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A comparison of semantic and syntactic event related potentials generated by children and adults

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Abstract

The present study employs event related potentials (ERPs) to verify the utility of using electrophysiological measures to study developmental questions within the field of language comprehension. Established ERP components (N400 and P600) that reflect semantic and syntactic processing were examined. Fifteen adults and 14 children (ages 8–13) processed spoken stimuli containing either semantic or syntactic anomalies. Adult participants showed a significant N400 in response to semantic anomalies and P600 components in response to syntactic anomalies. Children also show evidence of both ERP components. The children's N400 component differed from the adults' in scalp location, latency, and component amplitude. The children's P600 was remarkably similar to the P600 shown by adults in scalp location, component amplitude, and component latency. Theoretical implication for theories of language comprehension in adults and children will be discussed.

Keywords: Child language; Event related potentials; P600; Syntactic processing; Semantics

1. Examining semantic and syntactic event related potentials in children

Electrophysiological measures of brain activity, which are derived from the examination of time-course dependent fluctuations in electroencephalographic signals, have proven to be an informative window on language comprehension (see Kutas & Van Petten, 1994; Osterhout & Holcomb, 1992, for review). The study of event related potentials (ERPs) has provided insight into phonological, syntactic, and semantic elements within the language comprehension system. Among the array of neuroimaging techniques available to brain researchers, ERPs are especially well suited for language studies because of high levels of temporal resolution (Donchin, 1979; Fabiani, Gratton, & Coles, 2000; Hillyard & Picton, 1987). Furthermore, there exists a well-defined set of ERP brainwave components that may be considered brain correlates of language comprehension operations (Kutas, 1993; Kutas & Van Petten, 1994; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1995). The aim of the current research was to examine spoken language comprehension in children and adults by looking at ERP signals that are elicited by semantic or syntactic processing (Friederici & Hahne, 2001; Hahne & Friederici, 1999; Holcomb, Coffey, & Neville, 1992; Neville, Coffey, Holcomb, & Tallal, 1993). The current research represents one of a few studies that has examined concurrently semantic and syntactic processing using electrophysiological responses from children who are listening to spoken language. Therefore, the primary intent of this research was to verify the potential utility of using ERPs to examine developmental questions within the domain of language processing.

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1.1. Adult ERP language research

In the adult research, two ERP language components are arguably the best described and established of the components that have been identified as being sensitive to variations in the linguistic content of experimental stimuli. The first of these components is referred to as the N400. This terminology indicates that the component is a negative-going component that shows its greatest amplitude at around 400 ms post-stimulus. This component is thought to be sensitive to the semantic content of words or sentences (Bentin & McCarthy, 1994; Hagoort & Brown, 2000; Kutas, 1997; Kutas & Hillyard, 1980). An additional defining characteristic of the N400 is its spatial distribution across the scalp. The classic N400 has a scalp location that is maximal over posterior midline scalp locations, particularly the parietal (Pz) and centroparietal (CPz) electrodes.

First described by Kutas and Hillyard (1980), the N400 component has been extensively studied across many experiments employing different kinds of semantic contexts and across different languages and modalities (see Kutas & Van Petten, 1994; Osterhout & Holcomb, 1995, for a review). The N400 magnitude is inversely related to the semantic plausibility of a word given its current linguistic context. In a sentence context every word in the sentence is thought to induce an N400 with the relative amplitude of this component being highest when the word is a clear semantic anomaly. For example, we would expect a large N400 in response to the sentence-final word in sentence 1b but not in sentence 1a.

(1a) *The man baked the bread.*
(1b) *The man baked the cloud.*

Because of the N400s sensitivity to semantic context, it has been discussed as an additional metric, much like semantic priming, that can reflect the pattern of spreading activation in the semantic network of the language user. Additionally, it is thought to provide insight into a participant's ability to integrate this semantic information into a cohesive discourse representation (Osterhout & Holcomb, 1999; Rugg, 1995; van Berkum, Hagoort, & Brown, 1999).

The second ERP component that will be focused on in the current research is generally referred to as the P600 (Osterhout & Hagoort, 1999) or the late positive shift (Hagoort, Brown, & Groothusen, 1993). Again, the nomenclature indicates that this ERP component is characterized by a positive shift in the waveform that peaks at around 600 ms post-stimulus. The P600 component is somewhat more controversial than the N400. Nonetheless there is a growing literature that lends support to the idea that the P600 is sensitive to aspects of language comprehension. Specifically, the P600 seems to be sensitive to the syntactic characteristics of a word in sentential context (Hagoort et al., 1993; Neville et al., 1991; Osterhout & Holcomb, 1995; Osterhout & Nicol, 1999). Analogous to the N400 component previously discussed P600 amplitude is larger if a word represents a syntactic anomaly. For example, in some of the first research examining syntactic processing using ERPs, Osterhout and Holcomb (1992) showed that there was a late positive fluctuation in the ERP waveform that was related to violations of phrase structure. Consider sentences 2a and 2b.

(2a) *The broker hoped* ***to*** *sell the stock.*
(2b) **The broker persuaded* ***to*** *sell the stock.*

Because the verb in sentence 2a is intransitive the clausal complement (*to sell the stock*) can be directly attached to the main clause and the sentence is grammatical. However, by using the transitive verb in sentence 2b, this same sentential structure is now ungrammatical. Osterhout and Holcomb collected ERP data following the word "*to*" in each sentence because this infinitival marker should be the first anomalous word in the ungrammatical sentence (such as sentence 2b). Osterhout and Holcomb found a large positive wave following this infinitival marker in sentences that contained a transitive verb (*persuaded*) but not in sentences that contained an intransitive verb (*hoped*). In other words, a P600 occurred if the eliciting word was anomalous given the grammatical structure of the sentence. Like the N400, the P600 is maximal over more posterior sites on the scalp.

To a much greater degree than the N400, the specificity of the P600 has been questioned in the literature. This is in part because of its polarity and scalp location. Multiple researchers (for a review see Osterhout & Hagoort, 1999; Osterhout & Holcomb, 1992) have argued that the P600 is an independent component that is specifically generated by a neurofunctional module that is specialized for syntactic processing. Others suggest that this component is actually a member of the more general class of P300 components that are modulated in amplitude by many kinds of unexpected stimuli (see Coulson, King, & Kutas, 1998a, 1998b; for a review of this alternative argument). Regardless of the conclusion that one draws regarding the syntactic specificity of the P600, it is generally accepted that this late positive shift in the ERP waveform is sensitive to syntactic anomaly.

