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The N400 Event-Related Potential in Children Across Sentence Type and Ear Condition

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ABSTRACT

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This study investigated the neurophysiology of semantic language processing in children, ages 5 to 12 years. A well-established marker of semantic processing, the N400 event related potential (ERP), was analyzed within and across child age groups. Child N400s were recorded in response to correct sentences, semantically incorrect sentences, and syntactically incorrect sentences. N400s were also recorded across ear condition to examine potential processing differences.

Children across all age groups consistently demonstrated N400s in the semantic error condition. N400s were also regularly observed in the syntactic error condition; especially, for younger children. Younger children also demonstrated N400s even in response to correct sentence types. Interestingly, clear N400 effects (i.e. N400 amplitude differences between correct and semantically incorrect sentences) were only observed for one age group. While these findings indicate that children across all age groups detect semantic errors, the ability to consistently parse error types develops later.

Keywords: N400, event-related potentials, right ear advantage, language development, semantics

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Introduction

Research that investigates the neural basis of language processing promotes an improved understanding of language development across the lifespan. As children develop adult-like patterns of language processing, the neurophysiologic underpinnings of this development are of particular interest. Age-related changes have been well established behaviorally, but these same changes are much less understood from a neurophysiologic standpoint. Hahne, Eckstein, and Friederici (2004) noted that “there is a growing consensus that children have acquired the basic phonological, morphosyntactic, and semantic regularities of their target language by the age of 3 (Gleitman, 1990; Jusczyk, 1997; Pinker, 1994)” (p.1302). However, a small body of neurophysiologic-based work is finding that subtle processing differences still exist between adults and children as old as 10 years of age. These findings indicate that the mechanisms used to comprehend language develop gradually and that children do not develop stabilized, adult-like patterns of language processing until as late as 13 years of age (Hahne, Eckstein, & Friederici, 2004).

To better understand this transition to adult-like language processing, a careful description of the neurophysiologic development of language comprehension in children is also needed in addition to existing behavioral descriptions. Moreover, findings that document neurophysiologic changes associated with language development have significant theoretical and clinical implications for the management of clients with language impairment. The present study’s purpose was to provide a more complete description of language processing in 5- to 12-year-old children using electrophysiologic measures. Specifically, a well-established language-related event related potential (ERP), the N400 component, was examined in response to correct and error sentence types across ear condition. Results from this study showed language

processing differences across child age groups. Processing differences were also observed across sentence types and ear conditions.

Review of Literature

In the study of the neurophysiology of language processing, ERPs or event related potentials have proven especially useful. An ERP is a pattern of brain electrical activity that occurs in response to a particular stimulus event (such as speech) and can be time-locked to that stimulus event (Friederici, 2004). Therefore, ERPs can be measured at the scalp to reflect neural activity during various language tasks. Certain ERPs that have been associated with specific aspects of language processing are of special interest. These ERPs, as they have been observed in the literature for both children and adults, are discussed.

ERPs and ERP Measurement

The earliest studies investigating the physiology of language processing relied on correlating behavioral deficits in language with specific damaged areas in the brain. These early brain lesion findings, in combination with more recent findings from brain imaging technologies, such as fMRI and PET, have allowed researchers to provide a basic representation of the neural networks that underlie language processing (Friederici, 2004). However, the processing system that allows for language comprehension and production is dynamic and complex, requiring rapid computations in real time (Canseco-Gonzalez, 2000). While lesion studies, neuroanatomy and brain imaging techniques have begun to localize some of these processes with high spatial resolution, they give less precise temporal resolution of language-related brain activity (Friederici, 2004).

Conversely, event-related electroencephalography (EEG) and magnetoelectroencephalography (MEG) measurements offer poor spatial resolution but precise temporal resolution, measuring postsynaptic activity as it unfolds over time, millisecond by millisecond (Friederici, 2004). ERPs are EEG measurements commonly used to study language processing. Since ERPs are continuous, real-time measures, they have the advantage of examining the processes of language comprehension and production as they occur. ERP measures are also non-intrusive, meaning that they do not require behavioral responses, and can limit the influence of the measurement itself on the neural processes under investigation. Finally, ERPs estimate the location of neural generators, helping more closely tie brain activity to existing models of language comprehension (Osterhout & Holcomb, 1995). In sum, event-related EEG measures (i.e., ERPs) provide a time-sensitive, physiologic research approach that expands current theories of language processing (Picton & Stuss, 1984).

Some early researchers doubted the utility of ERPs in the study of language processing, largely because ERPs failed to show consistent hemispheric lateralization for language-related effects (Hillyard & Woods, 1979; Picton & Stuss, 1984). However, with the advent of ERP language studies, researchers shifted their interest away from hemispheric specialization and toward the cognitive processes that underlie language comprehension (Osterhout & Holcomb, 1995). This shift is reflected in current ERP study research designs. Generally, research methods involve presenting participants with language errors at specified levels of linguistic processing (e.g., phonological, semantic, syntactic). ERP patterns time-locked to the error stimulus event can then be observed to investigate processing at that specific linguistic level. This research design implies the basic assumption that distinct cognitive processes are mediated by distinct patterns of neural activity. More specifically, distinct ERP patterns of brain activity are assumed to represent separate linguistic representational levels in the brain (Canseco-Gonzalez, 2000).

In the ongoing EEG, ERPs show patterns of electrical change as a series of positive and negative voltage peaks, known as ERP components, which are measured at the scalp (Osterhout & Holcomb, 1992). These voltage peaks or components are distributed over time and have been found to reflect changes in cognition. Each ERP component is multidimensional in that it can be identified and described within five main domains: (a) functional identity; (b) polarity, positive or negative; (c) amplitude, polarity displacement from baseline; (d) latency, time in ms from the onset of a stimulus to the point of greatest displacement; and (e) scalp distribution. Therefore, ERP components show topographical variations as well as variations in latency, polarity, and amplitude (Friederici, 1997).

As observed by Osterhout and Holcomb (1993), “certain late-occurring (‘endogenous’) components appear to be sensitive to specific aspects of language comprehension” (p. 415). Put another way, long-latency ERP components are thought to reflect specific aspects or subcomponents of language processing. Three such language-related, long-latency ERP components have been consistently identified in the literature: (a) the ELAN, an early left anterior negativity occurring approximately between 100 and 200 ms after critical stimulus presentation; (b) the N400, a broadly distributed negativity occurring approximately 400 ms post stimulus onset; and (c) the P600, a centroparietal positivity occurring approximately 600 ms after presentation of the stimulus event (Friederici, 2004).

In order to identify these ERP components of interest against the continuous electrical background activity of the brain, averaging procedures are employed (Friederici, 1997). In particular, signal-averaging increases the signal-to noise ratio for ERPs. Background brain activity is random and therefore tends to decrease (i.e., cancel out) as a stimulus event is repeated and measurements are averaged. Conversely, the ERP remains constant across trials and therefore increases in the decreasing background noise during signal averaging (Picton & Stuss, 1984).

A Temporal Model of Language Processing

Beyond identifying specific language-related ERP components in isolation, the temporal interaction of these components must be described in order to provide what Friederici (1997) called an “adequate description of the brain/language relationship” (p. 65). Perhaps for this reason, Friederici has proposed three functionally distinct phases during language comprehension. Each phase in her model corresponds to one of the language-related ERPs introduced above. First, she proposed that during an initial processing phase, the parser (i.e., syntactic analyzer) builds initial, syntactic structures. This processing is reflected by the ELAN. During a second, intermediate phase, lexical-semantic processing occurs and this processing is reflected by the N400. In the third and final phase of language processing, a reanalysis occurs as syntactic information is mapped onto lexical-semantic information in a structural reanalysis. Friederici hypothesized that the P600 reflects this reanalysis of semantic and syntactic information.

In a later publication, Friederici (2004) further explained the temporal phases of language comprehension specific to syntactic processing. During the first phase of syntactic analysis, initial phrase structures are created based on word category information (e.g., noun, adjective, etc.). Similar to her earlier temporal model, this analysis is evidenced by the ELAN. In the second phase of syntactic analysis, relations are created between phrases, as grammatical roles are assigned (e.g., subject, object, etc.). Friederici postulated that this second phase of syntactic reanalysis is reflected in an additional left anterior negativity, the LAN component, occurring between 300 and 500 ms. Syntactic processing occurs a third and final time to achieve message-level comprehension. During this final stage of syntactic parsing, structural information, grammatical information, and lexical-semantic information is integrated in order to create overall meaning. Similar to her earlier temporal model, this integration of semantic and syntactic information is thought to be reflected in the P600 (Friederici, 2004).

Electrophysiology of Syntactic Processing

The N400, along with three separate ERP's associated with semantic processing will be discussed. Because of the importance of these ERP's in the present study, a brief discussion of the electrophysiology of syntactic processing is warranted.

