of the N400, thus demonstrating increased ease during semantic processing. Within sentential context, the amplitude of the N400 varies in regards to semantic expectancy. Additionally, the amplitude of the N400 varies according to the word's frequency within the language (Friederici, 1997, 2004).

In summary, the N400 reflects lexical-semantic processing, not dependent on stimuli modality. Studies have reported observation of the N400 in both sentence and word pairing contexts. Canseco-Gonzalez (2000) clarified that "rather than being elicited specifically by semantic anomalies, the N400 component is inversely related to the semantic expectation of given word in relation to its context" (p. 232). The N400 has also been observed in several languages including English, French, Dutch, and German in both visual and auditory modalities (Friederici, 2004).

Electrophysiology of Syntactic Processing

Syntactic processing is central to language comprehension. One study demonstrated the significance of intact syntactic processing with behavioral observations of Broca's aphasia during syntactic and semantic tasks. Subjects completed tasks with available semantic and syntactic information with relative ease but were unable to complete tasks when only syntactic information was provided (Caramazza & Zurif, 1976).

Syntactic processing is complex, multi-layered, and is utilized at several stages during language comprehension. Early studies have found two ERPs associated with syntactic processing; the P600 and the ELAN (Friederici, 2004). According to Friederici's model (1997), the ELAN is associated with initial syntactic structure building while the P600 is associated with syntactic reanalysis. Both components may be elicited with a single syntactic violation type, illustrating a high level of interaction between the two components (Canseco-Gonzalez, 2000).

The neural basis for the P600 and ELAN has been investigated in patients with brain lesions. Studies found an absent ELAN in patients with lesions in the left anterior cortex and the anterior temporal lobe. The P600 was found to be reduced or absent in those with lesions in the basal ganglia; however, some have observed a present ELAN in those with lesions in the left basal ganglia. These results suggest that early syntactic processing is supported in temporal and frontal regions of the cerebral cortex, more specifically involving the left anterior portion of the superior temporal gyrus and the left inferior frontal gyri. Later processing appears to involve deep structures, such as the basal ganglia (Friederici, 2004).

The P600. The final stage of syntactic processing is represented by the P600, a large positive waveform also termed the syntactic positive shift (Canseco-Gonzalez, 2000). It is characterized by a centroparietal distribution beginning around 500ms. The P600 is associated with violations of structural preferences, syntactic violations, and difficulty with syntactic integration. Based on these findings, it is suggested that the P600 is associated with syntactic reanalysis (Friederici, 1997).

The P600 is a reflection of the revision of sentence structure during linguistic processing. Early studies of the P600 considered violations of structural preferences. Osterhout and Holcomb (1992) observed the P600 with non preferred or garden path sentences (i.e., *The broker persuaded to sell the stock*). When presented with this type of sentence, the listener typically expects a noun phrase after the verb (e.g., *The broker persuaded the man to sell the stock*). The infinitive marker *to* elicited a centroparietal positivity that peaked at approximately 600 ms. The authors suggested that the observed late positivity was apparent when revision was required for sentence comprehension (Osterhout & Holcomb, 1992).

In addition to structural preference studies, the P600 is also elicited with syntactic violations. Within many of these studies both a left anterior negativity (LAN) and later P600 were observed, reflecting a biphasic ERP response (Canseco-Gonzalez, 2000; Friederici, 2004). For example, one study presented auditory sentences with either syntactic structure errors or morphological errors. A LAN was observed peaking between 300 and 600 ms followed by the P600 for morphosyntactic errors (Friederici, 1993).

Further studies concluded that the P600 is a function of linguistic processing reanalysis of both syntactic and semantic input. Munte, Matzke, and Johannes (1997) investigated agreement violations using pseudoword sentences to observe if the P600 was elicited without semantic input. During the pseudoword grammatical task a short negative effect between 280 and 500 ms was found in the absence of the P600. The P600 was reported for real word grammatical violations without the occurrence of a negativity. These results support the concept that the P600 is a reflection of linguistic reanalysis of both meaning and structure when a syntactic error is encountered during processing. A similar study completed in English verified these findings; however, an ELAN was observed in addition to the P600 for real word grammatical violations (Canseco-Gonzalez, 2000).

Differences in the latency of the P600 have been observed independent of earlier negative components. Mecklinger, Schriefers, Steinhauer, and Friederici (1995) observed an earlier centroparietal positivity (around 350 ms) and absence of earlier negativity with garden path sentences. The authors concluded that the sentences used in the study were more simplistic and hypothesized that the latency of the P600 is dependent on the difficulty of syntactic revision process. Findings from another study identified an early positivity occurring at approximately 300 ms for sentences that were considered easy to revise and a later positivity for more difficult sentences. The authors suggested that the latency of the P600 varies in regard to the level of difficulty to recover from sentence structure processing (Friederici & Mecklinger, 1996).

Some studies have investigated the relationship between the P600 and P300 elicited during language tasks. An initial study completed by Kutas and Hillyard (1980c) considered visual linguistic stimuli with physical deviations, such as different font sizes for each word in each presented sentence. A positivity (later described as the P300) was elicited by target words with physical deviations but was not observed during stimuli with only semantic errors. The P300 was observed to be elicited by surprising events related to the task but independent from language processing (Friederici, 1997). Osterhout, McKinnon, Bersick, and Corey (1996) completed a similar study that included syntactic violations in addition to sentences with physical deviations. Syntactically and physically deviant sentences elicited two distinct ERPs, which supports the proposal that the two effects are independent.

Conversely, some studies have argued that the P600 is not a language based process, but is instead a reflection of the P300 due to findings of both components elicited by syntactic errors (Coulson et al., 1998). A more recent study has defined the P300 and P600 as separate components. Frisch, Kotz, Yves von Cramon, and Friederici (2003) observed subjects with basal ganglia lesions and temporo-parietal lesions. During syntactic tasks, only those with temporo-parietal lesions demonstrated a P600 while both groups demonstrated a P300, indicating that the basal ganglia may play a role in P600 generation. The difference between groups indicated differences in energy generation, supporting the theory that the P300 and P600 are separate components.

In summary, the P600 is elicited by violations of structural preferences, syntactic violations, and difficulty with syntactic integration (Friederici, 2004). There is current debate concerning the P600 and its role in language processing; however, evidence has consistently found this positivity in relation to syntactic anomalies.

The ELAN. The ELAN is correlated with early structure construction processing with peak latency present between 100 and 200 ms. This component displays an anterior distribution, initiating as early as 250 ms and is mainly distributed over the left hemisphere. The ELAN is usually only observed with outright syntactic violations or word category violations (Canseco-Gonzalez, 2000; Frederici, 1997). More specifically, the ELAN represents interruptions in the initial phase of syntactic processing or syntactic structure building phase. The LAN usually occurs between 300 and 500 ms post stimuli. Syntactic violations involved with the LAN component include agreement information and verb-argument structure information (Friederici, 2004).

Initial ERP studies investigating the N400 documented negative waveforms with components different from the N400. The observed negativities were later attributed to syntactic processing. An early study completed by Kutas and Hillyard (1983) presented semantic and syntactic errors visually, one word at a time. As expected, a N400 component was observed for semantic errors but smaller and less consistent negativities were observed for morphosyntactic violations. The authors found these components to be distinctly different from the latency and distribution of those observed with the N400.

Another early study of syntactic processing further explored several types of syntactic errors in order to determine the sensitivity of ERP measures for syntactic processing. Utilizing rapid visual presentation both an ELAN and LAN were observed with phrase structure anomalies, while the N400 was not observed during syntactically incorrect sentences, again underlining the division between syntactic and semantic processing. Word category errors (e.g., *Max's of proof the theorem*) evoked an ELAN around 125 ms, which was followed by a left temporal parietal negativity (LAN) between 350 and 500 ms (Neville, Nicol, Barss, Forster, & Garrett, 1991). A similar study using rapid visual presentations also observed an ELAN between 100 and 200 ms; however, the ELAN was only observed when stimuli were presented with high visual contrast. With low visual contract only a LAN was observed (Gunter, Friederici, & Hahne, 1999).

