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Cognitive Brain Research 23 (2005) 247–258

COGNITIVE BRAIN RESEARCH

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Research report

An event-related brain potential study of sentence comprehension in preschoolers: semantic and morphosyntactic processing

Juan Silva-Pereyra*, Maritza Rivera-Gaxiola, Patricia K. Kuhl

Institute for Learning and Brain Sciences (I-LABS), University of Washington, Seattle, WA, USA
Department of Speech and Hearing Sciences, University of Washington, Seattle, WA, USA

Accepted 21 October 2004
Available online 22 December 2004

Abstract

The goal of this study was to investigate the distinctiveness and the relative time course of the event-related brain potentials (ERP) elicited by syntactically and semantically anomalous words within sentences in 36- and 48-month-old children. ERPs were recorded while children listened to semantically anomalous (i.e., My uncle will blow the movie*), syntactically anomalous (i.e., My uncle will watching the movie*) and control sentences (i.e., My uncle will watch the movie). Semantic violations elicited a negative slow wave with different peaks at 400, 600 and 800 ms in both age groups, whereas the morphosyntactic violations elicited two positive shifts: the first starting at 200 ms with a frontal distribution over the scalp and the second starting at 600 ms and peaking around 800 ms with a broad distribution across the scalp in 36-month-olds and anteriorly distributed for 48-month-olds. These results show that preschoolers display different ERP patterns to syntactic and to semantic violations within sentences. It is possible that the ERP effects here reported are analogous to those elicited in adults by the same type of stimuli, although differences in topography are evident.

Theme: Neural Basis of Behavior
Topic: Cognition; Language

Keywords: Sentence processing; Children; Preschoolers; Auditory ERP responses; Morphosyntactic processing; Semantic processing

1. Introduction

1.1. Language ERP effects in adults

Language is a complex system that involves different types of information. The well-formedness of a sentence is determined by constraints applied at various levels of representation (i.e., phonological, syntactic, semantic, etc.) [5]. Although the integration of these levels is widely accepted as a formal description of language, it remains unclear how the computation of information provided by each one of these levels is integrated for language comprehension and production.

There are several psychophysiological approaches that may help to determine the characteristics of the language processing system. One widely used method is the recording of brain electrical activity time-locked to some external or internal event, commonly known as event-related brain potentials (ERP). ERPs reflect the sum of the simultaneous postsynaptic activity of large groups of neurons. Different patterns of brain electrical activity recorded during sentence processing may reflect different levels of language representation. ERP components are classified according to their polarity (i.e., positive or negative deflections in the waveform) and the time in milliseconds of their initial or peak occurrence and their topographical distribution over the scalp. One ERP component that has traditionally been associated with semantic processing in adults is the so-called

* Corresponding author. Institute for Learning and Brain Sciences, University of Washington, Box 357988 Seattle, WA 98195-7988, USA. Fax: +1 206 221 6472.
E-mail address: jfsp@u.washington.edu (J. Silva-Pereyra).

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doi:10.1016/j.cogbrainres.2004.10.015

N400 component [30]. This is a negative wave occurring between 250 and 500 ms after stimulus onset and peaking around 400 ms. The N400 elicited by sentences having semantically incongruous endings tends to have a larger amplitude over right posterior sites [31]. The amplitude of the N400 to a particular word is highly sensitive to the immediate context in which it occurs, whether the context is a single word, a sentence or discourse [29].

In the adult literature, syntactic processing of sentences has been associated mainly with two ERP components: (a) a negative-going wave between 300 and 500 ms after target onset, which is largest over left frontal sites (left anterior negativity LAN) [14,28,47]; and (b) a late parietally distributed positivity with an onset around 500 ms called P600 [23,24,49,50]. The LAN component has been observed to phrase-structure violations [43,47], the processing of subcategorization information [46] and agreement violations [22]. The functional interpretation of LAN effects is not yet agreed upon. The LAN has been hypothesized to reflect a first stage of syntactic parsing [12,14]. It has also been reported that LAN effects occur in the processing of violations of word-category constraints [14]. However, other studies have shown that this effect also appears when the word category is correct but the morphosyntactic features are incorrect [42,43].

A more consistent finding than the reported LAN effect is the P600. In adults, this component is a positive wave distributed over centroparietal regions with a long latency. It begins at approximately 500 ms and has a duration of a few hundred milliseconds, with a peak at approximately 600 ms. The P600 has been found to covary with several syntactic anomalies, such as phrase structure violations [23,47], subjacency violations [33,47], agreement violations [6,23,51] and subcategorization violations [49,50,53]. Friederici et al. [16] have put forward the idea that the P600 is a component that reflects a mixture of subcomponents, including diagnosis, prosodic and syntactic reanalysis, and revision and syntactic integration. The P600 has been observed as a response to multiple syntactic violations during sentence comprehension in different languages (English, Dutch, German, Spanish, Italian) using auditory or visual stimuli, and even in "jabberwocky sentences"—sentences in which the content words have been replaced by pseudowords and the function words are kept as morphological markers [25]. The P600 component is also elicited by sentences that are grammatically correct but have a structural indeterminacy, as represented by garden-path sentences [53]. It has been proposed that the P600 component evoked by syntactic violations represents a repair process while the P600 elicited by ambiguity resolution represents a reanalysis process [17].