The N400. The N400, as mentioned previously, is a negative wave peaking approximately 400 ms after the onset of a critical stimulus. Although the N400 component is broadly distributed over the left and right hemispheres, MEG studies have indicated that the neural generators of the N400 are located near the auditory cortex bilaterally (Friederici, 2004). An MEG study by Halgren et al. (2002) measured widespread left hemispheric activity at the peak of the N400. This activity spanned the anterior temporal, dorsolateral prefrontal, perisylvian, frontopolar, and orbital cortices in the left hemisphere. In the right hemisphere, less activation was observed for the N400. However, activity was observed in the orbital cortex and, to a lesser extent, in the anterior temporal cortex of the right hemisphere. The researchers reported these findings to be in harmony with fMRI and intracranial recordings.

Halgren et al. (2002) also investigated the neural generators for the N400. Using equivalent current dipole source modeling, the researchers localized the N400 generators to the left superior temporal sulcus. Intracortical recordings from a study by Halgren et al. (1994) also supported the left superior temporal gyrus, as well as additional frontal areas, as the neural generators for the N400. These findings are in agreement with brain imaging studies that have recorded activation of the left superior temporal gyrus during semantic processing (Friederici, 2004).

The ELAN. The ELAN is an early left anterior negativity that is distributed in temporofrontal networks including the left anterior superior temporal gyrus and the left inferior frontal gyrus (Friederici, 2004). The ELAN has been correlated with outright syntactic violations. More specifically, the ELAN is thought to reflect interruptions in early structure building processes or first pass parsing processes (Friederici, 1997, 2004). Sentences that change obligatory word categories or violate phrase structure constraints (e.g., *Max's of proof the theorem*) typically elicit the ELAN.

The ELAN occurs approximately 100 to 200 ms post stimulus and has been shown to be highly automatic as it is minimally affected by attentional factors (Friederici, 2004). Although variations in ELAN latencies have been recorded, Friederici explained that these changes could be explained by examining the point at which relevant information within words became available. A characteristically short latency was observed for the ELAN so long as the component was measured from the point at which critical word category information became available, not from the word onset.

The LAN. An additional syntax-related component showing a left dominant, centrofrontal distribution, the LAN (left anterior negativity), has also been described in ERP studies of language processing (Friederici, 2004). Various types of syntactic stimuli have been shown to elicit a LAN. A left anterior negativity has been observed in response to grammatical violations in word-pairs as well as in psuedoword sentences. A range of syntactic violations including errors of word category/phrase structure, verb agreement, and verb subcategorization have elicited a LAN (Canseco-Gonzalez, 2000). Independent of input modality, the LAN has been elicited by morphosyntactic violations, particularly inflectional errors that affect agreement information or verb-argument structure information. These findings have led to the conclusion that the LAN is related to the identification of grammatical relations between words (Friederici, 2004). However, LAN recordings in response to filler-gap constructions, regardless of grammatically, have challenged this interpretation and suggest that the LAN reflects aspects of working memory load demands (Canseco-Gonzalez, 2000).

The P600. The final syntax-related component is the P600, a late positive wave distributed over centroparietal regions of the brain. Lesion studies indicate that the basal ganglia are involved in generating this ERP component (Friederici, 2004). Like the ELAN, the P600, reflects outright syntactic violations and has been measured in response to many morphological and word-order errors. More specifically, the P600 has been associated with outright phrase structure violations; subadjacency violations; and agreement violations, including subject-verb number violations and reflexive-antecedent disagreements (Canseco-Gonzalez, 2000).

The P600 has also been elicited by syntactically nonpreferred structures known as garden path sentences. Garden path sentences are "locally ambiguous syntactic structures whose ultimate resolution is toward non-preferred syntactic representations" (Friederici, 1997, p. 67). A study by Osterhout and Holcomb (1992) demonstrated a P600 effect in response to disambiguating words within garden path sentences. In other words, a P600 effect was observed at the point in which subsequent input did not match previously assigned structures. For example, in the sentence *the broker persuaded to sell the stock*… the infinitive marker *to* does not match a simple active analysis of the sentence. Instead, it serves as a disambiguating word that creates a nonpreferred reduced relative clause structure interpretation of the sentence. Although such garden path sentences do not interrupt parsing of initial phrase structures (i.e., first pass parsing), they do require syntactic reanalysis in order to resolve syntactic anomaly created from the comprehender's initial attempt of a less complex analysis over a more complex interpretation (Osterhout & Holcomb, 1992). Various garden path sentence types have elicited the P600 component in English and in German (Friederici, 1997).

The P600 is elicited by outright syntactic violations as well as by perceived syntactic violations that result from comprehension strategies (Osterhout & Holcomb, 1995). Although there has been considerable debate over the language processing specificity of the P600, this component has shown a robust effect to syntactic anomalies (Friederici, 1997; Osterhout & Holcomb, 1992).

The N400 and Language Processing

The N400 is thought to primarily reflect lexical-semantic or message-level processing (Kutas & Hillyard, 1980a, 1980b, 1980c). This component is especially sensitive to the appropriateness or the semantic relationship of a word within a given context. In an early study by Kutas and Hillyard (1980c) participants were visually presented with seven-word sentences, one word at a time, with 25% of the sentences ending in semantically inappropriate words. These semantically incongruent seventh words elicited an N400 component, beginning around 250 ms and peaking around 400 ms post stimulus. Additionally, strong semantic mismatches resulted in the largest N400s. For example, a semantically anomalous completion (e.g., *I take coffee with cream and dog*) elicited a larger N400 amplitude than a semantically unexpected completion (e.g., *I take coffee with cream and milk*). The researchers proposed that the N400 resulted from an interruption and subsequent ‘reprocessing’ during the semantic processing of anomalous sentences.

A later study by Kutas and Hillyard (1984) provided additional support for these findings by once again recording ERPs in response to sentence-final words that completed meaningful sentences. The terminal word’s *cloze probability*, measuring the participant’s expectancy for a word within a given context, showed an inverse relationship with the amplitude of the N400. Cloze probability was determined by having a large number of participants fill in the missing final word of incomplete sentences. Although all final words were semantically appropriate, less-expected final words (e.g., *The bill was due at the end of the hour*) resulted in a larger N400 than more-expected final words (e.g., *The bill was due at the end of the month*). An additional finding was that N400 amplitudes were lower if the less-expected words were semantically related to highly expected words. This second finding lends support to the N400 as a sensitive marker of semantic priming and automatic spreading activation within the lexicon (Kutas & Hillyard, 1984).

The N400 component shows a similar effect in prime-target word recognition studies, in which a second word is presented after a first. Such word pair studies have shown a reduced N400 when the second word is semantically related to the first (or when the second word has been primed), as compared to when the second word is semantically unrelated to the first word (Osterhout & Holcomb, 1995). From these word-pair findings, as from sentence studies, researchers have postulated that the N400 reflects the extent to which a word is semantically primed.

Additionally, the N400 is evident in both visual and auditory modalities. However, the N400 is sensitive to presentation mode, showing topographical differences as a function of modality. The N400's distribution is greater over the right hemisphere when elicited visually but symmetric or even lateralized to the left hemisphere when elicited auditorily. The auditory presentation of words also creates an earlier N400, and the component is more prolonged. In sum, the auditory presentation of words results in an earlier, more symmetric distribution of the N400 when compared to the visual presentation of words (Holcomb & Neville, 1990). Finally, the N400 has been shown to be sensitive to word frequency in general language use (Friederici, 2004). Van Petten and Kutas (1990) measured an interaction effect for the N400 between word frequency and sentence position; a larger N400 was observed in response to less frequent words so long as these eliciting words were present early on in the sentence.

The linguistic specificity of the N400 has also been investigated. ERPs other than the N400 have also been found to reflect variations in stimulus expectancy; namely the P300 family, a series of positive components occurring approximately 300 ms post stimulus. For this reason, researchers have questioned whether the N400 specifically detects semantically deviant words or whether it is elicited by a broader class of unexpected stimuli. A study by Kutas and Hillyard (1983) helped establish the lexical-semantic specificity of the N400 by including grammatical errors that had minimal impact on the meaning of sentence stimulus items. A large N400 was observed only in response to semantically anomalous words, suggesting that grammatical deviations are processed qualitatively or quantitatively differently than semantic deviations. Kutas and Hillaryd (1980a) also reported that physical deviations in letter size or font elicited a late positive ERP (i.e., the P300), distinct from N400 components elicited by semantic deviations.

Holcomb and Neville (1990) added further support to the linguistic specificity of the N400 by contrasting psuedoword targets with backward word targets (i.e., words spelled or played backward) in a lexical decision task. Although backward words are unexpected stimuli, they are un-word like in nature. While the pseudowords showed an N400 response, the backward words did not. Researchers have also failed to observe an N400 in response to unexpected completions of common melodies, musical scales, and geometric shapes, although these stimuli did elicit a P300 response (Osterhout & Holcomb, 1995).

Challenging the language-specific nature of the N400 are findings of N400 effects between related and unrelated pictures (Barrett & Rugg, 1990; Holcomb & McPherson, 1994) and between words either semantically related or semantically unrelated to pictures (Nigam, Hoffman, & Simons, 1992). However, both pictures and words are represented in the conceptual memory system. This leads to the hypothesis that the N400 may be language specific at the conceptual level rather than at the lexical level (Osterhout & Holcomb, 1995).

