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Auditory and Visual Correlates of the Processing of Gapping Structures in Adults

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AUDITORY AND VISUAL ELECTROPHYSIOLOGICAL CORRELATES OF

THE PROCESSING OF GAPPING STRUCTURES IN ADULTS

by

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ABSTRACT

AUDITORY AND VISUAL ELECTROPHYSIOLOGICAL CORRELATES OF THE PROCESSING OF GAPPING STRUCTURES IN ADULTS

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The purpose of this study was to compare event-related potential (ERP) effects of speech processing and effects in sentence reading elicited by sentences containing gapping structures, or a “missing” verb. N400 and P600 waveforms were collected in 20 adults between 18 and 30 years of age. Two experiments were conducted with each participant. In the two experiments ERP recordings were collected as sentences, some containing gapping structures, were presented to the subjects. In one experiment sentences were presented through headphones in sentences spoken at normal rate and with normal intonation. In the second experiment sentences with the same gapping structures were presented on a computer screen word by word at a rate of four words per second. Results suggest that all gapping structures are processed at approximately the same time. Amplitude and topography differences were seen between stimuli types and modalities.

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Introduction

Language processing occurs very rapidly (in real time) requiring an on-line measurement describing the process as it unfolds. Electrophysiological measurements of event-related brain potentials (ERPs) are non-invasive tools used to study cognitive processes represented by electrical activity of the brain. ERPs measure changes in brain electrical activity associated with sensory or psychological processes (Picton & Stuss, 1984). These measurements provide an estimate of localization and lateralization of brain activity which have been shown to allow the connection of "behavior and behavioral models of language comprehension more closely to brain function" (Osterhout & Holcomb, 1995). A great amount of language processing research utilizing ERPs has been focused on adults with normal language (e.g., Canseco-Gonzalez, 2000; Friederici, Pfeifer, & Hahne, 1993; Gunter & Friederici, 1999; Kutas & Hillyard, 1980a, 1980b, 1980c, 1984;Osterhout, 1997; Picton & Stuss, 1984; Van Petten & Kutas, 1991). Event-related brain potentials in normal language processing suggest three major components. A negativity around 400 ms distributed over the centroparietal areas of the scalp has been named the N400 component and is related to lexical-semantic access and integration processes of language.

An early left anterior negativity (ELAN), observed between 200 and 400 ms, has been attributed to first-pass syntactic processes of initial syntactic structure building while a late centroparietal positivity, or P600, has been attributed to secondary syntactic processes, including structural reanalysis in case a mismatch between lexical and structural information has occurred (Friederici, 1997).

Similar findings from other studies have agreed that the N400 component is a function of semantic processing. However, results of the P600 observations have been less conclusive, resulting in debate among researchers as to its function. While some researchers state that the P600 is a specific function of syntactic processing (Gunter & Friederici, 1999; Osterhout, 1997), others have found that it is elicited by several elements (Gunter, Stowe, & Mulder, 1997; Münte, Heinze, Matzke, Wieringa, & Johannes, 1998), not solely syntactic information.

The N400 and P600 waveforms have been observed in response to various types of sentence structures containing syntactic and semantic anomalies. These waveforms have been observed and compared as functions of sentence stimuli type as well as the input modality. Language processing by the brain has been studied using both auditory and visual stimuli (Holcomb and Neville, 1990; McCallum, Farmer, & Pocock,1984; Osterhout & Holcomb, 1992; 1993). However, few studies have been conducted in which the auditory and visual modalities were assessed in the same subjects during language processing (Hagoort & Brown, 2000; Holcomb & Neville, 1990). Therefore, the current need for research examining same-subject ERP differences due to stimulus modality is addressed in this study.

Review of Literature

ERPs

Event-related potentials can be recorded from electrodes placed across the scalp. Scalp-recorded ERPs are electrical fields generated in the brain. However, ERPs are too small to be accurately evaluated by scalp-recorded EEGs (electroencephalograms), due to other large neurogenic or mylogenic noise. This noise interferes with obtaining reliable measures of smaller components of interest, specifically language event-related potentials. An averaging technique is employed to increase the signal-to-noise ratio for the events of interest. Electrical recordings are taken at the same point in time in response to repeated events. These are then averaged together to facilitate the recognition of the ERP, as it remains constant throughout the averaging process (Friederici, 1997; Hillyard & Kutas, 1983; Picton & Stuss, 1984).

Picton and Stuss (1984) outline four principles for understanding the utilization of ERPs in the study of language. First, the source of electrical activity recorded at the scalp is not purely cerebral. Electrical fields can be generated by other sources, such as the physical movement of the eyes, the scalp muscles, the skin, and the tongue. These movements result in artifactual contaminates in the ERP recordings and cause difficulty in the examination of language processes due to the use of tongue and facial muscles for speech and eye muscles for reading.

Second, scalp-recorded ERPs only perceive electrical fields from a distance. “Closed fields” may result from events in neurons that are not similarly oriented or synchronously activated. Many language processes may occur in these “closed fields” which are rendered inaccessible to scalp recordings. This implies that the absence of an ERP does not indicate that the neuronal processes do not exist. Third, the cerebral source of a scalp-recorded electrical activity is difficult to localize. It is important to keep in mind that the neuronal generator is not necessarily localized where the signal amplitude is the greatest. Extreme caution must be taken in making assumptions about the source of scalp-recorded potentials. Fourth, because ERP waveforms are produced by several sources with temporally and spatially overlapping fields, each peak does not necessarily indicate a distinct cerebral process. Specific processes may further be determined by observing how the waveform changes with experimental manipulation.

ERP Measurement

ERPs are measured by four different aspects in order to evaluate cerebral activity in connection with language processes: topographic location, latency (time in milliseconds relative to the onset of the stimulus), polarity (positive or negative), and amplitude (Friederici, 1997). ERPs have been commonly divided into two subtypes: exogenous and endogenous components. Exogenous components have an earlier onset than other components, occurring before approximately 80 ms post-stimulus. They are often termed "stimulus-bound" components due to their relative sensitivity to the physical parameters to the stimulus and insensitivity to changes in information processing demands, such as attentional state. (Hillyard & Kutas, 1983; Picton & Stuss, 1984). Endogenous potentials are described as longer latency components which are most affected by psychological state and appear in conjunction with specific perceptual or cognitive processes (Hillyard & Kutas, 1983; Osterhout & Holcomb, 1992; Picton & Stuss, 1984). Attention effects are significant for endogenous ERP responses, especially those occurring beyond 150 ms post-stimulus (McPherson & Ballachanda, 2000).

Four types of attentional states exist which may affect ERP measurement: *selective, active, passive*, and *ignore* (McPherson & Ballachanda, 2000). *Selective* attention occurs when an active discrimination task (such as a same-different task) is employed. *Active* attention is maintained when the subject is asked to physically respond to the stimuli by, for example, pushing a button. A third attentional state, *passive* attention, describes the individuals who are awake and alert, but not necessarily attending to the stimuli. Finally, individuals who are distracted from the stimuli are said to be in the *ignore* state of attention. Careful comparisons must be made across studies due to the fact that different attentional states over various tasks have different effects on the ERPs.

Artifacts. Artifact activity, as mentioned previously, is described as frequencies that are outside those of interest to the researcher. They are caused my muscle movement rather than brain activity. Two major sources of artifact that contaminate ERP studies are movements of the eyes and eyelids. Movements of the eye act as an electrical dipole, emitting fluctuating electrical fields of positive and negative charges that are propagated back onto the scalp and picked up by scalp electrodes, contaminating the recording of the brain activity (Coles & Rugg, 1995). This high-frequency activity, often occurring after 50 ms, cannot be filtered because the movements occur at the same frequencies as significant features of the ERP waveforms (Coles & Rugg, 1995; McPherson & Ballachanda, 2000). Eye movement artifacts may obscure the desired response or even be mistaken for the desired response (McPherson & Ballachanda, 2000).

Three methods exist for managing these artifacts. First, researchers can instruct the subjects to resist blinking until the measurement has been taken. The subjects should gaze at the fixation point and only blink between tasks. This approach, however, places an additional demand on the subject, which may interfere with their performance on the task of interest. A second method is to discard all epochs that have been affected by an artifact. An oblique electrode placement allows eye movement and eye blinks to be monitored, which, in turn, activates artifact rejection (McPherson & Ballachanda, 2000). This approach may limit the researcher to an insufficient number of artifact-free trials for studies specifically requiring eye movement for good performance or studies investigating certain populations, for example, the young and the aged, whom may have difficulty keeping their eyes still. A third method involves estimating and removing the contribution of the eye movement to the ERP signal, thus preserving a pure ERP signal for the desired task (Coles & Rugg, 1995).

Long Latency ERPs and Language

Three long latency components have been discovered in relation to language processing. The N400 component is a negative wave occurring at approximately 400 ms post-stimulus, which reflects lexical-semantic processes (Friederici, 1997; Hillyard & Kutas, 1983). The late centroparietal positivity is a slow positive-going wave in response to syntactically anomalous words. The P600 component does not have a clearly defined peak, rather it is a mean voltage within a latency window of 500 to 800 ms post-stimulus with a midpoint at 600 ms (Osterhout & Holcomb, 1992). The early left anterior negativity (ELAN) occurs between 200 and 400 ms post-stimulus, and is usually only seen with outright syntactic violations, in particular, those that disrupt first-pass parsing processes, or word category violations (Friederici, 1997).

Semantic ERP Component-N400

Function of Semantic Processing. Kutas and Hillyard observed the N400 component in relation to semantic anomalies across several studies (1980a, 1980b, 1980c, 1984). These early studies indicated that the N400 component was sensitive to semantically deviant words in visually presented sentences. Semantically inappropriate words were substituted within sentences or as the final word of the sentence. Regardless of where the semantic anomaly was located in the sentence, researchers noted a broad, monophasic negative wave, peaking between 400 to 500 ms over the centroparietal region of the right hemisphere. Kutas and Hillyard (1980b) attributed the manifestation of the N400 in relation to these grammatical errors as a reflection of the interruption of sentence processing by the semantically inappropriate word. This interruption requires online reprocessing or a “second look” in order to extract meaning from senseless sentences. The researchers also discovered that the N400 wave was significantly larger following the strong semantic mismatches than the moderate semantic mismatches (Kutas & Hillyard, 1980b). As the inappropriateness of the word increased, the amplitude of the N400 increased as well.

In addition to evaluating the effects of semantic anomalies on the N400, Kutas and Hillyard (1980b, 1980c) examined the effects of physical incongruities. Sentences were presented word by word, visually, ending in either a semantically appropriate or inappropriate word. The last word in each sentence was typed in an unusually large and bold font, contrasting with the regular font used in the rest of the sentence. Semantically appropriate and inappropriate final words presented in an unexpected oversize, bold-faced font were found to elicit a later positive complex of waves, later to be termed the P600 (Osterhout & Holcomb 1992). In contrast, a strong N400 was only elicited by semantic incongruities with no subsequent positivity. The N400 was not found as a result of the physical incongruities. Kutas and Hillyard (1980c) concluded that the N400 is only affected by semantic components of comprehension while the late, positive component is affected by other stimuli, including the physical characteristics of the word presentation.

In a study by Polich (1985), the N400 as a function of semantic processing was questioned. Two experiments were conducted using two sets of visual stimuli. One set of stimuli was made up of 80 sets of seven-word series. In half the sets all seven words belonged to the same semantic category. In the other half of the series-sets, the seventh word did not match semantically with the first six words. The second set of stimuli employed sentences, half of which ended with a semantically appropriate word, and the other half containing a semantically inappropriate final word. The presentations of stimuli were the same across both experiments, but they differed in their attention tasks. In the first experiment, subjects were asked to read the stimuli in a simple selective attention condition. The second experiment required the subjects to push a button to indicate whether the final word was appropriate or inappropriate in relation to the category or sentence, thus engaging in an active attention condition. Results indicated that the N400 was elicited by word series and sentences ending in both semantically congruent and incongruent words. In addition to the N400, a positive component appeared during the active participation paradigms

Polich concluded that the positive component was the P300, a component typically elicited in response to unexpected task-relevant stimuli requiring a motor response or a cognitive decision (Canseco-Gonzalez, 2000; Hillyard & Kutas, 1983). At this time the P600 component had not been defined (Osterhout & Holcomb, 1992). Polich then interpreted the N400 as a delayed N200, which is seen in relation to the processing of similar or dissimilar stimuli (Ritter, Simson, & Vaughn, 1983). Polich concluded that while the semantic appropriateness of words seemed to elicit the negative waves occurring approximately 400 ms post-stimulus, the effect may also be attributed to "the system's overall capability to comprehend complex similarities and relationships among stimulus items rather than a unique response to semantic incongruities" (p. 318-319).