1.2. Child ERP language research

Most of the previous spoken language studies with children have examined semantic processing (Friederici & Hahne, 2001; Hahne & Friederici, 1999; Holcomb et al., 1992; Juottonen, Revonsuo, & Lang, 1996) while only a few have examined the processing of syntactic anomalies (Friederici & Hahne, 2001; Hahne & Friederici, 1999). Holcomb et al. (1992) completed the most thorough examination of the influence of age on the N400 component, in their study of 130 participants between the ages of 5 and 26. This large sample size provided at least 6 participants per age group (ranging in size from 6 to 22 participants) in each of 10 different age bands. Each participant listened to 80 different sentences (40 semantically anomalous and 40 control sentences). After each sentence, participants indicated via button press whether or not the sentence made sense. Both children and adults produced a larger N400 to anomalous sentences relative to well-formed sentences. For the N400, Holcomb et al. found an effect of age of participant on both component latency and component amplitude. Both N400 latency and amplitude decreased as age increased from 5 to 16 years. A second finding was an interaction involving the age of the participant, scalp location of the N400, and influence of sentence context on N400 amplitude. The younger participants (aged 5–14) showed a large amplitude N400 in response to all sentence types (semantically anomalous and control) and, unlike the older participants, this component was maximal over more anterior scalp sites. However, when the waveforms generated by anomalous and control conditions were compared, Holcomb et al. found that this semantic comparison resulted in waveforms that were most dissimilar at posterior scalp locations. This pattern seems to indicate that N400 in children is highly distributed and not limited to only posterior scalp locations as seen in adults. Results from the older participants were similar to previous research on the N400 in adults and showed a recognizable N400 only for anomalous sentences and this component was largest over more posterior locations. The children's large N400-like component over anterior scalp locations is a finding not seen in adults. Holcomb et al. suggest that this pattern might reflect the presence of a second negative component that is seen only in children and which overlaps the N400 in time course. A similar component was seen in ERP attention research involving children (Courchesne, 1978; Holcomb, Ackerman, & Dykman, 1985) and is thought to be a component that is unique to children that reflects attentional capture.

Auditory ERP results similar to those of Holcomb et al. in English were also found in Finnish (Juottonen et al., 1996) and German (Friederici & Hahne, 2001). Juottonen et al. (1996) examined children between the ages of 5 and 11 years old while Friederici and Hahne (2001) tested children between 6 and 9 years old. Both studies report significantly larger N400 amplitude components for children as compared to adults. Significant effects were also observed for N400 peak latency, with children showing longer latencies than adults. For the Friederici and Hahne study, this later onset of the N400 only occurred for the younger children; the older children patterned similar to the adults. Although the amplitude and latency results are in agreement with the Holcomb et al. study, slight differences in scalp location of the N400 components are reported. Like Holcomb and colleagues (1985); Juottonen et al. (1996) show larger amplitude effects in parietal regions as compared to anterior regions for the younger participants. Friederici and Hahne (2001), however, state that children and adults differ in the scalp location of the N400 waveform, with children showing more widely distributed activation, including central, parietal, and frontal electrodes. An interesting additional finding of Friederici and Hahne is the extended duration of the N400, ending around 1000 ms for children.

Fewer studies have examined the P600 component in children. Friederici and Hahne (2001) report their research on syntactic processing in children (also see Hahne & Friederici, 1999). In a study including 16 German-speaking 6–7-year-olds and 16 German-speaking 8–9-year-olds, they found evidence that children were sensitive to phrase structure violations. In German, a case-marked preposition requires a following noun or noun phrase. In the Friederici and Hahne study, the phrase structure violations were realized by a case-marked preposition ('im' *in the*) that was followed by a past participle verb (for example, 'geangelt' *caught*). Therefore, syntactically correct sentences ('Der Fisch wurde geangelt' *The fish was caught*) were compared to syntactically incorrect sentences ('Der Fisch wurde im geangelt' *The fish was in the caught*). Friederici and Hahne found that the P600 is significantly larger in amplitude in children than in adults. Moreover, this late positivity elicited by the syntactically anomalous sentences appeared significantly later for children, beginning at around 750 ms post-stimulus and extending beyond 1500 ms post-stimulus.

In summarizing the ERP data from children, the most common feature of the N400 component is its tendency to be greater in amplitude, more delayed in latency, and more widely distributed in terms of scalp location than that observed in adults. For the P600, there is a tendency for this component to be greater in amplitude and more delayed in latency as compared to that observed in adults.

1.3. Current study

The goal of the present set of ERP experiments was to further investigate language processing in children using spoken language. Both semantic and syntactic conditions are included using the same experimental methods. While variability due to language of presentation (i.e., German vs. English) may not influence the outcome of the semantic conditions, it may be an important consideration when examining syntactic processing. Furthermore, our selection of syntactic violations was guided by recent investigations of children's acquisition that have focused on morphosyntax (cf. Wexler, 1994) rather than syntactic violations involving simply word category errors. Behavioral studies report that young English-speaking children follow a child grammar that allows omission of *DO* from questions and omission of copula and auxiliary *BE* from declaratives and questions. This tendency is evident in spontaneous utterances (Rice, Wexler, & Hershberger, 1998), probe elicitation tasks (Rice & Wexler, 1996; Rice, Wexler, & Cleave, 1995), and in grammaticality judgments (Rice et al., 1998; Rice, Wexler, & Redmond, 1999; Rice & Wexler, 2000). By 8–10 years of age, typically developing children's performance reaches the adult range of accuracy in judgment data. Interestingly, growth curve analyses consistently find that acquisition of this morphosyntactic element is not predicted by children's semantic knowledge (Rice et al., 1998), suggesting distinct processing elements of morphosyntax and semantics.