Regardless of specificity, the N400 has shown to be a robust marker of semantic integration. The N400 component appears in both sentence contexts and in prime-target word pairs, as well as in both visual and auditory modalities. The N400 has also been observed across languages including English, Dutch, French, German, Hebrew, and even American Sign Language (Friederici, 2004).

Relating to Semantic Priming. As mentioned above, findings of greater N400 amplitudes in response to unrelated and unexpected words have led researchers to conclude that the N400 reflects the extent to which a given word has been semantically primed. The phenomenon of semantic priming is evident in faster processing times for related targets over unrelated targets. One explanation of semantic priming is offered in the theory of Automatic Spreading Activation. In this account, words are semantically organized in the lexicon and therefore, a given word has strong ties to and is located closer to related words. Because of this semantic organization, when a word’s representation is retrieved, energy passively spreads to semantically related items. Such related items (i.e., targets) can then be accessed more efficiently, having been passively activated by the prime. This explanation of priming is pre-lexical in nature, as the priming occurs before the target is recognized.

Other accounts of priming have been proposed that are more active in nature and involve attentional factors. For example, a participant may improve efficiency of semantic processing by actively expecting a target word based on the prime. Such accounts of priming may even be post-lexical in nature, meaning that priming effects occur after a target word's representation has been activated in the lexicon. Post-lexical priming mechanisms such as relatedness strategies and other decision factors help explain priming effects seen in lexical decisions tasks. Osterhout and Holcomb (1995) proposed *strategic attention* as a versatile post-lexical priming mechanism that may allow participants, to "deal with information from a variety of sources, depending on the demands of the task at hand" (p. 177). To better understand the level of cognitive processing during semantic priming, particularly its automatic versus attentional nature, researchers have examined the N400 response under various conditions.

A study by Holcomb (1988) attempted to determine whether the N400 reflects pre- or post-lexical priming effects by presenting sentences in two blocks. The first block was designed to produce only pre-lexical, automatic spreading effects by including a relatively small ratio of semantically-related word pairs (i.e., the *automatic block*). The second block was designed to elicit post-lexical, strategic priming processes by including a relatively high ratio of semantically-related word pairs (i.e., the *attentional block*). Although an N400 was observed in response to unrelated word pairs in both conditions, the N400 was larger in the attentional block condition. Holcomb concluded that the N400 is sensitive to automatic spreading activation as well as strategic attention priming. An additional finding was that no N400 differences were observed between neutral and unrelated targets, which led to the conclusion that the N400 is not sensitive to inhibitory effects that may be created by unrelated targets. However, a late slow wave did differentiate between unrelated and neutral targets in the attentional block.

Holcomb's (1988) conclusion that the N400 is sensitive to priming through automatic spreading activation is consistent with an interpretation of the N400 as an indicator of resource demands during word recognition. In this interpretation, no N400 effect is observed for a target word that has been primed through automatic spreading activation because fewer resources are required for word recognition of the prime. Put another way, spreading activation benefits word retrieval processes, less resources are required, and no N400 effect is observed. While various studies (Besson, Fischler, Boaz, & Raney, 1992; Kutas & Hillyard, 1989) have supported the N400 as a sensitive marker of spreading activation, they have failed to rule out the possibility of above-mentioned additional priming effects from strategic, post-lexical processes (Osterhout & Holcomb, 1995). Certain studies have attempted to eliminate these post-lexical priming effects by masking the prime to prevent attentive possessing of its meaning (Brown & Hagoort, 1993; Neville, Pratarelli, & Simons, 1989). In these studies, N400 priming effects were not observed under masked-prime conditions. One explanation for this finding is that the N400 does not represent automatic priming at the pre-lexical level. Rather, the N400 may represent priming at the post-lexical level of the conceptual memory system. This conclusion would also explain cross-modal N400 effects between words and pictures and between written and spoken words because each modality taps into a common system of conceptual representation.

Chwilla, Brown, and Hagoort (1995) added further support to the interpretation of the N400 as a marker of post-lexical priming effects. Moreover, their findings suggest that the N400 is selectively sensitive to the process of lexical integration during the word recognition process. The authors explained that models of word recognition include the distinct sub-processes of lexical access, selection, and integration. Lexical access involves mapping form representations onto the lexicon and the subsequent automatic activation of a subset of lexical elements.

Therefore, the process of lexical access shares core characteristics with the pre-lexical priming mechanism of automatic spreading activation. Lexical selection and integration, in which an element is selected from the activated subset and integrated into a message-level representation, are higher level processes that share core characteristics with post-lexical priming mechanisms such as strategic attention or expectancy-induced priming.

Chwilla et al.'s (1995) study involved the visual presentation of prime-target word pairs in two task conditions: (a) a lexical decision task condition, which was consistent with semantic analysis of stimuli; and (b) a physical task, which discouraged semantic analysis. To establish the pre-lexical nature of the physical task, the researchers assessed the *lexicality effect* in both conditions. The lexicality effect is that words are processed faster than nonwords during lexical processing. The physical task condition showed no lexicality effect (i.e., no reaction time differences between words and nonwords), indicating non-lexical processing.

ERP results from Chwilla et al. (1995) showed an N400 priming effect in the lexical decision task but not in the physical task, indicating that the N400 is not sensitive to pre-lexical priming effects, and is therefore not sensitive to automatic spreading activation. Instead, results indicated that the N400 is sensitive to post-lexical priming mechanisms. These findings are compatible with the N400 as a marker of semantic integration over semantic access. Of interest, a P300 response was observed in the physical task based on word category expectedness, with a greater P300 for less-expected word categories. This finding indicates access of word meaning in semantic memory during the non-lexical physical task. The researchers postulated that although semantic aspects of the words themselves did not become part of the episodic representation (as indicated by the absence of an N400), categorization of stimulus events as more or less likely did become part of the episodic trace (Chwilla et al., 1995).

The N400 has been well established as a neurophysiologic marker of semantic processing, showing an inverse relationship between N400 amplitude and semantic expectedness (i.e., greater N400 amplitudes to less expected words). N400 effects have been observed in prime-target word pairs and in sentence contexts, leading researchers to conclude that the N400 reflects semantic priming processes, such as lexical-semantic integration during word retrieval. Studies that have investigated the linguistic specificity of the N400 suggest that the N400 may be language-specific at the conceptual, rather than lexical, level of processing.. The N400 shows a broad topographical distribution with neural generators thought to be located near the superior temporal gyrus.

Role in Reflecting Semantic Processing. The N400 component has specifically been investigated in children. Child ERP data provides valuable insight into the study of language development and its electrophysiologic correlates. Child neuronal activity during language processing can be compared with adult language processing to further our understanding of the development of language comprehension. Child ERP data is scarcer than adult data and the majority of child language ERP research has focused on semantic processing. Such studies have revealed similarities and differences in the electrophysiology of semantic processing between children and adults, as well as between younger and older children. Differences have been observed in the domains of latency, amplitude, and scalp distribution.

Atchley et al. (2006) explored semantic processing in children using electrophyisologic measures. The researchers gathered ERP data from children, ages 8 through 13 years, in response to the auditory presentation of sentences containing either syntactic or semantic errors. ERP recordings were also taken from adult participants in the same conditions. Both children and adults showed an N400 response to the semantic violation condition, leading the researchers to conclude that the N400 is a sensitive marker of lexical-semantic integration in children as well as in adults. Important differences between children and adults were observed in the N400 component in the domains of latency, amplitude, and scalp location.

Compared to adults, the latency of the N400 in children was increased. The largest N400s were observed at 437 ms and 448 ms for children and at 364 ms and at 368 ms for adults, suggesting the N400 latency was increased by approximately 75 ms in children as compared to adults. The amplitude of the N400 in children also differed from adults, showing an age group by sentence type interaction; over frontal sites, children showed a larger N400 than adults. Finally, the scalp location of the N400 differed between children and adults. While adults showed an N400 distributed over parietal and centroparietal regions, the distribution of the N400 in children was centered over frontal sites with little to no activity over parietal and centroparietal regions. Children also showed a more widely distributed N400 at multiple electrodes (Atchley et al., 2006).

Atchley et al. (2006) cited two possibilities to explain these child-adult differences. The child ERP results may reflect physiological immaturity in the language processing of children. Another explanation is that children show task-specific developmental differences. That is, children may process specific stimuli differently than adults, and their sensitivity to these stimuli may change as they mature.

Friederici and Hahne (2001) also observed differences in scalp distribution between children and adults while studying the N400 in children ages 6 through 9 years. Similar to Atchley et al. (2006), their results showed that children’s N400 was more widely distributed than adults’ showing activation over frontal, central and parietal regions. These researchers also found an increased N400 amplitude and latency in children, but the increased latency was only present for younger children. An additional finding by Friederici and Hahne (2001) was an increased duration for the N400 in children as compared to adults, with the component ending around 1000 ms.