1.2. ERP studies of early language acquisition

Before infants can engage in linguistic analysis and understand the mappings between language and events, they must recognize the link between elements of the acoustic stream and specific events [18]. Evidence from ERP studies has shown that by 6 months of age infants display differences in the processing of words and non-words [35,44]. At 13–17 months of age, ERPs to known words differ from those to unknown words. Larger N200s and N350s are observed to known when compared to unknown words, and the differences are broadly distributed over the scalp [37,39,40]. Between 16 and 20 months, most children display a burst or acceleration in the rate of vocabulary growth [3,4]. By 20 months of age, ERP differences between known and unknown words become lateralized and more differentiated over the temporal and parietal regions of the left hemisphere, possibly reflecting an increasing specialization of those areas for language processing [36].

First word combinations usually appear between 18 and 20 months of age [4]. The ability to comprehend and use sentences implies an understanding of links between words that are not physically contiguous. To appreciate these relationships, children must detect which units are structurally dependent on which other units. Children must also be able to distinguish between words that bear content (open-class words) and words that carry more abstract, grammatically informative meaning (closed-class words). It has been reported that even newborns can discriminate the acoustic differences between syntactic and lexical words [57]. The ability of neonates to categorically discriminate lexical from grammatical words does not imply that they have "knowledge" of the grammatical categories of language; however, it does indicate that they have a set of acoustic-perceptual biases that could provide a starting point for eventually breaking into more complex aspects of speech and language (i.e., syntax). At 6 months of age, infants show a preference for lexical over grammatical words, contrary to the symmetrical categorical discrimination displayed by neonates [56]. This asymmetrical preference for lexical items may help infants to focus on refined subcategories within lexical categories and thus assist them in sentence parsing and word learning.

Between 24 and 30 months of age, most children show a kind of "second burst" with the development of morphosyntax [4]. By 28 and 30 months, when children typically begin to speak in short phrases, ERPs to open- and closed-class words elicit different patterns of brain activity. Closed-class words elicit a right greater than left asymmetry whereas open-class words elicit a left-hemisphere asymmetry [45]. By 36–42 months of age most typically developing children have mastered the basic morphological and syntactic structures of their language; they speak in sentences and use closed-class words appropriately to specify grammatical relations [18]. Like those of adults, ERPs from 3-year-olds display a left hemisphere asymmetry to closed-class words [45].

To date, very little is known about how a young child's brain processes semantic and grammatical information within sentences. Only one previous study [1] has examined ERP evidence of syntactic processing in 36–38-month-old children during sentence processing. In this study, phrase structure violations and semantically anomalous sentences were used, since children at this age are typically able to distinguish the order of words within each sentence and note that some phrases have a specific position within the sentences. In this study, a significant larger positive shift in the waveform was observed during the processing of syntactically anomalous sentences when compared to non-anomalous sentences. This effect was comprised only of a long-duration positive effect that was largest over anterior regions of the scalp from 500 to 1500 ms. The interpretation was that the effect was consistent with P600 results from adults during syntactic processing, but in contrast to the effects observed in adults [13,24], the ERP syntactic effect observed in these preschoolers had an anterior distribution over the scalp. Another important difference observed in these children was the lack of a LAN effect. This effect has been shown to occur in adults in response to a wide range of grammatical violations. It has been proposed that the LAN reflects automatic processing, in which information about a word's lexical category is used to interpret the phrasal structure of the sentence [14]. The children also displayed a larger negativity for semantically anomalous sentences compared to non-anomalous sentences [1], as has been reported in adults in numerous previous studies (for a review, see Ref. [29]), but they displayed the negative effect largest over posterior regions of both hemispheres of the scalp. In contrast to the adult N400 latency, the effect in children was most prominent between 600–800 ms. Studies of semantic processing in children have likewise shown similar components to those observed in adults, although at longer latencies. In a major cross-sectional study, Holcomb et al. [26] recorded ERPs from subjects aged 5–26 years while they were listening to or reading sentences that were either well-formed or that ended in a semantically unexpected word. Their results showed that the latency and amplitude of the N400 decreased with age (i.e., 5-year-old children showed an N400 latency around 620 ms, whereas teenagers around 500 ms and young adults usually display it at 400 ms).

1.3. The goals of the present study

Language acquisition occurs very early in development; many cognitive processes as well as their underlying brain structures specialize over a short period of time. From the very earliest stages of human life, electrophysiological evidence has suggested that different brain systems are involved in processing different aspects of language [37,45]. These early specific brain responses have been observed, for example, in differentiating speech and non-speech [41] and between comprehended and unknown words [37]. By the age of 3, preschool children have had extensive experience with the important grammatical elements of a language; they use syntactic structures that are very similar to those used by adults, are beginning to apply morphosyntax rules, and have a rapidly growing lexicon [3,18]. Accordingly, there is no reason to believe that their brain electrical responses to sentences would not be affected when syntactic or semantic features are violated. It is also known that during the preschool period dramatic changes in neural development take place. These include subtractive (i.e., synaptic pruning) and additive events (i.e., synaptogenesis) in synaptic density and myelination [4,27]. In general, it is clear that some ERP components show developmental changes in either latency, wave morphology or topographic distribution from childhood to adulthood [44]. It has been proposed that ERP effects in children are more widely distributed across the scalp than those found in adults [7]. Some language ERP effects, for example, are at first broadly distributed over the scalp; later in development, those ERP components become more modular and shift predominantly to the left frontal and temporal cortex [37]. The goal of this study was to investigate the distinctiveness and relative time course of the ERPs elicited by morphosyntactically and semantically anomalous sentences in 36- and 48-month-old children. We hypothesize that: (a) brain areas will respond differentially to syntactically and semantically anomalous sentences when compared to the non-anomalous control sentences; (b) semantically and syntactically anomalous sentences will elicit different ERP components, reflecting different underlying brain systems; and (c) ERP effects in preschool children will be broadly distributed across the scalp.