Our most basic expectations were that we would observe a divergence between the ERP waveforms generated by semantic anomalous and semantic control conditions and that this divergence would fall between 300 and 500 ms post-stimulus. For the investigation of the semantic N400 component, semantically well-formed and anomalous sentences were compared (e.g., *Where does a boy like to play*? and *Where does a chair like to play*?, respectively). For both of these sentence types, the ERP components generated by the sentence-final word (e.g., *play*) will be examined. This is because it is this word that is inconsistent with the ongoing established semantic context in the anomalous condition. It was expected that children, as well as adults, would be sensitive to this semantic violation.

For the syntactic P600 ERP component, we expected to see divergence in the waveforms of the syntactic violation conditions and the syntactic control conditions falling in the time window between 500 and 800 ms post-stimulus. Two syntactically anomalous conditions are of interest, involving wh-questions that require insertion of *DO* in the finite verb position (e.g., *Where does a boy like to play*?; Rice & Wexler, 2000). In one condition, the *DO* form is omitted, e.g., **Where a boy like to play*? (henceforth referred to as the verb drop violation). In a second condition, the *DO* form shows an error of subject/verb agreement, e.g., **Where do a boy like to play*? (henceforth referred to as the agreement violation). This design allows us to examine any differences in processing between children and adults as well as between the two different syntactic structures within each age group. In both of these violation conditions the first anomalous word in the ungrammatical sentences is the word "*a*." Therefore, by comparing the same determiner (i.e., *a*) in all three syntactic conditions (verb drop violations, agreement violations, and syntactic control sentences) we expect to find evidence that both children and adults are sensitive to these morphosyntactic violations.

In summary, the present ERP study using spoken language will examine N400 and P600 components for both adults and children. The semantic condition and the two syntactic conditions will be compared to baseline control sentences. Results will be analyzed in terms of amplitude, latency, and scalp location of the ERP components. The relevant comparisons include that between age groups for each condition, that between the two types of syntactic violations for each age group, and that between semantic and syntactic processing.

2. Methods

2.1. Participants

Fourteen young participants (six females and eight males) were recruited and paid for their participation. Average age was 10.5 years (range 8.5–13 years) for this sample. Adult participants were undergraduate students attending the University of Kansas. The 15 adult participants (seven females and eight males) received course credit in exchange for their participation. The average age of adult participants was 20 years (range from 18 to 27 years). All participants in both age groups were native English speakers. Data were collected from five additional participants (2 young participants and 3 adult participants) but not analyzed because of excessive motion artifacts in the data. Participants were given the Peabody Picture Vocabulary Test (PPVT-R; Dunn & Dunn, 1981). The average PPVT standard score for young participants was 111.2 and the average score for adult participants was 110.4, therefore both participant groups sampled had a normal vocabulary for their age group.

2.2. Materials

Experimental materials, which were adopted from previous research with both SLI and normally developing children in this age group (Rice et al., 1998, 1999; Rice & Wexler, 2000), included 50 stimuli that were each presented twice, so that each participant heard a total of 100 stimuli. In subsequent discussions of this research, stimuli will be divided into two categories (semantic and syntactic stimulus conditions). The semantic condition had two types: semantically anomalous and semantically valid stimuli. The syntactic condition was subdivided into three sentence types: verb drop violations, agreement violations, and syntactically valid stimuli. There were 10 items for each of the five sentence types (1 semantic violation experimental condition, 2 syntactic violation experimental conditions, and 2 control conditions). Table 1 illustrates each of the critical experimental conditions included in the experiment, as well as their relevant control conditions.

The speech stimuli in this experiment were produced by a female native speaker of English and digitally recorded (Fostex D-5 DAT recorder) in an anechoic chamber. All words were individually produced. Stimuli were digitized at a sampling rate of 22050 Hz and segmented using Praat speech analysis software (www.praat.org). Sentences were created by concatenating the individual words, using a 200 ms silent interval between words. The fundamental frequency (F0) of the resulting sentence was slightly modified, using Praat, to provide a natural sentence contour for the entire utterance. Control and experimental sentences were identical with the exception of the word representing the anomaly. For the semantic conditions, only the noun was replaced. For the syntactic conditions, either 'does' was

Table 1
Experimental conditions included according to sentence type

Semantic conditions
Semantic anomalous: Where does a chair like to **play**?
Semantic control: Where does a boy like to **play**?
Syntactic conditions
Verb drop violation: Where **a** boy like to play?
Agreement violation: Where do **a** boy like to play?
Syntactic control: Where does **a** boy like to play?

ERP data collection began at the onset of the word indicated in bold.

replaced by 'do' or it was eliminated. As in the study designed by Holcomb et al. (1992) this stimulus construction procedure allowed for control of the temporal location of the target words such that identical timing relations existed in both well-formed and anomalous versions. Regarding stimulus presentation during the experimental session, the stimuli were presented via a pair of external computer speakers and the sound level of stimulus presentation was between 60 and 80 dB (with sound level being adjusted for each individual participant).

2.3. Procedure

Participants sat in a comfortable, padded chair in a copper shielded suite of rooms. Participants were first exposed to 24 practice stimuli. The construction of the practice stimulus list mimicked the stimulus conditions included in the experimental list. Behavioral and electrophysiological responses to these practice stimuli were not included in later analyses. Each trial consisted of an auditory question stimulus. The questions last for about 3800 ms in total. Following the question-final word, there was a 1500 ms silent pause before the onset of a visual prompt that indicated that the participant should make a grammaticality judgement. Following the grammaticality judgment procedures for children developed by Rice and Wexler and colleagues, the prompt was 1 = good, 2 = not so good. The word choice for the prompt was motivated by earlier work by Rice and Wexler (for example see Rice & Wexler, 2000) that found that some children (particularly young girls) are hesitant to endorse a grammaticality judgment if they must indicate that the experimental sentence or question is "bad" or "wrong." The term "not so good" has been a successful alternative for young children. To maintain consistency across age groups this same prompt was used for adults. The prompt remained on the computer screen until the subject made a button response. During the practice stimuli, special effort was made to ensure that participants learned to withhold their grammaticality judgement until after the prompt was presented. They were told that they should push the 1 key on the button box whenever the stimulus was correct and press the 2 key if the stimulus is problematic in any way. We informed participants that the errors might be either semantic or syntactic and we provided practice stimuli with both kinds of errors to illustrate. The stimuli were organized into two blocks of experimental trials that contained the same set of experimental stimuli in a different randomized order. Each block took about 7.5 min to complete.