Typicality Effect. "Typicality" describes the "goodness of fit" a particular word has in relation to a specific category. Stuss, Picton, and Cerri (1988) conducted a study in which subjects were to judge the level of typicality, or how well a word fit into a particular category. The researchers expected to find a more latent N400 component in response to those words which were determined to be a categorical mismatch. They attributed this assumption to the increased lexical search the processor would have to perform in comparison to the search executed for a more easily accessed lexical item.

Stuss et al. (1988) discussed two major findings in this study. First, they observed that the N400 peak amplitude was the largest for atypical words. The words displaying the most atypicality were those that elicited the largest peak amplitudes. However, in opposition to their theory of lexical access, the longest peak latencies occurred with high-frequency words, rather than low-frequency words which were said to require more effort with a longer lexical search time. Other researchers have since suggested that the N400 does in fact represent lexical access as a longer peak latency N400 was elicited for non-meaningful words than meaningful words (Attias and Pratt, 1992).

A second event observed in the Stuss et al. (1988) study was the presence of a late positive component (LPC) following the N400. The LPC had a tendency to be largest for high-frequency words. The researchers suggested that the LPC varies with the stimulus's frequency of use and recall from the long term-memory.

Semantic Priming. Another significant feature of language processing that seems to affect the N400 component is semantic priming. Semantic priming, or the presentation of a word in a semantically appropriate context, has been found to increase the speed and accuracy of semantic processing (Bentin, Kutas, and Hillyard, 1993; Mitchell, Andrews, & Ward, 1993). Mitchell et al. (1993) examined the response of N400 to semantic priming in their study involving young adults. The study was completed in two phases. The first phase was a training session for the subjects. They were familiarized with a list of sentences, some congruous and some incongruous. ERPs were recorded during the second phase of the study while the participants silently read 180 sentences. The sentences included sentences previously seen in the training session, unfamiliar sentences, and reorganizations, in regards to sentence structure, of previously seen sentences. ERP responses for familiar sentences (whether previously seen or reorganizations of previously seen sentences) showed a reduced N400 negativity in comparison with the peak amplitudes for unfamiliar sentences. A late positive component was observed at approximately 600 ms in association with incongruously completed sentences. This LPC occurred prior to the 600 ms mark for primed sentences. The authors suggested that the observed LPC (P600) reflected episodic memory retrieval and is sensitive to task requirements.

Another study investigating semantic priming was conducted by Radeau, Besson, Fonteneau, and Castro (1998). ERPs were used to examine semantic, phonological, and repetition priming for words that were presented auditorily. The results indicated that the N400 responds with the smallest peak to words preceded by a semantic prime and an intermediate peak to words preceded by a phonological prime (a word which sounded similar but did not necessarily rhyme). The largest peaks were elicited when the word was preceded by an unrelated word.

A study by Fujihara, Nageishi, Koyama, and Nakajima (1998) studied the combined effects of semantic priming and typicality. Typical words within a category were found to act as semantic primes for typical target words. Atypical target words were processed more slowly than typical target words because they were not primed by typical words in the same category. These results support the idea that category is based on a category prototype and categorization is based on how similar a target item is to the category prototype.

Ambiguous Words. Class-ambiguous words can act as nouns or verbs, depending on the context in which they are presented. They have the same form, but may have two or more meanings. ERPs are used to understand how the brain stores and uses the information associated with these words in sentences which are then rendered ambiguous. Two recent studies demonstrate how ambiguous words affect the N400 component.

Federmeier, Segal, Lombrozo, and Kutas (2000) assessed word class processing. Visually presented stimulus sentences contained the following four types of words: word class-ambiguous items that could be used as nouns or verbs (e.g. smoke, promise), unambiguous nouns (desk, valley), unambiguous verbs (eat, teach), and pronounceable pseudowords (breat, dight). Two minimally contrasting sentences, each containing a different target word type, were presented. The following example set containing each condition is taken from the study:

He learned to joke and became the life of the party.

He learned the joke and repeated it incessantly.

Jim learned to solution but then wasn't allowed to used his calculator.

Jim learned the solution but went blank when it was time for the test.

The girl learned to carve but found it was more tedious than she had thought.

The girl learned the carve but hated working with the material.

Cindy learned to phream from watching her grandfather at work.

Cindy learned the phream from her ballroom dance professor.

The researchers reported that ERPs were more negative in response to word-class ambiguous items. Pseudowords elicited the most increased N400 and P600, especially when used as verbs as opposed being used as nouns. However, ambiguous items elicited a greater negativity when used as nouns rather than when they were used as verbs. Unambiguous nouns also elicited a greater negativity than unambiguous verbs. Unambiguous words, embedded in incorrect contexts (i.e., a noun was used when a verb should have been used), elicited larger N400 and P600 responses. Similarly, Osterhout and Holcomb (1993) found that grammatically incorrect sentences elicited larger N400 and P600 responses as compared to grammatically correct sentences. A unique left-lateralized frontal positivity was observed only for unambiguous verbs embedded in appropriate contexts, or when they were actually used as verbs. Federmeier et al. (2000) concluded that the processing of word class is also affected by the level of ambiguity.

A subsequent study conducted by Swaab, Brown, and Hagoort (2002) investigated the temporal aspects of the processing of ambiguous words. The N400 was measured in response to target words following the aural presentation of sentences. Three types of context sentences were used: concordant, discordant, and unrelated control conditions. In concordant context sentences, context primed the listener's interpretation of the final ambiguous word toward the meaning related to the target word. Discordant context sentences biased the meaning to be unrelated to the target. The unrelated control condition provided sentences with unambiguous final nouns which were unrelated to the target. The target word followed the context sentence after an interval of silence. This allowed the study of the relationship between context and frequency or dominant meaning of ambiguous words in real-time sentence comprehension. Swaab et al. (2002) found that the discordant and unrelated contexts elicited greater N400 amplitudes than the concordant context. However, discordant contexts and unrelated contexts produced differing N400 amplitudes. Unrelated contexts elicited a greater N400 amplitude than did the discordant context.

Visual versus Auditory Modality. The N400 has proven to be a robust component in response to semantic anomaly. The N400 has been shown to be evoked by semantic anomalies across different languages (Friederici, 1997) such as English, French (Besson & Macar, 1987), Dutch (Brown and Hagoort, 1993; Gunter, Jackson, & Mulder, 1992) and German (Friederici et al.,1993; Münte, Heinz, & Mangun, 1993; Rösler, Friederici, Püz, & Hahne, 1993). In addition, the component has been elicited in the visual and auditory modalities (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). However, some topographical differences exist as a function of the presentation mode. Holcomb and Neville (1990) report that the N400 effect for auditory presentation was earlier and more prolonged than for visual presentation. In addition, the visual N400 was slightly lateralized to the right hemisphere but the auditory N400 was symmetric or slightly larger over the left hemisphere.

N400 Summary. The N400 component has been shown to respond to a variety of semantic functions. The amplitude has been observed to be smaller for semantically primed words, words with greater typicality, and function words rather than content words. While several variables have been shown to affect the N400 ERP component, it is generally accepted to be associated with semantic processing. Recently, ERP research has shifted from manipulating the influencing factors of the N400 in isolation to the study of other language processing parameters, such as syntactic errors. This provides further insight into how each ERP component relates to language processing (Gunter & Friederici, 1999; Gunter et al., 1997; Kaan & Swaab, 2003; Osterhout, 1997).

Syntactic ERP Component- the P600

Early ERP studies investigating linguistic processing did not separate syntactic processes from semantic processes. One of the first ERP studies addressing the role syntactic violations play in sentence comprehension was conducted by Van Petten and Kutas (1991). Two types of stimulus sentences were employed: syntactically correct but semantically incoherent sentences, and sentences that were both semantically and syntactically correct. N400 was measured in relation to function words and content words. Function words, also termed closed-class words, cause the sentences to be syntactically correct or incorrect while content words, or open-class words, determine the sentences' semantic coherence. Results of the study showed that the N400 was only slightly smaller for function words than content words. The authors stated that there was not sufficient evidence to assume that syntactical errors elicit a separate and distinct waveform from the N400 elicited by semantic anomalies. They conclude that evidence did not suggest a separate processing mechanism for semantic and syntactic information.

In response to the findings of Van Petten and Kutas (1991), further efforts were made to identify an ERP correlate of syntactic processing similar to the N400 correlate of semantic processing. Osterhout and Holcomb (1992) succeeded in distinguishing unique ERP responses to syntactic versus semantic anomalies. Their stimuli utilized garden-path sentences which contain temporary syntactic ambiguity. When the syntactic representation not "preferred" by the parser is presented, backtracking and reanalysis is required to make sense of the sentence. The researchers evaluated the time course of anomaly recognition in search for an electrophysiological marker of the garden-path that was a separate response from the N400 component. In the example "The broker persuaded to sell the stock," they found that the infinitival marker *to* elicited a centroparietal positivity starting at approximately 500 ms post-stimulus. Mismatch in structural preference occurs because a noun phrase complement is expected after the verb (the broker persuaded the man…), which is a simpler structure and preferred over the reduced relative clause structure (The broker persuaded to sell the stock met the man). The infinitive *to* requires a reanalysis of the prior structure.

Results showed that a widely distributed positive component was elicited by words inconsistent with the "preferred" structural analysis of the sentence. The positive waves' largest amplitudes were located over the fronto-central portion in the right hemisphere. It did not have a clearly defined peak, but its midpoint rested at approximately 600 ms poststimulus, warranting the name P600. A follow-up experiment was conducted to replicate the finding of P600 in relation to syntactic anomaly. Their results support claims that the P600 is a distinct response from the N400 and indicates the syntactic garden-path effect. Similar centroparietal positivities have been reported with other types of garden-path sentences (Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Osterhout, et al., 1994).

Osterhout (1997) went on to use open- and closed-class words, similar to stimuli in the Van Petten & Kutas study (1991) to further compare the associated ERP responses. Results revealed a large N400 component in response to semantically anomalous words as well as a late positive wave (P600) in response to syntactically anomalous words regardless of its position and word class. These results contradict those found in the Van Petten and Kutas study (1991).

Specificity of the P600. Further exploration of the behavior of the P600 components has led some researchers to challenge the specificity of the P600 as a function of syntactic processing. Münte, Heinze, Matzke, Wieringa, and Johannes (1998) elicited the P600 with the use of three types of errors: morphosyntactic (e.g., the witch used her broom's to fly to the forest), semantic (e.g., The witch used her dream to fly to the forest), and orthographic (e.g., The witch used her broome to fly to the forest). They observed similar positivities occurring at approximately 600 ms post-stimulus for syntactic, semantic, and orthographic violations alike. The authors suggest that the P600 is not a function of syntactic anomaly specifically. Additionally, they indicated that the syntactic and orthographic violations elicited a wider distribution across the scalp, suggesting that different neural generators may all contribute to the similar positivities seen across stimuli conditions. However, this should be considered carefully in regards to the fact that ERP generation sites do not always correspond perfectly to surface electrodes on the scalp (Picton & Stuss, 1984).

Another study aimed to determine whether the P600 is language-specific or it can be elicited by non-linguistic stimuli (Patel, Gibson, Ratner, Besson, & Holcomb, 1998). They studied the ERP response to deviant notes in musical chords through the use of Western European tonal music. They then compared the results to ERPs elicited by structurally manipulated sentences or syntactic anomalies. In Western European tonal music, musically experienced listeners could detect harmonic incongruities in unfamiliar sequences. This finding implied that the listener knows “musical grammar,” or appropriate tonal structure. The authors investigated how the P600 would differ in response to language incongruities in comparison to musical incongruities.

The P600 effect was obtained in both conditions. Results showed that the late positivities elicited by these two sets of stimuli were the same in amplitude and scalp distribution regardless of the degree of structural anomaly. The researchers suggested that the P600 component reflects the use of a processing mechanism shared by linguistic and musical processes. They further attributed the P600 component to a structural integration process rather than a pure reflection of syntactic processing.

P600 as a Member of the P300 Family. The P300, also known as the P3b, is a centroparietal component, like the P600, which is sensitive to unexpected, task-relevant stimuli (Canseco-Gonzalez, 2000). Osterhout (1997) states that the P300 can be elicited by a variety of unexpected events, linguistic and non-linguistic.

Osterhout and Holcomb (1993) provided three reasons for suspecting that P600 is a member of the P300 family. First, subjects may assume that the sentences they read or listen to will be grammatically correct. Coming upon a grammatically incorrect sentence or a word/category mismatch may provide the unexpected event required to elicit the P300 waveform. Secondly, in acceptability judgment trials, P300 components tend to be larger in response to stimuli that provide complete information in regards to the outcome of a trial (determining the correct response; Ruchkin, Johnson, Canoune, Ritter, & Hammer, 1990). Thirdly, modality-related differences in scalp distribution seem to indicate that P300 displays a modality-dependent shift in response to visual versus auditory stimuli (Johnson, 1989). This finding is consistent with Osterhout and

Holcomb's (1992; 1993) observations of the P600 distribution shift due to modality.