2. Methods

2.1. Participants

Children were recruited from the Infant Studies Subject Pool at the University of Washington. All participants were healthy full-term 36- and 48-month-olds with monolingual English experience and had no known hearing deficits. Parents initially signed UW ethics committee approved consent forms and were informed of the procedures: cap placement, use of conductive gel, experimental session and aims of the study. In order to select children that could understand the sentences used during the experimental session, parents were required to mark the words that their children might not have heard at home. If the child had not heard at least 95% of the words from the experimental sentences, his/her data were not considered in the analysis.

Seventy-five children completed the experiment and an additional 10 children refused to participate. For 40 children, the recordings were not usable due to excessive artifacts. Sixteen 36-month-old children (10 females, mean age = 36.03, range = 34.65–36.66) and nineteen 48-month-old children (12 females, mean age = 48.09, range = 47.01–50.4) were included in the final analysis. All children included in the analysis had no family history of left handedness. Children had no more than two mild ear infections before testing and were healthy at the time of testing. Parents received US$25 for their participation and the children received a small toy.

2.2. Stimuli

All words used in this study were taken from the MacArthur Communicative Development Inventories lexical database [8] for 36-month-old children. Thirty-four verbs were used to build 53 correct control sentences. Based on these sentences, 53 syntactically anomalous sentences were created by adding the inflexion *ing* to the verb (verb tense violations). Fifty-three semantically anomalous sentences were created by changing the last word and creating incongruence with the meaning of the verb. Examples of sentences for the different conditions and the mean time elapsed from the sentence onset to the critical word onset are displayed in Fig. 1.

The same syntactic structure was used for every sentence from our experimental and control conditions. These sentences had the same number of words before and after the critical word. Mean time duration for syntactically anomalous sentences from the sentence onset to the critical word onset was 730.9 ms (STD = 110.3 ms) whereas for non-anomalous sentences during the same window time was 963.9 ms (STD = 125.1 ms). The mean time duration for verbs+ing was 390.1 ms (STD = 111) and for verbs was 305.96 ms (STD = 111), which was relatively small. There was a really small time difference between semantically anomalous sentences (mean = 1356 ms, STD = 153.8 ms) and non-anomalous sentences (mean = 1384.3 ms, STD = 131.3) from the sentence onset to the critical word onset.

Fifty additional sentences were included as filler sentences to prevent participants distinguish the violations based just in the oddity of presentation. In order to keep the proportions of anomalous sentences constant across the experiment, filler sentences with and without syntactic and semantic violations were inserted. Filler sentences were longer (1802.82 ms) and with a higher variance in duration (452.27 ms) than our experimental and control sentences, because they consisted of different syntactic structures and different numbers of words.

All sentences were spoken by a female native English speaker. The sentences were recorded on a digital-audio system, sampled at 20 kHz with a 16-bit resolution in stereo. The speaker rehearsed all the sentences prior to recording to ensure that they were produced fluently. Each spoken sentence was presented from loudspeakers placed in front the child. The average sound pressure level ranged from 63 to 67 dB SPL. In order to ensure that the time locking of the ERP to each individual sentence was precise, the onset of each word was marked by careful inspection of the auditory signal and its visual waveform.

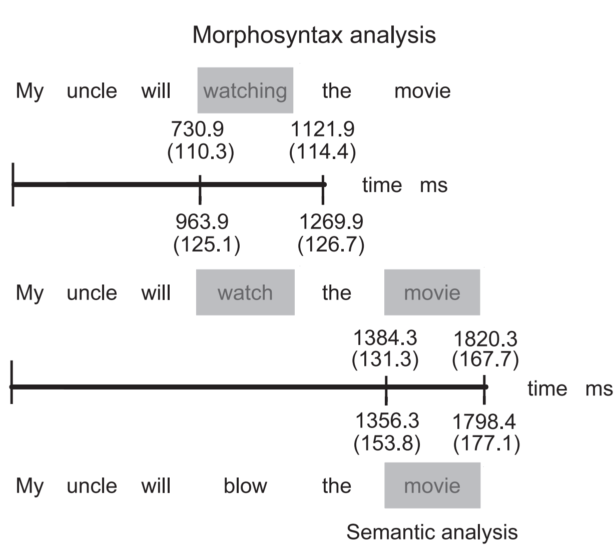

Fig. 1. Examples of sentences used for each condition and their mean time (standard deviation) in milliseconds from the sentence onset to the critical word onset.

2.3. Procedure

Each child was fitted with a 20-channel electrode cap (Electrocap International) while playing with a research assistant. Once the conducting gel was applied to each electrode site of the cap, participants and experimenters moved into the sound-proof testing booth. Inside the booth, the impedances were measured and the child was seated in a comfortable chair close to his/her parent and approximately 1 m in front of a puppet theater. Subjects passively listened to the stimuli while watching a puppet show. The puppet show served as entertainment and to focus visual attention therefore decreasing eye movement artifacts. Each spoken sentence was presented via loudspeakers which were placed at 1 m in front the child. The entire session, including fitting the cap, lasted 45 min to 1 h.

Sentences were presented in a randomized order. Each participant received the following number of sentences per condition: 73 in the correct condition, 73 in the semantic violation condition and 73 in the syntactic violation condition. The inter-stimulus interval was 1500 ms.