2.4. Electrophysiological recording

The electroencephalogram (EEG) was recorded with silver–silver chloride electrodes mounted in a commercially available "Quick cap" (Neuromedical Supplies; www.neuro.com/neuromed/quikcap.htm). Midline frontal (Fz), frontal-central (FCz), central (Cz), and centroparietal (CPz), parietal (Pz), and occipital (Oz) recording sites were used, as defined by the 10–20 system (Jasper, 1958). Each scalp site was referred to the linked mastoids. All electrode impedance was lower than 5 kΩ. Electrodes were placed above and below the left eye and at the outer canthi to monitor blinks and eye movements.

The EEG was amplified with a NeuroScan Synamps amplifier (Neuroscan, www.neuro.com) with bandpass cutoffs of 0.01–50 Hz and digitized on-line with a sampling rate of 250 Hz. Neuroscan's eye movement correction protocol was used to eliminate eye-blink artifact. Trials with movement artifacts of greater than ±70 μV were rejected prior to averaging. Continuous EEG data was collected throughout the experimental blocks and a trigger pulse passed between the stimulus presentation computer and the SynAmps amplifier at the onset of the critical word in each stimulus condition (see Table 1). This means that an epoch was recorded including the question-final word in the semantic conditions (for example, *Where does a chair like to* ***play***?) and including the word "*a*" in the syntactic conditions (for example, *Where do* ***a*** *boy like to play*?). Epochs from 100 ms pre-stimulus to 1000 ms post-stimulus were averaged for each stimulus condition in each age group.

3. Results

3.1. Grammaticality judgments

For both participant groups, the average accuracy for grammaticality judgments was greater than 90%, indicating that both groups have a good ability to make accurate semantic and syntactic judgments. Children were significantly less accurate than adults in their behavioral responses [young participants = 90.3%, adult participants = 97.8%; $F(1,27) = 11.45$, $p < .01$, $Mse = .153$]. Another way to summarize grammaticality judgment outcomes is with a measure of sensitivity which takes into account correct and incorrect items and is adjusted for children's tendency to respond "yes." This measure, A', can be interpreted as the proportion of correct responses attainable in a two-alternative, forced-choice procedure (Green, 1964; Grier, 1971). This is calculated by determining the values x, the proportion of false alarms, and y, the proportion of hits following the formula from Linebarger et al. (1983), $A' = 0.5 + (y - x)(1 + y - x)/4y\,(1 - x)$. Perfect discrimination yields an A' of 1.00. The mean A' results for children and adults across conditions are summarized in Table 2. An ANOVA of Age group × Sentence types yielded a significant interac-

Table 2
A' for children and adults across conditions

Age group (N)	Syntactic		Semantic
	Verb drop violations	Agreement violations	
Adult (15)	.993	.980	.998
Child (14)	.932	.929	.966

tion effect for Age × Sentence type $F(2,27) = 7.27$, $p < .01$, $Mse = .005$, with no main effects for Sentence type or Age. The interaction is attributable to the fact that the adults were at ceiling levels across the sentence types whereas the children performed somewhat lower (although still at high levels) on the syntactic and semantic anomalies.

The mean results for response latencies are summarized for children and adults across conditions in Table 3.

An ANOVA of Age group × Sentence type yielded a significant main effect for Age [$F(1,27) = 14.60$, $p < .001$, $Mse = 10.45$], Sentence type [$F(2,27) = 12.153$, $p < .01$, $Mse = 1.39$] and no interaction of Age × Sentence type. Older participants responded more quickly than the children; semantic anomalies were responded to more quickly than syntactic anomalies.

3.2. N400 analyses

Figs. 1 and 2 display ERPs elicited by sentence-final words in each of the two semantic processing conditions (semantic anomalous vs. semantic control) in the two age groups for the time period beginning 100 ms prior to the stimulus and ending about 900 ms post-stimulus. Waveforms for four electrode sites are depicted (Fz, FCz, CPz, and Pz) to highlight the scalp distributions for the N400 waveforms that reflect age differences.

Because our analysis of this data was designed to examine the N400 ERP component, the mean voltages across five 50-ms time windows: 312–362, 363–413, 414–464, 465–515, and 516–566 ms were examined. An initial ANOVA of this 312–566 ms latency range included time window as one independent variable. Additionally, the variables of Sentence type (anomalous vs. control), Scalp site (6 levels: Fz, FCz, Cz, CPz, Pz, and Oz) and Age group (children vs. adults) were included. Because of inflated degrees of freedom a Geisser-Greenhouse correction for degrees of freedom was performed for all analyses where there is more than one degree of freedom in the numerator. For all such ANOVAs, Geisser-Greenhouse epsilon corrected p values and uncorrected degrees of freedom are reported.

These analyses yielded a main effect of Sentence type [$F(1,27) = 8.16$, $p < .01$, $Mse = 35.46$]. The Age variable [$F(1,27) = 3.04$, $p < .05$, $Mse = 94.93$] and Scalp site variable [$F(5,135) = 9.28$, $p < .001$, $Mse = 10.81$] also resulted in main effects. A three-way interaction between Age group, Sentence type, and Scalp site was also significant [$F(5,135) = 4.04$, $p < .05$, $Mse = 8.56$]. The independent variable of time window did not result in a significant main effect or in an interaction with the other independent variables (Fs < 1.5). However, by running simple planned comparisons for each of the time windows examined we found that the adults displayed significant N400 at the parietal

Table 3
Mean response latency (in ms) for children and adults across conditions

Age group (N)	Syntactic		Semantic
	Verb drop violations	Agreement violations	
Adult (15)	699	671	525
Child (14)	940	732	520