The above studies considered rapid visual stimuli to elicit the ELAN and LAN. One study observed ERPs elicited from word pairs either semantically related or grammatically incorrect (e.g., *your-write*). Utilizing longer pauses between stimuli (three to six seconds) did not elicit an ELAN. Instead, the authors observed a LAN between 300 and 700 ms (Munte, Heinze, & Mangun, 1993). In addition, Munte et al. (1993) attempted to investigate whether the LAN and the N400 were a result of similar underlying processes or if they represented separate electrophysiological functions. A general similarity of negative waveforms was observed in both syntactic and semantic presentations; however, differences were observed in onset latency and distribution. These early studies also seem to report that the ELAN may only be observed when visual information is presented quickly with good visual quality (Kotz & Friederici, 2003).

The ELAN and LAN were later observed with auditory sentences. Friederici, Pfeifer, and Hahne (1993) observed an ELAN for violations of phrase structure, peaking around 180 ms with an anterior frontal distribution. The ELAN was followed by another negative wave peaking at 400 ms with a distribution similar to the ELAN. It is also noted that morphological errors evoked a LAN at about 400 ms followed by a weak positivity and a posterior lateral distribution. Based on these results, the ELAN was interpreted to reflect highly automatic processing during initial structure building.

In relation to the P600, a biphasic ERP response has been observed in the form of an elicited ELAN or LAN followed by the P600 (Canseco-Gonzalez, 2000). Kutas and Hillyard (1983) observed early negativities significantly different from those observed for semantic errors. Negativity between 200 and 300 ms was observed for incorrect verb or noun number (e.g., *All turtles have long leg* or *When the wind blows we knows*). A positive peak was also observed for the grammatical errors (Kutas & Hillyard, 1983). In addition, Coulson, King, and Kutas (1998) also observed this biphasic pattern with morphosyntactic violations.

As suggested in the above studies, the range of syntactic violations studied to elicit the ELAN and LAN are wide. Canseco-Gonzalez (2000) reported studies involving violations of word-category errors, phrase structure, verb agreement, verb subcategorization, and grammatically anomalous word-pairs. Specifically, morphosyntactic violations elicit a LAN around 400ms, which is then followed by a P600. Both components are elicited independent of stimuli modality (Kotz & Friederici, 2003).

Klunder and Kutas (1993) questioned the role of the ELAN and LAN as a component of pure syntactic processing by observing the results of ERPs and filler-gap constructions. The wh-question *Who did John hit* ___? contains the filler *who*, which is moved to the beginning of the sentence leaving a gap or vacant position at the end of the sentence. The filler and gap are dependent on each other for successful sentence interpretation. While processing the sentence, the filler word must remain in working memory until the corresponding gap is located (Canseco-Gonzalez, 2000). It was concluded that the observed LAN during filler-gap constructions was a result of holding the sentence in working memory until syntactic processing and interpretation could occur. The authors argue that previous studies observing the LAN may need to be reinterpreted as a reflection of the demands of working memory instead of a pure syntactic processing (Klunder & Kutas, 1993).

Friederici (1997) argued, based on her temporal model of language, that these observations reflect working memory in relation to syntactic structure building processes. Waters and Caplan (1996) further examined the relationship between working memory and syntactic processing. Sentences that are more difficult to process (garden path sentences) and sentences that can be processed with relative ease were compared with various serial visual presentation rates. In other words, each garden path sentence was presented word by word at different rates. A measure of the subject's working memory capacity was determined. Increased difficulty for sentence comprehension was observed as presentation rates increased; however, no significant difference was observed for sentence comprehension between working memory capacity and level of sentence processing difficulty. In other words, those considered to have low span working memory were not found to be less efficient at processing garden path sentences. Based on these results, the authors argue that syntactic processing is independent of working memory processing (Waters & Caplan, 1996). Further research utilizing other brain imaging techniques, in addition to ERPs, are required to determine the independence of working memory and syntactic processes (Friederici, 1997).

Few studies have investigated syntactic ERP components in populations with language impairments. Friederici, Hahne, and Yves von Cramon (1998) observed the effect of syntactically incorrect and semantically incorrect sentences in a patient with Wernicke's Aphasia and in a patient with Broca's Aphasia. The patient classified with Wernicke's Aphasia demonstrated an ELAN with a late positivity during syntactically incorrect stimuli and an absent N400 during semantic tasks. The patient with Broca's Aphasia did not demonstrate an ELAN;

however, the P600 and N400 were observed. A later study involved subjects with cortical lesions and lesions within the basal ganglia. Those with left frontal cortical lesions demonstrated a P600 with an absent ELAN. In contrast, those with basal ganglia lesions demonstrated all three components (Friederici, Yves von Cramon, & Kotz, 1999). These results reflect the participation of the left frontal cortex during early syntactic processing in contrast to the minor role of the basal ganglia in early syntactic processing.

In summary, the ELAN is distributed in the left anterior superior temporal gyrus and the left inferior frontal gyrus, occurring approximately 100 to 200 ms post stimuli. The ELAN is usually elicited with outright syntactic violations. Conflicting results have questioned the linguistic specificity of the ELAN, suggesting that it is a reflection of working memory demands (Waters & Caplan, 1996). According to Friederici's (1997) language processing model, the ELAN is thought to reflect interruptions in early structure building processes while the LAN suggests discrepancies in the formation of grammatical roles.

Electrophysiology of Language Development

Few studies have investigated the development of ERPs in children during language processing tasks. Most have investigated the relationship between adult and child populations, attempting to identify when children acquire adult-like processing (Atchley et al., 2006; Friederici & Hahne, 2001; Hahne et al., 2004). There is sparse research investigating ERPs related to the development of semantic and syntactic processing in younger populations.

Semantic processing. ERPs reflecting semantic processing have been observed in child and adult populations. ERP research has indicated that children rely on contextual information for semantic processing as evidenced by a larger N400 in childhood (Hahne et al., 2004).

A large proportion of developmental ERP studies have examined semantic processing exclusively. An early study completed by Holcomb, Coffey, and Neville (1992) examined developmental changes of the N400 with 130 participants between 5 and 26 years of age. Each age group listened to linguistically correct and semantically incorrect sentences. A decrease in amplitude and latency of the N400 was observed with increasing age. An N400 effect was seen for both sentence types in younger children. Hahne et al. (2004) reported similar results. Children 6 years of age also demonstrated a N400 in both correct and incorrect semantic conditions, which may be due to increase in semantic demands for younger populations. By ten years of age, the latency of the N400 was adult-like. No variance in amplitude was observed in this study, which may be due to short sentences used with this study.

Atchely et al. (2006) observed differences in distribution, amplitude, and latency of the N400 between child and adult groups. The N400 peaked approximately 75 ms earlier in the younger population when compared to the adult group. Friederici and Hahne (2001) also observed children between 6 and 9 years of age with auditory sentences. A larger amplitude and longer latency (extended to 1000 ms) were observed in children 6 years of age while older children demonstrated a more adult-like N400.

The distribution of the N400 was significantly different for younger children when compared to adults. The N400 was widely distributed in children and not restricted to posterior locations as seen in adults. Holcomb et al. (1992) hypothesized that these patterns reflected a second negative component that is unique to children. Atchely et al. (2006) described the N400 distribution in children centered over frontal areas, while adults displayed distribution over centroparietal sites. The authors suggest that the variance observed between these populations may be due to physiological immaturity. Other observations of the N400 in child populations have included greater displacement in central, parietal, and frontal locations (Friederici & Hahne, 2001).

Generally, the N400 component in children tends to have greater amplitude, is more delayed, and more widely distributed when compared to a N400 produced in adult populations (Atchley et al., 2006). Variance in the N400 component reflects continuous semantic processing development throughout childhood and early adulthood (Holcomb et al., 1992).

