Event Related Potentials: A Study of the Processing of Gapping Structures in Adolescents

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EVENT RELATED POTENTIALS: A STUDY OF THE PROCESSING
OF GAPPING STRUCTURES IN ADOLESCENTS

by

Michelle M. Nishida

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

Master of Science

Department of Audiology and Speech-Language Pathology
Brigham Young University
December 2005
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As chair of the candidate’s graduate committee, I have read the thesis of Michelle M. Nishida in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

EVENT RELATED POTENTIALS: A STUDY OF THE PROCESSING OF GAPPING STRUCTURES IN ADOLESCENTS

Michelle M. Nishida

Department of Audiology and Speech-Language Pathology

Master of Science

Many questions remain unanswered regarding the intricacies of the human brain, especially with regard to the complexities of language processing. One essential component of human sentence processing is the ability to detect, decipher, and recover from errors in the interpretation of both verbal and written language. This process of repair of ungrammatical sentences and revision or reinterpretation of ambiguous sentences has been studied extensively in recent years. A variety of tools have been developed, including the use of event-related potentials (ERPs) in order to assess how language is processed and developed, and to help better identify the nature of these processes. The purpose of this study was to compare event-related potential effects of speech processing of spoken and written sentences containing both incorrect and correct semantic and syntactic information. Specifically, sentences containing correct and incorrect gapping structures, each with a “missing” verb, were presented along with other
grammatical and ungrammatical sentences in order to elicit and measure the P300, N400, and P600 amplitudes and latencies. The aim was to determine some of the commonalities and differences in these electrophysiological responses via the auditory and visual modalities. Two experiments were conducted with each participant, one in the auditory modality, and one within the visual using two sets of stimuli. Amplitude and topography differences were noted within and between modalities for each of the components (P300, N400, and P600), as well as between stimulus types. Significant findings suggest that in the adolescent population, incorrect gapping structures are generally processed as semantic errors, as evidenced by the N400 response, followed by the P600 response in both the auditory and visual modalities. The exact nature of the P600 component within gapping structures remains unclear. Of particular interest was the involvement of the occipital area of the brain for the processing of gapping structures. Minimal differences were noted overall between adolescents and the adult populations.
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Introduction

Many attempts have been made to determine the characteristics of the brain’s language processing system through various methods and techniques. This complexity can be analyzed partially using event related potentials (ERPs), which can be defined as minute voltage fluctuations of the electrical activity produced by the neurons in the brain that are recorded from various locations on the scalp (Featherston, Gross, Münte, & Clahsen, 2000). Canseco-Gonzalez (2000) defined ERPs as brain electrical activity time-locked to some external motor or cognitive event. In order to produce and understand language in real-time, the human brain is required to compute and carry out very rapid, demanding, and complex processes. ERPs have provided useful information in the study of language processing in the brain for more than twenty years, and have been used in the study of the brain’s response to visual and auditory stimuli as well as changes from one stimulus type to another (Kutas & Hillyard, 1980a, 1980b, 1980c, 1984).

Previous studies utilizing ERPs have centered around three major components: a negativity around 400 ms distributed over the centroparietal areas of the scalp, named the N400 component, found to be elicited by semantically related stimuli (Gunter & Friederici, 1999); an early left anterior negativity (ELAN) observed between 200 and 400 ms, correlated with primary syntactic processes; and a late centroparietal positivity, or P600, which does not have a clearly defined peak, but has a midpoint that occurs at approximately 600 ms poststimulus and is attributed to secondary syntactic processes (Friederici, 1997).

Most of the ERP studies focusing on the N400 and the P600 have utilized visual stimuli with adult participants (Gunter & Friederici, 1999; Gunter, Stowe, & Mulder,
However, recent studies have begun to focus more on auditory stimuli (Federmeier, McLennan, De Ochoa, & Kutas, 2002; Swaab, Brown, & Hagoort, 2003). Further, most of the research that utilizes ERPs in general has focused on adults with normal language (e.g., Canseco-Gonzalez, 2000; Kutas & Hillyard, 1983). Also, 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).

Research strongly suggests that as more ERP data are accumulated concerning normal language processing, pathological deviances will be more reliably diagnosed (Friederici, 1997). Since the N400 and P600 waveforms have been observed in response to various sentence structures containing either semantic or syntactic anomalies, the present study used the N400 and P600 ERP components to evaluate and provide normative information on the semantic and syntactic processing of language in adolescents with normal language. Occurrence, latency, amplitude, and topographic information were gathered from participants 14 to 18 years of age with normal language
skills using both grammatically correct and incorrect stimuli containing gapping structures.

Review of Literature

Event Related Potentials

ERPs measure changes in brain electrical activity that are associated with a sensory or psychological process (Picton & Stuss, 1984). The use of the ERP technique rests on the assumption that different cognitive processes are mediated by differential patterns of brain activity. Thus, distinct ERP patterns can be used to investigate separate linguistic representational levels based on their functional polarity (positive or negative), amplitude (peak height), latency (time in milliseconds relative to the onset of a stimulus), and distribution (Canseco-Gonzalez, 2000). These attributes are recorded from electrodes placed across the scalp. ERPs reflect the electrical activity of the brain time-locked to the presentation of a given target averaged over several instances of the same event (Friederici, 1997). Averaging is necessary in order to increase the signal-to-noise ratio for the brain activity and the events not of interest. Electrical recordings are taken at the same point in time in response to recorded events. This facilitates the recognition of the ERP, as it remains constant throughout the averaging process (Friederici, 1997; Hillyard & Kutas, 1983; Picton & Stuss, 1984).

Other brain imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have done much to enhance existing knowledge about the brain regions involved in the processing of language. They have very good spatial resolution, though are much less precise in their temporal resolution. It has also been suggest that the technique of intersubject PET image averaging may be
inappropriate due to intersubject variability (Steinmetz & Seitz, 1991). Thus when focusing on the temporal aspects of the activation of different subcomponents during online language processing, ERPs are the only noninvasive techniques available (Friederici, 1997), especially suited for a child population.

**ERP Measurement**

In order to evaluate cerebral activity in connection with language processes, ERPs are measured by four different aspects: topographic location, latency (time in milliseconds relative to the onset of the stimulus), polarity (positive or negative), and amplitude (Friederici, 1997). ERPs are scalp-recorded and reflect the sum of simultaneous postsynaptic activity of many neurons. ERPs have been commonly divided into two subtypes: exogenous, which have an earlier onset than other components, occurring before approximately 80 ms post-stimulus, and endogenous components. Exogenous components 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 most affected by psychological state. They are longer latency components 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). Since different attentional states over various tasks have different effects on ERPs, comparisons must be
made across studies. 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.

Other brain activity that is not time-locked to particular events of interest produces noise that interferes with obtaining reliable measures. This artifact activity is described as frequencies that are outside those of interest to the researcher. In general, an averaging procedure can be used to increase the signal-to-noise ratio for the events of interest (Friederici, 1997). Artifacts are caused by muscle movement rather than brain activity. In ERP studies, movements of the eyes and eyelids are two major sources of artifact contamination. 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 for managing these artifacts must be considered, each of which includes disadvantages. First, researchers can instruct the subjects to resist blinking until the measurement has been taken, instructing the subjects to gaze at the fixation point and
only blink between tasks. Since this approach places an additional demand on the subject, it may interfere with overall performance. A second possible method includes discarding 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, including the young and the aged, who 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). The latter is the preferred method for the present study.

*Long Latency ERPs*

ERPs occurring after approximately 80-200 ms post-stimulus onset are considered longer latency ERPs (McPherson & Ballachanda, 2000). Endogenous potentials occur with, and are sensitive to, processing demands and the attentional state of the participant (Picton & Stuss, 1984). The N400, the early left anterior negativity (ELAN), and the P600 are three long latency ERPs associated with language processing. The N400 typically occurs as the most negative peak at approximately 400 ms post-stimulus (Kutas & Hillyard, 1980a, 1980b, 1980c, 1984; McPherson & Ballachanda, 2000). It has been associated with lexical-semantic processing and is elicited by sentences with incorrect or unexpected semantic relations (Attias & Pratt, 1992; Bentin, Kutas, & Hillyard, 1993; Fujihara, Nageishi, Koyama, & Nakajima, 1998; Gunter et al., 1997; McPherson &
Ballachanda, 2000). 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 300 to 800 ms post-stimulus peaking at a midpoint of 600 ms (Osterhout & Holcomb, 1992). The P600 is a positive long latency ERP and has a duration of several hundred ms with a centroparietal positivity (Osterhout, 1997). The ELAN typically occurs between 200-400 ms post stimulus onset and may be associated with syntactic processing. It is usually only seen with outright syntactic violations, in particular, those that disrupt first-pass parsing processes, or word category violations (Friederici, 1997). Both the ELAN and the P600 have been elicited by syntactic processing (Friederici et al., 1993; Gunter & Friederici, 1999; Gunter et al., 1997; Osterhout, 1997; Osterhout & Holcomb, 1992).