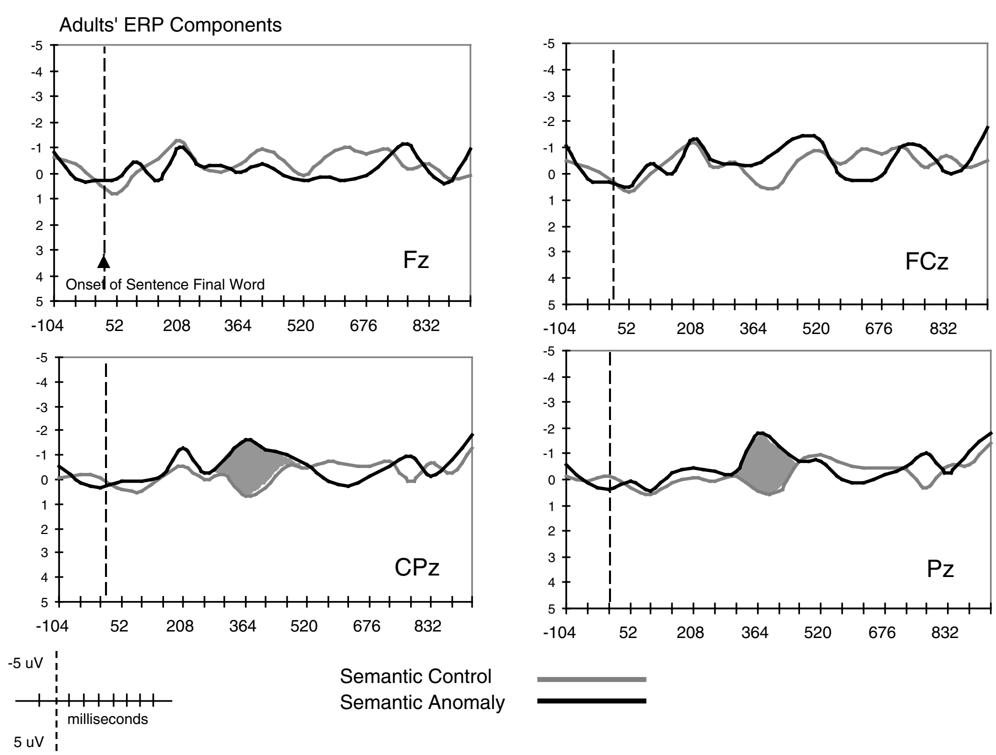

Fig. 1. Averaged ERP waveforms generated by the sentence-final, critical word in the semantic processing conditions (semantic anomalies and semantic controls) are displayed for adults at four electrode sites. Shaded areas represent time periods during which the two waveforms are significantly diverging.

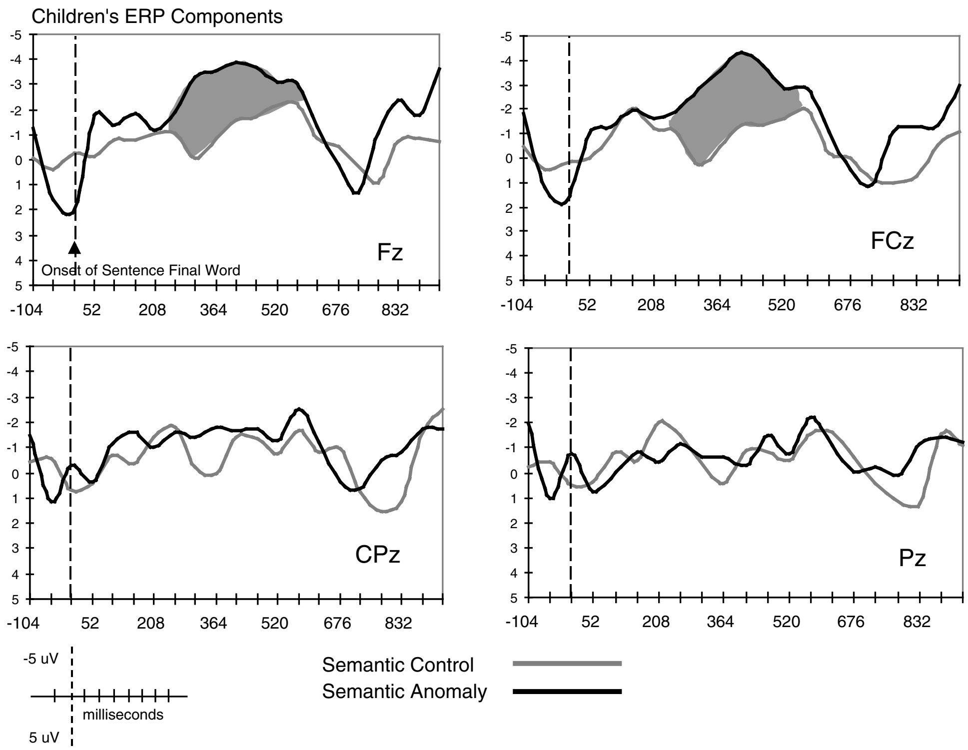

Fig. 2. Averaged ERP waveforms generated by the sentence-final, critical word in the semantic processing conditions (semantic anomalies and semantic controls) are displayed for children at four electrode sites. Shaded areas represent time periods during which the two waveforms are significantly diverging.

electrode scalp site [$F(1,14) = 17.07$, $p < .01$] and at the centroparietal scalp site [$F(1,14) = 24.74$, $p < .01$] that is maximal during the 363–413 ms time window. The children also showed a significant negative deflection in the ERP waveform for the anomalous sentences over multiple scalp sites during the 312–566 ms window. However, the children's N400 was maximal (in terms of both greatest mean amplitude and greatest statistical reliability) over the FCz [$F(1,14) = 8.69$, $p < .05$] and Fz [$F(1,14) = 4.47$, $p = .05$] scalp sites and peaked during the 414–464 ms time window.

Differences between adults and children in waveform amplitude were also observed. Planned comparisons for each of the scalp sites indicate that there is a significant Age group × Sentence type interaction for both the FCz [$F(1,30) = 6.65$, $p < .05$] and Fz [$F(1,30) = 3.87$, $p < .05$] scalp sites. This interaction is due to a greater difference between the anomalous and control conditions (a larger N400) for children than for adults.