Syntactic processing. There have been few studies investigating the electrophysiological development of syntactic language processing in children. Recently, an increasing amount of research has addressed the physiology of language development. This trend may be due to implications that this research has for identification and treatment of those with language disorders.

Atchley et al. (2006) completed a comparison study involving the P600 in fourteen children between 8 to 13 years of age and fifteen adults. This study differed from previous developmental studies due to selection of type of syntactic violation. Morphosyntactic errors were utilized based on developmental behavioral studies. Specifically, the authors utilized sentences with syntactic errors that children 8-10 years of age could judge with adult-like accuracy. In addition, judgment of these errors was determined to be independent of the child’s semantic knowledge. No significant differences in distribution, amplitude, and latency of the P600 were observed between child and adult groups. In contrast, Friederici and Hahne (2001) observed ERPs during auditory sentences with structural discrepancies for 32 children from 6 to 9 years of age. A significantly larger P600 was observed when compared to adult ERP responses. The P600 was initiated around 750 ms and extended up to 1500 ms post stimuli for children 6 to 9 years of age.

Adult-like biphasic syntactic processing is not established until early adulthood. Hahne, Eckstein, and Friederici (2004) investigated syntactically incorrect sentences in children from 6 to 13 years of age. A late positivity around 1250 to 1500 ms was observed in children 6 years of age while an adult-like P600 was observed in children 7 to 12 years of age. The P600 effect observed in younger groups was smaller in amplitude and presented with a delayed latency. In addition, an ELAN was observed only with children 13 years of age. Based on observations of the P600 and ELAN, younger age groups demonstrate increased syntactic demands for language processing; however, these observations may be due to complexity of the stimuli.

Friederici and Hahne (2001) observed an ELAN in children older than 8 years of age, peaking between 150 and 350 ms. In addition, a P600 was also observed around 750 ms and continued through approximately1500 ms. Unlike adults, the P600 was displaced to the right hemisphere indicating that the first stage of syntactic structure building is adult-like by 8 years of age; however, more time is required for secondary syntactic processing (structure repair.) Children between 7 and 10 years of age demonstrated a later ELAN peaking around 400 ms and extended through 1000 ms.

More recently, Clahsen, Luck, and Hahne (2007) observed a broad negativity with an absent positivity in younger children (about 6 years of age) with morphological errors. The authors hypothesized that younger children process morphological errors as semantic violations. Hahne et al. (2004) also observed a widely distributed negativity between 100 and 300 ms for both syntactically correct and incorrect conditions with this age group. The authors described this negativity as a combination of both the ELAN and N400. Palolahti, Leino, Jokela, Kopra, and Paavilainen (2005) identified a broad negativity for sentences simultaneously containing semantic and syntactic errors in adult populations, indicating an interaction between syntactic and semantic processing.

Overall, children demonstrate syntactically related ERP components similar to adults. The P600 tends to display greater amplitude and more delayed latency when compared to the P600 observed in adult populations (Atchley et al. 2006). The ELAN has been observed as early as 8 years of age and in conjunction with the N400 in younger populations.

Present Study

The purpose of the current study was to provide a more complete and thorough description of the development of language processing in children 5 to 12 years of age. An examination was completed of the ELAN in response to linguistically correct, syntactically incorrect, and semantically incorrect stimuli. In addition, differences observed between age groups and stimuli presentation condition were addressed.

Stimuli sentences were presented in monaural left, monaural right, and binaurally, in order to investigate differences between ear conditions. The presence of cerebral dominance in normal listeners in demanding auditory tasks, such as dichotic listening tasks, is known as the REA phenomenon (Bellis, 2003). The left hemisphere is usually considered the language dominate hemisphere. Due to contralateral pathways, auditory linguistic information from the left ear must cross from the right hemisphere, through the corpus callosum to the left hemisphere for language processing. Auditory linguistic information from the right ear is processed more efficiently due to absence of interhemispheric processing. In addition, the more complex the linguistic stimuli the more pronounced the REA effect. Specifically, the REA is more distinct in children than in adults with observable behavioral effects decreasing with age (Bellis, 2003). Previous research of the REA consists of only behavioral observations. The current study investigated electrophysiological observations of possible differences between linguistic stimuli type and ear conditions in relation to the ELAN.

Method

Participants

The participants consisted of typically 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). Each group consisted of six participants. A total of 30 participants were included in the study. Each participant met the following criteria:

1. No 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.
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 an intellectual disability 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 3000 ohms. Eye movements were monitored by placing electrodes on the outer cantha on 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 participants' responses would trigger the presentation of the following 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 when all electronic equipment was operating.

A female native English speaker produced the sentences. 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 talker'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, taking care to not adjust above peak recording levels. Two tokens were digitally edited to eliminate noise artifacts 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 intensity level of each sentence was determined to be perceptually equivalent by three judges.

Stimuli

Sentences were presented to the participants in three conditions: (a) monaurally to the right ear, (b) monaurally to the left ear, and (c) binaurally. The sentences were presented through insert phones (ER3-A) at 65 dB HL in a sound-attenuated chamber using the GSI-61 audiometer.

Sentences were taken from Houghton Mifflin English Textbooks and were determined to be at the comprehension level of a typically developing child 5 years of age (Houghton Mifflin English Textbook, 1990; Houghton Mifflin English Textbook, 1995). One hundred and two sentences were used to create the stimuli. Three versions of each sentence were used, totaling 306 sentences. One version of the sentences was correct, one version contained a semantic error, and the third version contained a syntactic error. Syntactic errors included one of the following: (a) a plural noun syntactic error, (b) a past tense *–ed* verb syntactic error, (c) a past tense irregular verb syntactic error, or (d) a third person verb syntactic error. These syntactic forms are used appropriately by typically developing children 5 years of age (Brown, 1973). The errors were relative to 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. Three randomized versions from the 306 sentences were constructed to prevent bias. Each version contained approximately 50 sentences with syntactic errors, 50 sentences with semantic errors, and 50 correct sentences.

Each participant listened to a different version of the sentences in each of the three ear conditions. The presentation order of these versions and of ear condition was randomized between participants. Each participant listened to a total of 450 sentences. 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 or *good* sentence and a frowny-face was attached to the button for an incorrect or *bad* 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 C for the complete set):

No Syntactic Errors

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

Four Examples of Semantic Error

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

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. 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 ELAN was defined as a prominent negative peak within the latency range of 150 to 300 ms at the Fz 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.

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. Visual inspection determined that any significant ERPs did not occur after 800 ms. Descriptive statistics, including means and standard deviations, were determined for the ELAN latency and amplitude for each age group in all ear and sentence conditions. Grand average waveforms were created for each group in all ear and sentence conditions. Finally, the percentage of participants who demonstrated an identifiable ELAN was determined for each age group.

Results

The purpose of the current study was to provide a more detailed account of the development of syntactic processing. Specifically, differences in latency and amplitude of the ELAN in relation to language development of children 5;2 to 12;5 years of age were analyzed. Within each age group, differences were observed between ear conditions and stimuli type. Additionally, developmental differences were observed between each age group, reflecting findings from previous research.

Descriptive Statistics for the ELAN

Table 1 presents the descriptive statistics for the youngest age group, 5;2 to 6;5 years of age. Mean latencies for left ear stimulation for correct, syntactically incorrect, and semantically incorrect are similar with values extending between 303.80 ms and 314.10 ms. In the linguistically correct condition, right ear mean latency was 284.60 ms while left ear mean latency was 314.10 ms. The difference between these two values is more than one standard deviation. This same pattern is noted in both the syntactically incorrect and semantically incorrect conditions. In the syntactically incorrect condition, the mean latency for the left ear was 303.80 ms and the mean latency for the right ear was 272.85 ms. In the semantically incorrect condition, the mean latency of the left ear was 311.40 ms and the mean latency of the right ear was 247.64 ms. In general, the right ear mean latency values are consistently lower than left ear mean latency values across all sentence conditions.

Table 2 presents the descriptive statistics for 6;8 to 7;11 years of age, Group 2. Mean latencies for the left ear in the correct (299.67 ms), syntactic error (299.84 ms), and semantic error (213.80 ms) conditions are similar and range within 14 ms of each other.