*N400 as a Function of Semantic Processing*

The N400 can be elicited by both visual and auditory stimuli (Bessen, Faita, Czternasty, & Kutas, 1997; Friederici, 1997; Kutas & Hillyard, 1980a, 1980b, 1980c, 1983, 1984) and is understood to be elicited in response to semantic errors (Federmeier et al., 2002, Swaab et al., 2003). Kutas and Hillyard conducted several studies in which the N400 was observed. Two of the studies conducted by Kutas & Hillyard (1980a, 1980c) indicated that the N400 was affected by semantic errors. They also noted a late positive potential elicited by the stimuli. At that time, however, the P600 was not defined. They observed that the N400 has been found to appear with a semantically incorrect word was substituted within or at the end of a sentence using visual sentence stimuli (Kutas and Hillyard 1980a, 1980b, 1980c, & 1984), eliciting an enhanced negative peak at
approximately 400 ms post stimulus. In several of the studies (1980b, 1980c, 1984), they observed an inverse relationship between the amplitude of the N400 and the semantic appropriateness of the stimulus word.

In two studies, Kutas and Hillyard presented the final words of sentences (some ending with a semantically inappropriate word) in a large, bold-faced font in comparison to the normal typeset of the rest of the sentence, changing the presentation of the sentences semantically and visually (1980a, 1980c). Sentences that ended with a semantically inappropriate word elicited a strong N400 peak (Kutas & Hillyard, 1980a, 1980c).

Polich (1985), however, questioned the evidence presented by Kutas and Hillyard that the N400 is a function of semantic processing. Two different types of stimuli were presented visually to participants. The first set of stimuli included word series with an occasional semantically inappropriate word. The second set of stimuli used the same sentences as those used by Kutas and Hillyard (1980b). The participants were asked to perform both a selective and active attention task. In contrast to Kutas and Hillyard, Polich found that the N400 was elicited by word series and sentences ending in both semantically appropriate and inappropriate words. Additionally, the N400 was followed by a positive component during the active participation task. Polich concluded that the effect may also be attributed to the brain’s overall capability to comprehend complex relationships rather than a distinctive response to semantic incongruities.

Typicality and Semantic Priming of the N400

Stuss, Picton, and Cerri (1988) conducted a study which confirmed the involvement of the N400 where participants judged the “typicality” of a word, or how well a stimulus
word fit into a particular category. It was observed that the greater the atypicality, the greater N400 amplitude, which was independent of occurrence of usage and elicited at approximately 400 ms post-stimulus. A longer N400 latency was found for high usage atypical words as compared to low usage atypical words, supporting the idea that the N400 reflects lexical access. It appears that the N400 acted as a representation of lexical access or how easily and quickly words were accessed (Attias & Pratt, 1992). The presence of a late positive component (LPC) was another finding in the Stuss et al. (1988) study. The LPC occurred at approximately 745 ms post-stimulus and was believed to be elicited by infrequent stimuli or as a result of, “…how active the stimulus is in long-term memory” or the “analysis of stimulus meaning through access to long-term memory” (p. 269-70).

The N400 was further explored for the effects of semantic priming, which appears to affect the N400 component. Semantic priming is defined as the presentation of a word in a semantically appropriate context. Researchers have observed that the use of semantic priming increases the speed and accuracy of semantic processing (Bentin et al., 1993; Mitchell, Andrews, & Ward, 1993).

Radeau, Besson, Fonteneau, and Castro (1998) used ERPs to examine auditorily presented semantic, phonological, and repetition priming for words. They found 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. The largest peaks were elicited when the word was preceded by an unrelated word.

Fujihara et al. (1998) endeavored to combine both semantic priming and typicality and concluded that the category is based on a category prototype and categorization is
based on how similar a target item is to the category prototype. It was noted that the use of typical words within a category acted as semantic primes for typical target words. They concluded that atypical target words were processed slower than typical target words, however, because they were not primed by typical words in the same category.

**N400 and Ambiguous Words**

Class-ambiguous words (nouns or verbs) are those that have the same form, but may have two or more meanings. Federmeier, Segal, Lombrozo, and Kutas (2000) assessed word class processing in a study using visually presented stimuli sentences containing some class-ambiguous words. 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 to nouns. Ambiguous items, however, elicited a greater negativity when used as nouns. Unambiguous nouns also elicited a greater negativity than unambiguous verbs. Unambiguous words, embedded in an incorrect context (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.

**N400 and Visual versus Auditory Stimuli**

The N400 component has been elicited in the visual and auditory modalities (Holcomb & Neville, 1990; McCallum, Farmer, & Pocock, 1984). Connolly, Byrne, and Dywan (1995) and Byrne, Dywan, and Connolly (1995a, 1995b) conducted three related N400 studies using a combination of auditory and visual stimuli. The results of these studies indicated that the N400 could be elicited by semantic errors in both child and
adult participants. A large N400 amplitude, however, was only elicited when the vocabulary was understood by the participants.

The N400 has been shown to be evoked by semantic anomalies across many different languages (Friederici, 1997) such as English, French (Besson & Macar, 1987), Dutch (Brown & Hagoort, 1993), and German (Friederici et al., 1993; Munte, Heinz, & Mangun 1993). One difference in response for auditory versus visual stimuli includes an earlier and more prolonged effect of the N400 for auditory presentation, slightly lateralized to the right hemisphere (Holcomb & Neville, 1990).

**N400 Summary**

In summary, the amplitude of the N400 has been shown to be smaller for semantically primed words, words with greater typicality, function (as opposed to content) words, and a mismatch between auditory and visual stimuli. Though several variables may affect the N400 ERP component, it is generally accepted to be associated with semantic processing. ERP research has extended to the study of other language processing parameters, such as syntactic errors, in order to understand how each ERP component relates to language processing (Gunter & Friederici, 1999; Kaan & Swaab, 2003; Osterhout, 1997).

**Syntactic ERP Components—the P600 and P300**

Until the appearance of the N400, the P300 had been widely accepted as being the component elicited by a task-relevant, irrelevant, or unexpected event. As discussed previously, the N400 has more specifically been found to be elicited by unexpected semantic occurrences (McCallum et al., 1984). The amplitude of the P300 has been found to vary as a function of subjective and objective stimulus probability, task relevance of
the stimulus, and information transmission. The latency is thought to reflect the time taken for stimulus evaluation. With this in mind, some researchers have argued that the P600 is related, or even identical, to the P300 (Münte et al., 1998). Others have argued that they are neurally and functionally distinct (Osterhout, 1997).

Osterhout and Holcomb (1992) succeeded in distinguishing unique ERP responses to syntactic versus semantic anomalies. Their stimuli utilized garden-path sentences containing temporary syntactic ambiguity. When the syntactic representation not “preferred” by the parser is presented, the human brain backtracks and reanalyzes the sentence. The researchers found that the electrophysiological marker of the garden-path was a separate response from the N400 component. Results showed that a widely distributed positive component was elicited by words inconsistent with the “preferred” structural analysis of the sentence. There was no clearly defined peak, but its midpoint rested at approximately 600 ms poststimulus, warranting the name P600.

Osterhout and Holcomb (1993) concluded that the P600 seems to act as an electrophysiological marker of the syntactic garden-path effect, and is clearly distinct from semantically inappropriate response, namely, the N400. A follow-up experiment was conducted to replicate the finding of P600 in relation to syntactic anomaly. This study concluded that the P600 is a distinct response from the N400 and indicates the syntactic garden-path effect. Similar results have been reported in association with other types of garden-path sentences (Osterhout, et al., 1994; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995).

Like the P600, the P300 is a centroparietal component. Canseco-Gonzalez (2000) has found that the P300 can be elicited by a variety linguistic and non-linguistic events,
and are especially linked to the occurrence of unexpected (Osterhout, 1997) and task-relevant stimuli. Osterhout and Holcomb (1993) have suggested that the P600 is a member of the P300 family, and others have found that both the P600 and P300 components can be elicited by an unexpected event (Gunter et al., 1997). Münte et al. (1997) concluded that the P600 reflects a recomputation mechanism necessary to construct meaningful representations when the human brain encounters an error during sentence processing.