Hahne et al., (2004) also investigated developmental changes in language-related ERPs by identifying and describing the N400, ELAN, and P600 components in children, ages 6 through 13 years, and comparing these findings to adult ERP data. Child ERPs were measured in response to the auditory presentation of sentences in three language processing conditions: (a) correct, (b) semantically incorrect, and (c) syntactically incorrect sentences. As in the study by Atchley et al. (2006), an N400 was present for children from each age group in response to semantic violations. The N400 did show a smaller effect in the 6-year-old age group, but this result was interpreted to reflect the high lexical-semantic demands experienced by this young age group even in the correct condition.

Another major finding, consistent with results from the study by Atchley et al. (2006), was a decreased latency for the N400 component in older children. Alternatively, although the N400 component was consistently present in the semantic violation condition, latency was shortened as a function of increasing age. Despite this difference between younger and older children in N400 latency, the researchers concluded that no significant developmental changes occur in semantic processing between early childhood and adulthood (Hahne et al., 2004).

Another study which examined the N400 component in children was conducted by Holcomb, Coffey, and Neville (1992). The study employed over 130 participants, ranging in age from 5 to 26 years, whose neural activity was recorded in response to correct and semantically incorrect spoken sentences. Both older and younger age groups demonstrated an N400 peak in response to the semantically inappropriate sentences. However, younger age groups (5 to16 years) also demonstrated an N400-like negativity in response to semantically correct sentences, although this negativity was decreased from the anomalous condition.

Other age-related changes included a decrease in both latency and amplitude of the N400 as a function of age, following a linear trend from ages 5 through 16 years before stabilizing. This finding suggests that language development continues through the mid-teen years. As compared to the correct condition, the amplitude of the N400 showed a greater decline as a function of age in the error condition, thus lessening the N400 effect as a function of age. Holcomb et al. (1992) interpreted these age-related changes in the N400 waveform to represent increased context dependency during semantic processing in younger children. In this explanation, older age groups would benefit less from sentence context because they show more primed responses, requiring less semantic integration, even during the semantic error condition. This interpretation may account for Hahne et al.'s (2004) failure to observe a decrease in the amplitude of the N400 as a function of age because, as compared to the sentence stimuli used by Holcomb et al., the stimuli used by Hahne et al. were shorter sentences which provided less context to assist participants during semantic processing (Hahne et al., 2004).

It is also of interest to examine differences in N400 amplitude between children with language impairment and typically developing children. Neville, Coffey, Holcomb, and Tallal (1993) observed that a larger N400 amplitude was evident for children with language impairment as compared to typically developing children. This suggests that younger children and children with language impairment have more difficulty with semantic processing as compared to older children, adults, and typically developing children.

Scalp distribution differences in the N400 between older and younger participants were also of particular interest in the study by Holcomb et al. (1992). Across sentence type conditions, younger age groups (5 to 16 years) showed greatest N400 amplitudes over anterior regions. This seems consistent with Atchley et al.'s (2006) finding of an N400 centered over frontal sites in children. However, Holcomb et al. found that the N400 priming effect in children was greatest over posterior parietal regions. Juottonen, Revonsuo, and Lang (1996) found similar adult-child differences in scalp distribution and found that younger children showed the greatest amplitude effects over parietal sties. To explain these findings, Holcomb et al. (1992) hypothesized that "the negative mean amplitude between 300 and 500 ms [the N400] and its modulation by the sentence type variable [the priming effect] are generated by different ERP sources that are differentially affected by development" (p. 220). To explain these different neural generators, they proposed that a second negative-going ERP component, with a temporal distribution similar to that of the N400, may summate with the N400 in children. This second component has been recorded at frontal sites in response to novel stimuli in children but is absent in adults over 18 years of age.

The N400 is a robust marker of semantic integration in children as well as in adults, and has been recorded in children as young as 5 years of age (Holcomb et al., 1992). Children have consistently shown increased N400 latencies as compared to adults. Children also show greater N400 amplitudes and larger N400 effects than adults, possibly reflecting lessened context-dependency and more primed responses for adults; therefore, children demonstrate greater difficultly than adults during semantic processing. Younger children also show increased semantic processing demands as compared to older children. N400 scalp distribution in children has been described with somewhat conflicting results, showing N400 effects over frontal and parietal electrode sites.

Function in Syntactic Processing. Relatively few studies have investigated syntactic language processing in children using ERPs. Atchley et al. (2006) conducted one such study by examining the P600 to explore syntactic processing in children, ages 8 through 13 years. In response to spoken sentences containing verb-drop or agreement-violation syntactic errors, children showed a P600 that closely resembled adults' in scalp location, latency, and amplitude. However, the child P600 showed a longer duration, extending through the 674-724 ms time window, for the agreement-violation condition. A trend for greater P600 amplitudes in children was also observed, but this effect was only marginal. These results contrast with previous findings by Friederici and Hahne (2001) who recorded larger P600 amplitudes to phrase structure violations in children as compared to adults. Friederici and Hahne also observed that the child P600 occurred later than the adult P600, beginning at approximately 750 ms and extending to 1500 ms. Atchley et al. (2006) explained that these conflicting results may have been due to the different types of syntactic anomalies used between the two studies. The violations used by Atchley et al. may have been more suited to younger participants' comprehension.

Hahne, Eckstein, and Friederici (2004) also studied syntactic processing in children, by carefully examining ELAN and P600 effects between children and adults. In children ages 7 through 10 years, no ELAN was observed between 100 and 300 ms. Instead, a sustained anterior negativity extending beyond 400 ms was observed. In 6-year-old children, no ELAN effect was observed. However, a widely distributed negativity between 100 and 300 ms was recorded in the correct condition compared with the syntactic violation condition, suggesting a "processing aspect specific to the difference between those two conditions" (Hahne et al., 2004, p. 1314). Only 13-year -olds showed an ELAN that resembled adult processing. The P600 was observed in all ages (6 through 13 years), but was smaller and occurred later in younger ages. These findings are partly explained by the passive construction of the sentence stimuli which may have been more difficult for younger children.

In children, as in adults, syntactic language processing is reflected in the ELAN and P600 components. The P600 in children may be reduced in amplitude as compared to adults and may have a longer latency and increased duration. The ELAN in children may not resemble the adult ELAN until as late as 13 years of age.

Present Study

The aim of the present study was to provide a more complete description of language processing in 5- to 12-year-old children by examining their N400 responses to correct, semantically incorrect, and syntactically incorrect spoken sentences. Examining ERP responses across these conditions allowed for conclusions specific to syntactic vs. semantic language comprehension in children.

Sentence stimuli were presented in monaural left, monaural right, and binaural conditions to investigate potential differences between conditions. In challenging auditory tasks (e.g., dichotic listening tasks) normal listeners have shown a right ear advantage (REA) for linguistic stimuli (Bellis, 2003). This processing difference reflects hearing physiology, viz., the dominance of the contralateral pathway in auditory stimulation and left hemispheric specialization for processing of linguistic stimuli. When linguistic stimuli are presented monaurally to the left ear, the input must cross from the right hemisphere to left before processing can occur. Conversely, when linguistic stimuli are presented to the right ear monaurally, no interhemispheric processing is necessary, resulting in more efficient auditory processing. Research has shown that the REA in children is greater than in adults for dichotically presented sentences, and that the size of this REA decreases with increasing age (Willeford & Burleigh, 1994). These maturational effects are most pronounced in children when stimuli are linguistically loaded and complex (Bellis, 2003). The present study looked for electrophysiologic correlates to these behavioral findings and investigated possible hemispheric processing differences in children using ERP measures.

Method

Participants

The participants consisted of normally developing children between the ages of 5;0 and 12;5 (years;months). The participants were divided into five groups. The groups consisted of ages 5;0-6;5 (Group 1), 6;6-7;11 (Group 2), 8;0-9;5 (Group 3), 9;6-10;11 (Group 4), and 11;0-12;5 (Group 5). Each group consisted of six participants. A total of 30 participants were included in the study. Each participant met the following criteria:

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

Instrumentation

An electrode cap (Electrocap International) was used to place silver-silver chloride electrodes over the scalp at 32 electrode positions according to the 10-20 International System (Jasper, 1958). Electrode impedances were kept below 3000 ohms. Eye movements were monitored by placing electrodes on the outer cantha on one eye and above the supra-orbital foramen of the opposite eye. During post-hoc averaging, trials containing eye movement were rejected.

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

A female native English speaker was used to record the sentences. The sentences were digitally recorded in a sound-isolated chamber using a low impedance dynamic microphone (DPA 4011). The microphone was positioned approximately six inches from the talker's mouth. An A/D converter (Mini-me) by Apogee Systems was used to convert the stimuli. All recordings were made at 44.1 kHz with 24-bit quantization. The sentences were down-sampled and segmented with Adobe Audition Software to 18-bit quantization to interface with NeuroScan software. Selections were cut at a zero crossing and ramped over the initial and ending 25 ms. In addition, all files were high-pass filtered to eliminate any extraneous noise below 65 Hz. To make the tokens relatively equivalent with regard to intensity, the average RMS of each token was measured and digitally adjusted to a standard level, taking care to not adjust above peak recording levels. Two tokens were digitally edited to eliminate noise artifacts produced during recording. As a final step, the sentences were listened to and judged auditorily to be clear with no sudden changes in loudness or extraneous noises. The loudness level of each sentence was perceptually equivalent.