Table 1

Descriptive Statistics for the ELAN in Participants 5;2 to 6;5 Years of Age (Group 1)

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=6)				
Latency (ms)	314.10	55.69	245.00	399.00
Amplitude (µV)	-5.16	6.40	-15.70	3.08
Right Ear (n=4)				
Latency (ms)	284.60	92.21	219.40	349.80
Amplitude (µV)	8.99	10.64	1.47	16.52
Binaural Ear (n=3)				
Latency (ms)	341.32	86.06	221.60	439.80
Amplitude (µV)	-3.41	6.75	-14.15	3.44
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	303.80	78.89	251.40	418.20
Amplitude (µV)	-3.80	5.34	-9.12	3.21
Right Ear (n=4)				
Latency (ms)	272.85	60.57	217.20	358.40
Amplitude (µV)	-6.29	13.23	-18.23	11.22
Binaural Ear (n=4)				
Latency (ms)	302.85	106.95	225.80	461.20
Amplitude (µV)	-3.57	4.41	-10.05	-0.16
Semantic Error				
Left Ear (n=5)				
Latency (ms)	311.40	81.94	213.00	403.40
Amplitude (µV)	-7.09	5.59	-14.63	-2.17
Right Ear (n=5)				
Latency (ms)	247.64	47.14	204.40	305.00
Amplitude (µV)	-7.12	8.18	-19.08	00.95
Binaural Ear (n=3)				
Latency (ms)	246.47	44.01	200.20	287.80
Amplitude (µV)	-5.53	2.50	-8.31	-3.49

Table 2

Descriptive Statistics for the ELAN in Participants 6;8 to 7;11 Years of Age (Group 2)

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=3)				
Latency (ms)	299.67	52.89	238.60	330.60
Amplitude (µV)	-0.55	6.30	-7.55	4.68
Right Ear (n=3)				
Latency (ms)	282.07	20.53	260.00	300.60
Amplitude (µV)	2.98	5.47	-0.78	9.26
Binaural Ear (n=4)				
Latency (ms)	235.90	34.97	215.00	287.80
Amplitude (µV)	-3.59	8.19	-11.88	7.21
Syntactic Error				
Left Ear (n=5)				
Latency (ms)	299.84	77.97	213.00	384.20
Amplitude (µV)	-4.84	6.84	-14.29	2.73
Right Ear (n=5)				
Latency (ms)	262.88	34.44	225.80	302.80
Amplitude (µV)	-5.39	4.38	-9.51	1.84
Binaural Ear (n=6)				
Latency (ms)	325.73	66.31	249.40	407.60
Amplitude (µV)	-5.54	2.67	-10.49	-3.33
Semantic Error				
Left Ear (n=3)				
Latency (ms)	312.80	36.48	275.00	347.80
Amplitude (µV)	-8.30	7.34	-14.51	-0.20
Right Ear (n=2)				
Latency (ms)	237.60	65.05	191.60	283.60
Amplitude (µV)	-0.91	11.24	-8.86	7.04
Binaural Ear (n=5)				
Latency (ms)	277.96	62.15	195.80	352.00
Amplitude (µV)	-10.41	5.13	-14.94	-1.76

Mean latencies for right ear simulation in correct (282.07 ms), syntactic error (262.88 ms), and semantic error (237.60 ms) conditions are consistently less than mean latency values for left ear stimulation for all sentence presentation types.

In the syntactically incorrect condition the left ear mean latency was 299.84 ms, right ear mean latency was 262.88 ms, and the binaural mean latency was 325.73 ms. Mean latency for the right ear stimulation is lower than the mean latencies for left and binaural stimulation, with a difference greater than one standard deviation. Mean latencies for binaural stimulation in the correct condition was 235.90 ms and 325.73 ms in the syntactically incorrect condition. The difference between the mean latencies for binaural stimulation in the correct and the syntactically incorrect conditions is greater than one standard deviation

Table 3 displays the descriptive statistics for participants between 8;3 and 9;3 years of age, Group 3. Mean latencies for the left ear (280.35 ms) and right ear (286.20 ms) stimulation in the correct condition are similar, being less than 6 ms apart. The mean latency for binaural stimulation for the linguistically correct presentation was 246.47 ms. The difference between left and right ear stimulation compared to the binaural presentation in the correct condition is greater than one standard deviation.

Mean latencies for left ear stimulation in the correct condition (280.35 ms) and semantically incorrect condition (291.40 ms) are similar being less than 12 ms apart. Mean latencies for binaural simulation in the correct condition (246.47 ms) and in the syntactically incorrect condition (267.76 ms) are greater than one standard deviation. Additionally, mean latencies for the right ear in the correct condition (286.20 ms) and the syntactically incorrect condition (362.28 ms) are greater than one standard deviation.

Table 3

Descriptive Statistics for the ELAN in Participants 8;3 to 9;3 Years of Age (Group 3)

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=4)				
Latency (ms)	280.35	47.73	217.20	324.20
Amplitude (µV)	-8.15	8.14	-16.17	2.79
Right Ear (n=4)				
Latency (ms)	286.20	31.30	257.80	322.00
Amplitude (µV)	-6.52	5.31	-11.56	-1.58
Binaural Ear (n=3)				
Latency (ms)	246.47	13.04	232.20	257.80
Amplitude (µV)	-7.79	0.92	-8.59	-6.78
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	251.40	50.01	208.60	315.60
Amplitude (µV)	-11.10	8.45	-22.41	-3.27
Right Ear (n=5)				
Latency (ms)	362.28	76.43	266.40	439.80
Amplitude (µV)	-3.99	4.23	-10.09	0.99
Binaural Ear (n=5)				
Latency (ms)	267.76	55.71	200.20	352.00
Amplitude (µV)	-5.25	4.83	-9.66	3.05
Semantic Error				
Left Ear (n=3)				
Latency (ms)	291.40	22.29	266.40	309.20
Amplitude (µV)	-5.46	3.79	-8.82	-1.35
Right Ear (n=1)				
Latency (ms)	221.60		221.60	221.60
Amplitude (µV)	-0.80		-0.80	-0.80
Binaural Ear (n=1)				
Latency (ms)	260.00		260.00	260.00
Amplitude (µV)	-11.05		-11.05	-11.05

Table 4 displays the descriptive statistics for children between 9;6 and 10;6 years of age, Group 4. Mean latencies for left ear presentation (287.85 ms) and binaural presentation (282.87 ms) in the linguistically correct condition are similar. The difference between these two mean latencies is less than 5 ms. Additionally, the difference between the mean latencies for the right ear presentation (271.25 ms) and binaural presentation (282.87 ms) in the linguistically correct sentence condition is less than 12 ms. The difference between the mean latency for the right ear presentation in the correct condition (271.25 ms) and the right ear presentation in the syntactically incorrect condition (346.65 ms) is greater than one standard deviation. The difference between the mean latency for the binaural presentation in the correct condition (282.87 ms) and the syntactically incorrect condition (330.30 ms) is also greater than one standard deviation. Finally, the mean latency for binaural presentation in the syntactically incorrect condition (330.30 ms) and the semantically incorrect condition (241.80) is greater than one standard deviation.

Table 5 presents the descriptive statistics for 11;0 to 12;5 years of age, the oldest age group. In the syntactically incorrect condition, the mean latency for the left ear presentation (263.85 ms) is similar to the mean latency for the right ear presentation (259.60 ms), being only 5 ms apart. Additionally, mean latencies for left ear stimulation (263.85 ms) and binaural stimulation (279.10 ms) are 16 ms apart in the syntactically incorrect condition. The difference between the mean latencies for the left ear presentations in the linguistically correct condition (232.93 ms) and the syntactically incorrect condition (263.85 ms) are greater than one standard deviation.