Visual versus Auditory Modality for P300 and P600

The P300 component was studied in females ages 7 to 20 in both the visual and auditory modality by Johnson (1989). He found that auditory and visual P300 latencies, but not amplitudes, changed at significantly different rates over this age range. Latencies in the auditory modality showed a relatively abrupt change around the age of 12. After that age, P300 latencies only minimally changes, and were essentially at their adult levels. The P300 latencies in the visual modality, however, showed a smaller and more steady decrease with age. P300 latencies in the visual modality were longer than auditory P300s present in older children. This study confirmed that P300 activity is not independent of modality.

Osterhout and Holcomb (1992, 1993) conducted two studies using identical stimuli (one in the visual and the other in auditory modality) in order to test the reliability of the N400 and P600 waveforms across modalities. The P600 was elicited by syntactically ambiguous phrases (the garden-path effect) by both the visual and auditory modality. They found that stimuli presented auditorily elicited a P600 with an earlier onset than did visual stimuli. When presented auditorily, syntactically anomalous words elicited a left
hemisphere negativity that was longer in duration and more pronounced. Since the P600 effect was elicited by the same words in both modalities, Osterhout and Holcomb (1993), concluded that language processing occurs with the same parsing strategy over both modalities.

Hagoort and Brown (2000) also compared the P600 component across input modalities and hypothesized that the P600 is a more complex component consisting of two aspects of the parsing process. The researchers found that the P600 consisted of two parts, the first occurring between 500 and 750 ms 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 results for both modalities were very similar though the study found 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, and support the hypothesis that reading and listening share central aspects of sentence processing.

Specificity of the P600

Some researchers have concluded that the P600 is specific to syntactic processing of language (e.g., Hagoort et al., 1993; Osterhout & Mobley, 1995). Other ERP research, however, does not concur with this conclusion (Gunter & Friederici, 1999; Gunter et al., 1997; Kaan & Swaab, 2003; Münte et al., 1998). It is important to note problems that were found upon further examination of other studies evaluating syntactic and semantic violations that did not report a P600 (e.g., Kutas & Hillyard, 1983). Some of the problems found in the studies include presenting 30 or fewer trials for each condition,
using an insufficient number of participants, or not assessing the epoch containing the P600.

Münte et al. (1998) conducted a study comparing responses elicited by visually presented semantic errors, orthographic errors, and morpho-syntactic errors. The findings of this study questioned the idea of the P600 being elicited exclusively by syntactic anomalies. Semantic, orthographic, and syntactic violations all elicited similar positive waves occurring at approximately 600 ms post-stimulus. Patel, Gibson, Ratner, Besson, and Holcomb (1998) endeavored to determine how the P600 would differ in response to language incongruities in comparison to musical incongruities. The researchers suggest that the P600 component reflects the use of a processing mechanism shared by linguistic and musical processes and attribute the P600 component to a structural integration process rather than a pure reflection of syntactic processing.

*Role of ELAN in Syntactic Processing*

Syntactic anomalies not only elicit a positive ERP component peaking at approximately 600 ms post-stimulus, but also evoke the presence of the ELAN. Canseco-Gonzalez (2000) found that an early negativity (i.e., ELAN) was elicited by syntactic anomalies (e.g., subcategorization, and phrase structure) as well as morphosyntactic violations (e.g., verb number and subject-verb agreement), and is noticeably distinct from the negativity elicited by semantic anomalies (N400; Gunter et al., 1997). It was noted that the ELAN exhibits a more frontal distribution and a smaller amplitude than the N400 (Canseco-Gonzalez, 2000).

Gunter et al. (1997) conducted a study in which syntactic errors were used to elicit the ELAN. Since the ELAN, unlike the P600, was not affected by changes in syntactic
complexity or semantic errors, it was concluded that the ELAN was “more specialized for syntactic analysis” and seemed to reflect a less complex syntactic analysis (p. 670).

**Gapping**

An ellipsis refers to an omission of a grammatical constituent found in common language that involves missing words or phrases from the auditory or written form, but still contributes to the interpretation of the sentence (Kaan, Wijnen, & Swaab, 2004). The three categories of ellipsis include initial ellipsis, medial ellipsis, and final ellipsis, and are determined according to where the ellipsis, or omission, occurs within the construction (Greenbaum & Quirk, 1990).

Gapping is a type of ellipsis (Kaan et al., 2004) that deletes identical elements (usually a finite verb) within the second of two conjoined sentences (Carlson, 2001). A well-formed gap must consist of flanking material, which appears to play no crucial role in the process of forming a verb phrase ellipsis (Lobeck, 1995). Jackendoff (1971 as cited in Lobeck, 1995) outlined 4 differences between a gap and an ellipsis. First, a gap must be flanked by lexical material, but an ellipsis can be phrase-final. Second, 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. Third, a gap cannot precede its antecedent, but an ellipsis can precede its antecedent under certain conditions. Finally, a gap need not be a phrase. An ellipsis must be a phrase.

Due to the missing constituent in many gapped phrased, these types of sentences cannot be processed by the human brain immediately. Instead, it is held in working memory until the brain can process the nature of the missing element (Felser, Clahsen,
and Münte, 2003). A verb gap only omits elements from one of the two conjuncts, as in “Sarah baked the pie, and Aaron (baked) the cake,” and consequently, the brain is not only required to detect the gap, but to retrieve the missing piece of information.

Kaan et al. (2004) studied the processing of verb gaps with the use of ERPs in order to understand how, when, and by what mechanism ellipsis constructions are processed by the human brain. In this study, ERPs were recorded as participants read sentences that contained verb gaps. They found that the ERP components affected by gapping included the N400, P600, and ELAN. The N400 effect was observed at the head of the noun of the second noun phrase, and suggested that the N400 peak is associated with the human brain integrating the noun phrase with the missing verb. The P600 was observed following the N400, possibly demonstrating syntactic revision processing or more difficulty processing the syntactic difference. As part of the results of a study conducted by Osterhout et al. (1994), they researchers suggested that individual perceptions and preferences for language processing affect the P600 as much as obvious ungrammaticality.

It has been postulated that the human brain may have two methods available for the processing and analysis of syntactic structures (Frazier & Clifton, 2001). The first method involves attaching the item of interest to a syntactic tree, building the structure of the written or spoken sentence step by step as it is processed. Consequently, a greater number of elements require greater processing time. Osterhout, Holcomb, and Swinney (1994) have referred to this method as minimal attachment. The second method involves a copying mechanism. When an ellipsis occurs, it is postulated that the human processor copies the antecedent clause and then makes an inference based on the information supplied. In contrast with the syntactic tree model, there is no additional processing time
required for the presence of an increased number of elements (Frazier & Clifton, 2001).

Frazier and Clifton (2001) found that it takes less effort to process structurally parallel sentences presented in succession. Research indicates that this parallelism, especially in gapping sentences, decreases processing time because the human processor can analyze the second conjunct based on previously built syntactic trees (Carlson, 2001). The present study will only contain highly parallel sentences wherein the omitted verb in the second conjunct can be automatically filled in.

The Present Study

Although many studies have focused on understanding the underlying mechanisms of the elicitation of the P300, N400, P600, and ELAN waveforms in response to language processing, limited research has been conducted with the use of ERPs that specifically concern the processing of gapping structures. As outlined, Kaan et al. (2004) examined ERPs elicited by the visual input of gapping structures and noted the input’s effect on the N400, P600, and ELAN waveforms. 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 fundamental aspects of postlexical sentence processing. It could be assumed that the ERP waveforms P300, N400, and P600 would be similarly observed across visual and auditory modalities for gapping structures. It is hypothesized that larger amplitudes for each of these elements might be elicited for semantically incorrect gapping structures when compared to syntactically correct sentences.

The N200 and the P300 within the visual modality have been the primary focus for
ERP studies with child participants (Canseco-Gonzalez, 2000; Kutas & Hillyard, 1983). Since adolescents are the population of study, it would be expected that there will be significant differences in P300 latencies between modalities (Johnson, 1989). Normative data collected from this study of adolescents, including the analysis of the P300, N400, and P600 components, will aid in further understanding language processing and provide a comparison of event related potentials found in children, adolescents, and adults. This research will allow for greater understanding of language disorder diagnosis and treatment. It may also be helpful in determining the effectiveness of language intervention programs.