Other studies have also suggested that P600 may belong to the P300 family. A study by Gunter et al. (1997), observed the P600 in relation to the level of expectedness. The P600 and P300 components were both elicited by unexpected event. A later study by Gunter and Friederici (1999) compared the P600 and P300 elicited by visual stimuli. Stimuli consisted of words in upper and lower case letters. The components displayed similar scalp distributions in response to the unexpected visual presentation of stimuli.

Visual versus Auditory Modality. To test the reliability of the N400 and P600 waveforms across modalities, Osterhout and Holcomb (1993) continued their investigation by conducting a study involving the same stimuli, but presenting them auditorily instead of visually. Syntactically ambiguous (garden-path) sentences were presented as continuous, natural speech. Results between the two studies (Osterhout & Holcomb, 1992; 1993) were similar in that the P600 was elicited by the garden-path sentences. Since the P600 effect was elicited by the same words in both modalities, it was assumed that language processing occurs with the same parsing strategy over both modalities. However, some modality-related differences were noted. P600 was observed to appear with an earlier onset when elicited in the auditory modality. The auditory modality elicited left hemisphere negativity that was more pronounced and of longer duration than elicited by the visual modality.

A more recent study comparing the P600 component across input modalities was conducted by Hagoort and Brown (2000). In their first experiment, subjects read sentences containing grammatical errors including number agreement violations, subcategorization violations, and phrase structure violations. The researchers found that the P600 consisted of two parts, the first occurring between 500 and 750 post-stimulus with relatively equal distribution along the anterior-posterior axis. The second part, occurring after 750 ms post-stimulus, was distributed over the posterior sites with longer duration. The authors hypothesized that the P600 is a more complex component consisting of two aspects of the parsing process. Straightforward violations have been know to elicit a more posterior distribution than more subtle syntactic violations, which are located more anteriorly (Kaan, Harris, Gibson, & Holcomb, 2000).The first phase indicates increased syntactic integration difficulty when the syntactic manipulation is not a straight-forward violation, resulting in a more frontal distribution. The second phase indicates a failure or revision of the parse with a more posterior distribution. Subcategorization violations elicited a positive shift typically over the second part of the P600. This suggests that the two aspects of the P600 are not associated. The researchers attributed this finding to the possibility that the N400 and P600 components overlap because subcategorization condition is both semantic and syntactic in nature. The overlap was stronger in the first phase of the P600, resulting in a more visible posterior phase.

The second experiment was conducted with the auditory presentation of the same stimulus sentences. As with the written sentences, the spoken sentences elicited a clear P600 for each violation type. The P600 showed a clear posterior distribution for all three violations. The results for both modalities were very similar with P600 onsets which were almost identical. The authors found, however, that the auditory P600 was distributed more posteriorly than the visual P600. They concluded that auditory and visual input elicit the P600 effect in much the same way, suggesting that reading and listening share central aspects of sentence processing.

The Role of ELAN in Language Processing

A third language-elicited component is the early left anterior negativity (ELAN). Appearing as early as 250 ms post-stimulus, ELAN is an anteriorly distributed component with a larger left hemisphere amplitude (Canseco-Gonzalez, 2000). It has been shown to be elicited solely by outright syntactic violations, in particular, those that disrupt the first-pass parsing processes or word category violations as in the following example: “Max’s of proof the theorem” (Friederici, 1997). ELAN has been observed in response to various grammatical structures including syntactic (e.g., phrase structure, subcategorization) and morphosyntactic (e.g., subject-verb agreement, pronoun case, and verb number) violations (Canseco-Gonzalez, 2000). It has also been elicted through visual and auditory modalities and in response to word-pairs as well as sentences (Coulson, King, & Kutas, 1998; Friederici et al., 1993; Osterhout & Holcomb, 1992).

Studies have shown that ELAN and P600 can be produced by a single violation type (Coulson et al., 1998; Osterhout & Holcomb, 1992). Gunter et al., (1997) stated that the ELAN was “more specialized for syntactic analysis” than the P600. ELAN seemed to reflect a less complex syntactic analysis (p. 670) after observing that ELAN was not affected by changes in syntactic complexity or semantic errors, unlike the P600.While these two syntax-related components are clearly distinct from the semantic-related N400, their roles in syntactic processing separately as well as in conjunction with one another, are still under investigation (Canseco-Gonzalez, 2000).

Ellipsis

Everyday language often involves missing words or phrases in the spoken or written form. This omission of a grammatical constituent is termed *ellipsis* and still allows the interpretation of the sentence (Kaan, Wijnen, & Swaab, 2004). Greenbaum and Quirk (1990) state that "ellipsis requires verbatim recoverability; that is, the actual word or words that are implied must be precisely recoverable." (p. 255) For example, the infinitive marker *to* occurs in the following sentences without the infinitive which it normally introduces:

If she does the dishes, I won't have to.

The predication of *does the dishes* has been ellipted to.

There are three categories of ellipsis: initial ellipsis, medial ellipsis, and final ellipsis. The category is determined according to where the ellipsis, or omission, occurs within the construction (Greenbaum & Quirk, 1990). Thus, the following illustrations exemplify an initial, medial, and final ellipsis, respectively:

(I) wish I could go.

Meg rides a bike and Joshua (rides) a skateboard.

We have not been to California yet, but we will (go to California).

Gapping. Gapping is a type of ellipsis that occurs in complex coordination (Kaan et al., 2004). It is a syntactic process that deletes identical elements (usually a finite verb and, possibly, adjacent material) from the second of two conjoined sentences (Carlson, 2001). The ellipsis in these constructions occurs in the medial position, deleting the verb and possibly other constituents such as the object. This causes the elements in the second conjoin to be incongruous with the elements in first conjoin (Greenbaum & Quirk, 1990). For example:

(a) Subject + object; One man read the newspaper, and the other a magazine.

(b) Subject + adverbial; Kim completed the test today, and Bob yesterday.

(c) Subject + compliment; George has become more heavy, and Hal more lean.

In cases where a gapped and a non-gapped interpretation can be made, non-gapped interpretations are more likely to be intended (Greenbaum & Quirk, 1990). Interpretation (a) of the sentence *Gina gave Patty a book and Anne a picture* is favored over interpretation (b):.

(a) Gina gave Patty a book and Gina gave Anne a picture.

(b) Gina gave Patty a book and Anne gave Patty a picture.

Jackendoff (1971 as cited in Lobeck, 1995) outlined 4 differences between gap and ellipsis:

1. A gap must be flanked by lexical material. An ellipsis can be phrase-final.
2. A gap must occur in a coordinate, but not subordinate (adjunct or complement) clause separate from that containing its antecedent. An ellipsis can occur in a coordinate or subordinate clause separate from that containing its antecedent.
3. A gap cannot precede its antecedent. An ellipsis can precede its antecedent under certain conditions.
4. A gap need not be a phrase. An ellipsis must be a phrase.

The above examples suggest that gapping can operate on a phrasal constituent, but is not required to. Rather, the fundamental element for a well-formed gap is the presence of flanking material, which appears to play no crucial role in the process of forming a verb phrase (VP) ellipsis (Lobeck, 1995).

Sentences containing syntactically displaced constituents are challenging to the human processor. This is due to the fact that the dislocated element cannot be integrated into the current parse immediately. Rather, it "must be held in the working memory until it can be linked to its subcategorizer or reconstructed at its canonical structural position" (Felser, Clahsen, & Münte, 2003, p.345). Though a verb gap does not involve the displacement of a constituent (Kaan et al., 2004), but rather omits elements from one of two conjuncts, the sentence processor must detect the gap and retrieve the missing information. The human parsing mechanism is efficient in assigning a 'complete' interpretation to an 'incomplete' sentence (Kaan et al., 2004).

The human parsing mechanism has two separate methods available for the building and analysis of syntactic structures (Frazier & Clifton, 2001). The first method attaches input items to a syntactic tree, assuming only the required number of nodes according to the grammar of the language, the input, and the data the parser has received so far. The syntactic structure is thus built step-by-step and inference-by-inference as input is received. The more structure is built, the more processing is involved because more inferences are required. This has been known in some literature as minimal attachment (Osterhout, Holcomb, & Swinney, 1994). The second method is a copying mechanism (*Copy α*) wherein the structure is made by copying its antecedent clause. This copying device is available for ellipsis displaying unambiguous syntactical structure. Only the inference needed to identify the ellipsis site and its syntactic scope are copied. Consequently, there is not necessarily a greater 'cost' associated with building more structure by means of this copying method (Frazier & Clifton, 2001). Frazier and Clifton (2001) specify that the operation of *Copy α* may be applied to ellipsis in coordinations, but not to gapping, since the sentences are rendered ambiguous due to the syntactic scope of the missing structure. For example, *Mike took Jake to the gym and Jenny to the movies*, can be interpreted as a verb phrase (VP) conjunction (*Mike took Jake to the gym* *and (Mike took) Jenny to the movies*), or an inflection phrase (IP) conjunction analysis with gapping (*Mike took Jake to the gym and Jenny (took Jake) to the movies*). However, this does not mean that the syntactic scopes of all gapped constructions are ambiguous (Kaan, 2004).

Similar to the *Copy α* theory, an accepted conclusion to the study of sentence production states that as a grammatical structure is perceived, it is more likely to be used in future sentence formulations (Kaan et al., 2004; Pickering, Branigan, Cleland, & Stewart, 2000). It is likely that the grammatical structure is stored in working memory and re-accessed in later processing. This finding has been extended to the study of comprehension as well. When reading two successive clauses or sentences, the second is read faster if syntactically structured the same as the first. Structurally parallel sentences processed in succession appear to be processed with less effort for the second sentence or clause in comparison to non-parallel cases (Frazier & Clifton, 2001, Frazier, Munn, & Clifton, 2000, Kaan et al., 2004). Evidence suggests a strong impact of parallelism on sentence processing, particularly with regard to ellipsis. In gapping sentences, the second conjunct is analyzed based on re-accessing previously built parse trees, thus more easily and quickly comprehended than ellipsis which contain non-parallel structural coordinations (Carlson, 2001; Frazier & Clifton, 2001). This experiment will only contain highly parallel coordinations in which the omitted structure can be automatically filled in.

With the use of ERPs, Kaan et al. (2004) rendered a description of the time course of identification and resolution of verb gaps in written sentences. ERPs were recorded as subjects read sentences containing verb gaps. They aimed to understand how ellipsis sentence meaning is constructed, when this occurs during processing, and with the use of which mechanisms. They discovered that the processing of gapping sentences did not yield any additional ERP components, but rather affected components that have been known to be elicited by closed class words, namely N400, P600, and ELAN.

The N400 effect was observed at the head of the noun of the second noun phrase in the second conjunct clause. The researchers attribute this effect to the fact that the noun was an implausible object for the gapped verb which created semantic integration difficulty. They suggest that the processor attempts to integrate the critical noun phrase with the missing verb and that the N400 peak signals the availability of information associated with this verb.

A P600 effect followed the N400, possibly indicating a syntactic revision process, or an increased syntactic integration difficulty, triggered by the semantic anomaly. Osterhout et al. (1994) proposed that the amplitude of P600 reflects "cost of syntactic processing" (p. 18) with higher processing costs being correlated with a higher amplitude. They suggested that syntactic anomalies elicit the P600 due to the perceiver's own parsing preferences (such as in garden-path sentences) in addition to outright ungrammaticality. This effect could have also been elicited by the acceptability judgment task which was employed in the study (Hahne & Friederici, 2002; Osterhout & Holcomb, 1992).

Neither a left anterior negativity nor a P600 was elicited by the determiners (*a, an,* or *the*) following a gap. Rather, researchers observed an early centro-posterior negativity (100-300 ms), or CPN, on post-gap determiners, followed by an increased fronto-central positivity (300-500 ms). It is suggested that the gap is perceived early on in the process, which may be related to early left anterior negativity (ELAN). If this is so, the presence of ELAN may signify an initial interpretation of the occurrence of a determiner as a phrase structure violation. This may, in turn, trigger the retrieval of the preceding verb information, as indicated by the fronto-central positivity.

Kaan and Swaab (2003) took into account the two common parsing methods in analysis of their results. In accordance to minimal commitment parsing, which states that a full sentence structure requires a finite verb or a complementizer (i.e., a function word that unequivocally marks a subordinate clause). The authors' stimuli did not meet these requirements, as the list was made up of sentences with gapped verbs containing neither a finite verb nor a complementizer. Therefore, the results of their study did not agree with minimal commitment parsing models. Kaan and Swaab (2003) associate the interpretations of gapping structures in their study to an adaptation of the *Copy α* process. Their alternate approach favors the idea that the grammatical structure (parse tree) is stored in the working memory and then built by re-accessing the stored parse tree. In other words, "the syntactic representation constructed in the processing of the first sentence is 'recycled' in the processing of the second" (pg 590).