To more clearly define the latency differences between our adult and child sample, *t* tests were run for each of the 4 ms segments that make-up the time windows with the greatest peak differences according to the planned comparisons reported above (363–413 for adults and 414–464 for children) to allow for comparisons of the latency of the N400s maximal amplitude. Based both on our a priori expectations and on the results of the above ANOVAs we will focus on the results from the parietal and centroparietal scalp locations in these more fine-grained temporal analyses of the data for adults and we will focus on the frontal–central and frontal medial sites for the children. The adults showed the greatest peak-to-peak difference between anomalous and control sentences at around 364 ms [$t(14) = 2.09$, $p < .05$] at the CPz site and at around 368 ms [$t(14) = 2.52$, $p < .05$] at the Pz. For the children, the greatest peak-to-peak difference occurred at around 437 ms post-stimulus for the frontal Fz electrode [$t(13) = 2.01$, $p < .05$], and at around 448 ms [$t(13) = 2.31$, $p < .05$] for the FCz electrode. This examination of the non-windowed data suggests that the latency of the peak of the N400 component in adults is about 75 ms less than the average latency shown by our sample of children.

3.3. P600 analysis

Figs. 3 (adults) and 4 (children) represent the epochs from approximately 100 ms pre-stimulus to 900 ms post-stimulus for each of the morphosyntactic stimulus conditions in each age group. Within each of these figures a separate graph is provided for the comparison of noun–verb agreement violations versus control and verb drop violations versus control, given that this comparison of anomaly and control condition is the contrast used to determine the presence and magnitude of a P600 ERP component. Also, as in the N400 analyses, we have highlighted in our figure only the scalp locations that resulted in a significant ERP waveform. Scalp locations not depicted in the figures did not result in a reliable P600.

For the P600 analyses we focused on a particular time frame of interest in the ANOVAs including the following 50 ms time windows, 572–622, 623–673, 674–724, 725–775,

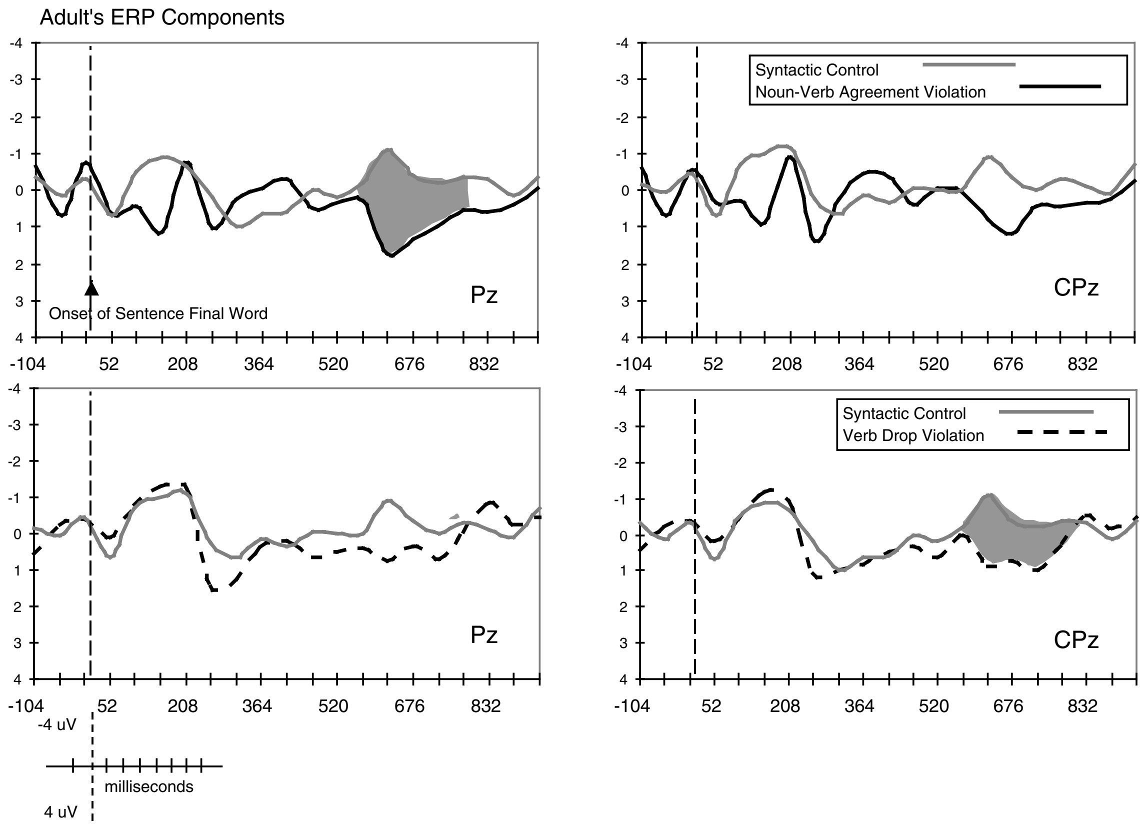

Fig. 3. Results for adults comparing noun–verb agreement violations versus controls and verb drop violations and controls over Pz and CPz scalp sites are illustrated. Shaded areas represent time periods during which the two waveforms are significantly diverging.

and 776–826 ms. The initial ANOVA of this 572–826 ms latency range again included the variables of Time window (five levels), Sentence type (three levels: agreement violation stimuli, verb drop violation stimuli, and syntactic controls), Scalp site (six levels: Fz, FCz, Cz, CPz, Pz, and Oz) and Age of participants (children vs. adults) as factors. These analyses yielded only a main effect of Time window [$F(4,108) = 2.96$, $p < .05$, $Mse = 27.09$]. All other main effects yielded Fs < 1.5. Two significant two-way interactions [Sentence type × Scalp site, $F(10,270) = 4.35$, $p < .001$, $Mse = 5.11$; Scalp site × Time window, $F(20,540) = 2.11$, $p < .05$, $Mse = 2.81$] and a three-way interaction of Age group, Sentence type, and Time window [$F(8,216) = 2.55$, $p < .05$, $Mse = 19.84$] were found. However, these interactions are probably best understood in the context of the significant four-way interaction between Age group, Sentence type, Scalp site, and Time window [$F(40,1080) = 1.76$, $p < .05$, $Mse = 2.32$]. Figs. 3 and 4 provide some help in illustrating this complex analysis by showing the divergence between the anomalous and control conditions during the time windows included in the ANOVA.