Method

Participants

Eighteen (6 males, 12 females) native English speaking adolescents participated in the study, ranging in age from 14 to 18 years ($M = 16.85$). The age range for the male participants was from 14.7 to 18.11 years ($M = 16.72$) and the female participants 15 to 18.7 years ($M = 16.9$). The participants were recruited from the local community through the use of flyers and word of mouth. Participants were given gift certificates for pizza at a local restaurant for their participation.

A parent or guardian of each participant reported a negative history of neuropsychiatric disorders, and the participants demonstrated no evidence of a language delay or disorder. Each participant received a passing score on the grammatic competency subtest of The Fullerton Language Test for Adolescents—Revised Edition (Thorum, 1986). Additionally, all participants were presented with a sample gapping sentence as part of the subtest, and all participants correctly identified the appropriate
grammaticality of the gapping sentence. The participants had normal speech skills, indicated by the presence of no consistent speech sound error during a conversational sample. Each participant demonstrated normal hearing with pure-tone thresholds of $\leq 15$ 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 Human Subjects Review Board at Brigham Young University and all participants, as well as a parent or guardian, 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 tip of the nose 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 plausible and implausible gapping conditions were constructed in the same format. In 51 out of 60 the 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. The 60 stimuli 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. The lists presented also included ten semantically correct, 10 semantically incorrect, 10 syntactically correct, and 10 syntactically incorrect sentences that were interspersed with the gapping structures. All participants were presented the
same stimulus list visually. Similarly, the same stimulus set was used for all participants in the auditory modality. 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.

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, appearing for 300 ms and 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 B.

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. Ambient noise did not exceed ANSI S3.1 - 1991 maximum permissible levels for air conduction testing with ears uncovered (American National Standards Institute [ANSI], 1991). Participants were instructed to remain still, relaxed, and awake during auditory stimulus presentation. At the end of each sentence
they 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 resist blinking until the end of the sentence. Again, they were prompted to push a button at the end of the sentences indicating that the sentence was acceptable or unacceptable.

**Data Analysis**

Peak-to-peak amplitude and peak latency of the P300, N400, and P600 waveforms were measured on individual-average waveforms and grand-average waveforms. All Components were analyzed at the Cz electrode site. The P300 peaks were identified as the two most positive peaks occurring after 300 ms from the onset of the target word (P300a and P300b). The N400 was identified as the most negative peak occurring between 300 and 600 ms, and the P600 was identified as the most positive peak occurring between 500 and 800 ms from the onset of the target word of each sentence. Latency is defined from the onset of the event to the peak, or center of a broadly distributed peak. Amplitude is defined as the peak-to-peak measurement. Baseline was not corrected for offset therefore positive and negative in waveform identification refers to a positive or negative-going leading slope.

The mean, standard deviation, and range were computed for the latency and amplitude of the P300, N400, and P600 waveforms. An epoch beginning around 300 ms was analyzed for the P300 waveform. An epoch beginning at 300 ms and ending at 600 ms was analyzed for the N400 waveform. An epoch beginning at 500 ms and ending at
800 ms was sampled for the P600 waveform.

Analysis of variance (ANOVA) was performed to evaluate the differences between the modalities. A repeated measures ANOVA was also performed on the P300, N400, and P600 waveforms for both amplitude and latency for each condition. The within-subjects factor was the correctness or incorrectness of the sentences. A one-tailed post hoc t-test was performed on each of the two on each of the two independent variables for semantically correct sentences versus semantically incorrect sentences, syntactically correct sentences versus syntactically incorrect sentences, and correct versus incorrect gapping structures. The selection of a one-tailed t-test was based on the observation that the event-related component can change in only one direction due to stimulus differences.

Results

Descriptive Statistics

Auditory semantic structures. Table 1 shows descriptive statistics for the amplitudes and latencies of semantically correct and incorrect structures in the auditory modality. Although the amplitudes of the P300 and N400 for correct structures are larger than those for the incorrect structures, they are within one standard deviation of each other. The P600 amplitudes for correct gapping structures are slightly smaller than those for the incorrect structures, and are within one standard deviation. Latencies for all components (P300, N400, and P600) for correct structures were also found to be within one standard deviation of the incorrect structure latencies.

Auditory syntactic structures. Table 2 shows descriptive statistics for the amplitudes and latencies of syntactically correct and incorrect structures in the auditory
Table 1

*Descriptive Statistics for the Amplitudes (in $\mu$V) and Latencies (in ms) of Semantically Correct and Incorrect Structures in the Auditory Modality*

<table>
<thead>
<tr>
<th>Component</th>
<th>$M$</th>
<th>$SD$</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
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<tr>
<td><strong>Amplitudes</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P300a</td>
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</tr>
<tr>
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<tr>
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<tr>
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Table 2

Descriptive Statistics for the Amplitudes (in $\mu$V) and Latencies (in ms) of Syntactically Correct and Incorrect Structures in the Auditory Modality

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<th>Minimum</th>
<th>Maximum</th>
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<td>N400</td>
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<td>17.54</td>
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modality. The amplitudes of the P300, N400, and P600 for syntactically correct structures are slightly larger than those for the incorrect structures, and are within one standard deviation of each other. Latencies for correct versus incorrect structures were also within one standard deviation.

*Auditory gapping structures.* Table 3 shows descriptive statistics for the amplitudes and latencies of correct and incorrect gapping structures in the auditory modality. Although the amplitudes of the P300 and N400 for correct gapping structures are smaller than those for the incorrect gapping structures, they are within one standard deviation of each other. The P600 amplitudes for correct structures are slightly larger than those for the incorrect structures, and are within one standard deviation. Latencies for correct structures were also within one standard deviation of the incorrect structures.

*Visual semantic structures.* Table 4 shows the descriptive statistics for the amplitudes of semantically correct and incorrect structures in the visual modality. With the exception of the P600 amplitude, all amplitudes and latencies for correct structures were found to be slightly smaller than for incorrect structures and were within one standard deviation.

*Visual syntactic structures.* Table 5 shows the descriptive statistics for the amplitudes of semantically correct and incorrect structures in the visual modality. Amplitudes and latencies for all components (P300, N400, and P600) for correct syntactic structures were within one standard deviation of amplitudes and latencies of incorrect structures.

*Visual gapping structures.* Table 6 shows the descriptive statistics for the amplitudes of semantically correct and incorrect structures in the visual modality.
Table 3

*Descriptive Statistics for the Amplitudes (in µV) and Latencies (in ms) of Correct and Incorrect Gapping Structures in the Auditory Modality*

<table>
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<tr>
<th>Component</th>
<th>M</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
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Table 5

Descriptive Statistics for the Amplitudes (in $\mu V$) and Latencies (in ms) of Syntactically Correct and Incorrect Structures in the Visual Modality

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Table 6

*Descriptive Statistics for the Amplitudes (in µV) and Latencies (in ms) of Correct and Incorrect Gapping Structures in the Visual Modality*

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Although the amplitudes of the P300 and N400 for correct gapping structures are smaller than those for the incorrect gapping structures, they are within one standard deviation of each other. The P600 amplitudes for correct gapping structures are slightly larger than those for the incorrect structures, and are within one standard deviation. Latencies for all components (P300, N400, and P600) for correct structures were found to be approximately equal to, or within one standard deviation of, the incorrect structures.

**ANOVA**

An ANOVA was performed for both the auditory and visual modalities for each contrast (semantically correct versus incorrect sentence structures, syntactically correct versus syntactically incorrect structures, and correct versus incorrect gapping structures). A repeated measures ANOVA showed significant ($p < .05$) differences between the visual and auditory modalities for each component (P300, N400, and P600). Post hoc $t$ tests were performed in order to determine both amplitude and latency differences between modalities (auditory and visual) and between stimulus types.

Table 7 shows the results of differences in stimuli between modalities as indicated by the ANOVA. It was observed that there were significant differences between the visual and auditory modalities for the P600 amplitudes, $F (1, 26) = 6.081, p = .021$ for semantically correct structures. The P600 amplitude also showed significant differences between modalities in the processing of semantically incorrect information, $F (1, 28) = 4.264, p = .048$. There were also significant differences observed in the latencies of the P300, $F (1, 28) = 4.506, p = .043$, and N400, $F (1, 28) = 7.790, p = .009$, between modalities for the processing of semantically incorrect structures.