Stimuli

Sentences were presented to the participants in three conditions: (a) monaurally to the right ear, (b) monaurally to the left ear, and (c) binaurally. The sentences were presented through insert phones (ER3-A) at 65 dB HL in a sound-attenuated chamber using the GSI-61 audiometer. Sentences were taken from the Houghton Mifflin English Textbooks and were determined to be at the comprehension level of a typically developing 5-year-old (Houghton Mifflin English Textbook, 1990; Houghton Mifflin English Textbook, 1995). One hundred and two sentences were used to create the stimuli. Three versions of each sentence were used, totaling 306 sentences. One version of the sentences was correct, one version contained a semantic error, and the third version contained a syntactic error. Syntactic errors included one of the following: (a) a plural noun syntactic error, (b) a past tense *–ed* verb syntactic error, (c) a past tense irregular verb syntactic error, or (d) a third person verb syntactic error. These morphemes are used appropriately by typically developing 5-year-olds (Brown, 1973). The errors were relative to the participants' regional dialect. All syntactic and semantic errors occurred in the final word of the sentence. The correct and incorrect versions of the same sentence were randomized and never occurred consecutively. Three randomized versions from the 306 sentences were constructed to prevent bias. Each version contained approximately 50 sentences with syntactic errors, 50 sentences with semantic errors, and 50 correct sentences. Each participant listened to a different version in each of the three ear conditions. The presentation order of these versions and of ear condition was randomized between participants. Each participant listened to a total of 450 sentences. Each participant was given a five-minute training period in which they were instructed to listen carefully to each sentence, decide if the sentence was correct or incorrect, and push the corresponding response button (a smiley-face was attached to the button for a correct or *good* sentence and a frowny-face was attached to the button for an incorrect or *bad* sentence). After the first and second presentations of sentences, each participant was offered a five-minute break. Examples of the sentences are listed below (see Appendix C for the complete set):

No Syntactic Errors

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

Four Examples of Semantic Error

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

Four Examples of Syntactic Error

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

Analysis

The auditory evoked potential waveforms obtained for each participant were averaged for the standard linguistically correct and the deviant conditions (syntactically and semantically incorrect). Grand averages were also computed across participants in the standard and deviant conditions and analyzed. The latency of the N400 was defined as the prominent positive peak within the latency range of 300-600 ms at the Cz (central midline) recording site or at recording sites adjacent to the Cz recording site. The magnitude of the N400 was obtained by measuring the amplitude of the waveform from the baseline to the peak amplitude of the N400.

From the raw EEG data, epochs were created. A three point baseline correction and smooth function was then performed. Averages were then taken in the three separate ear conditions from -200 to 1700 ms post-stimulus.

Descriptive statistics, including means and standard deviations of the N400 latencies and amplitudes, were determined for each age group in all ear and sentence conditions. Grand average waveforms were also created for each group in all ear and sentence conditions. Finally, percentage of participants who demonstrated identifiable N400s was determined for each age group.

Results

The purpose of the present research was to provide a more complete temporal and topographical description of the neurophysiology of semantic language processing in children, 5 to 12 years of age. The N400, a well-established marker of semantic processing, was described within the domains of latency and amplitude for each age group. Differences in the N400 were observed within age groups for ear presentation and sentence condition. Developmental differences were also observed across age groups. The findings of the present study were in partial agreement with previous ERP studies of language processing in children.

Identifiable N400s across Age Groups

Table 1 shows the percentage of identifiable waveforms for each age group across the three sentence conditions. In the correct condition, there appears to be a greater reduction in the percentage of present waveforms as a function of increasing age, with the highest percentage present for the youngest age group and the lowest percentage present for the oldest age group. Of the three stimulus conditions, the lowest percentages of identifiable N400s were observed in the syntactic error condition for the four youngest age groups, with the lowest percentage for Group 3 at 41.7% and the other four age groups ranging from 58.3 to 66.7%. In the semantic error condition, each age group showed a high percentage present, ranging from 83.3 to 100%.

Figure 1 shows N400 grand averages for each age group and for each sentence condition. Each age group demonstrated N400s in the semantic error condition. However, only children in the two oldest age groups (Groups 4 and 5) showed an N400 response exclusively in the semantic error condition. Children in the younger age groups (Groups 1, 2, and 3) demonstrated N400s in the syntactic error condition as well as in the semantic error condition. Additionally, children in the two youngest age groups (Groups 1 and 2) showed N400 responses in the correct sentence condition.

Table 1

Percentage Identifiable N400s for Stimulus Conditions Across Age Groups

Age (years;months)	Correct	Syntactic Error	Semantic Error
5;0 to 6;6	91.7	66.7	83.3
6;7 to 8;0	83.3	66.7	100.0
8;1 to 9;6	83.3	41.7	83.3
9;7 to 11;0	75.0	66.7	100.0
11;1 to 12;6	50.0	58.3	91.7

N400 Latencies and Amplitudes within Age Groups

Descriptive statistics showed amplitude and latency differences for each age group across sentence condition and across ear condition. For Group 1, differences in N400 latency were observed between ear and sentence condition (see Table 2). In the correct sentence condition, a greater latency was observed for binaural presentation as compared to monaural presentations, with the shortest latency for right ear presentation. However, in the syntactic error condition, left ear presentation showed a greater latency than binaural and right ear presentations, again with the shortest latency for right ear presentation. A general trend for longer N400 latencies in the syntactic error condition as compared to the correct condition was observed, especially, for left ear presentation. Latencies in the syntactic error condition were also longer than in the semantic error condition.

Table 2 also shows differences in N400 amplitude for Group 1. Differences in ear presentation included the greatest negativity for right ear presentation in the correct condition, and the greatest negativity for left ear presentation in the syntactic error condition. Across