2.4. ERP recording

The EEG was recorded from 20 tin electrodes secured in an elastic cap (Electrocap International) at the following locations (according to the international 10–20 system): Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz and Pz. The vertical electrooculogram (VEOG) was recorded from one infraorbital electrode placed on the infant's left cheek. The recordings were referenced against the left mastoid and the brain electrical activity over the right mastoid was also recorded and did not reveal any condition-specific variations. Electrode impedances were kept below 15 kΩ. The EEG signal was amplified with a gain of 20,000 by an Isolated Bioelectric

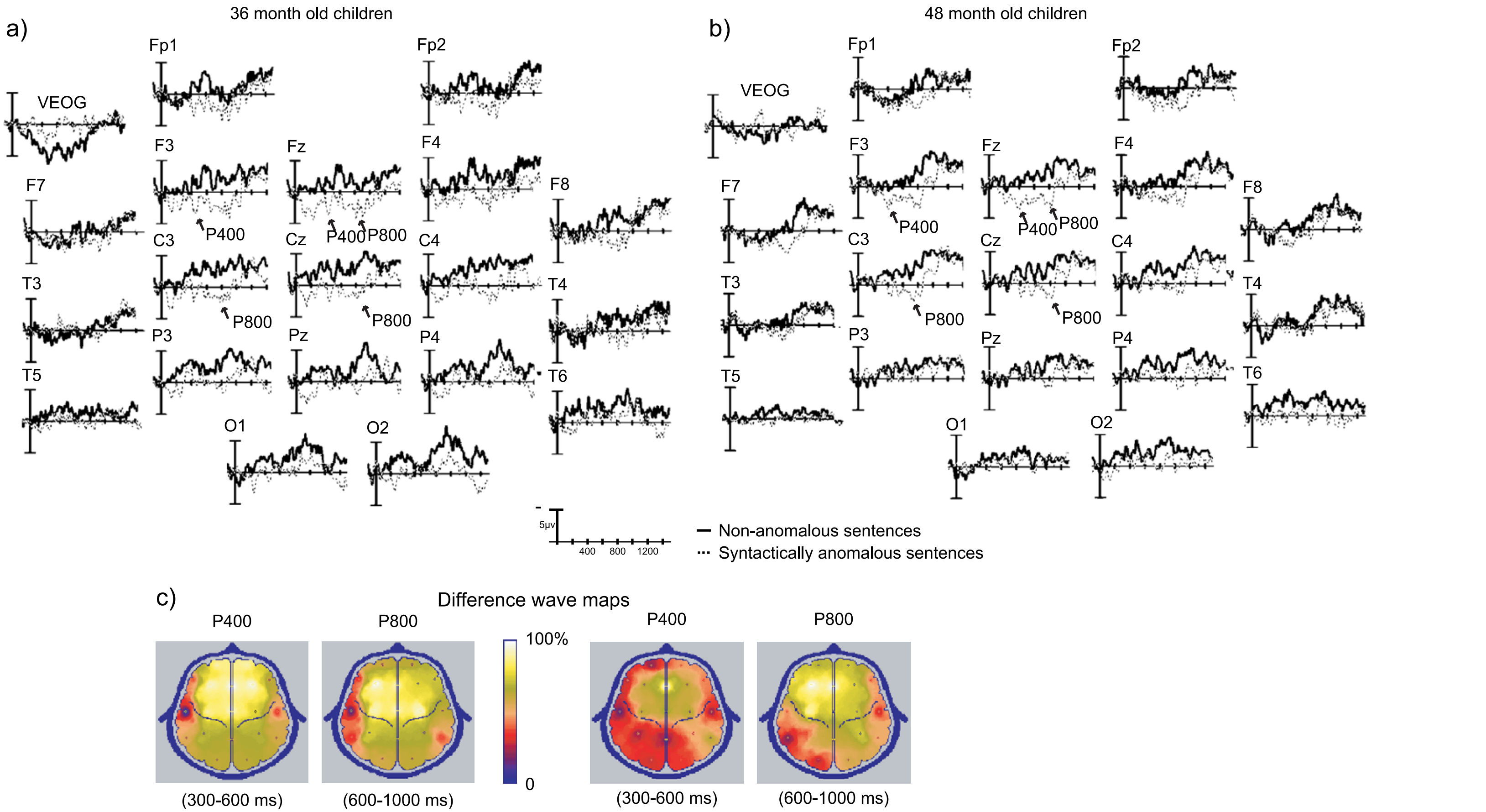

Fig. 2. This figure shows grand average ERPs to syntactically anomalous (dotted line) and non-anomalous sentences (solid line) for: (a) 36- (N = 16) and (b) 48-month-old (N = 19) children. Negative is plotted up. A positive going wave can be observed in the 36-month-olds peaking at 800 ms and two clear positive waves in the 48-month-olds: one peaking at 400 ms and the other one at 800 ms; (c) amplitude topographic maps from the difference wave between ERP responses to non-anomalous and anomalous sentences in two time windows (300–600 and 600–1000). Bright areas indicate the maximum positive peak percentage during that time window; dark regions display less percentage of the peak amplitude.

Amplifier System Model SC-32/72BA (SA Instrumentation, San Diego, CA) with a bandpass of 0.1–100 Hz and was continuously sampled at 250 Hz by an analogue-to-digital converter and stored on a hard disk for further analysis.