Present Study

The study of the N400, P600, and ELAN waveforms in response to language processing has been broad. Some recent ERP studies include the examination of the processing of open- and closed- class words (Brown, Hagoort, & ter Keurs, 1999), morphosyntactic violations (Coulson et al., 1998), control and raising constructions (Featherston, Gross, Münte, & Clahsen, 2000) and filler-gap dependencies (Felser et al., 2003). Little research has been done with the use of ERPs specifically concerning the processing of gapping structures. As described above, a single study by Kaan et al.

(2004), examined ERPs elicited by the visual input of gapping structures. They specifically noted the input's effect on the N400, P600 and CPN waveforms. The question arises regarding the similarity of these ERP responses to stimuli across modalities. As shown in a previous study observing visual and auditory stimuli (Hagoort & Brown, 2000), the P600 effect was obtained by both reading and listening to syntactic violations. They concluded that the similarity of the effects support earlier claims that both modalities "share central aspects of postlexical sentence processing" (p. 1548).

It could be assumed that the ERP waveforms, namely N400, P600, and CPN, would be similarly observed across visual and auditory modalities for gapping structures in regards to amplitude and latency. Larger amplitudes for the N400, P600, and CPN components would be expected for semantically incorrect gapping structures versus correct gapping structures within both modalities. The presence of the CPN component and the absence of the ELAN component would be expected in response to gapping structures. Finally, a more posterior P600 distribution would be expected for auditorily presented stimuli than visually presented stimuli. The following study was designed with these hypotheses in mind. The normative data collected in adults during this study will further our understanding of language processing and pave the way for future endeavors with language disorder diagnosis and treatment.

Method

Participants

Twenty subjects (10 males and 10 females) between the ages of 18 and 30 years (M = 23.15) participated in the study. The subjects were all right handed, native English speaking adults. The age range for the male participants was from 21 to 30 years

(*M* = 24.83*)* and the age range for the female participants was 21 to 25 years (*M* = 22.43). Participants were recruited from Brigham Young University campus and were given gift certificates for local restaurants for their participation.

Each participant self-reported a negative history of neuropsychiatric disorder and did not demonstrate evidence of a language delay or disorder. The participants had normal speech skills, indicated by the presence of no consistent speech sound errors during a conversational sample, and normal hearing with pure-tone thresholds of ≤ 15 dB HL at 250, 500, 1000, 2000, 4000, and 8000 Hz bilaterally under earphones (American National Standards Institute [ANSI], 1996). All the participants had normal or corrected-to-normal vision as indicated by a vision screening. The study was approved by the Institutional Review Board for Human Subjects at Brigham Young University and all participants signed a consent form prior to participation (see Appendix A).

Instrumentation

Sentences were recorded in a single-walled sound suite using a DPA 4011 Cardioid microphone attached to an Apogee Electronics Mini-Me microphone preamplifier and A/D converter. A two inch foam windscreen was used on the microphone which was placed six inches from the talker at 0° azimuth. Speech was digitized at 44.1 kHz using 16-bit quantization and stored on a hard disk for later editing. The sentences were edited using Audigy and converted into ".wav" files for use with the NeuroScan Laboratories data acquisition system.

A Grason-Stadler 1761 audiometer was used for hearing screenings. An electrode cap (NeuroScan Laboratories) was used to place silver-silver chloride electrodes over the scalp at 32 electrode positions according to the 10-20 International System (Jasper, 1958) using the right earlobe as a reference. Electrode impedances were at or below 3000 ohms. Eye movement was monitored by electrodes placed on the outer cantha of one eye and above the supra-orbital foramen of the opposite eye. Trials contaminated by eye movement artifact were rejected from the average.

Visual sentences were presented on a Dell UltraSharp monitor in conjunction with a Dell Pentium 4 personal computer. The stimuli were presented using NeuroScan Stim-2 software on a 15” monitor at a distance of 75 cm.

A NeuroScan computer using Scan 4.2 software was used to collect and analyze the event-related potentials. Raw electrical potentials were bandpassed from 0.05 to 70 Hz. A 2000 ms sample was taken from the onset of the trigger word in each sentence. Auditory stimuli were presented at 65 dB HL through a binaural soundfield speaker placed at 0º azimuth. The soundfield speaker was calibrated at 0º azimuth in accordance with ANSI S3.6 - 1996 standards.

Stimuli

Sixty coordinate sentence pairs of plausible and implausible gapping conditions were constructed in the same format as each other. In 51 out of 60 sentences the subjects of the two clauses were proper names, so as to make the two clauses syntactically and semantically parallel and the verb gapping as natural as possible. Thirty of the sentences were taken from the Kaan et al. (2004) study. The sixty stimulus sentences were randomly distributed over two presentation lists, one for the auditory experiment and the other for the visual experiment. The separate lists contained 15 plausible gapping structures and 15 implausible gapping structures. Neither set included both the plausible and implausible version of any sentence. All participants were presented the same stimuli visually. Similarly the same stimulus set was used for all participants in the auditory modality. One hundred filler sentences consisting of syntactic garden-paths, unambiguous attaching relative clauses, and pseudocleft sentences were distributed over the two presentation lists in order to serve as distracter items. Sentences were randomized using Matlab 6.5.

For the auditory stimulus set, sample recordings of three female talkers were collected. Ten individuals, unfamiliar with the talkers listened to the recordings and chose the "best" talker. The "best" talker produced three samples of each stimulus sentence and the "best" sentence of each set was chosen for use during the study. The sentences were spoken with normal prosody and rate. Stimulus sentences were presented binaurally through headphones at 65 dB HL in a single-walled sound suite using a Grason-Stadler 1710 audiometer.

The visual stimulus sentences were presented one word at a time in white, lower-case letters against a black background in Arial, 72 point font. Individual words were centered on the computer monitor. Each word appeared for 300 ms and was followed by a black screen for 200 ms. Each sentence was preceded by a fixation cross for 1500 ms and a 500 ms delay before the presentation of the first word. The last word of each sentence was followed by a blank screen for 1500 ms and then a graphic prompt which stayed on the screen until a button was pushed, indicating that the sentence was acceptable or unacceptable. The comma connecting the two clauses in each sentence was attached to the previous word. The complete set of stimulus sentences is outlined in Appendix C.

Procedure

Each participant was fitted with an electrode cap. Each electrode was filled with ECI Electro-gel to reduce impedance to 10 kOhms or less. Participants were then seated comfortably in a reclining chair with the neck well supported. Ambient noise did not exceed ANSI S3.1 - 1991 maximum permissible levels for air conduction testing with ears uncovered. Participants were instructed to remain still, relaxed, and awake during auditory stimulus presentation. At the end of each sentence the subjects were prompted to push a button that indicated that the sentence was acceptable or unacceptable. The subjects were told that some sentences would be grammatically incorrect, but they were given no information regarding the kinds of grammatical errors that would occur. In the visual stimulus experiment the subjects were instructed to focus on comprehending the whole sentence and to resist blinking until the end of the sentence. Again, they were prompted to push a button at the end of each sentence indicating if the sentence was acceptable or unacceptable. The participants were not given practice trials. However, the first 3 sentences of each stimulus set were specifically selected to be filler sentences rather than gapping structures, during which time the participant could ask questions or get clarification of the directions without affecting the data collection.

Analysis

The N400 was identified as a negativity occurring between 200 and 500 ms following the onset of the determiner (*a, an,* or *the*) of the noun within the second noun phrase in the second conjunct clause. The P600 was similarly identified as a positivity occurring between 500 and 800 ms from the onset of the determiner of the noun within the second noun phrase in the second conjunct clause. The latency of both the N400 and the P600 was defined as that time interval in the waveform where maximum amplitude occurred. Area means for the N400 waveforms are defined as the area between the first and last peaks in the waveform. The ELAN was identified as an early left-anterior negativity taken from the FTZ electrode at approximately 180 ms (Friederici et al., 1993). The CPN identified as a centro-posterior negativity taken from the CPZ electrode between approximately 100 and 300 ms (Kaan et al., 2004).

The mean, standard deviation, range, and 95% confidence interval were computed for the latency and amplitude of the N400 and P600 waveforms. Multivariate analyses of variance (ANOVA) were performed to evaluate the differences between the ELAN and CPN amplitudes and N400 and P600 latencies and amplitudes for each condition. The within-subjects factor was the correctness or incorrectness of the sentences.

Results

A multivariate analysis of variance showed no significant difference between trials, $F(18, 124) = .779$, $p = .721$, therefore, trial 1 was used for all data analysis. Likewise, no significant differences were seen for trial and stimulus type, $F(18, 124) = .483$, $p = .961$, reinforcing the absence of interaction between trial and other components. Trial 1 was selected for analysis use because it has been shown that the repetition of trials in electrophysiological experiments may affect the data collected. No significant differences were noted for latency in any of the conditions. No further analysis of latency will be reported.

Descriptive Statistics

Auditory. Table 1 shows descriptive statistics for the amplitudes of semantically correct and incorrect gapping structures in the auditory modality. The amplitudes for both the ELAN and the CPN components in correct gapping structures in the auditory modality are approximately equal to amplitudes for incorrect gapping structures in the auditory modality. Although the amplitudes for both the N400 and P600 components for incorrect gapping structures in the auditory modality are larger than amplitudes for correct gapping structures in the auditory modality, they are within one standard deviation of each other.

Table 1

Descriptive Statistics for the Amplitudes (in µV) of Semantically Correct and Incorrect Gapping Structures in the Auditory Modality.

			Range		95% Confidence Interval	
Component	*M*	*SD*	*Minimum*	*Maximum*	Lower	Upper
			Correct			
ELAN	-5.197	8.823	-33.584	8.218	-7.220	-3.172
CPN	-6.468	5.447	10.932	10.932	-7.718	-5.218
N400	-6.145	8.432	9.195	9.195	-8.079	-4.211
P600	2.912	9.273	16.151	16.151	0.785	5.039
			Incorrect			
ELAN	-5.764	7.994	-26.245	5.459	-7.598	-3.930
CPN	-9.744	5.038	-25.671	-0.310	-10.900	-8.588
N400	-7.292	6.250	-20.735	6.516	-8.716	-5.868
P600	3.338	8.015	-12.397	16.144	1.499	5.177

Visual. Table 2 shows the descriptive statistics for the amplitudes of semantically correct and incorrect gapping structures in the visual modality. Amplitudes for the ELAN component are equal for correct and incorrect gapping structures in the visual modality. However, the ELAN amplitudes for both correct and incorrect gapping structures in the visual modality are considerably larger than the ELAN amplitudes for the correct and incorrect gapping structures in the auditory modality. Incorrect gapping structures in the visual modality produce the largest ELAN amplitude across all conditions.

The CPN amplitudes are approximately equal for correct and incorrect gapping structures in the visual modality. The CPN amplitudes for correct gapping structures in the visual modality are slightly larger than CPN amplitudes for correct gapping structures in the auditory modality; however the values are within one standard deviation of each other. The CPN amplitudes for incorrect gapping structures in the visual modality are considerably larger than the CPN amplitudes for incorrect gapping structures in the auditory modality, and exceed one standard deviation of each other.

Table 2

Descriptive Statistics for the Amplitudes (in µV) of Semantically Correct and Incorrect Gapping Structures in the Visual Modality.

			Range		95% Confidence Interval	
Component	*M*	*SD*	*Minimum*	*Maximum*	Lower	Upper
			Correct			
ELAN	-0.247	4.068	-6.011	6.321	-1.234	-0.740
CPN	-5.046	3.927	-10.745	2.030	-5.998	-4.094
N400	-2.345	5.180	-6.211	11.991	1.089	3.601
P600	6.337	6.097	-3.280	16.337	4.860	7.818
			Incorrect			
ELAN	-1.635	5.009	-11.155	11.122	-2.782	-0.488
CPN	-5.036	4.534	-13.778	-3.587	-6.076	-3.996
N400	-6.258	7.596	-8.123	18.498	-4.515	8.001
P600	11.889	9.193	-7.113	28.178	9.780	13.998

The N400 and P600 amplitudes for correct gapping structures in the visual modality are larger than the N400 and P600 amplitudes for the correct gapping structures in the auditory modality, and are within one standard deviation of each other. Amplitudes for the N400 and P600 components for correct gapping structures in the visual modality are even larger in comparison to the N400 and P600 amplitudes for incorrect gapping structures in the auditory modality.