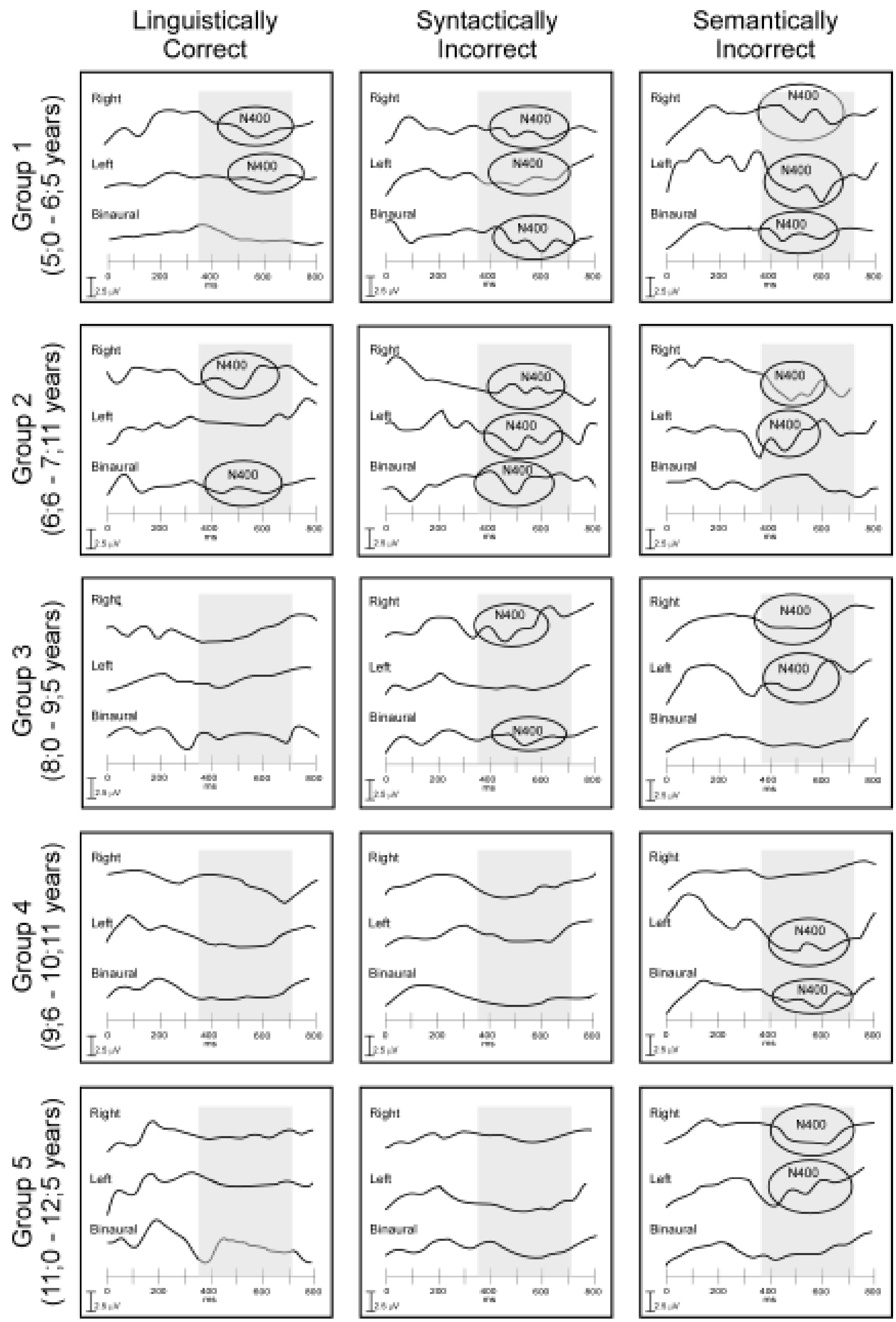

Figure 1. *Grand average N400s for each age group across all conditions.*

Table 2

Descriptive Statistics for the N400 in Participants Ages 5;2 to 6;5 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=6)				
Latency (ms)	499.20	84.86	424.80	611.00
Amplitude (µV)	-5.38	4.39	-13.04	.06
Right Ear (n=5)				
Latency (ms)	479.52	112.18	358.40	623.80
Amplitude (µV)	-8.51	4.10	-12.97	-2.42
Binaural Ear (n=4)				
Latency (ms)	537.65	77.20	459.00	638.80
Amplitude (µV)	-6.01	4.54	-10.05	.49
Syntactic Error				
Left Ear (n=3)				
Latency (ms)	603.80	19.87	581.00	617.40
Amplitude (µV)	-9.05	8.31	-17.58	-.98
Right Ear (n=5)				
Latency (ms)	522.36	68.04	437.60	611.00
Amplitude (µV)	-8.15	4.63	-13.53	-2.15
Binaural Ear (n=4)				
Latency (ms)	545.64	52.86	476.20	593.80
Amplitude (µV)	-5.37	6.48	-12.84	2.60
Semantic Error				
Left Ear (n=6)				
Latency (ms)	488.60	59.48	422.60	574.60
Amplitude (µV)	-6.03	3.79	-10.70	-1.20
Right Ear (n=4)				
Latency (ms)	488.45	73.80	431.20	596.00
Amplitude (µV)	-6.35	10.94	-22.09	2.70
Binaural Ear (n=6)				
Latency (ms)	481.83	44.30	420.40	548.80
Amplitude (µV)	-5.61	4.80	-12.71	1.46

conditions for Group 1, slightly greater negativities were seen in the syntactic error condition than in the control condition. However, the control condition showed slightly greater negativities than the semantic error condition for this young age group.

For Group 2, N400 latency differences were observed between ear presentations in the correct and syntactic error conditions (see Table 3). In the correct condition, latency for right ear presentation was shorter than latency for left ear presentation. Conversely, in the syntactic error condition, N400 latency was slightly longer for right ear presentation than for left ear presentation. Latency differences were also observed between correct and syntactic error conditions. Latency for right ear presentation was longer in the syntactic error condition than in the correct condition. Although no large differences in latency were observed between correct and semantic error conditions, N400 latency for left ear presentation in the correct condition was slightly longer than all ear presentation latencies in the semantic error condition. A general trend was that the shortest latencies were observed in the semantic error condition, slightly longer latencies were observed in the correct condition, and the longest latencies were observed in the syntactic error condition.

The N400 amplitudes for Group 2 also showed differences between ear presentations and between sentence conditions (see Table 3). In the correct sentence condition, the greatest negativity was observed for binaural presentation, while in the syntactic error condition, the greatest negativity was observed for left ear presentation. Across sentence conditions, greater negativities were observed in the semantic and syntactic error conditions than in the correct condition. This difference in amplitude between the correct and semantic error conditions represents an N400 effect for this age group across all ear presentations, with a slightly lesser effect for binaural presentation as compared to monaural presentations.

Table 3

Descriptive Statistics for the N400 in Participants Ages 6:8 to 7:11 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=5)				
Latency (ms)	559.32	45.01	527.40	634.40
Amplitude (µV)	-.75	8.83	-9.66	13.18
Right Ear (n=5)				
Latency (ms)	481.28	25.18	456.80	512.60
Amplitude (µV)	.80	3.64	-2.74	6.40
Binaural Ear (n=3)				
Latency (ms)	492.53	97.53	405.60	598.00
Amplitude (µV)	-4.28	2.90	-7.40	-1.65
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	525.85	89.66	416.20	600.20
Amplitude (µV)	-8.49	.67	-9.29	-7.68
Right Ear (n=4)				
Latency (ms)	549.95	26.55	514.60	572.40
Amplitude (µV)	-5.57	1.98	-7.61	-2.94
Binaural Ear (n=3)				
Latency (ms)	528.13	58.47	463.20	576.60
Amplitude (µV)	-4.17	3.76	-7.18	.04
Semantic Error				
Left Ear (n=6)				
Latency (ms)	500.03	57.92	446.20	606.60
Amplitude (µV)	-7.79	7.66	-18.12	.34
Right Ear (n=6)				
Latency (ms)	476.83	57.47	409.80	566.00
Amplitude (µV)	-5.21	3.66	-9.25	-.72
Binaural Ear (n=6)				
Latency (ms)	503.07	57.77	407.6	561.80
Amplitude (µV)	-6.38	5.90	-12.75	3.10

Group 3 showed differences in latency between ear presentations (see Table 4). In the correct sentence condition, latency for right ear presentation was longer than latency for left ear or binaural presentations. However, in the syntactic error condition, the longest latency was observed for left ear presentation, especially over binaural presentation. The semantic error condition also showed the longest latency for left ear presentation over binaural presentation and, to a lesser effect, over right ear presentation. Only slight differences in latency were observed across sentence conditions, with a longer latency in the syntactic error condition than in the correct and semantic error conditions for left ear presentation. Generally, the shortest latencies were observed for binaural presentation across sentence condition.

N400 amplitude for Group 3 varied across ear presentations (see Table 4). In the correct condition, a greater negativity was observed for binaural presentation than for monaural presentations. Conversely, in the syntactic error condition, the largest negativity was observed for left ear presentation and only a slight negativity was observed for binaural presentation. Finally, in the semantic error condition, a greater negativity was observed for right ear presentation than for left ear presentation and, to a lesser effect, for binaural presentation. Between sentence conditions, greater negativities were observed in the semantic error condition than in the correct sentence condition for right and left ear presentations, creating an N400 effect for monaural presentation. The same N400 effect was not observed for binaural presentation. Greater negativities were also observed in the syntactic error condition than in the correct condition, but again, only for monaural presentation.

Differences were observed between ear presentations for Group 4 (see Table 5). In the correct condition, the shortest latency was observed for right ear presentation. In the semantic error condition, latency was slightly shorter for binaural presentation than for left and right ear presentations. No large latency differences were seen between sentence conditions. However, slight latency differences were observed between correct and semantic error conditions for right ear presentation, with a slightly shorter latency in the correct condition than in the semantic error condition. Conversely, for binaural presentation, a slightly shorter latency was observed in the semantic error condition than in the correct sentence condition.

Group 4 showed amplitude differences between ear presentations (see Table 5). In the correct and syntactic error conditions, the greatest negativity was observed for binaural presentation. In the semantic error condition, the greatest negativities were seen for right ear and binaural presentations over left ear presentation. Between sentence conditions, only a slight N400 effect was observed for right ear presentation. For left ear and binaural presentations, greater negativities were observed in the correct condition than in the semantic error condition. Negativities were also greater in the correct condition than in the syntactic error condition for all ear conditions.

Group 5 showed various differences in N400 latency values (see Table 6). In the correct condition, longer latencies were observed for left ear and binaural presentations than for right ear presentation. Conversely, in the syntactic error condition, the longest latency was observed for right ear presentation. In the semantic error condition, the longest latency was observed for binaural presentation and the shortest latency was observed for left ear presentation. Between sentence conditions, longer latencies were consistently observed in the syntactic error condition over the correct sentence condition. Longer latencies were also observed in the syntactic error condition than in the semantic error condition for left and right ear presentations. Between correct and semantic error conditions, a longer latency was observed in the semantic error

Table 4

Descriptive Statistics for the N400 in Participants Ages 8:3 to 9:3 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=5)				
Latency (ms)	460.28	27.25	431.20	489.00
Amplitude (μV)	-3.45	4.72	-7.33	4.10
Right Ear (n=5)				
Latency (ms)	510.80	57.22	469.80	602.40
Amplitude (μV)	-4.71	2.20	-7.08	-2.22
Binaural Ear (n=3)				
Latency (ms)	466.13	71.88	418.40	548.80
Amplitude (μV)	-7.92	2.05	-10.22	-6.28
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	540.85	64.53	467.60	613.00
Amplitude (μV)	-8.52	4.16	-13.87	-3.38
Right Ear (n=1)				
Latency (ms)	501.80	0	501.80	501.80
Amplitude (μV)	-7.18	0	-7.18	-7.18
Binaural Ear (n=3)				
Latency (ms)	436.67	93.94	362.80	542.40
Amplitude (μV)	-1.80	3.07	-4.28	1.64
Semantic Error				
Left Ear (n=6)				
Latency (ms)	512.87	54.32	435.40	573.40
Amplitude (μV)	-5.30	3.04	-9.25	-.44
Right Ear (n=4)				
Latency (ms)	469.70	60.13	386.20	514.60
Amplitude (μV)	-7.01	2.95	-10.63	-4.27
Binaural Ear (n=5)				
Latency (ms)	455.84	76.07	379.80	563.80
Amplitude (μV)	-5.92	1.49	-7.99	-4.35