2.5. Data analysis

ERPs were computed off-line from 2048-ms epochs for each subject in each experimental condition. Epochs were comprised of the 100 ms preceding and 1948 ms following the presentation of individual critical words within the sentences. Automatic rejection of segments was carried out (electrical activity ±150 μV and amplifier blocking for 200 ms at any electrode site were considered artifact and the whole segment was rejected). EEG segments from each subject also were visually inspected and those segments in which eye artifact was detected in the EOG were rejected. Electrical activity from F7 minus F8 (used as HEOG criterion) that exceed +50 μV was considered as artifact. Subjects with fewer than 18 artifact-free trials for each condition were excluded from the average. Further band-pass filtering was set from 0.5 to 30 Hz. Baseline correction was performed in relation to the 100 ms pre-stimulus time mentioned above. The ERPs to different critical words were analyzed as follows: (a) for the non-anomalous sentences, the ERPs were time-locked to the verb; (b) for syntactically anomalous sentences, they were time-locked to the inflected verb (*ing*); (c) for semantically anomalous sentences, they were time-locked to the last word; (d) for non-anomalous sentences (to compare with the semantically anomalous sentences), they were time-locked to the last word (see Fig. 1).

Statistical analyses were performed on mean amplitude values from four windows for the comparisons between well-formed and syntactically anomalous sentences: 150–300 (i.e., looking for the most negative peak), 300–600 (maximum negative peak), 600–1000 (max positive peak) and 1000–1400 ms (max positive peak). Three different windows were used for the comparisons between well-formed and semantically anomalous sentences, looking for the most negative peak: 300–500, 500–800 and 800–1200 ms. These time windows for syntactically and semantically anomalous sentences were determined according to previous adult studies [15,48,52] and from inspection of both individual and grand average waveforms.

Repeated measures ANOVAs were performed separately for each age group, each time window and each type of sentence comparison. Data acquired at midline and lateral sites were also treated separately to assess the scalp distribution of ERP effects and the significance of differences between left- and right-hemisphere scalp locations. Two-way repeated-measures-ANOVAs with sentence type (non-anomalous and anomalous sentences), and anterior–posterior localization (Fz, Cz and Pz) as factors, were performed. Three-way repeated measures-ANOVAs (sentence type×left–right hemisphere×electrode location Fp1–Fp2, F3–F4, C3–C4, P3–P4, O1–O2, F7–F8, T3–T4, T5–T6) were performed on data from lateral sites. In order to assess the effect of age on the scalp topography of the ERP components, the wave signals were normalized according to McCarthy and Wood's [32] procedure. Huynt-Feldt correction was applied to all analyses with more than one degree of freedom in the numerator. The Newman–Keuls tests for post-hoc pairwise comparisons ($p < 0.05$) in the repeated-measures analysis were used. The size of each effect (η_p^2) is also provided.

3. Results

3.1. Syntactic effects

3.1.1. 36-month-old children

Grand average ERP waves elicited by critical words in syntactically anomalous and control sentences are shown in Fig. 2, panel (a) for the 36-month-old children.

Two positive waves are visible in the syntactically anomalous condition. The first positive wave begins at around 200 ms after the onset of the critical word and was more prominent over the anterior electrodes. It became maximal around 400 ms and lasted until about 600 ms. The next wave and clearer than the previous one, is another positivity with duration of 400 ms, starting at 600 ms with a maximal amplitude around 800 ms and ending at 1000 ms. This shift was more prominent over frontocentral regions as it can be seen in Fig. 2, panels (a) and (c).

The results of the statistical analyses for the 36-month-old children are shown in Table 1. In the 300–600-ms window, syntactic anomalies elicited a frontally distributed

Table 1
Syntactic processing

Source	Epochs					
36 months	300–600			600–1000		
Lateral sites	F	df	η_p^2	F	df	η_p^2
S	4.5*	1,15	0.23	8.7*	1,15	0.38
Midline						
S	3.2[a]	1,15	0.18	17.1**	1,15	0.53
48 months						
Lateral sites						
S	3.4[a]	1,18	0.16	15.3**	1,18	0.46
S X E X H				2.5*	6.9,123.3	0.12
Midline						
S	4.9*	1,18	0.21	29.8***	1,18	0.62
S X E	3.1[a]	1.75,31.6	0.15			

S = sentence type, E = electrode location, H = hemisphere.
[a] $p < 0.08$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