The P300 amplitude showed significant differences between modalities for the
processing of syntactically correct information, $F(1, 28) = 11.293, p = .002$, though the P600 showed no significant differences. For the processing of syntactically incorrect information, significant differences were found between modalities for the P300, $F(1, 29) = 6.513, p = .016$, and N400 amplitudes, $F(1, 29) = 9.635, p = .004$, as well as the latencies of the N400, $F(1, 29) = 4.545, p = .042$.

Table 7

*Results of ANOVA Showing Significant Differences in Stimulus Type Between Visual and Auditory Modalities*

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*Topography*

*Auditory correct semantic.* Figure 1 shows the scalp distribution for semantically correct structures in the auditory modality. There is a small left frontal negativity which occurs throughout the entire epoch (0-1000 ms) that occurs in the central-occipital area. A positivity in both the left and right parietal areas is observed with a similar distribution seen over the left hemisphere throughout the epoch. This begins at 150 ms and maximizes at 450-500 ms. Also at 450-500 ms, a positivity is seen over the left frontal area. This partially diminishes by about 550 ms, reappears at 700-750, then completely diminishes. These structures show a scalp distribution similar to the incorrect gapping
Figure 1. Scalp Distribution for Semantically Correct Structures in the Auditory Modality.
structures in the auditory modality (see Figure 6), which will be discussed later.

**Auditory incorrect semantic.** Figure 2 shows the scalp distribution for semantically incorrect structures in the auditory modality. These distributions show little activity across the scalp except for some left frontal-central positivity seen between 350-400 ms. Unlike the semantically correct structures in the auditory modality, there is no spread of activity of this response throughout the epoch. Additionally, the activity seen in the frontal, occipital, and parietal areas for the semantically correct structures is absent in the semantically incorrect distributions.

**Auditory correct syntactic.** Figure 3 shows the scalp distribution for syntactically correct structures in the auditory modality. Syntactically correct structures show a frontal positivity developing beginning at about 200 ms and maximizing between 700-750 ms.

**Auditory incorrect syntactic.** Figure 4 shows the scalp distribution for syntactically incorrect structures in the auditory modality. Syntactically incorrect structures show a left frontal positivity between 300 and 450 ms. Unlike the syntactically correct structures, however, there is no later frontal positivity between 550-750 ms.

**Auditory correct gapping.** Figure 5 shows the scalp distribution for correct gapping structures in the auditory modality. These distributions show some left frontal-central positivity beginning at about 50 ms, with an initial maximum occurring between A second positivity in this same scalp location begins at about 400 ms, and peaks between 550-600 ms, with diminished amplitude beginning between 650-700 ms. Negativities are seen slightly to the left in the frontal areas and in the mid-occipital areas. There is little variation throughout the epoch. This is also true for a left and right parietal positivity, with a larger area on the right that extends to the right posterior
Figure 2. Scalp Distribution for Semantically Incorrect Structures in the Auditory Modality.
Figure 3. Scalp Distribution for Syntactically Correct Structures in the Auditory Modality.
Figure 4. Scalp Distribution for Syntactically Incorrect Structures in the Auditory Modality.
Figure 5. Scalp Distribution for Correct Gapping Structures in the Auditory Modality.
temporal areas.

Auditory incorrect gapping. Figure 6 shows the scalp distribution for incorrect gapping structures in the auditory modality. The incorrect gapping distributions are similar to the correct gapping structures in the frontal, occipital, and parietal areas. However, the left frontal-central positivity seen in the correct gapping structures begins later, at about 150-200 ms. This positivity has a maxima at 350-400 ms (similar to the correct auditory gapping) and essentially diminishes, unlike the correct gapping distribution, which has a secondary positivity in the same location peaking at about 550-600 ms. Of note is a greater negativity in the occipital areas for the incorrect gapping distribution.

Visual correct semantic. Figure 7 shows the scalp distribution for semantically correct structures in the visual modality. These structures show processing patterns similar to the correct gapping structures in the visual modality. There is no initial left temporal activity, however, beginning at approximately 50 ms and extending throughout approximately 200 ms, as in the correct gapping structures.

Also noteworthy is the relative quiet activity across the scalp as compared to the two visual gapping conditions. This phenomenon is also seen for the semantically and syntactically incorrect structures in both the auditory and visual modalities. In general, it was observed that, for the visual modality, ambiguities demonstrated a much higher level of activity across the scalp than in the visual, non-ambiguous conditions. It was also observed that ambiguities in the visual modality caused more activity across the scalp than ambiguities in the auditory modality.

Visual incorrect semantic. Figure 8 shows the scalp distribution for semantically
Figure 6. Scalp Distribution for Incorrect Gapping Structures in the Auditory Modality.
Figure 7. Scalp Distribution for Semantically Correct Structures in the Visual Modality.
Figure 8. Scalp Distribution for Semantically Incorrect Structures in the Visual Modality.
incorrect structures in the visual modality. Semantically incorrect structures show processing patterns similar to the semantically correct condition in the visual modality. However, the left temporal processing begins at about 200 ms, and continues through to approximately 500 ms, at which point it shifts to more frontal regions until about 700 ms. The activity then shifts back to a left temporal-frontal area, finally diminishing after 850. Additionally, it was observed that there was somewhat of an increase in activity across the entire scalp.

**Visual correct syntactic.** Figure 9 shows the scalp distribution for syntactically correct structures in the visual modality. These structures demonstrate a pattern similar to the correct gapping structures in the visual modality. There is more frontal processing seen in the syntactically correct condition than in the semantically correct condition within the auditory modality. Specifically, there is additional activity in the left temporal areas, and increased activity observed in the left temporal areas beginning about 500 ms and lasting throughout the remainder of the epoch.

**Visual incorrect syntactic.** Figure 10 shows the scalp distribution for syntactically incorrect structures in the visual modality. Syntactically incorrect structures show a marked increase in left temporal and frontal activity relative to the syntactically correct structures from about 100 to 400 ms within the visual modality. This phenomenon is also true for the time period from about 600 to 850 ms. Beginning at about 750 ms, there is an overall increase in activity across the scalp with somewhat greater activity seen in the mid-occipital to occipital areas.

**Visual correct gapping.** Figure 11 shows the scalp distribution for correct gapping structures within the visual modality. There is evidence of some early left
Figure 9. Scalp Distribution for Syntactically Correct Structures in the Visual Modality.
Figure 10. Scalp Distribution for Syntactically Incorrect Structures in the Visual Modality.
Figure 11. Scalp Distribution for Correct Gapping Structures in the Visual Modality.
temporal processing between 50 to about 200-250 ms, and then again between 400 and 500 ms. Likewise, this activity occurs later between 750 and 1000 ms. However, this left temporal processing in the semantically correct structures for the visual modality does not appear until about 450 ms.

*Visual incorrect gapping.* Figure 12 shows the scalp distribution for incorrect gapping structures within the visual modality. The distribution shows a pattern similar to the distribution of correct gapping structures within the same modality, with the addition of a strong left temporal negativity between 500 and 700 ms. This negativity is also noted between 500-550 ms and 900-1000 ms. Furthermore, beginning at about 200 ms, a strong frontal positivity is observed throughout the remaining epoch.

**Discussion**

The results observed in this study show that the P300, N400, and P600 components are elicited for both the visual and auditory modalities with in the presence of gapping structures, as well as semantic and syntactic structures. The N400 component is produced in response to semantically incorrect structures, while the P600 is produced in response to syntactically incorrect sentences, or as a sign of syntactic integration difficulty. The more general P300 is commonly observed in response to task-relevant, or unexpected stimuli, and represents cognitive function. Significant differences in amplitude and latency were noted between the correct and incorrect conditions of each structure, as well as between modalities (see Table 7) for the P300, N400, and P600.

**Amplitude**

*Amplitude of the N400.* The present study found that non-gapped sentences with syntactic anomalies elicited similar N400 amplitudes as those elicited by non-gapped
Figure 12. Scalp Distribution for Incorrect Gapping Structures in the Visual Modality.
grammatically correct sentences in both the auditory and visual modalities. These results indicate that not all incorrect gapping sentences are processed as semantic errors. Osterhout and Holcomb (1993) as well as Balconi and Pazzoli (2004) also found similar results. For the processing of syntactically incorrect information, significant differences were found in this study between modalities for the amplitudes of the P300 and N400. Hansen (2005) also found that while the N400 and P600 could be observed for various non-gapped syntactic anomalies regardless of modality, the modality of stimulus presentation was a key factor in the processing of gapping structures with regard to the presence of the N400 component.