Table 5

Descriptive Statistics for the N400 in Participants Ages 9:6 to 10:6 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=4)				
Latency (ms)	520.50	81.67	424.80	591.60
Amplitude (µV)	-2.73	7.33	-13.25	3.74
Right Ear (n=5)				
Latency (ms)	466.08	54.45	407.40	542.40
Amplitude (µV)	-3.07	4.20	-7.40	1.98
Binaural Ear (n=4)				
Latency (ms)	505.05	83.05	405.60	596.00
Amplitude (µV)	-7.69	4.17	-12.45	-3.22
Syntactic Error				
Left Ear (n=3)				
Latency (ms)	489.20	31.71	465.40	525.20
Amplitude (µV)	-.80	1.76	-2.74	.69
Right Ear (n=5)				
Latency (ms)	485.92	90.64	375.40	602.40
Amplitude (µV)	-1.86	1.82	-4.24	.32
Binaural Ear (n=4)				
Latency (ms)	509.80	74.18	422.60	576.60
Amplitude (µV)	-3.73	3.89	-8.31	1.22
Semantic Error				
Left Ear (n=6)				
Latency (ms)	517.43	78.51	407.60	604.60
Amplitude (µV)	.13	8.21	-13.27	8.27
Right Ear (n=6)				
Latency (ms)	501.07	90.50	358.40	610.80
Amplitude (µV)	-3.98	6.08	-8.63	7.52
Binaural Ear (n=5)				
Latency (ms)	469.28	52.63	414.00	531.80
Amplitude (µV)	-3.80	9.23	-15.61	7.39

condition than in the correct condition (i.e., an N400 effect) for binaural presentation. However, a longer latency was seen in the correct condition than in the semantic error condition for left ear presentation.

Amplitude differences were observed between ear presentations for Group 5 (see Table 6). In the correct sentence condition, the greatest N400 amplitude was observed for left ear presentation, with a slightly lesser negativity for binaural presentation and the smallest negativity for right ear presentation. In the syntactic error condition, slightly greater negativities were observed for right and left ear presentations than for binaural presentation. In the semantic error condition, binaural and left ear presentations resulted in greater negativities than right ear presentation, with the greatest negativity for binaural presentation. Across sentence conditions, an N400 effect (i.e., greater negativities in the semantic error condition than in the correct sentence condition) was observed for right ear and binaural presentations. Generally, the smallest negativities were observed in the syntactic error condition.

N400 Latencies and Amplitudes across Age Groups

Across age groups, certain trends were observed for N400 latency and amplitude. One observation of N400 latency based on ear presentation was that in the correct sentence condition, the shortest latencies were observed for right ear presentation for Groups 1, 2, 4, and 5. However, the effect was not observed for Group 3. Another observation based on ear presentation was that in the syntactic error condition, the longest latencies were observed for left ear presentation, especially, over binaural presentation for Groups 1 and 3. Groups 3 and 4 in the semantic error condition also showed the longest latencies for left ear presentation and the shortest latencies for binaural presentation. However, this effect was reversed for Group 5, with the longest latency for the binaural presentation and the shortest latency for left ear presentation.

Table 6

Descriptive Statistics for the N400 in Participants Ages 11:0 to 12:5 Years of Age

Condition	*M*	*SD*	Minimum	Maximum
Correct				
Left Ear (n=2)				
Latency (ms)	476.10	96.87	407.60	544.60
Amplitude (µV)	-6.77	7.02	-11.73	-1.81
Right Ear (n=4)				
Latency (ms)	458.70	93.27	352.00	566.00
Amplitude (µV)	-3.18	3.26	-5.51	1.63
Binaural Ear (n=4)				
Latency (ms)	483.10	37.32	448.40	536.00
Amplitude (µV)	-4.60	3.28	-9.47	-2.50
Syntactic Error				
Left Ear (n=4)				
Latency (ms)	494.40	51.83	434.20	559.60
Amplitude (µV)	-3.94	1.98	-6.43	-2.01
Right Ear (n=3)				
Latency (ms)	546.07	67.54	501.80	623.80
Amplitude (µV)	-4.31	1.64	-5.58	-2.46
Binaural Ear (n=5)				
Latency (ms)	504.52	72.83	405.40	585.20
Amplitude (µV)	-3.04	2.07	-6.59	-1.33
Semantic Error				
Left Ear (n=6)				
Latency (ms)	434.87	75.43	335.20	536.40
Amplitude (µV)	-7.14	5.46	-14.35	-.27
Right Ear (n=5)				
Latency (ms)	469.48	29.93	432.20	510.40
Amplitude (µV)	-4.58	2.39	-7.29	-.90
Binaural Ear (n=4)				
Latency (ms)	518.80	84.46	398.60	587.40
Amplitude (µV)	-8.89	4.14	-14.23	-4.14

Other N400 latency differences were observed based on sentence condition. Groups 1 and 2 consistently showed the shortest latencies for the semantic error sentence condition and the longest latencies for the syntactic error condition. Group 5 also showed the longest latencies in the syntactic error condition. However, Group 3 generally only showed slightly longer latencies for the syntactic error condition, and Group 4 showed no clear latency differences among sentence conditions.

N400 amplitude differences were also observed across age groups. An N400 effect was observed for Group 2, as greater negativities were observed in the semantic error condition than in the correct condition across ear presentations. An N400 effect was also observed for Group 3 for monaural presentations, and for Group 5 for binaural and right ear presentations. Only a slight N400 effect was seen for Group 4 for right ear presentation; negativities for other ear presentations were greater in the correct sentence condition. Group 1 also showed a very slight N400 effect for left ear presentation, but negativities for other ear presentations were greater in the correct condition. Across all age groups, Group 2 showed the smallest amplitudes in the correct condition, which accounts for the large N400 effect for this group. Also, greater negativities were observed in the syntactic error condition than in the correct condition for Group 2 across ear presentation and for Group 3 for monaural presentations. The effect was seen to a lesser extent for Group 1.

Other observations were made for N400 amplitude based on ear presentation. In the syntactic error condition, the greatest negativities were observed for left ear presentation and the smallest negativities were observed for binaural presentation. Group 5 also showed the smallest negativities for the binaural presentation. Conversely, Group 3 showed the greatest negativities for binaural presentation in the syntactic error condition. In the correct sentence condition, the greatest negativities were observed for binaural presentation for Groups 2, 3, and 4.

Discussion

It is apparent from the present research that children across all age groups (ages 5;0 to 12;6) regularly detect semantic anomalies in spoken sentences. The high percentage of identifiable N400s in the semantic error condition from Table 1 illustrates that all child age groups detect semantic errors with a high level of occurrence. The grand average waveforms for each age group show N400s in the semantic error condition (see Figure 1), indicating that children across all age groups detect semantic errors. These findings are consistent with previous studies in which children across age groups consistently demonstrated N400s in response to semantic errors (Atchley et al., 2006; Hahne et al., 2004; Holcomb et al., 1992). Participants in Hahne et al. ranged from 6 to 13 years, participants in Holcomb et al. ranged from 5 to 26 years, and participants in Atchley et al. ranged from 8 to 13 years.

While the data contained in Table 1 indicates that children across all age groups are able to detect semantic errors, it also reveals developmental differences in processing different sentence types. These data show that the occurrence of the N400 in the correct sentence condition decreases with increasing age (approximately a 40% decrease from the youngest to the oldest age group). Younger children, however, show a high percentage of identifiable N400s in the correct condition as well as in the semantic error condition, indicating semantic processing demands for younger children even in the correct condition. Only the two oldest age groups show a large difference in the percentage of present N400s between the control and semantic error conditions, suggesting matured semantic processing. Hahne et al. (2004) and Holcomb et al. (1992) reported that younger children demonstrated N400s in response to correct sentences. Hahne et al. specifically noted N400s in the correct condition for children aged 4;11 to 6;6, roughly corresponding to the present study’s Group 1. The researchers hypothesized that younger children have increased difficulty with lexical-semantic integration for both semantic error and correct sentence types.

A distinction was observed in the percentage of identifiable N400s between the syntactic and semantic error conditions across age groups. The occurrence of the N400 was reduced in the syntactic error condition as compared to the semantic error condition, helping to establish the specificity of the N400's role in semantic processing. In children as young as 5 years of age, there appears to be a parsing of semantic versus syntactic error types. However, the identification of N400s in the syntactic error condition (58.3 to 66.7% present across age groups) indicates some semantic processing demands during the comprehension of syntactic error sentences for children.

The data illustrated in Figure 2 also suggests developmental differences in processing, specifically, developmental differences in ability to categorize semantic errors. Although grand average waveforms for all age groups showed N400s in the semantic error condition (indicating that each age group detected semantic errors), only the two oldest age groups showed N400s exclusively in the semantic error condition. Younger age groups (Groups 1, 2, and 3) showed N400s in the syntactic error condition, and Groups 1 and 2 showed N400s in the correct condition. This indicates that only children in Groups 4 and 5 were able to categorize error types. For children 5 to 8 years of age, the categorization of semantic and syntactic errors is variable. However, by approximately 9 years of age, children are able to classify errors neurophysiologically as semantic errors. Again, this finding is consistent with Hahne et al. (2004) who observed N400s in the correct sentence condition for the study's youngest age group.