Table 4

Descriptive Statistics for the ELAN in Participants 9;6 to 10;6 Years of Age (Group 4)

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=4)				
Latency (ms)	287.85	57.89	232.20	369.20
Amplitude (µV)	-5.71	12.34	-21.43	6.38
Right Ear (n=4)				
Latency (ms)	271.25	20.91	251.40	294.20
Amplitude (µV)	-6.96	1.67	-8.70	-5.47
Binaural Ear (n=3)				
Latency (ms)	282.87	38.87	238.60	311.40
Amplitude (µV)	-4.01	3.49	-7.84	-1.01
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	250.40	62.16	206.60	341.40
Amplitude (µV)	-5.45	2.29	-8.84	-3.93
Right Ear (n=4)				
Latency (ms)	346.65	73.90	247.20	422.60
Amplitude (µV)	-1.41	6.14	-5.41	7.74
Binaural Ear (n=4)				
Latency (ms)	330.30	71.83	265.00	429.00
Amplitude (µV)	-5.17	2.99	-7.13	-0.82
Semantic Error				
Left Ear (n=1)				
Latency (ms)	281.40		281.40	281.40
Amplitude (µV)	2.96		2.96	2.96
Right Ear (n=3)				
Latency (ms)	282.60	71.62	233.60	364.80
Amplitude (µV)	-9.06	4.53	-14.29	-6.24
Binaural Ear (n=2)				
Latency (ms)	241.80	16.69	230.00	253.60
Amplitude (µV)	-4.58	2.88	-6.62	-2.54

Table 5

Descriptive Statistics for the ELAN in Participants 11;0 to 12;5 Years of Age (Group 5)

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=3)				
Latency (ms)	232.93	6.52	225.80	238.60
Amplitude (µV)	-5.44	10.33	-17.16	2.36
Right Ear (n=2)				
Latency (ms)	270.40	79.20	214.40	326.40
Amplitude (µV)	-5.20	7.78	-10.70	0.30
Binaural Ear (n=1)				
Latency (ms)	292.20		292.20	292.20
Amplitude (µV)	-0.95		-0.95	-0.95
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	263.85	46.30	223.80	320.00
Amplitude (µV)	-3.93	4.66	-7.54	2.52
Right Ear (n=5)				
Latency (ms)	259.60	35.58	223.60	309.20
Amplitude (µV)	-5.07	4.54	-12.02	0.31
Binaural Ear (n=4)				
Latency (ms)	279.10	43.30	222.80	320.00
Amplitude (µV)	-4.00	1.26	-5.72	-3.03
Semantic Error				
Left Ear (n=1)				
Latency (ms)	307.00		307.00	307.00
Amplitude (µV)	-0.75		-0.75	-0.75
Right Ear (n=2)				
Latency (ms)	226.90	10.61	219.40	234.40
Amplitude (µV)	-6.50	5.68	-10.51	-2.48
Binaural Ear (n=3)				
Latency (ms)	334.20	93.79	225.80	392.60
Amplitude (µV)	-11.63	10.19	-23.39	-5.44

The mean latency for the right ear stimulation for the syntactically incorrect condition was 259. 60 ms and the mean latency for the right ear stimulation for the semantically incorrect condition was 226.90 ms. The difference between these two mean latencies is greater than one standard deviation. Finally, the difference in the mean latencies for binaural presentations in the syntactically incorrect condition (279.10 ms) and the semantically incorrect condition (334.20 ms) is greater than one standard deviation.

Developmental ERP Waveforms of the ELAN

Figure 1 presents the ERP waveforms for the ELAN. For each age group, the waveforms for all three linguistic conditions (linguistically correct, syntactically incorrect, and semantically incorrect) are shown. Each linguistic condition displays the waveforms for right ear, left ear, and binaural presentations. Arrows marking the ELAN indicate the peak amplitude of the ERP.

For Group 1, the ELAN waveform was present in the left and right ear for the linguistically correct condition. For both syntactically and semantically incorrect conditions, the ELAN was present for right ear and binaural presentations and was absent for the left ear presentation. In Group 2 the ELAN waveform was present in all conditions. For linguistically correct and syntactically incorrect conditions, the ELAN was present for both right ear and binaural presentations. The ELAN was present for all presentation types in the semantically incorrect condition. In Group 3, the ELAN was present only in linguistically incorrect conditions. Specifically, the ELAN was present for left and binaural presentations for the syntactically incorrect condition and it was present for right and left ear presentations for the semantically incorrect condition. In Group 4, the ELAN was present for all stimulation types in the correct condition.

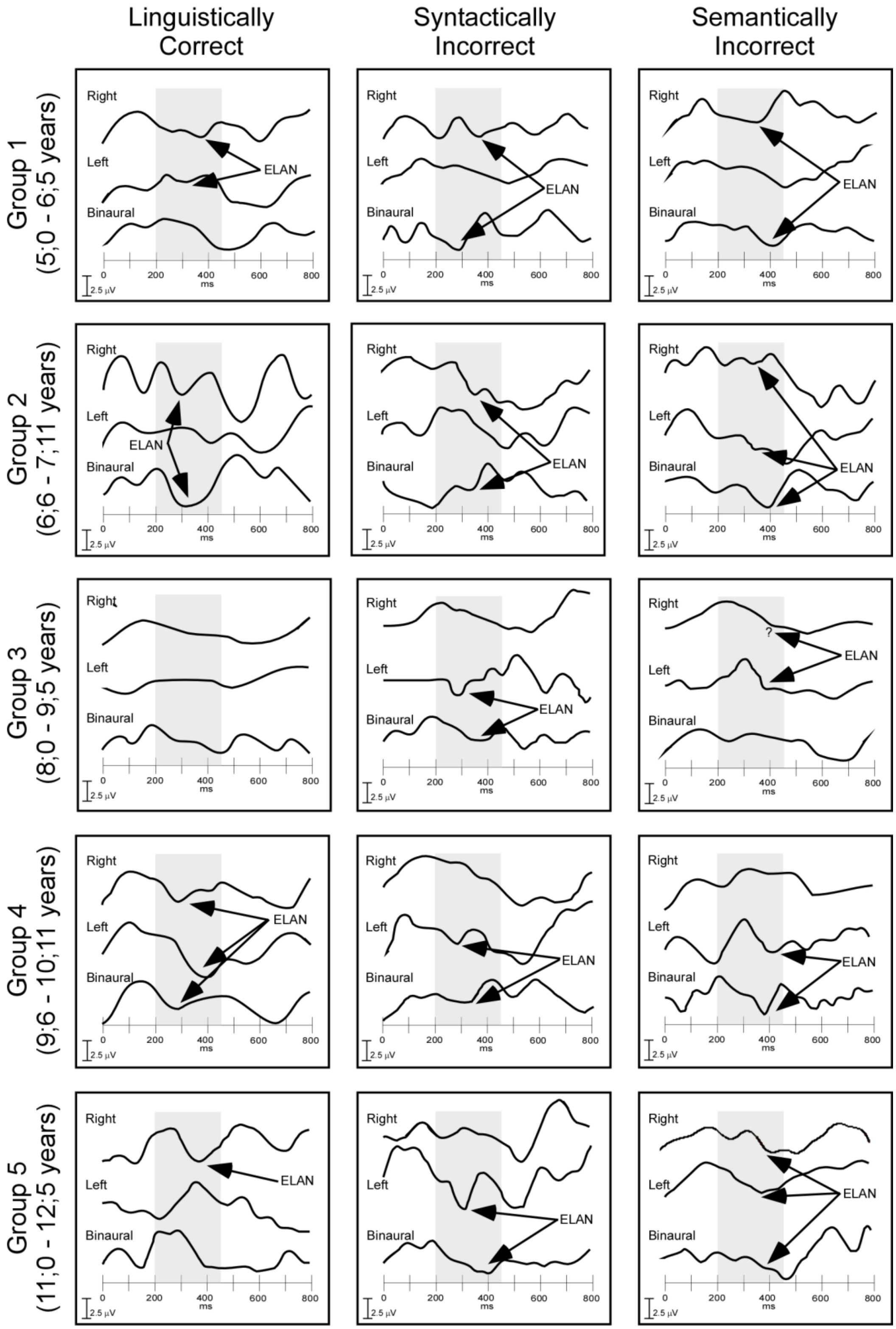

Figure 1. *Grand average ELANs for each age group across all conditions.*

In syntactically and semantically incorrect conditions, the ELAN was only seen in left and binaural stimulation. In Group 5, the ELAN was observed for the right ear stimulation in the linguistically correct condition. Additionally, the ELAN was present in left and binaural presentations for the syntactically incorrect condition and was present for all stimulation types in the semantically incorrect condition.