Amplitude of the P300 and P600. The results of the present study indicated that the P300, N400, and P600 occur via both the visual and auditory modalities. Balconi and Pazzoli (2004) as well as Osterhout and Holcomb (1993) have reported similar measures for the N400 and P600 components in both modalities. In the present study, the P300 amplitude showed significant differences between modalities for the processing of syntactically correct information, though the P600 showed no significant differences. This may indicate that there is no difference in the way syntactic information is processed between the visual and auditory modalities. Osterhout and Holcomb (1993) have suggested that the human brain uses a comparable parsing strategy for both the visual and auditory modalities, indicated by the presence of, but no significant differences in, the P600 component for both modalities.

It has been suggested that a larger N400 and P600 amplitude would be elicited for sentences with semantic errors than for semantically correct sentences (Gunter & Friederici, 1999; Osterhout & Holcomb, 1993). In the present study, it was observed that
there were significant differences between the visual and auditory modalities for the P600 amplitudes for the processing of semantically correct structures, $F(1, 26) = 6.081, p = .021$, indicated by an auditory mean of 2.41 µV and a visual mean of 12.01 µV. This suggests that for semantically correct presentations there is a difference in the way information is processed in the visual and auditory modalities.

The P300 and N400 showed significant differences for the processing of syntactically incorrect information between modalities. The P600 amplitude also showed significant differences between modalities in the processing of semantically incorrect information. It should be noted that other studies also reported significant differences in the amplitudes and latencies of the P600 for different types of syntactic violations, or even for the same type of violations (Münte et al., 1998). It can be concluded that the P600 is part of a process that can be initiated by various violations. In the case of the gapping structures, when there is semantic integration difficulty or errors, a syntactic revision process may be triggered, reflected by the presence of the both the N400 and P600 components (Kaan et al., 2004), which was seen in the present study. It is also important to note that the P600 has been shown to be triggered by an acceptability judgment task (Hahne & Friederici, 2002), regardless of whether a syntactic anomaly was present. Such a task was employed in the present study, which may have contributed to the consistent presence of the P600 for all structures.

There were no significant differences observed in the amplitudes of the P600 between correct and incorrect gapping structures in the present study. It was also observed that in adolescents, the P600 may be triggered because of sentence complexity, regardless of correctness. Kaan, Harris, Gibson, and Holcomb (2000) found that the P600
was not restricted to reanalysis or syntactic violation, but was associated with the syntactic integration process in general. Kaan and Swaab (2003) found similar results, and concluded that the more posterior P600 is an index of syntactic processing difficulty, including repair or revision, and that a frontally distributed positivity (frontal P600) is related to ambiguity resolution and/or to an increase in discourse level complexity.

**Latency**

There were significant differences between modalities for the P300 and N400 latencies for the semantically correct and incorrect structures contrast in the present study. For the processing of syntactically incorrect information, significant differences were also found between modalities for the latencies of the N400, with an auditory mean latency of 446.33 ms and a visual mean of 428.60 ms. These latency differences may indicate that for syntactic anomalies, semantic integration difficulties also occurred, which was slightly more prominent in the visual modality. Kaan et al. (2004) postulated that any difficulty with semantic integration may actually be the trigger for the syntactic integration system, which is represented by the presence of the P600 component. This was found to be true for the present study.

There were significant differences in the latencies of the P300 between modalities for semantically correct, syntactically correct, and syntactically incorrect structures. These results indicate that the amount of time needed to process semantically incorrect information is different for information processed in the auditory modality than information processed visually, generally represented by greater latencies in the auditory modality than in the visual modality.

Osterhout and Holcomb (1993) reported that there was a significantly earlier P600
component present in response to syntactic anomalies. Unlike Osterhout and Holcomb, the present study did not show significant differences for the latencies of the P600 with either the presentation of syntactic violations or correct and incorrect gapping structures. However, the present study does concur with the results of Hagoort and Brown (2000) and Hahne and Mecklinger (1996) who found that the P600 latencies remained the same across modalities for several different types of grammatical errors, indicating the system’s ability to adequately retrieve the missing information.

**Topography**

*Auditory semantic.* For semantically incorrect structures in the auditory modality, it was observed that the activity in the frontal, occipital, and parietal areas for the semantically correct structures is absent for the semantically incorrect structures. From these results, it would appear that in adolescents a semantically incorrect auditory sentence does not receive the same processing attention as a semantically correct auditory sentence.

*Auditory syntactic.* Coulson, King, and Kutas (1998) looked across studies for a cohesive account of late positivity elicited by syntactic violations. They found the data to be lacking continuity. Neville et al (1991) reported laterally symmetric positivity largest over occipital regions, whereas Osterhout and Holcomb (1992) report a positivity with a right anterior distribution for similar sorts of phrase structure violations. In the present study, for syntactically incorrect structures in the auditory modality, there is a left frontal positivity between 300 and 450 ms. Unlike the syntactically correct structures, however, there is no later frontal positivity between 550 and 750 ms. This would suggest that the syntactic error is identified at an earlier stage in the left frontal region and may not be
considered for later processing.

*Auditory gapping.* For incorrect gapping structures in the auditory modality, the distributions are similar to the correct gapping structures in terms of the frontal, occipital, and parietal areas. Of note, however, is a greater negativity in the occipital areas for the incorrect gapping distribution. This greater negativity in the occipital area supports findings of Horwitz and Braun (2004) who found, using fMRI, a strong connection between the occipital and temporal areas of the brain for the processing of semantics. Neville et al (1991) also reported a laterally symmetric positivity that was largest over occipital regions. It appears from this data that incorrect gapping structures presented in the auditory modality cause the neural system to “look” for a semantically correct solution, therefore increasing the activity in the occipital area.

*Visual semantic.* For semantically correct structures in the visual modality, the distributions show processing patterns similar to the correct gapping structures in the visual modality, without evidence, however, of initial left temporal activity. This early left frontal processing of the correct and incorrect gapping structures in the visual modality suggest the system is seeking to process the information as language, but due to the inconsistencies, is involved in a look-up system, and is reprocessing the information again at about 450-500 ms in the correct and incorrect visual gapping distributions. Taylor, Horwitz, Shah, Fellenz, Muller-Gaertner, and Krause (2000) have proposed a functional model of “brain traffic” to word association. As part of this model, there is a “checking system” to determine if the word is consistent within the context. The findings in the current study appear to lend support for this part of their model.

Also noted is the relative quiet activity across the scalp for visual semantically
correct structures as compared to the two visual gapping conditions. It would appear that
the presence of a visual gap activates a wider range of neural activity in an attempt to sort
through the ambiguity. This phenomenon is also seen in the semantically and
syntactically incorrect recordings in both the auditory and visual modalities. In general, it
was observed, in the visual modality, that ambiguities demonstrated a much higher level
of activity across the scalp than in the visual, non-ambiguous conditions. Federmeier et
al. (2000) observed that the left frontal positivity elicited by unambiguous verbs in
appropriate contexts was suppressed when these same lexical items appeared incorrectly
in a noun position in the sentence. As a result, early on in a word’s processing, context
acts to direct the search for word class-related information.

It was also observed in the present study that ambiguities in the visual modality
caused more activity across the scalp than ambiguities in the auditory modality. Since
perhaps it is not possible in a sentence presented in the auditory modality to “revisit” the
material and confirm the ambiguity, the neural system ceases its attempt to process the
information. In the visual modality, however, it is possible to re-asses the sentence and,
due to a learning effect, the neural system continues to attempt to process the
information. Since this is not possible under the experimental conditions of this project, it
becomes “confused” or unable to reprocess that information, and continues attempts to
sort through the ambiguity.

*Visual syntactic.* Scalp distributions for syntactically correct structures and correct
gapping structures in the visual modality are similar. Within the visual system, there is
more activity in the left temporal areas and more frontal processing seen in the
syntactically correct condition than in the semantically correct condition. This suggests
that the syntactical information requires more complex neural processing, which was also observed by Haagort and Brown (2000). Münte et al. (1998) found that semantic violations showed a clear parietal maximum, whereas syntactic violations seemed to have a wider distribution. The syntactic errors were associated with a low amplitude negativity and a more frontal distribution than the N400 distribution found with semantic violations. A similar left anterior negativity has been described in studies involving the presentations of morphological violations (Münte et al., 1998). In the present study, for syntactically incorrect structures in the visual modality, there was a marked increase in left temporal and frontal activity relative to the syntactically correct structures. Beginning at about 750 ms, there is an overall increase in activity across the scalp, with somewhat greater activity seen in the mid-occipital to occipital areas, which suggests that the neural system is trying to access additional information to resolve the ambiguity.