Amplitudes for the ELAN, CPN and N400 components for correct gapping structures in the visual modality are larger than the amplitudes for all other conditions. The P600 amplitudes for incorrect gapping structures in the visual modality are considerably larger than the P600 amplitudes for all other conditions.

ANOVA

ANOVA showed significant amplitude differences for stimulus type across each component (ELAN, CPN, N400, and P600) and each condition, $F = 2.165$ (27, 181.714), $p = .002$. Post hoc *t* tests were performed to determine amplitude differences between specific stimulus types and modality variables.

Auditory and Visual. Table 3 shows the results of a one-tailed, paired samples *t* test. No significant differences were observed within the auditory modality between correct gapping structures versus incorrect gapping structures for N400 and P600 amplitudes. In contrast, significant differences were observed within the visual modality between correct gapping structures versus incorrect gapping structures for the N400 and P600 amplitudes (see Appendix D for a full table of paired samples tests).

Correlations. Correlations were noted in both the ELAN and CPN components. As the ELAN amplitudes for correct gapping structures increased, the amplitudes for incorrect gapping structures also increased, r = .576, p = .008. As CPN amplitudes for correct gapping structures increased in the auditory modality, the amplitudes for correct gapping structures also increased in the visual modality, r =.512, p = .030.

Table 3

Pairs from t Test Showing Significant Difference Between Stimuli Type of Modality

Component	Parameter 1	Parameter 2	*df*	*Std. Error Mean*	*t*	*p*
ELAN	Aud. Cor.	Vis. Cor.	17	2.300	-2.412	0.014
ELAN	Aud. Inc.	Vis. Inc.	19	2.230	-1.888	0.027
CPN	Aud. Cor.	Vis. Cor.	17	0.853	-2.637	0.009
CPN	Aud. Inc.	Vis. Inc.	19	1.719	-2.466	0.012
N400	Aud. Inc.	Vis. Inc.	19	2.419	-5.370	0.000
N400	Vis. Cor.	Vis. Inc.	17	1.869	-1.933	0.035
P600	Aud. Inc.	Vis. Inc.	19	3.185	-2.515	0.012
P600	Vis. Cor.	Vis. Inc.	17	2.444	-2.220	0.020

Topography

Auditory Correct. Figure 1 shows the scalp distribution for semantically correct gapping structures in the auditory modality. A left temporal negativity is seen beginning at about 400 ms through about 600 ms. Also a left posterior-parietal occipital negativity is seen beginning at about 550 ms and continuing through 1000 ms. There is no discrete maximum observed, but seems to asymptote between 800 and 1000 ms. Beginning at

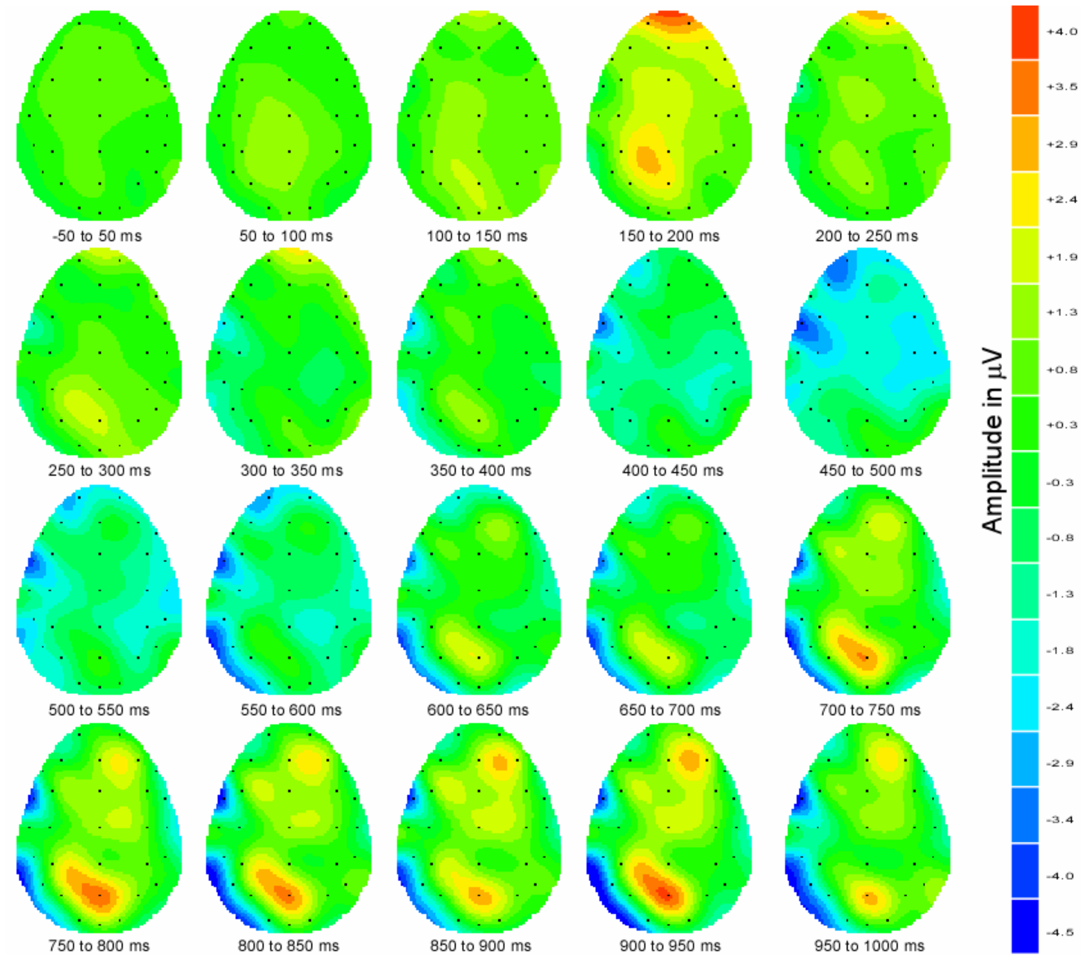

Figure 1. Scalp distribution for correct gapping structures in the auditory modality.

about 700 ms a posterior-central-parietal positivity is seen, which then continues through about 1000 ms with a maxima seen at about 900 to 950 ms.

Auditory Incorrect. Although the correct (Figure 1) and incorrect gapping structures (Figure 2) within the auditory modality generally elicit the same pattern, the incorrect gapping structures elicit a broader frontal and left temporal negativity beginning at about 300 ms, maximizing at about 500-550 ms, and diminishing through about 750 ms. Also,the posterior central activity, as seen for the correct gapping structures, is more broadly distributed by the incorrect gapping structures, and becomes somewhat distinct as two areas by 950 ms. Likewise, during this same time frame, there is a broader positivity on the right mid-central areas for the incorrect gapping structures.

Auditory Difference. The differences between the scalp distribution of the correct and incorrect gapping structures in the auditory modality are seen in Figure 3. Beginning at about 250 ms and continuing through approximately 750 ms, a rather large difference in scalp distribution is seen in the frontal areas. The largest difference is seen between approximately 500 and 550 ms. Subsequently, central-parietal activity is observed between approximately 900 ms and maximizing between 950 and 1000 ms.

Visual Correct. Figure 4 shows the scalp distribution for semantically correct gapping structures in the visual modality. There is an initial positivity in both the left and right occipital areas, which appears to be symmetrical from approximately 250 ms through 700 ms. Beginning at about 600 ms through 1000ms a frontal and left frontal positivity is observed. The magnitude of the positivity spreads across the scalp resulting

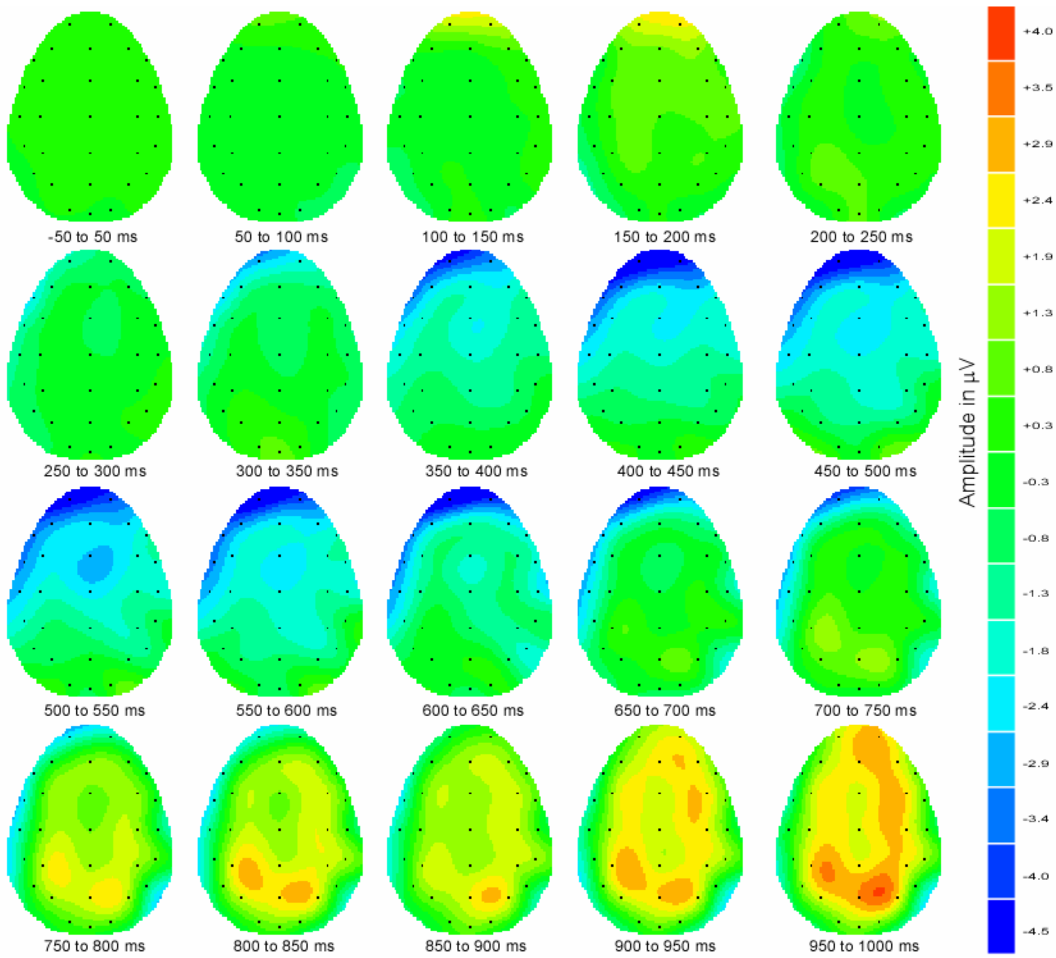

Figure 2. Scalp distribution for incorrect gapping structures in the auditory modality.

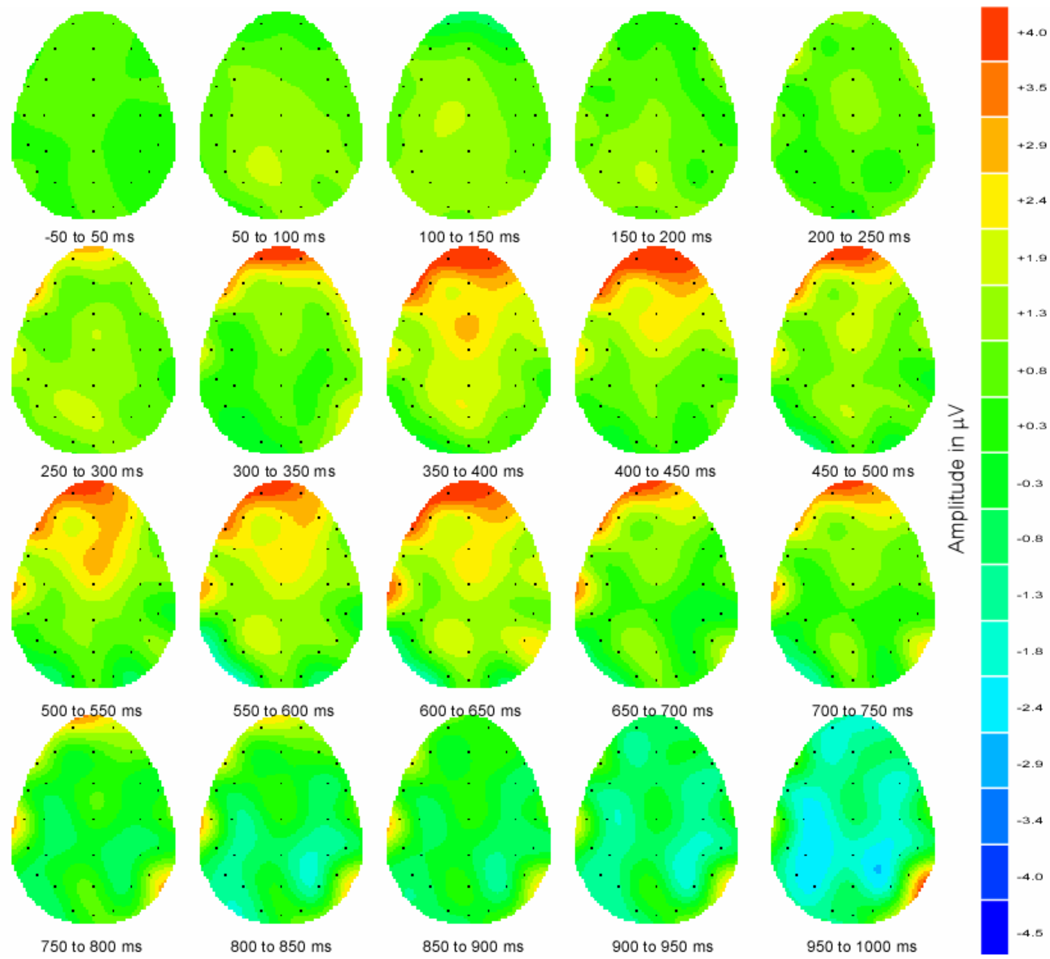

Figure 3. Scalp distribution differences between correct and incorrect gapping structures in the auditory modality.