Percent of an Identifiable ELAN Component

Table 6 shows the percent of identifiable ELAN waveforms for the three stimulus conditions across each age group. For the correct condition, there was a reduction in the percent of identifiable components with the lowest percentage for 11;0 to 12;5 years of age. Similarly, a more dramatic percentage decrease was observed for the semantically incorrect condition, starting at 83.3% for children 5;2 to 6;5 years of age and decreasing to 25.3% for children 11;0 to 12;5 years of age. There does not appear to be any consistency for the presence of the ELAN in the syntactically incorrect condition, with the highest percentage occurring in age Group 2 (83.3%) and the lowest percentage for Groups 1 and 2 (66.7%).

Table 6

Percentage Identifiable ELAN Component for the Three Stimulus Conditions Across Age Groups

Age (years;months)	Correct	Syntactic Error	Semantic Error
5;2 to 6;5	66.7	66.7	83.3
6;8 to 7;11	50.0	83.3	41.7
8;3 to 9;3	66.7	75.0	33.3
9;6 to 10;6	66.7	66.7	33.3
11;1 to 12;6	41.7	75.0	25.3

Discussion

Data from the current study indicated that children between 5;2 year and 12;0 years are developing the ability to process and identify syntactic anomalies with adult-like syntactic processing apparent after 12 years of age. The following section compares results from the current study with previous research, including findings related to the REA phenomenon.

The mean latencies for binaural stimulation from Tables 1 through 3 are similar to results reported by Friederici and Hahne (2001) and Hahne et al. (2004). In Figure 1, the ELAN waveform is present in all linguistic conditions in the first two age groups, indicating that these groups were unable to correctly discriminate between linguistically correct and incorrect stimuli. These findings also indicate high processing expenses for language comprehension, even for linguistically correct sentences (Hahne et al., 2004).

The amplitude of the ERP is a marker for linguistic processing demands. Smaller amplitudes indicate lower processing demands while larger amplitudes suggest higher processing demands. The highest mean amplitude for binaural stimulation in the syntactically incorrect condition was -5.54 µV for Group 2, decreasing to -5.24 µV for Group 3, and -5.17 µV for Group 4. The smallest mean amplitude for syntactically incorrect stimuli with binaural stimulation occurred in Group 1 (-3.57 µV) and Group 5 (-4.00 µV). These results are consistent with findings from Friederici and Hahne (2001), who identified decreasing ELAN amplitudes with increasing age. Smaller amplitude values suggest fewer processing demands for language comprehension. Smaller mean amplitudes observed in Group 1 may demonstrate lower levels of linguistic comprehension and should be addressed in further study.

In the current study, Group 3 and Group 5 demonstrated the earliest and most adult-like mean latencies for binaural stimulation with syntactically incorrect stimuli. Group 3 did not demonstrate an ELAN waveform in the linguistically correct condition, indicating that these children recognized a linguistic error but were unable to distinguish between semantic and syntactic errors. Results from Friederici and Hahne (2001) indicate that an ELAN-like component is evident by 7 years for syntactically incorrect stimuli, however, latency and amplitude values are not adult-like. These results may indicate that adult-like syntactic processing for subtle syntactic errors begins to develop as early as 7 years, with mature processing after 12 years of age. Supporting behavioral child language studies indicate that the ability to judge the correctness of linguistic stimuli occurs after the child correctly produces the syntactic form (De Villiers & De Villiers, 1978).

Similar to younger age groups, in Group 4 and Group 5 the ELAN is identified for all linguistic conditions. Figure 2 from Tree (2009) shows P600 recordings from the same group of participants as in the current study (the data was obtained simultaneously). As discussed, the P600 component is an indicator of syntactic processing (Friederici, 2004). The P600 component is apparent in the syntactically incorrect conditions for all age Groups. Additionally, the P600 is absent for semantically incorrect conditions in Group 4 and 5 indicating that older participants are able to distinguish between syntactic and semantic errors. These observations demonstrate that children between 9;6 and 12;5 years of age perceive syntactic errors even though the ELAN component is observed for all three conditions during this age span.

As discussed, Palolahti et al. (2005) identified a negative component in the left hemisphere in adults with latencies similar to both the ELAN and the N400 when processing sentences with combined morphosyntactic and semantic violations. The authors suggest that this negativity is a reflection of the interaction between syntactic and semantic processing.

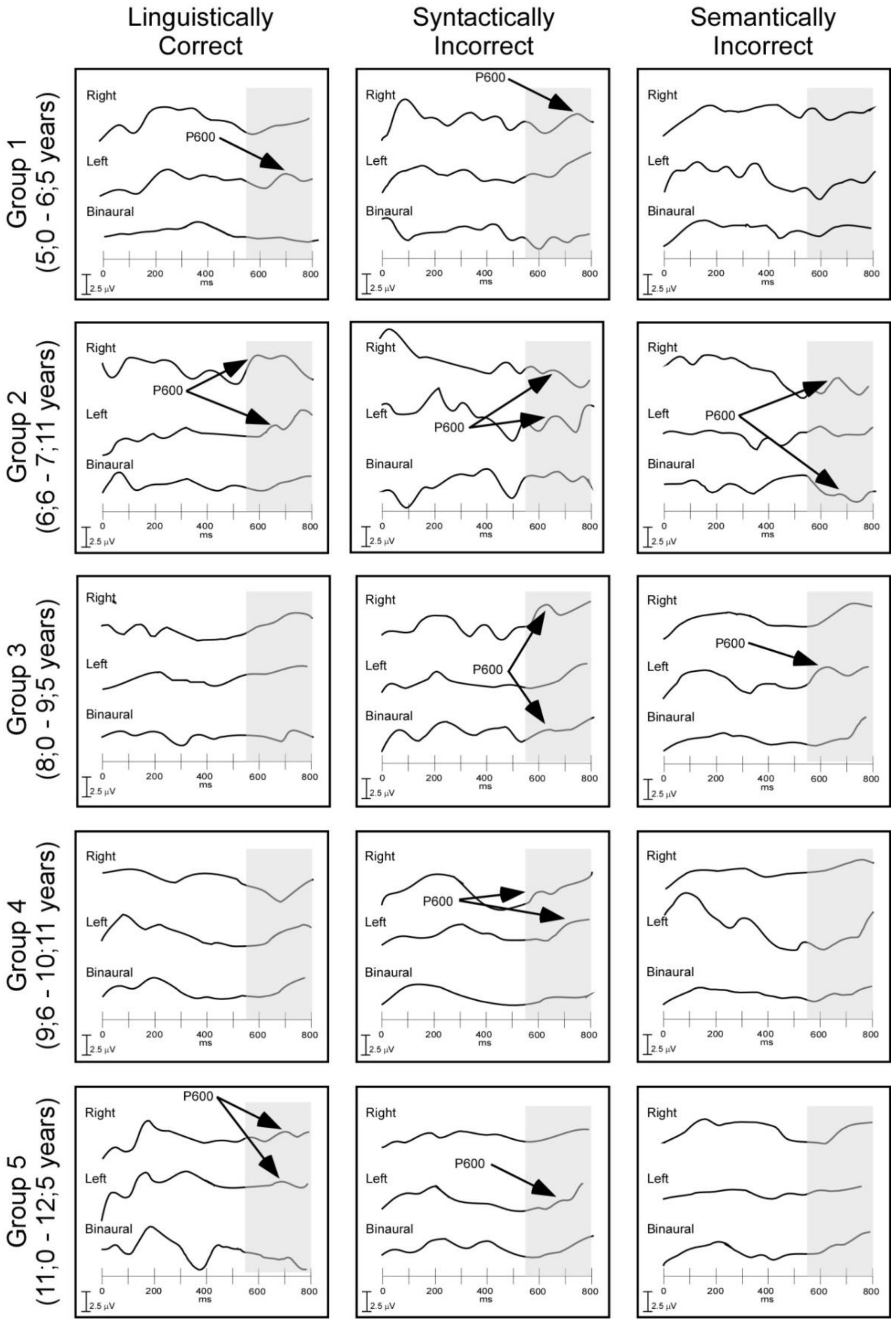

Figure 2. Developmental waveforms of the P600 for all conditions from Tree (2009) with permission.