Again, simple planned comparisons were done to examine adult and child P600 patterns. These analyses showed that the adults displayed a P600 component in response to the agreement violation condition [$F(1,30) = 3.96$, $p < .05$] at the Pz electrode scalp site whose peak was maximal during the 623–673 ms time window. At the CPz scalp site in adult's there was a trend towards a positive deflection in the agreement violation condition [$F(1,30) = 3.41$, $p = .07$] that was not statistically reliable. For the adults' responses to the verb drop violation condition, the results indicate that there is a significant P600 for this condition, but only over the CPz electrode [$F(1,30) = 5.91$, $p < .05$] and for this condition the maximal peak-to-peak difference occurs during the time window 674–724 ms. For the agreement violation condition presented to children there was a positive deflection that was significant during two of our critical time windows (623–673 and 674–724 ms) over both the parietal site [623–673 ms: $F(1,29) = 3.47$, $p = .07$; 674–724 ms: $F(1,29) = 4.62$, $p < .05$] and over the centroparietal site [623–673 ms: $F(1,29) = 5.43$, $p < .05$; 674–724 ms: $F(1,29) = 12.01$, $p < .01$]. Like the adults, the P600 generated by the verb drop violation condition was more pronounced over the centroparietal site than over the parietal site and it occurred later than the P600 generated in the agreement violation condition. The maximum peak-to-peak difference occurred for both sites during the 674–724 ms time window and there was a reliable P600 for the CPz site [$F(1,29) = 7.28$, $p < .05$] and a P600 that approached significance for the Pz site [$F(1,29) = 3.84$, $p = .05$]. Analyses were also done to determine if adults and children differed in component amplitude. Planned comparisons indicated that differences in amplitude for the P600 generated during verb drop violations were not reliable. The children did show a trend toward a larger P600 for agreement violations, but only at the CPz site [$F(1,29) = 3.11$, $p = .08$].

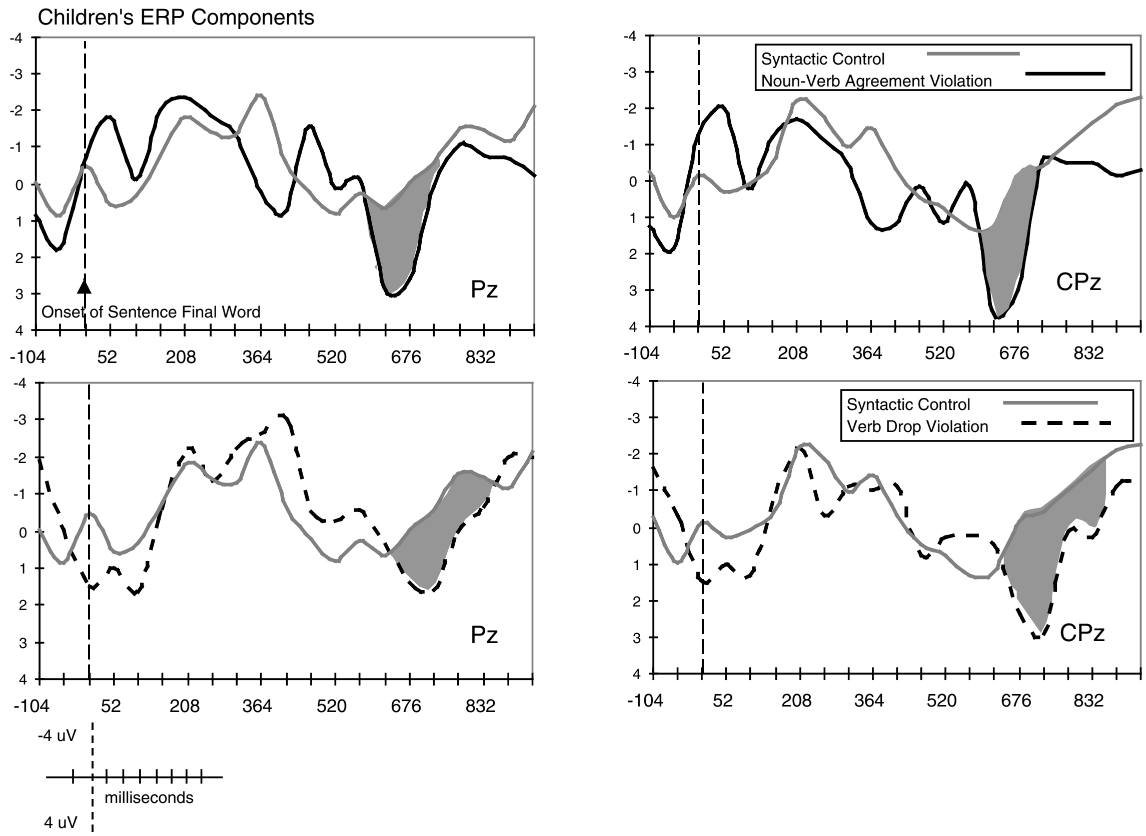

Fig. 4. Results for children comparing noun–verb agreement violations versus controls and verb drop violations and controls over Pz and CPz scalp sites are illustrated. Shaded areas represent time periods during which the two waveforms are significantly diverging.

As with the N400 analysis, it was part of our goal to determine if there existed a latency difference for the adult and child P600s. To explore the more fine-grained details of the P600 time course, t tests were again run at each 4 ms interval to determine the more precise latency of the P600 for our two age samples. As above we used the ANOVA results regarding component latency to focus our t test comparisons (adults: agreement violations = 623–673, verb drop = 674–724; children: agreement violations = 623–724, verb drop = 674–724). Also please note that in previous research, the P600 is primarily observed to be a slow rising component that generally does not show a pronounced peak of activity (for an example, please see Osterhout & Holcomb, 1992). However, in the current observations, we observed a more peaked P600 and therefore followed the same analysis protocols as used in the N400 analysis. For agreement violations, the adults show a significant positive deflection of the anomalous condition, as compared to the control condition, that is maximal at around 628 ms post-stimulus at both the CPz [$t(14) = 3.58$] and Pz [$t(14) = 3.78$]. For this same anomaly type the children show a maximal deflection at around 632 ms at CPz [$t(13) = 2.11$] and at around 656 ms for Pz [$t(13) = 2.51$]. For verb drop violations, both age groups show later peak-to-peak differences. For the verb drop violation condition adults show their greatest peak-to-peak difference occurring at around 692 ms for CPz [$t(14) = 2.98$] and for Pz [$t(14) = 2.45$]. The children show a similar latency at both CPz [680 ms, $t(13) = 1.94$] and Pz [700 ms, $t(13) = 1.68$] where the t score obtained did not reach the critical t value [$t_{.05}(13) = 1.771$]. Therefore, unlike the N400 component, the P600s obtained under the current research design seem to have very similar peak latencies for adults and children. However, one should not overlook the findings from our ANOVA analysis which suggest that for the P600 generated following an agreement violation, children show a component that is more extended in time as compared to adults (as reflected by a longer dissociation between the anomalous and control waveforms). Additionally, one should note the distinction in component latency observed for both children and adults between the two morphosyntactic violations examined. For both adults and children, the verb drop violations resulted in a P600 latency that was about 70 ms longer than that component latency for the agreement violations.