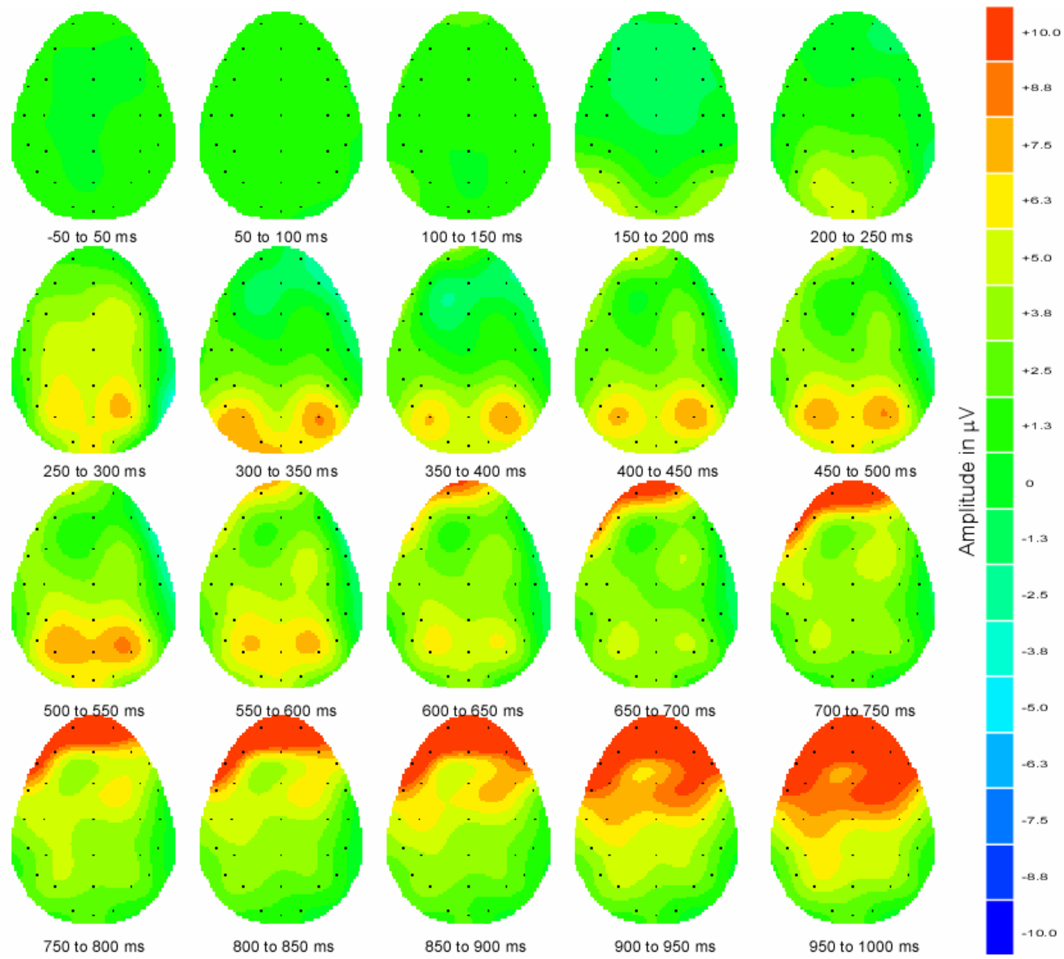

Figure 4. Scalp distribution for correct gapping structures in the visual modality.

in a symmetrical positivity within the frontal and the left, right, and central temporal areas.

Visual Incorrect. Figure 5 shows the incorrect gapping structures in the visual modality. It starts its initial positivity similar to that of the correct gapping structures, at about 600 ms, but over the right frontal areas. Similar to correct gapping structures, the spread of activity for incorrect gapping structures continues through 1000 ms and results in a more broadly distribution across the frontal and mid-frontal regions including the left, right, and central portions of the temporal areas. Again, similar to correct gapping structures, incorrect gapping structures elicit an occipital positivity from about 250 ms to about 600 ms. Besides this “reversal” in activity of the temporal lobes observed between 600 and 700 ms, for the incorrect gapping structures (Figure 5) a frontal negativity is also seen between 150 and 200 ms.

Visual Difference. Differences between the scalp distribution of the two visual conditions are seen in Figure 6. Differences are noted in the right temporal areas beginning at about 450 ms and continuing through about 950 ms. The maximum differences are seen over the frontal and right temporal areas from about 700 to 950 ms. Also, there is some slight increased activity over the left frontal-temporal areas beginning about 250 ms to about 400 ms, and then beginning about 550 ms through about 650 ms. This right temporal difference appears to be the most predominate processing difference seen between the two conditions in the visual modality.

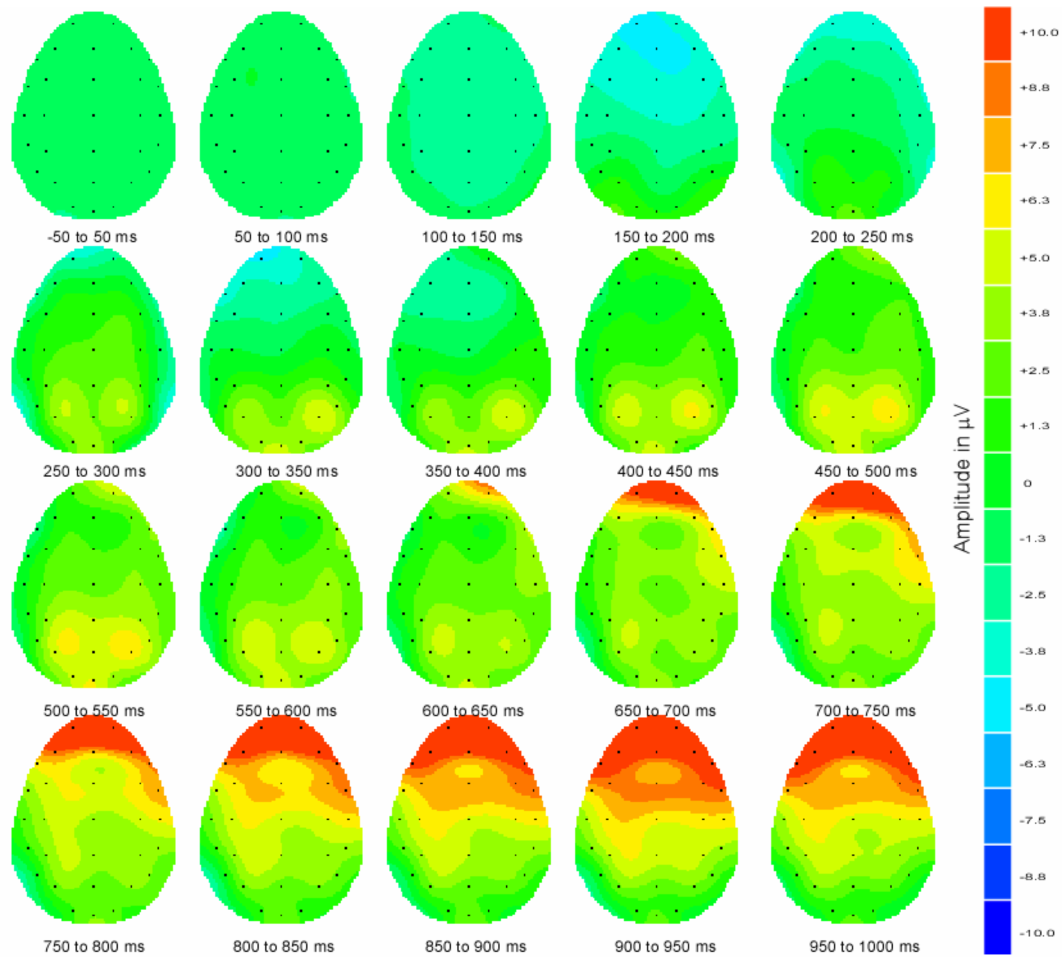

Figure 5. Scalp Distribution for incorrect gapping structures in the visual modality.

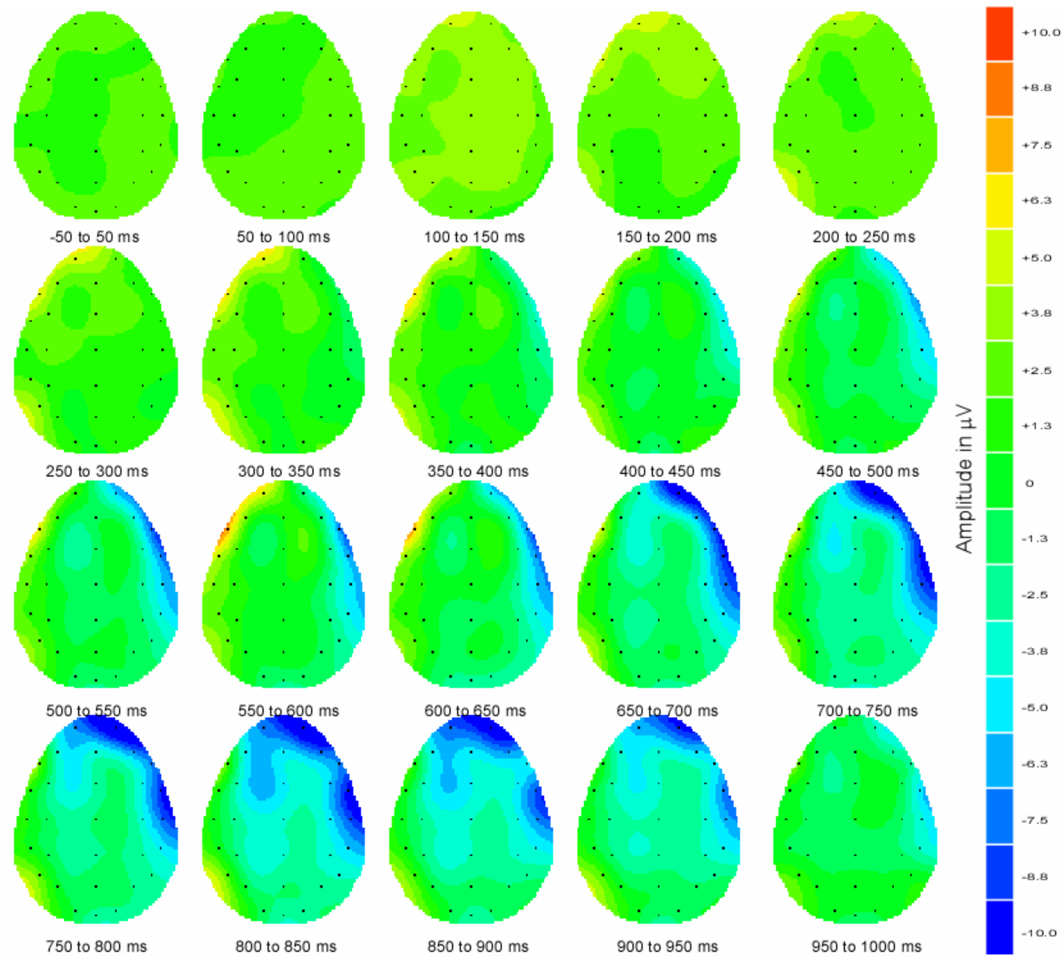

Figure 6. Scalp Distribution differences between correct and incorrect gapping structures in the visual modality.