Descriptive statistics allowed for comparisons between latency and amplitude values across age groups. Group averages of N400 latency in the semantic error condition ranged from

434.87 to 518.80 ms. This N400 latency range in children is similar to Atchley's (2006) finding of N400 latencies between 414 and 464 ms. One clear trend in N400 latency in the present study was shorter latencies for right ear presentation in the correct condition for Groups 1, 2, 4, and 5. This may represent a right ear processing advantage for these age groups which has not been previously reported for neurophysiological measures, although Bellis (2003) has reported similar behavioral observations.

Another fairly consistent trend in N400 latency was longer latencies in the syntactic condition as compared to the other sentence conditions for Groups 1, 2, 3, and 5. These longer latencies in response to syntactic errors may reflect the forced-choice nature of the testing in which participants were asked to discriminate between correct and error sentence types. Syntactic errors may have been more subtle and difficult to detect than semantic errors, creating increased processing demands and longer latencies for syntactic error types in children. The syntactic error stimuli in the present study consisted of morphosyntactic errors at the word level as opposed to more overt word-order errors at the phrase level (e.g., *The boy swim* as compared to *Boy the swim*). Morphosyntactic errors may be quite subtle to children who do not develop certain morphemes until over 4 years of age (Brown, 1973). These syntactic errors may have been especially difficult for children to detect as compared to the semantic error stimuli, which were designed to be overt and highly unexpected based on sentence context (e.g., *The boy was swimming in the peanut butter*).

Furthermore, child language studies have established that the metalinguistic awareness which allows children to judge between correct and syntactically incorrect sentences develops months or even years later than the ability to use syntactic forms in speech production and comprehension (J. G. De Villiers & P. A. De Villiers, 1978). For example, a child may use irregular past tense verb forms correctly well before he or she has the metalinguistic ability to detect irregular past tense verb errors in spoken sentences. Therefore, the metalinguistic demands created by the forced choice nature of the testing may have further increased the processing difficulty for the syntactic error sentences.

Descriptive statistics showed trends in N400 amplitude. Amplitude values in the present study generally agreed with amplitude values reported by Hahne et al. (2004) for children. N400 amplitude effects between correct and semantic error sentences in children were of specific interest. A clear N400 effect across all ear presentations was observed only for Group 2. N400 effects were also observed for Groups 3 and 5, but only for certain ear presentations. No clear N400 effects were observed for Groups 1 and 4. These findings are in partial disagreement with previous studies. Specifically, Holcomb et al. (1992) found an N400 effect across all participants, including children (participants ranged from 5 to 26 years of age). However, an explanation for this seeming inconsistency may be related to electrode site; the current study reflects only the Cz or adjacent electrodes while other studies observed greatest N400 effects over posterior or parietal regions for children (Holcomb et al., 1992; Juottonen, Revonsuo, & Lang, 1996). Furthermore, Atchley (2006) observed N400 effects centered over frontal sites with little to no N400 activity over centroparietal sites.

The lack of an N400 effect for Group 1 disagrees with Hahne et al.'s (2004) observation of an N400 effect for the study's 6-year-old age group. However, the N400 effect reported by Hahne et al. was small and observed only at lateral electrodes in a late time window (650-800 ms). Again, the current study only examined Cz or adjacent electrodes. Furthermore, the present study only examined N400s during an earlier time window (300-600 ms). Therefore, the present finding of no N400 effect for Group 1 at Cz or adjacent electrodes in the 300-600 ms time window may agree with findings from Hahne et al. However, the lack of an N400 effect for the present study's Group 4 seems to disagree with Hahne et al.'s finding of significant N400 effects at central electrode sites during a 400 to 650 ms time window for 10- to 12-year-old children.

Because the above-mentioned studies extended the time window of the N400 beyond what has been reported in the literature for this component to occur, it is most likely that the previous studies had mistaken other components for the N400. The reader is referred to Burkard, Don and Eggermont (2007) for a more in depth discussion of the distribution of the N400 and the technical parameters of identifying these components. Also, the tagging of the initialization of the latency measurement will cause an apparent latency shift (e.g., whether it is tagged at the beginning of the target word, the end of the target word, the beginning of the sentence, or the end of the sentence).

Another seeming discrepancy between the present study and previous child language ERP studies is the present study's lack of consistent developmental trends in N400 latency and amplitude across age groups. Previous child language ERP studies have observed decreased N400 latency as a function of increasing age (Atchley et al., 2006; Hahne et al., 2004; Holcomb et al., 1992). The lack of clear developmental trends in N400 latency in the present study may be explained by the small sample size of children represented in each age group and the corresponding high standard deviation values for N400 latency. Furthermore, Holcomb et al. reported decreased N400 amplitude as a function of increasing age. However, as in the present study, Hahne et al. also did not observe this decrease in N400 amplitude with increasing age. Hahne et al. accounted this disagreement to the short sentence stimuli used in their study as compared to passive sentence stimuli used by Holcomb et al. This explanation may also apply to the present study. Under Holcomb et al.'s interpretation that age-related N400 changes represent increased context dependency in younger children, Hahne et al.'s relatively short sentence stimuli would provide less context to assist participants during semantic processing and, therefore, lessened developmental changes in N400 amplitude. The present study also used relatively short sentence stimuli with basic canonical word-order structures (i.e., subject-verb-object sentences).

Conclusion

Consistent with the existing small body of child language processing ERP studies, the present study found that children across all age groups, ranging from 5;0 to 12;6, consistently detect semantic errors neurophysiologically. Also in agreement with previous studies, the present study observed N400 responses for correct sentence types for younger age groups, indicating increased processing demands for younger children even for correct sentences. Furthermore, the present study demonstrated that only the two oldest age groups were able to neurophysiologically distinguish between correct and error sentence types as well as between semantic and syntactic errors (i.e., only the two oldest age groups showed N400s exclusively in the semantic error condition). This indicates that the ability to categorize errors does not fully develop until approximately 9 years of age.

In comparison to previous studies, clear N400 effects (i.e., N400 amplitude differences between correct and semantic error types) were not observed for most age groups. However, this difference may be explained by the different time windows and electrode cites examined in previous studies as compared to the present study. The relatively small sample size employed as well as the short sentences used in the present study may also explain the lack of N400 effects as well as the lack of clear developmental trends in N400 latency and amplitude across age groups.

Although the existing body of child language processing ERP studies has not reported N400 responses to syntactically incorrect sentences, the present study observed various N400 responses to syntactic anomalies, especially for younger age groups. Although the full implications of this finding are still unclear, the observed N400 responses indicate that children demonstrate some semantic processing during the comprehension of syntactic error sentences. This overlap in semantic and syntactic processing indicates that young children are not yet able to consistently parse error types. Furthermore, longer N400 latencies were observed in the syntactic error condition, perhaps reflecting the subtle nature of the syntactic error stimuli.

The present findings also indicate directions for future investigations of semantic processing in children. Using data from the present study, child N400 responses could be examined across a longer time window (up to 1000 ms duration) to assess the possibility of other processes occurring in younger children during the processing of linguistic information. This would also be true for ERP waveforms at other electrode sites (specifically frontal, posterior, and parietal regions) being examined for N400 responses. Finally, behavioral, response-time data could be analyzed in light of the reported differences in N400 latencies across sentence conditions. A future study could also more thoroughly analyze child N400 responses to syntactically incorrect sentences, using a variety of syntactic error types. For such an investigation, a larger sample size is recommended.

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Appendix A

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

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

Name of Participant:____________________________ Date of Birth:__________________

Purpose of Study

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

Procedures

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

The study will be conducted at your child's school and in room 111 of the John Taylor Building on the campus of Brigham Young University. The testing at the school will consist of two sessions. One session will test your child's IQ and the second session will test your child's language. Each session at the school will take approximately 1 hour. Testing at Brigham Young University, including orientation and testing, requires one 2-3 hour session. Your child may ask for a break at any time during testing. Basic hearing tests will be administered during the first half-hour of the session.

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

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

Your child will wear the electrode cap while he/she listens to 648 sentences, during which time the electrical activity of his/her brain will be recorded on a computer. Your child will be asked to give responses during the hearing test, standardized language test, and the electrophysiological recording.

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

Risks

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

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

Benefits

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

Confidentiality

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

Other Considerations

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

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

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

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

____________________________ ______________
Signature of Parent/Guardian Date

____________________________ ______________
Signature of Witness Date

Appendix B

Child Informed Consent to Act as a Human Research Subject

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

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

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

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

I would like to be part of this study.

______________________________ _______________
Signature of Participant Date

______________________________ _______________
Signature of Witness Date

Appendix C

Stimulus Sentences

A. Correct Sentences

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

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

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

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

B. Semantic Errors

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

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

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

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

C. Syntactic Errors

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

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

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

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