The current study identified a negative waveform for all linguistic conditions in older age groups. As described, the presence of the P600 establishes that children in Groups 4 and 5 can discriminate between syntactic and semantic errors.

Supported by previous research from Palolahti et al. (2005), the similarities between Groups 4 and 5 may be an indication of the interaction between semantic and syntactic processing for all linguistic types due to language development and sentence stimuli complexity. These conclusions are in disagreement with Friederici's three phase model of language comprehension, which describes the ELAN and N400 as independent processes with syntactic and semantic integration reflected only by the P600 component. The evidence from the current study indicate a need for further research to determine a distinction between ERP components for syntactic and semantic processing as linguistic complexity increases with increasing age.

Figure 1 demonstrates several inconsistencies between each ear condition for all linguistic stimuli types. Previous research concerning the REA indicates that there are no behavioral differences during processing of monaural linguistic stimuli (Bellis, 2003). For syntactically incorrect stimuli the ELAN was present in right and binaural conditions but not in the left ear condition for younger participants (Groups 1 to 3), while the waveform was present in left and binaural conditions and not for right ear conditions in older ages (Groups 4 and 5). As described, the ELAN waveform was present for syntactically incorrect stimuli in all age groups; however, it was not present in all ear conditions. These differences in ear conditions may demonstrate the brain's ability to recognize certain errors at earlier ages, depending on the development of neural linguistic connections. This observation warrants further exploration.

As illustrated in Table 6, there is variability in the presence of the ELAN between linguistic conditions. This is consistent with previous research by Hahne et al. (2004) who identified an adult-like ELAN component for syntactically incorrect stimuli after 13 years of age. It is evident that the presence of the ELAN decreases with increasing age for both semantically incorrect and correct linguistic stimuli. Specifically, there was a decrease in 25% of an identifiable ELAN component for correct sentences between the youngest and oldest age groups. A more dramatic decrease of 53.3% of an identifiable ELAN occurred for semantically incorrect sentences between Group 1 and Group 5. Since the ELAN component is thought to be associated with syntactic errors and not semantic errors, this decrease may indicate that children are developing the ability to differentiate between semantic and syntactic errors as early as 6;8 years of age; however, this strong differentiation is not observed between linguistically correct and syntactically incorrect sentences. The largest difference for percent of identifiable ELAN component between linguistic conditions is found in the oldest age group. In summary, the results indicate that younger children have not acquired the linguistic ability to differentiate between syntactic and semantic errors. Additionally, the ELAN was less identifiable in correct and semantically incorrect conditions for the oldest age group due to higher levels of linguistic processing abilities, allowing for the capability to distinguish between syntactic and semantic errors.

Comparison of ear conditions and mean latencies revealed consistent differences between Groups 1 and 2 and older age Groups. For Group 1, right ear presentations had the shortest mean latencies in both correct and syntactically incorrect conditions. Similarly, right ear mean latencies were consistently earlier than left ear mean latencies in all conditions for Group 2. Trends or differences in mean latencies in Groups 3-5 for each ear condition were not apparent. Overall, right ear mean latencies for Groups 1-5 occurred earlier than mean latencies for left or binaural stimulation 53% of the time (8/15); indicating the presence of the REA phenomenon in children up to 7;11 years of age.

As discussed, syntactic and semantic information is typically processed in the left, language dominant hemisphere. Due to contralateral pathways in the brain, auditory linguistic information from the left ear generally must cross from the right hemisphere, through the corpus callosum to language processing regions within the left hemisphere. Consequently, auditory linguistic information from the right ear is processed more efficiently due to the absence of interhemispheric left-to-right transference of information. Behaviorally, the REA is more distinct in very young children than in adults, with observable effects decreasing with age (Bellis, 2003). Results from the present study indicate that the REA phenomenon is likely present in children up to 7;11 years of age. The presence of the REA in the current study may reflect increased syntactic processing demands due to more complex and subtle syntactic errors. The difference between behavioral and electrophysicological data for processing linguistic stimuli with increasing complexity warrants further investigation.

Conclusion

The results of the current study are similar to those of Hahne et al. (2004) in that younger children demonstrate ELAN components with later latencies and higher amplitudes when compared to adults; however, these differences are slight. Results from Friederici and Hahne (2001) suggest that children may begin to acquire adult-like syntactic processing by 8 years of age. The current study suggests that these processes may begin to develop around 8 years of age; however, the ability to differentiate between linguistically correct, semantically incorrect, and syntactically incorrect is not established until 11 or 12 years of age. Therefore, younger ages may be able to process at a low level of syntactic complexity but more adult-like processing of morphological errors at the sentence level is not established until later years, after 12 years of age. Based on these findings, further exploration into the development of each ERP language component, including variance in the complexity of linguistic stimuli, over a broad age span is warranted.

Results further indicate that the ear condition takes part in the processing of syntactic information. The purpose of the current study was to investigate the relationship between linguistic ERPs and different ear conditions. Findings from this study did not reflect past behavioral data concerning the REA, suggesting that the REA effect may exist in older children. Since behavioral studies utilize lower levels of linguistic stimuli (i.e. dichotic digits), while the current study used higher levels of linguistic information, placing greater demands on the neural system, the current findings indicate that the REA varies as a function of processing demands and not necessarily the development of neural pathways, *per se*. The relationship between electrophysiological processing and behavioral ear conditions needs further and more in-depth exploration in an attempt to separate the contributions of the crossed neural pathways and the demands of linguistic processing on REA.

Contrasting data was noted in regards to the mean latency of the ELAN across age groups. Friederici and Hahne (2001) identified an adult-like ELAN component by 8;3 years of age, while Hahne et al. (2004) did not identify an adult-like ELAN component until 13 years of age. The current study discovered a difference in ELAN waveforms between linguistic conditions for Group 3 (age 8;0 to 9;5 years); however, the differences between percentage of identifiable ELAN waveforms were most apparent in the oldest age group. These results indicate that children are more able to discriminate between correct, syntactically incorrect, and semantically incorrect stimuli by 12 years of age, which is more consistent with known neurophysiological development of higher cognitive processing (Buchwald & Guthrie, 1994; McPherson, 1996). Furthermore, various factors may affect these contrasting results, including population sample, regional area, or limited research into the development of the ELAN. Further research of the development of the ELAN component in regards to various linguistic errors and ear condition types would provide greater insight into the rapid development of language processing in children. Additionally, research including young children less than 5 years of age and children over 13 years of age may allow a better comparison of the ELAN as it develops.

The usefulness of continued electrophysiological research is apparent when clinical application is considered (Friederici, 1997). An ERP measurement does not require a conscious response to stimuli; therefore it presents potential for the diagnosis of language disorders, especially in young children with diminished verbal ability. For example, Byrne et al. (1999) recorded ERPs from typical developing children in conjunction with a standardized receptive vocabulary test. Based on their results, the authors reported that certain ERP components could be tools for determining receptive vocabulary ability. By increasing the understanding of linguistic development associated with differences in latency, amplitude, and distribution of

ERPs will assist in further understanding of neurological language development and language developmental disorders.