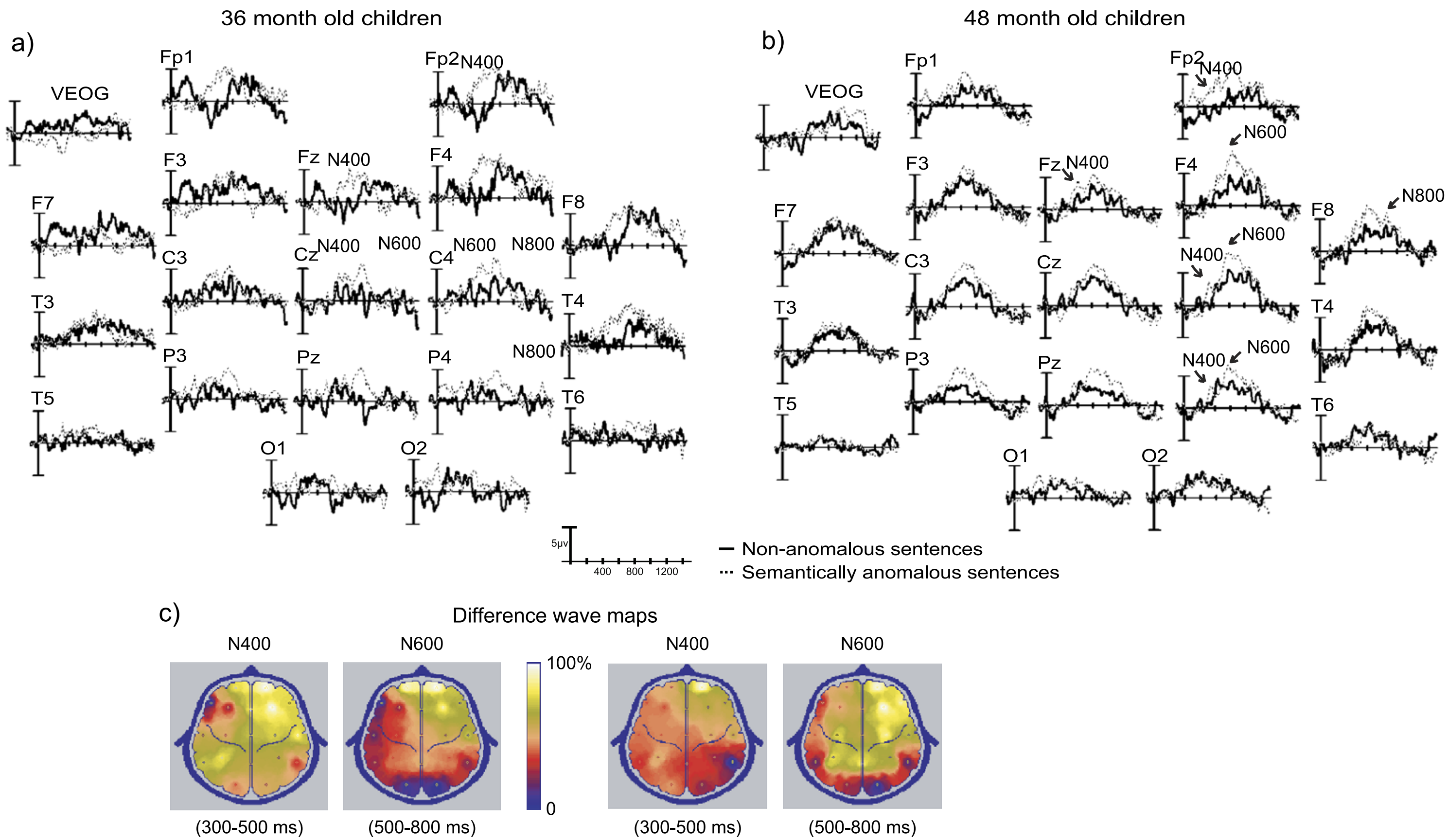

Fig. 3. Grand average ERPs to semantically anomalous (dotted line) and non-anomalous sentences (solid line) are shown for (a) 36- and (b) 48-month-old children. Negative is plotted up. Three larger negative waves, more prominent over the anterior sites, are elicited by the semantically anomalous sentences in both groups; (c) amplitude topographic maps of the difference wave are shown in two time windows (300–500 and 500–800). Bright areas indicate the maximum negative peak percentage during that time window; dark regions display less percentage of the peak amplitude.

positive shift, however, the difference was widely distributed (significant main effect for sentence type at lateral sites). Highly significant differences in the comparison between syntactically anomalous and non-anomalous sentences within the 600–1000-ms time window can also be observed.

3.1.2. 48-month-old children

In this age group, the syntactically anomalous sentences elicited two positive waves similar to those displayed by the 36-month-old children, but more clearly defined, as shown in Fig. 2, panel (b). The first one appeared predominantly over frontal regions; starting at 300 ms, peaking around 400 ms and ending at 600 ms; statistical analyses in the 300–600-ms window approached significance at lateral sites and a significant effect was observed at midline, as well as a greater effect at Fz, as indicated in Table 1. The second positivity elicited by the syntactically anomalous sentences started at 600 ms, reached its maximum at 800 ms and ended at 1000 ms. It was significantly larger than the non-anomalous condition in the 600 and 1000 ms window and it appeared to be a more specific response than those from the younger group because it displayed a more specific topography. Although this effect was observed in some anterior regions of the left hemisphere (Fp1, F3, C3 and F7), it was more prominent over the right hemisphere (Fp2, F4, C4, P4 and O2).

3.1.3. Age effects

There were significant differences between groups in the comparison between syntactically anomalous vs. non-anomalous sentences in the 600–1000-ms time window (type of sentence × electrode site × hemisphere × group interaction, $F(6.46, 213.05) = 2.8$, $p = 0.01$ ($\eta_p^2 = 0.08$)). A larger positivity to syntactically anomalous sentences was observed at most locations (Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F8 and T4) in the 36-month-old children. In contrast, this effect was mainly observed over anterior and right electrode locations (Fp1, Fp2, F3, F4, C3, C4, P4, O2 and F7) in the 48-month-old children.

3.2. Semantic effects

3.2.1. 36-month-old children

ERP grand-averages for 36-month-old children to the critical words in the semantically anomalous and non-anomalous sentences are shown in Fig. 3, panel (a).

Three negative-going waves can be observed, all of them larger in amplitude for the semantically anomalous sentences. The first negativity started at 400 ms over anterior electrodes after critical word onset, became maximum at 500 ms and ended at 550 ms. The results of the statistical analysis, displayed in Table 2, showed that this negative wave was significantly larger to the semantically anomalous sentences in the 300–500-ms window over the anterior right electrode locations (Fp2 and F4).

The second negativity started at 550 ms also over anterior electrodes and became maximum at 650 ms. This effect was only significant over the right hemisphere (Fp2, F4, C4, F8 and T4) in the second time window (500–800 ms). The last negativity became maximal at 800 ms and ended around 1000 ms.