*Visual gapping.* Correct gapping structures within the visual modality show relative quiet across the entire epoch as compared to the visual gapping structures. There is also evidence of some early left temporal processing between 50 to about 200-250 ms, and then again between 400 and 500 ms. This also occurs later between 750 and 1000 ms. This observation seems to suggest primarily a left temporal processing for the correct gapping structures in the auditory modality. However, this left temporal processing in the semantically correct structures for the visual modality does not appear until about 450 ms. These findings suggest that the presence of a gap in the visual modality causes some early additional processing over the left temporal area where language is generally processed.
Although the distribution for incorrect gapping structures within the visual modality shows a pattern similar to the distribution of correct gapping structures, there is a strong frontal positivity observed throughout the remaining epoch. The activation of these areas would possibly indicate the attempt of the neural system to access or search for information (Horwitz & Braun, 2004). This may also indicate that when visually processing a gapping structure, the system appears to need additional resources in the frontal areas, which involves the association areas (auditory and visual) as well as accuracy of word selection (Federmeier et al., 2000).

General trends. A general trend seen throughout all scalp distributions is that syntactic ambiguities in the auditory system seem to have an appearance of an inhibitory effect on neural processing of the information, whereas in the visual modality, it tends to result in increased overall activity in the visual ambiguous condition. This may indicate that the neural system is “searching” for a resolution that is generally possible in the visual modality, but not available in the auditory modality. Although this is somewhat speculative, there is support for this behavior in the visual system as noted by Taylor et al. (2000) as well as in some earlier studies by Krause et. al. (1998). That is, processing load, which increases during ambiguities, is affected by semantic memories and the retrieval process.

Conclusions

The purpose of the present study was to further investigate the human brain’s electrophysiological responses to gapping structures within adolescents for the P300, N400, and P600 components. From a psycholinguistic perspective, the results of the study add to a more broad understanding of the way the system seeks to interpret
language, specifically, semantically and syntactically correct and incorrect information in the form of gapping structures.

Significant findings suggest that incorrect gapping sentences are generally processed as semantic errors, as evidenced by the N400 response. It was also observed that a later P600 was present for gapping structures in both modalities. Results indicate that gapping structures require extra computational operations, which are not required for the processing of semantically and syntactically correct structures. When visually processing a gapping structure, the system appears to need additional resources in the frontal areas. Incorrect gapping structures take longer to process than correct structures within the auditory modality as evidenced in the N400 latencies, indicating that the processing system recognizes the incorrect gap as a semantic error and that modality of stimulus presentation was a key factor in the processing of gapping structures.

Significant semantic and syntactic differences suggest that for syntactic anomalies, semantic integration difficulties co-occur, which is slightly more prominent in the visual modality for the adolescent population. The differences in the P300 across modalities reflect the differences in the processing tasks; that is, longer latencies reflect an increase in the amount of cognitive processing for the presented information.

There appears to be no difference in the way syntactic information is processed between the visual and auditory modalities, as evidenced by few significant P600 amplitude differences. It is difficult to conclude, however, the exact nature of the P600 component within gapping structures between modalities. The human brain may use a comparable parsing strategy for both the visual and auditory modalities for syntactic information. One of several conclusions can be made from the presence of the P600 for
all contrasts. First, it may be concluded that the P600 is part of a process that can be initiated by various violations, including semantic, as well as by the process of reanalysis. In the case of the gapping structures, when there is semantic integration difficulty or errors, a syntactic revision process may also be triggered, reflected by the presence of the both the N400 and P600 component, as has been reported previously (Kaan et al., 2004). Secondly, the P600 may simply have been triggered by the acceptability judgment task, which was employed in this study. Lastly, these results may indicate that in adolescents, the P600 is triggered regardless of correctness, but because of sentence complexity, causing the subsequent onset of syntactic integration processing.

Greater negativity in the occipital area supports a strong connection between the occipital and temporal areas of the brain for the processing of semantics. It appears from this data that incorrect gapping structures presented in the visual modality cause the neural system to “look” for a semantically correct solution in other areas of the brain, therefore increasing the activity in the occipital area.

From the relative quiet activity noted across the scalp for visual semantically correct structures as compared to the two visual gapping conditions, it would appear that the presence of a visual gap activates a wider range of neural activity in an attempt to sort through the ambiguity. Visual ambiguities demonstrated a much higher level of activity across the scalp than in the visual, non-ambiguous conditions, suggesting that the presence of a gap in the visual modality causes some early additional processing over the left temporal area where language is generally processed.

In previous research, the P600 has been shown to be triggered by an acceptability judgment task (Hahne & Friederici, 2002), regardless of whether a syntactic anomaly was
present. Such a task was employed in the present study. It has been suggested that a future study should be conducted to compare the ERPs associated with non-ambiguous presentations of information both in the presence, and in the absence, of required motor responses. Additionally, this study endeavored to compare semantic, syntactic, and gapping structure errors within and between the auditory and visual modalities. It did not focus on comparing ELAN (early left anterior negativity) or CPN (centro-posterior negativity) components, which have been included in some studies. It may be beneficial to concentrate future studies on comparing these additional ERP components.

Overall, it was found that there is minimal difference in the way adolescents and adults process gapping structures (as compared with previous research), with the exception of the consistent presence of the P600 component for both the correct and incorrect structures. Because this study focused exclusively on the electrophysiological measures associated with gapping structures, these results do not lend themselves to immediate clinical application. They will, however, help provide a better overall picture of the human brain’s processing of semantic and syntactic information. Isolated studies such as these provide a broader view of ERPs and will aid in further understanding language processing, providing a comparison of potentials found in children, adolescents, and adults. ERP research will eventually allow for greater understanding of language disorder diagnosis and treatment, and may also be helpful in determining the effectiveness of language intervention programs.
References


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

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

Name of Participant: __________________________ Date of Birth: __________________________

Purpose of Study
This research is designed to examine the processing of language by the brain in adolescents 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
My child has been asked to participate in a research study conducted by Dr. David L. McPherson and/or such assistants as may be selected by him. My child has been recruited for participation in this study because of his/her normal hearing, language, vision (or corrected-to-normal vision), and because he/she has 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. My child may ask for a break at any time during testing. Basic hearing and vision tests will be administered during the first hour of the session.

Surface electrodes (metal discs about the size of a dime) will be used to record electrical activity of my child’s brain. These discs will be applied to the surface of the skin with a cream or gel and are easily removed with water. Blunt needles will be used as a part of this study to help apply the electrode gel. They will never be used to puncture the skin.

Language processing will be measured using an electrode cap, which simply measures the electrical activity of my child’s brain and does not emit electricity, and no electrical impulses will be applied to the brain. These measurements of the electrical activity are similar to what is known as an “EEG” or brain wave test. These measurements are of normal, continuous electrical activity in the brain.
My child will wear the electrode cap while he/she listens to and reads approximately 200 sentences, during which time the electrical activity of his/her brain will be recorded on a computer. My child will be asked to give responses during the hearing test, standardized language test, and the electrophysiological recording.

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

**Risks**

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

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

**Benefits**

Benefits from participating in this study include an assessment of hearing 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 or my child. However, the information obtained will help to further the understanding of language processing, which will be beneficial to professionals involved in treating speech and hearing disorders.

**Confidentiality**

Participation in this study is voluntary and my child has the right to refuse to participate or withdraw at any time. All information obtained from testing is strictly confidential and is protected under the laws governing privacy. No information specifically pertaining to my child, 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 or my child for participation in this study. There is no treatment or intervention involved in this study.
The procedures listed above have been explained to me and my child by: ___________________ in a satisfactory manner and any questions relating to such risks have been answered. If there are any further questions or concerns regarding this study, I may ask any of the investigators or contact David McPherson, Ph.D., Audiology and Speech-Language Pathology, 129 Taylor Building, Provo, Utah 84602; phone (801) 422-6458; email: david_mcperson@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: reneabeckstrand@byu.edu.

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

________________________  ______________________
Signature of Parent or Guardian  Date

________________________  ______________________
Signature of Witness  Date
Appendix B

Stimulus Sentences for Visual Modality

Semantically correct
1. The cat will chase that mouse in our backyard.
2. My sister might eat the cake after her lunch.
3. Russ might lick the lollipop in his hand.
4. Charles should wear his coat in our garden.
5. Grace can pet the lamb at this farm.
6. Connie can pour the milk into her red cup.
7. Aunt Liza will clean the garage with this broom.
8. Ann might smell the coffee in their kitchen.
9. Irene can blow the bubbles at that playground.
10. Jane can cut the meat with that sharp knife.