References

Atchley, R. A., Rice, M. L., Betz, S. K., Kwasny, K. M., Sereno, J. A., & Jongman, A. (2006). A comparison of semantic and syntactic event related potentials generated by children and adults. *Brain and Language, 99*(3), 236-246. doi:10.1016/j.bandl.2005.08.005

Bellis, T. J. (2003). *Assessment and management of central auditory processing disorders in the education setting: From science to practice* (2nd ed.). Clifton Park, NY: Delmar Learning.

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

Buchwald, J.S., Guthrie D., Schwafel, J., Erwin, R. J., & Vanlancker, D. (1994). Influence of language structure on brain behavior development. *Brain and Language,* 46(4), 607-619. doi:10.1006/brln.1994.1033

Caramazza, A., & Zurif, E. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: evidence from aphasia. *Brain and Language, 3,* 572-582. doi:10.1016/0093-934x7690048-1

Canseco-Gonzalez, E. (2000). Using the recording of event-related brain potentials in the study of sentence processing. In Y. Grodzinsky, L. P. Shapiro & D. Swinney (Eds.), *Foundations of neuropsychology: A series of textbooks, monographs, and treatises* (pp. 229-266). San Diego: Academic Press.

Clahsen, H., Luck, M., & Hahne, A. (2007). How children process over-regularizations: Evidence from event-related brain potentials. *Journal of Child Language*, *34*, 601-622. doi:10.1017/s0305000907008082

Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, *13*(1), 21-58. doi:10.1080/016909698386582

De Villiers, J. G., & De Villiers, P. A. (1978). *Language Acquisition*. Cambridge, MA: Harvard University Press.

Friederici, A. D. (1997). Neurophysiological aspects of language processing. *Clinical Neuroscience, 4*(2), 64-72. Retrieved from http://apps.isiknowledge.com/

Friederici, A. D., Hahne, A., & Yves von Cramon, D. (1998). First pass versus second pass parsing processes in a Wernicke's and a Broca's Aphasic: Electrophysiological evidence for a double dissociation. *Brain and Language, 62*, 311-341. doi:10.1006/brln.1997.1906

Friederici, A. D., & Mecklinger, A. (1996). Syntactic parsing as revealed by brain responses: First-pass and second-pass parsing processes. *Journal of Psycholinguistic Research, 25*(1), 157-176. doi:10.1007/bf01708424

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research, 1*, 183-192. doi:10.1016/0926-64109390026-2

Friederici, A. D., Yves von Cramon, D., & Kotz, S. A. (1999). Language related brain potentials in patients with cortical and subcortical left hemisphere lesions. *Brain, 122*, 1033-1047. Retrieved from http://brain.oxfordjournals.org/

Friederici, A. D., & Hahne, A. (2001). Developmental patterns of brain activity reflecting semantic and syntactic processes. In J. Weissenborn & B. Houle (Eds.), *Approches to bootstrapping: Phonological, lexical, syntactic, and neurophysiologcal aspects of early language acquistion* (pp. 231-246). Amsterdam/Philadelphia: John Benjamin.

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

Frisch, S., Kotz, S. A., Yves von Cramon, D., & Friederici, A. D. (2003). Why the P600 is not just a P300: The role of the basal ganglia. *Clinical Neurophysiology, 114*, 336-340. doi:10.1016/s1388-24570200366-8

Gunter, T. C., Friederici, A. D., & Hahne, A. (1999). Brain responses during sentence reading: Visual input affects central processes. *Neuroreport, 10,* 3175-3178. doi:10.1097/00001756-199910190-00009

Hagoort, P., Brown, C. M., & Swaab, T. Y. (1996). Lexical-semantic event-related potential effects in patients with left hemisphere lesions and aphasia, and patients with right hemisphere lesions without aphasia. *Brain, 119,* 627-649. doi:10.1093/brain/119.2.627

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

Halgren, E., Dhond, R. P., Christensen, N., Van Petten, C., Marinkovic, K., Lewine, J. D., et al. (2002). N400-like magnetoencephalography responses modulated by semantic context, word frequency, and lexical class in sentences. *Neuroimage, 17*(3), 1101-1116. doi:10.1006/nimg.2002.1268

Holcomb, P. J., Coffey, S. A., & Neville, H. J. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology, 8*(2 & 3), 203-241. doi:10.1080/87565649209540525

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 English: Teacher’s Edition, Level 2. (1995). Boston: Houghton Mifflin Company.

Houghton Mifflin English: Teacher's Edition, Level 3 (1990). Boston: Houghton Mifflin Company.

Jasper, H. H. (1958). The 10-20 electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, *10*, 371-375.

Kluender, R., & Kutas, M. (1993). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience, 5*(2), 196-214. doi:10.1162/jocn.1993.5.2.196

Kotz, S. A., & Friederici, A. D. (2003). Electrophysiology of normal and pathological language processing. *Journal of Neurolinguistics, 16,* 43-58. doi:10.1016/s0911-60440200008-8

Kutas, M., & Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences*, *4,* 463-470. doi:10.1016/s1364-66130001560-6

Kutas, M., & Hillyard, S. A. (1980a). Event-related brain potentials to semantically inappropriate and surprisingly large words. *Biological Psychology*, *11*(2), 99-116. doi:10.1016/0301-05118090046-0

Kutas, M., & Hillyard, S. A. (1980b). Reading between the lines: event-related brain potentials during natural sentence processing. *Brain and Language*, *11*(2), 354-373. doi:10.1016/0093-934x8090133-9

Kutas, M., & Hillyard, S. A. (1980c). 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. Retrieved from http://mc.psychonomic-journals.org/

McPherson, D. L. (1996). Late potentials of the auditory system. San Diego, Singular Publishing Group.

Mecklinger, A., Schriefers, H., Steinhauer, K., & Friederici, A. D. (1995). Processing relative clauses varying on syntactic and semantic dimensions: An analysis with event-related potentials. *Memory and Cognition*, *23*(4), 477-494. Retrieved from http://psychonomic-journals.org/

Munte, T. F., Heinze, H., & Mangun, G. R. (1993). Dissociation of brain activity related to syntactic and semantic aspects of language. J*ournal of Cognitive Neuroscience*, *5*(3), 335-344. doi:10.1162/jocn.1993.5.3.335

Munte, T. F., Matzke, M., & Johannes, S. (1997). Brain activity associated with syntactic incongruencies in words and pseudo-words. *Journal of Cognitive Neuroscience, 9*(3), 318-329. doi:101162/jocn.1997.9.3.318

Neville, H., Nicol, J. L., Barss, A., Forster, K., & Garrett, M. F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *3*(2), 151-165. doi:10.1162/jocn.1991.3.2.151

Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language, 31*(6), 785-806. doi:10.1016/0749-596x9290039-z

Osterhout, L., & Holcomb, P. J. (1995). Event-related potentials and language comprehension. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition*. Oxford: Oxford University Press.

Osterhout, L., McKinnon, R., Bersick, M., & Corey, V. (1996). On the language specificity of the brain response to syntactic anomalies: Is the syntactic positive shift a member of the P300 family. *Journal of Cognitive Neuroscience, 8*(6), 507-526. doi:10.1162/jocn.1996.8.6.507

Palolahti, M., Leino, S., Jokela, M., Kopra, K., & Paavilainen, P. (2005). Event-related porentials suggest early interaction between syntax and semantics during on-line sentence comprehension. *Neuroscience Letters*, 384, 222-227. doi:10.1016/j.neulet.2005.04.076

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

Tree, K. L. (2009). The P600 event related potential across ages and ear conditions. Unpublished master's thesis, Brigham Young University.

Waters, G. S., & Caplan, D. (1996). Processing resource capacity and the comprehension of garden path sentences. *Memory and Cognition, 24*(3), 342-355. Retrieved from http://mc.psychonomic-journals.org/

Appendix A

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

David L. McPherson, Ph.D.
Department of Audiology and Speech Language Pathology
Brigham Young University
(801) 422-6458

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.
Department of Audiology and Speech Language Pathology
Brigham Young University
(801) 422-6458

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
______________________________	______________

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 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

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.
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.