Table 2
Semantic processing

Source	Epochs								
36 months	300–500			800–1200			800–1200		
Lateral sites	*F*	df	η_p^2	*F*	df	η_p^2	*F*	df	η_p^2
S				4.1[a]	1,15	0.21			
S X E							2.4*	4.5,67.5	0.14
S X E X H	3.8**	6.2,92.2	0.2	2.3*	6.6,99.5	0.13			
Midline									
S				3.9[a]	1,15	0.21			
S X E							4.3*	1.53,22.9	0.22
48 months									
Lateral sites									
S				3.6[a]	1,18	0.17			
S X E X H	2.3*	5.5,98.5	0.11						
Midline									
S				4*	1,18	0.18			
S X E									

S = sentence type, E = electrode location, H = hemisphere.
[a] p < 0.08.
* p < 0.05.
** p < 0.01.

3.2.2. 48-month-old children

Forty-eight-month-old children displayed the first two negative-going waves that appeared in the 36-month-old children. The first wave was clearer in the 48-month-old children when compared to the 36-month-old children (see Fig. 3, panel (b)). This negativity began at 200 ms, peaked around 400 ms and ended at 500 ms over the anterior right electrodes after stimulus onset, but it was only significant at Fp2 and F4. The second negativity (500–800 ms) was significant across the scalp (see Table 2).

3.2.3. Age effects

There were no significant differences between age groups for all the time window comparisons between semantically anomalous vs. non-anomalous sentences.

4. Discussion

The present study examined ERP responses to syntactically and semantically anomalous spoken sentences in 36- and 48-month-old children. The syntactically anomalous sentences elicited two positivities whereas the semantically anomalous sentences elicited larger negative waves over right anterior sites than those elicited by non-anomalous sentences. These results demonstrate that brain's children at very early ages is sensitive to semantic content and syntactic structure manipulations during sentences processing even without any explicit attention to the sentences.

There were significant differences between groups on the ERP patterns during syntactic processing: A positive wave effect to syntactically anomalous sentences was observed to be more broadly distributed in 36-month-old children than in the older kids. In contrast, this effect was mainly observed over anterior regions in 48-month-old children. We know from comparisons with adult data that the ERP pattern displayed at 48 months is not the mature pattern of responding. However, it is interesting that from 36 months of age, the syntactic processing reflected by this ERP component is associated with an increasing anterior–posterior specialization. In other words, the change we have observed in this ERP component from 36 to 48 months of age moves in the direction that is more typical of responses at later stages in development. The broad distribution of this effect in 36-month-olds is consistent with previous studies of children [7] and may reflect the fact that the specialization of brain mechanisms continues to mature until the mid-teen years [3,4,27].

4.1. Syntactic effects

The results showed that 36- and 48-month-old children elicited two positive wave effects to syntactically anomalous sentences compared to the non-anomalous sentences. The first is a positive shift, more consistent in 48-month-olds, mainly observed over frontal regions, peaking at 400 ms and ending around 600 ms. The second one is a slow broadly distributed positive wave in 36-month-olds and anteriorially distributed in 48-month-olds, starting at 600 ms, peaking at 800 ms and ending at 1000 ms.

Considering the adult literature—but allowing for development too—we could have expected a LAN effect [14] instead of a positivity to the anomalous sentences. It is possible that a LAN-like effect overlapped with the early positive wave observed in these children. The early positive effect we observed could represent the same cognitive process as LAN but, given a different developmental stage of the cytoarchitecture of Broca's area [2], was generated by different brain electrical activity. Another possible explanation is that LAN reflects an automatic mechanism that does not develop until several years later [11]. It can be said that syntactic development is complete when syntactic processing functions automatically and is unaffected by interpretative factors [11]. It is most possible that 3- and 4-year-olds' syntactic processing lacks this automaticity.

Our observations are consistent with the hypothesized parser that analyzes sentences in two steps: In adults, Mecklinger et al. [34] found an early positivity as a function of required reanalysis (P345). Friederici et al. [17] have suggested that there are two aspects of the revision process in a sentence: a process of diagnosing the need for repair (possibly reflected in a P345) and the actual repair itself (reflected in a late positivity, or P600). The first positivity observed in our study may reflect the evaluation of the syntactic anomaly whereas the second positivity reflects this second process of repair once a syntactic anomaly has occurred. However, this early positivity has been found in sentences with different syntactic complexity and for relative clauses [34] rather than for morphosyntactic violations, which were used in the present study.

A more plausible account for the early frontal positivity and the broadly distributed late positivity in our study, and one we offer as a working hypothesis, is that attention to the syntactically anomalous sentences is enhanced by a lower proportion of this kind of sentences during the experimental session. In the present experiment, the syntactically anomalous sentences were created by adding an *ing* to the verb in future tense. Across the experiment, there was a lower proportion of sentences with verbs inflected by *ing* when compared to other sentences. These differences in the probability of occurrence could enhance the saliency of the syntactically anomalous condition and elicit a P300. This ERP component is an endogenous positive deflection with an average peak latency at 300 ms or more after stimulus onset, and is typically elicited by a rarely and randomly presented target stimulus in a detection task. It has a posterior topographical distribution in adults, but it is more frontally distributed in children [58]. One prominent interpretation of the P300 is that it represents stimulus evaluation and memory updating [9,55]. Some authors have suggested that the P600 is a late member of the family of the

P300 component and that it is not necessarily produced by linguistic events [6]. However, Osterhout et al. [54] found that the P600 is independent of the P300 effect and suggested that both ERP effects reflect different cognitive processes. Regarding the present results, it is likely that the first positivity (i.e., the P300) reflects a general purpose mechanism. This early detection of the anomaly might facilitate the occurrence of the second positivity, which may reflect a more language-specific type of processing similar to the P600 observed in adults. Probably during the first stages of development, this first positivity reflects the use of a general mechanism for processing the oddity, which precedes the use of a later, more language specific effect.