Discussion

The N400 component is produced in response to semantically incorrect sentences, while the P600 component is produced in response to syntactically incorrect sentences. The results observed in this experiment show that listening to gapped, semantically correct and incorrect sentences spoken at normal rate and reading gapped, semantically correct and incorrect sentences at a normal rate elicit similar electrophysiological responses in both the N400 and P600 components. However, significant differences in amplitude and topography measures were noted between the correct and incorrect conditions and between modalities for various components (see Table 3).

Latency

Kaan et al., (2004) found that the N400 component followed by the P600 component were elicited at the head noun of the second noun phrase in the second conjunct clause when the noun was an implausible object for the gapped verb. In the present study, the N400 component was not observed for correct or incorrect gapping structures in the visual modality; however, the P600 was observed for both stimuli types in the auditory modality. The N400 and P600 components were observed for correct and incorrect gapping structures in the visual modality. The latency of the N400 component in the auditory modality and the P600 component in both the auditory and visual modalities appear time-locked to the word that renders the preferred structural assignment possible.

No significant difference in latency of the N400 in the auditory modality and P600 components in the auditory and visual modalities was noted between correct and incorrect gapping structures. Thus, correct and incorrect gapping structures in both the auditory and the visual modalities are identified at approximately the same time, indicated by a positivity at 600 ms after the head noun of the second noun phrase in the second conjunct clause. This point may be considered the time at which the processor attempts to integrate the missing verb into the critical noun phrase. Semantic integration difficulty is observed in the correct and incorrect gapping structures as reflected by the presence of the N400 component in the auditory modality, but absent in the visual modality. Consequently, similar semantic integration difficulties were not observed in the visual modality. The semantic integration difficulty, noted in the auditory modality, may in turn trigger syntactic revision processes, or an increase in syntactic integration difficulty in general, as reflected by the presence of the P600 component (Kaan et al., 2004; Münte et al., 1998).

The absence of N400 component, but the presence of the P600 component in the visual modality may indicate that the P600 component is triggered independently from the N400. The visual modality may recognize a gapping structure as a syntactic anomaly only, while the auditory modality recognizes a gapping structure as semantic anomaly and also a syntactic anomaly, triggering the N400 component before the P600. Perhaps gapping structures are first processed as semantic anomalies which in turn complicates the syntactic process. This may be indicated by the triggering of the P600 component only in the auditory modality. However, it may be that the P600 is actually triggered independently from the N400 component, indicating that gapping structures are processed as semantic and syntactic anomalies. The results of this study further substantiate the observations of Kaan et al. (2004) that the verb gap is recognized and reconstructed at the earliest possible occasion. This reconstruction process is different from the reconstruction of antecedents in other filler-gap constructions such as WH gaps (Kaan et al., 2004).

Amplitude

N400 Amplitude. In the present study, the N400 was elicited auditorily by gapped sentences with semantic errors with a mean latency of 419.42 ms and a mean amplitude of -7.29 μV. The N400 component was not observed in the visual modality in response to gapped sentences with semantic errors. This may suggest that gapping structures are processed in the visual modality only as syntactic anomalies. These results are in contrast with those of Osterhout and Holcomb (1993) and Balconi and Pozzoli (2004) who found that non-gapped sentences with syntactic anomalies elicited similar N400 amplitudes as those elicited by non-gapped, grammatically correct sentences in both the auditory and the visual modalities. Therefore, while the N400 and P600 are observed for various non-gapped, syntactic anomalies regardless of modality, the modality of stimulus presentation is a key factor in the processing of gapping structures with regard to the presence of the N400 component.

A greater N400 component was observed in the auditory modality for incorrect gapping structures versus correct gapping structures. However, amplitudes for incorrect gapping structures were within one standard deviation of those for correct gapping structures in the auditory modality. This may indicate that the gapping structures are recognized in the auditory modality, but not in the visual modality.

P600 Amplitude. A larger N400 and P600 amplitude would be assumed for sentences with semantic errors than for semantically correct sentences (Gunter & Friederici, 1999; Osterhout & Holcomb, 1992, 1993; Polich, 1985).This assumption was true in the present study as a larger P600 component was observed in the auditory modality for incorrect gapping structures versus correct gapping structures. However, the amplitudes were within one standard deviation of each other. No differences in amplitudes were noted for correct versus incorrect gapping structures in the visual modality. These results may indicate that the visual modality processes both correct and incorrect gapping structures as syntactic anomalies, while the auditory modality recognizes incorrect versus correct gapping structures. While gapping structures in the auditory modality are recognized as a syntactic anomaly, incorrect gapping structures trigger a higher level of analysis than correct sentences. We must keep in mind, however, that the P600 has been observed to be particularly induced by an acceptability judgment task (see Coulson et al., 1998; Hahne & Friederici, 2002) which was employed in this experiment.

ELAN Amplitude. The ELAN component was elicited auditorily by sentences with correct gapping structures in the present study (mean amplitude of -5.20 μV) and with incorrect gapping structures (mean amplitude of -5.76 μV). A small ELAN component was elicited visually by correct gapping structures (mean amplitude of -0.25 μV) and by incorrect gapping structures (mean amplitude of -1.63 μV). Within both modalities, the ELAN amplitudes for correct gapping structures appeared approximately equal to amplitudes for incorrect gapping structures. However, ELAN amplitudes for the visual modality were observed to be larger than amplitudes for the auditory modality. Incorrect gapping structures presented in the visual modality elicited the largest ELAN amplitudes. Gunter et al. (1997) observed that that ELAN was not affected by changes in syntactic complexity or by semantic errors, unlike the P600. They stated that the ELAN was a better indicator of syntactic analysis than the P600 and seemed to reflect a less complex syntactic analysis. A substantial ELAN component was observed in the present study in the auditory modality, but only a small ELAN was noted for the visual modality. The results of the present study may indicate that both correct and incorrect gapping structures are processed the same way within the modality. However, the auditory modality processes gapping structures as syntactic errors, while the visual modality does not place syntactic error with gapping structures. Observations of a possibly non-existent ELAN component in the visual modality may confirm the findings of Gunter et al., (1997), that the ELAN component is affected by syntactic errors versus semantic errors. A more substantial ELAN would be expected if gapping structures were truly processed as syntactic errors. These findings correspond with those of Kaan et al. (2004) who observed the CPN component in response to gapping structures rather than the ELAN component. The substantial ELAN component in the auditory modality suggests that either the auditory modality parses gapping structures as syntactic errors, or the ELAN is not syntax-specific as previously suspected.

CPN Amplitude. A CPN component was elicited auditorily by sentences with correct gapping structures in the present study (mean amplitude of -6.47 μV) and with incorrect gapping structures (mean amplitude of -9.74 μV). A CPN component was elicited visually by correct gapping structures (mean amplitude of -5.05 μV) and by incorrect gapping structures (mean amplitude of -5.04 μV). As with the ELAN component, the CPN amplitudes for correct gapping structures appeared approximately equal to amplitudes for incorrect gapping structures within both modalities. Amplitudes for correct gapping structures in the visual modality are slightly larger than amplitudes for correct gapping structures in the auditory modality. Likewise, amplitudes for incorrect gapping structures in the visual modality are larger than amplitudes for incorrect gapping structures in the auditory modality. The CPN may be related to the ELAN, which various researchers found in response to phrase structure violations (Friederici et al., 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). The presence of the CPN component may indicate that the determiner is initially interpreted as a phrase structure violation.

Topography

N400. A distinct N400 component was noted in the left temporal area for correct gapping structures in the auditory modality. Likewise, the N400 component was noted for incorrect gapping structures in the auditory modality. However, the N400 was more broad than the N400 elicited by correct gapping structures in the auditory modality and was located in the frontal and left temporal areas. Past research has indicated the findings of a consistent posterior distribution for the N400 component for non-gapping structures in both the auditory and visual modalities (Balconi and Pozzoli, 2004; Coulson et al., 1998;Kutas & Federmeirer, 2000). This area was considered as a primary area used for semantic-information elaboration. It is evident, that the presence of a gapping structure alters the processing of the information and shifts the distribution to a more left-frontal area.

No N400 component was observed in the visual modality for correct or incorrect gapping structures. This is in clear contrast with the Kaan et al. (2004) study which observed a central parietal N400 in the visual modality for incorrect gapping structures but not for correct gapping structures. Because the two studies were similar, it is not possible to account for the differences in the N400 results for the incorrect gapping structures. There is currently no research with which to compare the N400 response of auditory input of gapping structures.

P600. A distinct P600 component was observed for correct gapping structures in the auditory modality in the posterior central parietal area. The P600 was also noted for incorrect gapping structures in the auditory modality. However, again, the P600 was more broadly distributed than the P600 for correct gapping structures in the auditory modality. The P600 distribution began in the posterior central parietal area and separated into two distinct, more posterior areas. The P600 was observed in the visual modality for correct gapping structures in the frontal and left frontal areas. The P600 component was observed for incorrect gapping structures in the visual modality in the right frontal area. A study by Osterhout and Holcomb (1992) showed a P600 effect more widely distributed over the right hemisphere than the left in the auditory modality as compared with the visual modality Balconi and Pozzoli (2004) noted a generally more homogenous scalp distribution for the P600 component for auditory and visual non-gapped, grammatically incorrect sentences. Generally, a more posterior distribution for the auditory P600 as compared to the visual P600 has been observed for non-gapped, grammatically incorrect sentences (Hagoort & Brown, 2000; Osterhout & Holcom,1993). However, the variability of the P600 localization reported in the literature suggests that different neural sites are activated during processing of syntactic information rather than the use of a single neural process (Coles & Rugg, 1995).

CPN and ELAN. An early left-anterior negativity has been seen in response to phrase structure violation (Friederici et al., 1993; Neville et al., 1991). The ELAN component was observed in the present study between approximately 150 and 300 ms for incorrect gapping structures in the visual modality. This finding is in clear contrast with the Kaan et al. (2004) study which, instead, found an early centro-posterior negativity between 100 and 300 ms on post-gap determiners, followed by an increased fronto-central positivity between 300 and 500 ms. A delayed fronto-central positivity was noted in the present study beginning at approximately 600 ms and continuing well past 1000 ms for correct and incorrect gapping structures in the visual modality. This positivity was not noted in the visual modality for correct gapping structures or in the auditory modality. The early negativity may indicate that the visual system initially interprets the determiner as a phrase structure violation. The later fronto-central positivity may indicate that, with visual input, the occurrence of a gapped structure triggers the retrieval of the preceding verb information.

Modality Differences

Research has shown homogeneous ERP measures for the auditory and visual conditions (Balconi and Pozzoli, 2004; Osterhout & Holcomb, 1993). Thus, we can conclude that the N400 and P600 occur during both auditory language comprehension and reading. Previous research has also shown that the auditory conditions show differences between the semantically incorrect and correct conditions for the N400 component when compared with the visual modality. It is also suggested that the presences of the P600 component in response to both modality inputs indicates that the comprehension system uses a similar parsing strategy regardless of the modality (Balconi and Pozzoli, 2004).

Latency. No difference was noted with either the N400 or the P600 component between the latency of gapping structures presented auditorily and those presented visually. These modality-related results correspond with those found by several other researchers. Hagoort and Brown (2000) and Friederici, Hahne and Mecklinger (1996) reported that the onset of the P600, elicited by each of several different types of grammatical errors, remained almost identical across modalities. However, these results are in clear contrast with those found by Osterhout and Holcomb (1993) who reported a significantly earlier P600 component in response to various types of spoken syntactic anomalies.

Amplitude. Amplitude differences for the N400 component were not found in the present study between stimulus types within the auditory modality, contradicting hypothesis (Hagoort & Brown, 2000). However, these results parallel those found by Balconi and Pozzoli, 2004. The lack of significant differences within the auditory modality between correct gapping structures versus incorrect gapping structures for N400 and P600 amplitudes indicate that gapping structures interfere with the processing of sentences input auditorily. Gapping structures are processed the same way as incorrect sentences. Therefore, in the auditory modality gapping structures are recognized as incorrect.

However, significant differences for stimulus type were noted in the visual modality, again in line with the Balconi and Pozzoli (2004) study and in contrast with the Hagoort and Brown (2000) study. The significant differences observed within the visual modality between correct gapping structures versus incorrect gapping structures for the N400 and P600 amplitudes indicate that the visual system processes gapping structures differently than incorrect sentences. The visual modality does not place an error within the gapping structure and recognizes gapping structures versus semantically and syntactically incorrect sentences. Therefore, gapping structures do not seem to interfere with the processing of sentences input visually because of the differences observed between the correct and incorrect gapping structures.

Conclusions

Significant findings suggest that all gapping structures are processed at approximately the same time, regardless of the stimulus type or input modality. No differences in latency were observed for correct and incorrect gapping structures in either the auditory or the visual modality.