4. Discussion

This study of English-speaking children aged 8–13 reveals interesting similarities and differences in semantic and syntactic processing relative to adult processing. As in previous studies, the adult participants showed a significant N400 in response to semantic anomalies and P600 components in response to syntactic anomalies. Children also showed evidence of N400 and P600 components. Additionally, the children's N400 (but not

P600) differed from the adults' in scalp location, component amplitude, and in component latency.

Overall, these findings contribute to the small body of evidence that indicates that children's comprehension, like the adults, shows a lexical-semantic integration with a negative deflection in the ERP waveform. Discrepancies between child and adult processing were evident in the latencies, in that the peak is about 75 ms earlier for the adults than the children, and the locations of the processing, in that children's processing centered over frontal sites whereas the adults' appeared over parietal and centroparietal sites, and in component amplitude, as indicated by a significant Age group × Sentence type interaction. It seems premature to speculate on the functional implications of these observed developmental differences in the N400 given the obvious need for replication and extension of the current research. However, if these differences prove robust then they could be very informative. In previous research exploring age related changes in component latency, for example, has been taken to indicate either task specific developmental difference (such developmental changes in sensitivity to stimulus parameters) or general slowing due to physiological immaturity (Friederici & Hahne, 2001).

The current results for the N400 component are very similar (for example, Holcomb et al., 1992) to previous findings (Friederici & Hahne, 2001; Hahne & Friederici, 1999; Holcomb et al., 1992; Juottonen et al., 1996). In our research and in earlier studies of N400 in children, the predominant differences between adults and children are differences in component amplitude, more delayed component latency, and more widely distributed scalp distribution than that observed in adults.

Regarding the P600 results, the findings suggests that there is a separate and later positive ERP component associated with the processing of syntactic information that appears in children as young as 8 years as well as adults. The sites did not seem to differentiate the children from the adults; parietal and/or centroparietal sites were evident in both groups. Also component latency and amplitude did not appear to differ between adults and children. In comparing our results for the conditions that should elicit the P600 with other studies in the existing literature, one might note that we have more variability in the P600 waveforms. These differences may be due to the specific kinds of syntactic anomalies we used, which might be considered more subtle for young language users than were the phrase structure violations employed by Friederici and Hahne (2001).

Interestingly, there was a subtle difference in the scalp distribution of the adult P600 in response to agreement violations, such as **Where do a boy like to play*? (which show a significant P600 at the Pz electrodes), as compared to verb drop violations, such as **Where a boy like to play*? (significant at CPz only). These outcomes have parallels in current models of the adult grammar, and current investigations of children's grammar. The two different syntactic violations studied here are hypothesized in the Minimalist model of Chomsky (1996) to involve two different functional heads that serve as landing sites for movement operations in clause structure, and both are thought to have uninterpretable elements, i.e., elements that are independent of semantic elements of a clause. Under this model, the auxiliary *DO* is inserted in questions to meet the clausal requirements for tense and agreement checking. The findings here suggest that the subtle but important syntactic difference between agreement violations and omitted *DO* may involve slight adjustments in neurocortical processing to resolve the detection of the nature of the syntactic anomaly.

The distinction between agreement violations and auxiliary *DO* omission has also been strongly supported in studies of children's acquisition of morphosyntax. Early on, in their spontaneous utterances, young English-speaking children sometimes omit the auxiliary *DO* but rarely show incorrect agreement when the form appears, and this pattern holds in their grammaticality judgments as well (Rice et al., 1998, 1999) whereas when they are younger they are likely to accept omitted *DO* in wh-questions at the same time that they reject forms that violate subject–verb agreement (Rice & Wexler, 2000). As indicated in Tables 2 and 3, by 8 years or older, children's performance on judgment tasks has improved to near-adult levels, but it is not quite as accurate as adults, particularly in the syntactic violations, and the latency of responding is highest in the dropped *DO* violation. Collectively, what is known about children's acquisition of morphosyntax and the new findings here support the hypothesis that children show some sensitivity to the difference between the agreement properties of *DO* and the need to insert *DO* in questions.

Previous research with German-speaking children found a tendency for the P600 component to be greater in amplitude and more delayed in latency as compared to that observed in adults (Friederici & Hahne, 2001; Hahne & Friederici, 1999). In the current study, the differences between adult and child P600s were much less pronounced. For the P600 generated by verb drop violations there were no significant differences in component amplitude, latency, scalp location, or component duration observed between adults and children. For the agreement violation condition children showed a longer component duration (as reflected by a significant P600 for the anomalous condition during both the 623–673 and 674–724 ms as compared to the adults who only evidenced a significant P600 during the 623–673 ms time window). Additionally, children showed a trend towards having greater component amplitude for this kind of morphosyntactic error. Though this effect was only marginal, this finding is consistent with the previous literature that has consistently found that children have larger amplitude ERP components than adults.

Overall, this research supports the emerging conclusion that a semantic component, indicated by a N400, and a syntactic component, indicated by a P600, are evident in children's comprehension processing, in ways very similar to, but not identical with, those of adults. These findings suggest that the semantic component appears more quickly in the adults and results in the same scalp distribution as the syntactic violations, whereas the ERP component generated during children's semantic processing appears at electrode sites that are different from the scalp distribution for the ERP component caused by syntactic violations. Future research is needed to confirm the suggestive results reported here.

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