Semantically incorrect
11. Stephanie can listen to the songs on that plate.
12. Kara can write the letters to her best dogs.
13. The babysitter can feed the children in her clean dirt.
14. At night, the hockey player will hang the skates in this refrigerator.
15. The dog might eat the food from his red straw.
16. Children can ride their bikes down those little lollipops.
17. For dinner, Mary will cook that steak on our dustpan.
18. Sally will serve some ice-cream with this brick.
19. Josh can blow these huge bubbles with his headphones.
20. My brother will eat the spaghetti with his glue stick.

Syntactically Correct
21. George can fix these cars in his garage.
22. Frank will open these doors with his keys.
23. Johnny can touch the rabbits at this petting zoo.
24. Steve will keep those mittens with his winter hat.
25. Bert shouldn't feed the dogs in his bedroom.
26. Lisa will get the chicken for our dinner party.
27. The dog will chase the stick at this park.
28. The squirrels will hide some nuts in those tall trees.
29. My brother will wash the dishes in his kitchen.
30. They can drink some coke with their hamburgers.

Syntactically Incorrect
31. Amy will got the ice cream from that freezer.
32. Margaret can smelled the flowers in that beautiful garden.
33. Sally can fed the ducks at this pond.
34. Carrie will gave these cards to her friends.
35. The parents will brought the blanket for their sleeping baby.
36. Lilly can built a castle with that wet sand.
37. James will bought some cookies from that store.
38. Adam will gave the banana to his little brother.
39. The girl might hid the hat from her sister.
40. Roger will opened some presents at his birthday party.

Gapping Correct
41. Scott asked his mom for a new bike, and Calvin the operator for the phone number.
42. My uncle teaches French, and my aunt math at a local school.
43. My sister is allergic to dust, and my brother to cats with long hair.
44. Nancy played with the child, and Martha the video game over the weekend.
45. Frank changed the lamp’s light bulb, and Liz the baby’s clothes.
46. Tracy mailed the letter to George, and Julie the package to Lisa.
47. The mailman gave the package to me, and the neighbor the dog to my sister.
48. Candice wrote a song for art class, and Ryan a poem for English class.
49. Jane held crying baby, and Tom the bag of groceries.
50. Gina made a card with paper and markers, and Ben sandwich with bread and meat.
51. Linda sketched the bugs on the stones, and Tom the vase on the table.
52. Peter pulled the school’s fire alarm, and Dan the girl’s hair.
53. Annie made a sculpture with sharp tools, and Rita a drawing with pencils.
54. Ron took the planks for the bookcase, and Bill the hammer with the big head.
55. Nathan liked the cake his mother made, and Adam the card his sister made.

Gapping Incorrect
56. Mary braided the hair of her mother, and Paula the hand of her father.
57. Larry filled a glass with ice cubes, and Todd a knife with a sharp blade.
58. Sally tried on the blouse with the bonnets, and Tracy the suitcase with the leather pockets.
59. John spread a bagel with jelly, and Ellen a glass of milk.
60. The nurse injected the antibiotics, and the surgeon the scalpel from the tray.
61. Fred wrote with his new pens at work, and Cindy her new telephone at home.
62. Jenny polished the silver in the kitchen, and Ken the carpets in the living room.
63. Lee donated the clothes to the homeless shelter, and Jessica the cookie to the child.
64. David wore his new shoes to school, and Ron his new computer to work.
65. Dana ripped the paper airplane, and Tom the wooden horse.
66. Harry snapped the wire across the floor, and Carl the staircase to the basement.
67. My mother smelled the beautiful flowers on the table, and my father the great baseball game on the television.
68. Matt surfed on the waves in the ocean, and James on the skateboard in the road.
69. Kevin swallowed the pill in his mouth, and Mario the money in his wallet.
70. Barbara climbed the tree in the garden, and Leo the flowers in front of the house.
Appendix C

Stimulus Sentences for Auditory Modality

Gapping Correct
1. Lisa liked the aria by Mozart, and Marc the landscape by Rembrandt.
2. Aaron ate a banana during recess, and Taylor a hot dog during lunch.
3. Phil attached the paper to the bulletin board, and Kim the mirror to the wall.
4. Lucy got three pairs of socks, and Bertha a picture in a nice frame.
5. The English teacher taught the story before recess, and the math teacher subtraction after recess.
6. Leo prepared the carrots for the stir fry, and Sally the steak for the grill.
7. William wrote a novel on his computer, and Hal a number on his wall.
8. My cousin jumped into the pool, and my brother over the hurdle.
9. Sue looked at the vase with the flowers, and Joe at the pillow on the couch.
10. Jack put some water in a pitcher, and Pam some sandwiches on a plate.
11. Jeff painted the door to the pantry, and Paul the walls of the bedroom.
12. David played in the pool in the afternoon, and John the yard in the evening.
13. Harry groomed the horse with the long mane, and Lisa the dog with the curly tail.
14. My grandmother closed the envelope for the card, and my grandfather the door.
15. Nan put the poster on the wall, and Minnie the clothes on the bed.

Gapping Incorrect
16. Bill did the crossword puzzle, and Paul the sports section in the morning paper.
17. Sam swam in the ocean, and Jim in the forest last weekend.
18. Peter cooked the steaks on the grill, and Liz the ketchup on the table.
19. Ella sang a song about a love affair, and Helen a story about a little bird.
20. Barb applied some makeup before dinner, and Suzie a dress before the dance.
21. Eliot blew the trumpet, and Joe the drums and the guitar.
22. Pat emptied the cabinets in the kitchen, and Ted the floor in the hall.
23. My mother drove to the store in the car, and my father to work on foot.
24. Nancy drove the car in the driveway, and Bob the dishes in the sink.
25. Lila baked the brownies in the oven, and Bonnie the juice in the fridge.
26. Brenda shredded the forms in the box, and Carrie the typewriter on her desk.
27. Mike chopped the wood in the shed, and Wilma the paper in the attic.
28. My brother wiped the counter with the rag, and my sister the carpet with the vacuum.
29. Jim started the car at noon, and John the radio at midnight.
30. Bill poured the cream into the bowl, and Anna the bread on the plate.

Semantically Correct
31. Melissa might spill the yogurt on that napkin.
32. Eric can call the student on this phone.
33. The mother will sing the lullabies to those sleepy children.
34. The children can drink this juice with their snack.
35. Julie should wear some socks with her pajamas.
36. Angie will pet the kittens at this pet store.
37. Nick will complete his homework in the bedroom.
38. People should drink the tea from their cups.
39. Kevin should wear the boots in this rain.
40. After dinner the man will clean the plates with this soap.

Semantically Incorrect
41. Chris can cook the eggs in this hot igloo.
42. Johnny can build some houses with these calendars.
43. The parents will push the children on these markers.
44. Sara can light the candles on her birthday pig.
45. The Grandmother will hold the baby on her glass.
46. Bobby can read those books at that quiet carnival.
47. Mike might spill the coke on this new bubble.
48. The man shouldn't drive the truck on that sky.
49. Liz might kiss the child in that pantry.
50. Joe will drive the car to my France.

Syntactically Correct
51. Jeremy wouldn't push the man into those big puddles.
52. Jimmy might find some strawberries in his garden.
53. Keith will eat his Cheerios at this table.
54. The children will bring the buckets to this beach.
55. Justin will drink the soda from his tall glass.
56. The mothers can push the strollers at this park.
57. Janet will warm the bread in this oven.
58. Mark wouldn't share the pizza with his big sister.
59. Amanda will keep the keys in her brown purse.
60. Dan might catch those butterflies in that big net.

Syntactically Incorrect
61. David should poured the juice in this glass.
62. Eddie shouldn't threw the ball in this house.
63. The family will watches the monkeys at this zoo.
64. The baby might dumps the Cheerios on our floor.
65. Abby will got some spoons for our ice-cream.
66. Debbie will hid those cookies in that box.
67. Maria will threw the stones into this lake.
68. Lynn shouldn't took the scissors on my desk.
69. Claire can wiped her face with this soft towel.
70. Bruce will made the toast in our new toaster.
Appendix D

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
- Perform otoscopic examination
- Collect tympanometry measures
- 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