Analysis of the N400 component suggests that the auditory processing system recognizes gapping structures as distinct grammatical structures as opposed to semantic errors. The N400 component was not observed for correct or incorrect gapping structures in the visual modality, suggesting that the visual processing system does not recognize gapping structures as incorrect semantically.

The P600 component was observed in all four conditions. The findings suggest that the auditory processing system distinguishes between gapping structures and syntactic anomalies while the visual processing system recognizes gapping structures as syntactic anomalies rather than distinct grammatical structures.

The ELAN component was observed with approximately equal amplitudes for correct and incorrect gapping structures for both the auditory and visual modalities, indicating that correct and incorrect gapping structures are processed the same way within the modality. The much more substantial ELAN component in the auditory modality suggests that the auditory processing system recognizes gapping structures as syntactic errors or that the ELAN component is not syntax-specific as previously suspected.

The CPN component was also observed to be approximately equal for correct and incorrect gapping structures within the modality. CPN amplitudes are larger for correct and incorrect gapping structures in the visual modality than the auditory modality suggesting that the visual processing system interprets gapping structures as grammatical violations. The presence of the CPN the ELAN components may indicate that the determiner is initially interpreted as a phrase structure violation.

Gapping structures are processed semantically in the left temporal area in the auditory modality, while incorrect gapping structures elicit a more broadly distributed activity in the same area. The visual modality does not trigger extra semantic processing. Syntactic processing of correct gapping structures occurs in the central area in the auditory modality, with a more broad distribution of activity for incorrect gapping structures. Syntactic processing for the visual modality occurs in left frontal area for correct gapping structures and right frontal area for incorrect gapping. The visual processing system recognizes the gapping structures before any other processing system and integrates the missing verb information, with the early negativity in the left frontal area.

It is difficult to determine electrophysiological differences between the processing of gapping structures and the processing of semantic and syntactic anomalies due to the lack of non-gapped stimulus conditions in this study. Further study of gapping structures should include the comparison of ERP results of gapping structures with those of correct and incorrect non-gapping structures within the same subjects. This type of study would yield clearer comparisons and contrasts for gapping structures and semantic and syntactic anomalies.

While the study of the electrophysiological responses to gapping structures only provides an isolated look at language processing, it is a step that contributes to the further understanding of the brain and language. Continued research of other “isolated” language processing factors will provide professionals from the area of neurophysiology to speech-language pathology with a more complete picture of how language works. Understanding where and how grammatical forms are processed in the normal and disordered brain will lead to the trial, testing, and perfecting of new forms of language therapy, which will bring the miracle of language to all those who live in a world absent of meaningful and fulfilling communication.

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Appendixes

Appendix A

Informed Consent to Act as a Research Participant
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 processing of language by the brain in adults with normal or disordered language 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 and will be useful to professionals who are responsible for diagnosing and treating language disorders.

Procedures

I have been asked to participate in a research study conducted by Dr. David L. McPherson and /or such assistants as may be selected by him. I have been recruited for participation in this study because I am an adult with normal hearing, language, vision (or corrected-to-normal vision), and have no known neurological disorders.

The study will be conducted in room 111 of the John Taylor Building on the campus of Brigham Young University. Participation in this study, including orientation and testing, requires one 2-3 hour session. I may ask for a break at any time during testing. Basic hearing and vision tests will be administered. These procedures will take about an hour.

Surface electrodes (metal discs about the size of a dime) will be used to record electrical activity of my 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.

Language processing will be measured using an electrode cap, which simply measures the electrical activity of my 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.

I will wear the electrode cap while I listen to and read approximately 200 sentences. As I listen to and read each sentence the electrical activity of my brain will be recorded on a computer. I 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 I have 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 I 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 and vision. I will be notified if any clinical deficits are found in the areas of hearing and/or vision. I also understand that there may be no direct benefit to me. 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 I have a 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 me, other than reporting of test results without identifying information may be released without my 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 me for participation in this study. There is no treatment or intervention involved in this study.

The procedures listed above have been explained to me 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, Chair of Institutional Review Board, 422 SWKT, Brigham Young University, Provo, Utah 84602; phone (801) 422-3873; email: renea_beckstrand@byu.edu.

I voluntarily consent to participate in the study explained above.

____________________________	_____________
Signature of Participant	Date
____________________________	_____________
Signature of Witness	Date

Appendix B

Stimulus Sentences

Visual

1. Scott asked his mom for a new bike, and Calvin the operator for the phone number.
2. Mary braided the hair of her mother, and Paula the hand of her father.
3. My uncle teaches French, and my aunt math at a local school.
4. Larry filled a glass with ice cubes, and Todd a knife with a sharp blade.
5. My sister is allergic to dust, and my brother to cats with long hair.
6. Sally tried on the blouse with the bonnets, and Tracy the suitcase with the leather pockets.
7. Nancy played with the child, and Martha the video game over the weekend.
8. John spread a bagel with jelly, and Ellen a glass of milk.
9. Frank changed the lamp's light bulb, and Liz the baby's clothes.
10. The nurse injected the antibiotics, and the surgeon the scalpel from the tray.
11. Tracy mailed the letter to George, and Julie the package to Lisa.
12. Fred wrote with his new pens at work, and Cindy her new telephone at home.
13. The mailman gave the package to me, and the neighbor the dog to my sister.
14. Barbara climbed the tree in the garden, and Leo the flowers in front of the house.
15. Candice wrote a song for art class, and Ryan a poem for English class.
16. Lee donated the clothes to the homeless shelter, and Jessica the cookie to the child.
17. Jane held crying baby, and Tom the bag of groceries.
18. David wore his new shoes to school, and Ron his new computer to work.
19. Gina made a card with paper and markers, and Ben sandwich with bread and meat.
20. Dana ripped the paper airplane, and Tom the wooden horse.
21. Linda sketched the bugs on the stones, and Tom the vase on the table.
22. Harry snapped the wire across the floor, and Carl the staircase to the basement.
23. Peter pulled the school's fire alarm, and Dan the girl's hair.
24. My mother smelled the beautiful flowers on the table, and my father the great baseball
    game on the television.
25. Annie made a sculpture with sharp tools, and Rita a drawing with pencils.
26. Matt surfed on the waves in the ocean, and James on the skateboard in the road.
27. Ron took the planks for the bookcase, and Bill the hammer with the big head.
28. Kevin swallowed the pill in his mouth, and Mario the money in his wallet.
29. Nathan liked the cake his mother made, and Adam the card his sister made.
30. Jenny polished the silver in the kitchen, and Ken the carpets in the living room.

Auditory

1. Lisa liked the aria by Mozart, and Marc the landscape by Rembrandt.

2. Bill did the crossword puzzle, and Paul the sports section in the morning paper.
3. Aaron ate a banana during recess, and Taylor a hot dog during lunch.
4. Sam swam in the ocean, and Jim in the forest last weekend.
5. Phil attached the paper to the bulletin board, and Kim the mirror to the wall.
6. Peter cooked the steaks on the grill, and Liz the ketchup on the table.
7. Lucy got three pairs of socks, and Bertha a picture in a nice frame.
8. Ella sang a song about a love affair, and Helen a story about a little bird.
9. The English teacher taught the story before recess, and the math teacher subtraction after recess.
10. Barb applied some makeup before dinner, and Suzie a dress before the dance.
11. Leo prepared the carrots for the stir fry, and Sally the steak for the grill
12. Eliot blew the trumpet, and Joe the drums and the guitar.
13. William wrote a novel on his computer, and Hal a number on his wall.
14. Pat emptied the cabinets in the kitchen, and Ted the floor in the hall.
15. My cousin jumped into the pool, and my brother over the hurdle.
16. My mother drove to the store in the car, and my father to work on foot.
17. Sue looked at the vase with the flowers, and Joe at the pillow on the couch.
18. Nancy drove the car in the driveway, and Bob the dishes in the sink.
19. Jack put some water in a pitcher, and Pam some sandwiches on a plate.
20. Nancy baked the brownies in the oven, and Bonnie the juice in the fridge.
21. Jeff painted the door to the pantry, and Paul the walls of the bedroom.
22. Brenda shredded the forms in the box, and Carrie the typewriter on her desk.
23. David played in the pool in the afternoon, and John the yard in the evening.
24. Mike chopped the wood in the shed, and Wilma the paper in the attic.
25. Harry groomed the horse with the long mane, and Lisa the dog with the curly tail.
26. Bill poured the cream into the bowl, and Anna the bread on the plate.
27. My grandmother closed the envelope for the card, and my grandfather the door for the garage.
28. Jim started the car at noon, and John the radio at midnight.
29. Nan put the poster on the wall, and Minnie the clothes on the bed.
30. My brother wiped the counter with the rag, and my sister the carpet with the vacuum.

Appendix C

Participant Checklist

Testing Session

Pre-test set up

- Turn on all three red power switches on the Tucker-Davis equipment
- Wait for SynAmps to show SN1/SN2
- Turn on Neuro Scan computer
- Turn on Stim computer
- Turn on Audiometer
- Open up Neuro Scan software
    - Open calibration screen on NeuroScan
- On Stim computer, open Stim program
- Turn on audiometer
- Biological check on audiometer
- Record participant information in lab book
- Set out supplies
    - Syringe
    - Syringe tip (blunt 16 gauge needle)
    - Alcohol wipe
    - NuPrep skin prepping gel
    - Electrode gel
    - Surgical tape strips (6) about two inches long
    - Thin wooden dowel
    - Clean cloth towels (2)
    - Electrode cap
    - Facial and ear electrodes
        - 2 white electrodes
        - 2 black electrodes
        - 2 gray electrodes
        - 2 purple electrodes
    - Measuring tape for cap

- Put surgical tape strips on facial electrodes and poke holes through the tape with the dowel
- Fill syringe with gel

Once participant arrives

- Participant voluntarily signs consent form and agrees to be a participant
- Audiogram
- Vision Screening

- Collect and analyze a conversational sample
- File the forms, and screening information
- Give an explanation of the study and instruct patient
- Place cap on the head of the participant
- Fill the cap electrodes with electrode gel via the blunt needle
- Clean skin where face and ear electrodes will be placed with alcohol wipe
- Clean the face with prepping gel and cotton swab where free electrodes will be placed
- Wipe off any excess prepping gel with clean cloth
- Apply prepared electrodes on face and ear lobes
- Fill facial electrodes with electrode gel
- Give tokens to participant
- Take participant into sound-attenuating booth and ask him/her to sit down
- Replace ground with electrode cap adapter on SynAmps 150 gain amplifier
- Plug the electrode cap into SynAmps 150 gain adapter
- Explain the usage of the response pad that will indicate psychophysical response
- Check electrode cap impedance and adjust electrodes with impedance above 10,000 ohms
- Give participant tokens
- Run sets of stimuli
- Once stimuli are complete, remove electrode cap and facial electrodes
- Give the participant a wet warm cloth to remove excess gel from the face
- Give participant incentive

Once participant departs:

- Wash free electrodes with soap and water
- Soak electrode cap in soapy water for 30 minutes
- Clean out electrode cap electrodes
- Set electrodes and electrode cap out to dry
- Turn off computers and equipment
- Turn off lights in booth
- Record any additional information in lab notebook as needed
- Record raw data into data analysis spreadsheet

Appendix D

Paired Samples Test

Paired Samples Test

Component	Parameter 1	Parameter 2	*df*	*Std. Error Mean*	*t*	*p*
ELAN	Aud. Cor.	Aud. Inc.	19	1.696	0.480	.637
CPN	Aud. Cor.	Aud. Inc.	19	7.634	1.645	.116
N400	Aud. Cor.	Aud. Inc.	19	10.096	0.297	.770
P600	Aud. Cor.	Aud. Inc.	19	9.899	-0.144	.887
ELAN	Vis. Cor.	Vis. Inc.	17	1.347	0.956	.352
CPN	Vis. Cor.	Vis. Inc.	17	1.343	-0.030	.977
N400	Vis. Cor.	Vis. Inc.	17	1.869	-1.933	.070
P600	Vis. Cor.	Vis. Inc.	17	2.444	-2.220	.040
ELAN	Aud. Cor.	Vis. Cor.	17	2.299	-2.412	.027
CPN	Aud. Cor.	Vis. Cor.	17	0.853	-2.637	.017
N400	Aud. Cor.	Vis. Cor.	17	2.103	-4.499	.000
P600	Aud. Cor.	Vis. Cor.	17	2.268	-1.667	.114
ELAN	Aud. Inc.	Vis. Inc.	19	2.231	-1.888	.074
CPN	Aud. Inc.	Vis. Inc.	19	1.719	-2.466	.023
N400	Aud. Inc.	Vis. Inc.	19	2.419	-5.370	.000
P600	Aud. Inc.	Vis. Inc.	19	3.185	-2.515	.021