Finally, the early positivity could also be a result of non-linguistic differences between experimental conditions. That is, given that the subject encounters the syntactic violation at the "ing"-onset and not at the verb onset, the subsequent word in theory occurs later in the syntactic violation than in the non-anomalous sentences. This non-linguistic difference alone—rather than the detection of syntactic violations—might evoke the early effect and even the late positivity observed in this study. In this way, it is necessary to carry out experiments on children's brain electrical responses using different kinds of syntactic violations and correlating those ERP waveforms with specific language processes.

4.2. Semantic effects

Our group of 36-month-olds clearly showed two negativities riding on a large slow negative wave and 48-month-old children clearly displayed three peaks also riding on a slow negative wave as a response to semantically anomalous sentences. These negativities were anteriorly distributed across the scalp. At both ages one can explore the whole ERP epoch as just one large phenomenon and interpret this as one large slow processing wave possibly reflecting a general semantic integration mechanism. On the other hand, it could also be interpreted as a general semantic wave but with multiple ERP components, each possibly reflecting different specific semantic mechanisms. Under the first approach, the main peak latencies that we report here match with those from Holcomb et al.'s [26] reported for semantic negative waves in the 5-year-old children (620 ms) as well as those reported by Adamson-Harris [1] in 32–38-month-old children. Longer latencies suggest that semantic information may be processed at a slower rate in preschoolers than in the mature brain. Holcomb's et al. [26] data showed that the latency and amplitude of the N400 decreases linearly with age, probably due to facilitation of lexical access and semantic integration processes [20], and it increases again in the elderly [10,21], in this case probably due to impairment of language-related capacities.

Under the more detailed approach, our results show that the electrical brain responses observed in these children were similar in latency to those peaks recorded in adults with sentences in which the last word makes an obvious anomalous completion. Forty-eight-month-old children displayed a clear negative wave that began at 200 ms, peaked around 400 ms and ended at 500 ms and a similar negative wave effect was found in the 300–500 ms window in our 36-month-old sample of children. Since sentence processing is arguably a task of enough complexity that it may draw upon neural systems that display clear functional specialization, we would expect more than one evaluation ERP component: children from the present study also displayed late negativities (N800). Latency and topographic distribution of these ERP effects are similar to those reported for adults during 'sentence closure' [15,48].

Regarding laterality, the left hemisphere typically displays greater effects than the right in language tasks [46], with the exception of ERPs to semantically anomalous information, in which case the asymmetry is reversed [29]. In this study, 48-month-old children displayed a clear negative wave mainly over the right electrodes after stimulus onset, significant at Fp2 and F4; a similar negative wave effect was found in our 36-month-old sample of children over anterior right electrode locations. Holcomb et al. [26] observed that most asymmetries increase with age; in fact, robust asymmetries were often not present until 13 years of age and thereafter. However, large ERP asymmetries have been observed in 20-month-old infants listening to words whose meaning is comprehended [37]. It is likely that the specific language-relevant brain areas that are active during spoken sentence processing appear very early in development and that they are observable as specific brain electrical responses. For example, Molfese and Molfese [41] reported that infant's discrimination between speech and non-speech auditory stimuli was reflected in a negative amplitude over the right temporal cortex.

5. Conclusion

The present study demonstrates that 36- and 48-month-old children show different ERP effects for syntactic and semantic processing without any explicit attention to the sentences, and that their responses change between 3 and 4 years of age. Thirty-six-month-old children displayed a broadly distributed positive wave effect to syntactically anomalous sentences. In contrast, this effect was mainly observed over anterior regions in 48-month-old children. This probably reflects a more specific brain response in the older children. Preschoolers also elicited negative waves to semantically anomalous sentences. Considering the ERP waves, we observed as multiple smaller ERP components, each reflecting different specific semantic mechanisms, one of these negativities was significant at the same time window as adult ERP effects (N400) but with a frontal distribution. The later negativities observed are possibly analogous to the "sentence closure" effect observed in adult studies. We did not expect the same adult ERP responses because development and brain maturation are still ongoing processes. However, children here studied showed two qualitatively different waveforms for syntactically and semantically anomalous sentences which suggests that grammatical and semantic information is processed by different neural systems as these early ages. In our study, the specific ERP patterns to syntactically anomalous sentences appear similar in polarity and overall latency to those observed in adults during analogous type of processing [52]. Although brain developmental changes do occur during the preschool years, previous child ERP studies using language paradigms have shown no significant effect of age on certain specific brain electrical responses, such as semantic priming [38] and phonological N400 effects [19]. Moreover, similar latencies were reported for the ERP components in children and those observed in adult ERP studies. Further implications for the latter in our study are too early to be drawn.

Acknowledgments

We wish to thank Lindsay Klarman, Denise Padden, Kathryn Schoolcraft and Robin Cabaniss for technical support. We thank Dr. Barbara Conboy for her comments on earlier versions of this article. This work was supported by grants to PKK from NIH (HD37954, HD35465), the University of Washington's Institute for Learning and Brain Sciences, and by the Talaris Research Institute and Apex Foundation, the family foundation of Bruce and Jolene McCaw.

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