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Visual and Auditory Sentence Processing: A Developmental Analysis Using Event-Related Brain Potentials

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Subjects aged 5 to 26 years listened to and read (7 to 26 years) sentences that ended either with a highly expected (best completion) or a semantically inappropriate (anomalous completion) word. Event-related potentials (ERPs) to sentence final words displayed effects of contextual priming in both modalities in all age groups. Early and late ERP components displayed large decreases in amplitude and latency with age. These changes necessitated normalization procedures so that overall changes in amplitude with age could be assessed separately from changes in the amplitude of the differences between best-completion and anomalous-completion words. There were significant reductions in the contextual priming effects with age. Moreover, these age-related changes were different for the auditory and visual modalities, and for the early and later phases of the priming effect. These results suggest that nonidentical systems, with different developmental time courses, generate

Over the past decade, event-related brain potentials (ERPs) have become increasingly powerful tools in uncovering the time course and structure of language processing and aspects of the operation of relevant neural systems (Fischler, Bloom, Childers, Roucos, & Perry, 1983; Friedman, Simson, Bitter, & Rapin, 1975; Holcomb & Neville, 1990; Kutas & Hillyard, 1984; Neville, Kutas, & Schmidt, 1982a; Rugg, 1990). This approach would thus appear very promising in the study of the acquisition and development of language and concomitant changes in brain organization. Retrospective developmental studies indicate that ERPs are sensitive indices of the effects of early language experience on the development of the functional specializations of different brain areas (Neville, Kutas, & Schmidt, 1982b; Neville,

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1991). Brain organization has also been probed during the earliest stages of language acquisition using the ERP technique (Mills, Coffey, & Neville, in press; Mills, Coffey, & Neville, 1991; Molfese, 1990). These studies attest to the power of the ERP technique, and more generally, to the important role that language experience plays in the functional development of the brain. In the present study, the combined behavioral-electrophysiological approach has been utilized to study changes in brain organization relevant to language processing during the middle and teenage years of childhood. In particular, the long-standing question of whether there are changes with age in contextual priming during language processing is addressed.

The role played by contextual factors during the acquisition of language comprehension skills has been the focus of numerous research reports over the past decade (Perfetti, Goldman, & Hogaboam, 1979; Schvaneveldt, Ackerman, & Semlear, 1977; Schwantes, 1981, 1982, 1985; Stanovich, Nathan, West, & Vala-Rossi, 1985; Stanovich, West, & Feeman, 1981; West & Stanovich, 1978). One somewhat counter-intuitive finding is that inexperienced/beginning readers appear to rely more heavily on sentence context for recognizing written words than do more experienced readers (e.g., Schwantes, 1985; Stanovich et al., 1985).

In one representative study (Stanovich et al., 1985), third-grade, fifthgrade, and college students read sentences, and subjects' speed in naming the final word in each sentence was measured. In the conditions of most interest the sentence final words were either related to the context provided by the prior sentence stem, neutral with respect to the prior sentence, or unrelated to the sentence context.

Related: The farmer planted the *corn.*
Neutral: They said it was the *corn.*
Unrelated: The musician played the *corn.*

Third graders benefitted the most from the context in the related sentences (84 ms of facilitation relative to the neutral condition), but also suffered the most from the unrelated context (38 ms of inhibition relative to the neutral condition). Adults showed a small facilitation effect in the related condition (32 ms), but little if any interference (8 ms) in the unrelated condition. The fifth graders fell in between the adults and third graders (48 ms facilitation, 26 ms interference). Stanovich et al. (1980) invoked their "two-process interactive, compensatory" model of word recognition to explain this pattern of findings (Stanovich, 1980, 1984). The critical assumption of this theory is that difficulties during one stage of comprehension can be compensated for by a greater use of information from other levels. Variables that tend to impede or to slow word recognition, such as inexperience in reading, are proposed to affect two processes involved in word recognition. Slowed recognition allows more time for associative links in the lexicon to act (e.g., automatic spreading activation), which produces greater facilitation of related over neutral items. Slowed recognition also allows more time for the reader to bring higher strategic processes to bear (e.g., expectancy). The use of an expectancy strategy during word recognition is thought to result in greater facilitation for related words and interference for unrelated words (because they cannot be anticipated). In the case of experienced readers, Stanovich et al. (1980) argued that word recognition is a rapid bottom-up process that does not rely on higher level processes (i.e., no compensation is necessary). However, word recognition can benefit from intralexical spreading activation, which accounts for the small facilitation of related final words in adults. The purpose of the present study was to extend the above research employing a different measure of contextual processing, across a greater number of ages during which reading and other language skills are acquired and refined.

ERPs

By placing electrodes on the scalp of human subjects it is possible to record the ongoing electrical activity of the brain. ERPs are stimulus-locked perturbations in this activity, which have been demonstrated to be sensitive to both sensory and cognitive processes (see Regan, 1989, for a review).

In several recent reports, ERPs have been used to study the effects of context on linguistic stimuli in adults. A number of these studies have reported changes in a negative component (the individual waves that make up an ERP are referred to as "components"), which onsets as early as 200 ms poststimulus onset and peaks near 400 ms. Kutas and Hillyard (1980, 1984) reported that this "N400" component was large (more negative) to sentence final words that were semantically anomalous and was small or nonexistent to highly probable, "best completion" sentence endings.

Best completion: He takes cream and sugar in his *coffee.*
Anomalous: He takes cream and sugar in his *attention.*

In contrast, manipulation of the physical parameters of the final word (e.g., using a different type font) did not elicit an N400 response, but instead resulted in a large, late positive component that peaked around 600 ms. In a related study, Kutas, Lindamood, and Hillyard (1984) demonstrated that N400 amplitude was a monotonic function of the cloze probability of sentence final words: N400 was greater in amplitude to less predictable words and smaller to more predictable words.

Less predictable: Captain Sheir wanted to stay with the sinking raft.
More predictable: She called her husband at his *office.*

The above studies used visual letter strings as stimuli. Holcomb and Neville (1990, 1991) studied context effects in the auditory modality (also see McCallum, Farmer, & Pocock, 1984). In their first study, subjects participated in two versions (one visual, one auditory) of a lexical decision task in which stimuli were word pairs consisting of a prime word followed by either a semantically related word, an unrelated word, or a nonword. N400s were larger to unrelated words than to related words in both modalities. However, this ERP "priming effect" began earlier in the auditory modality than in the visual modality. In addition, the distribution over the scalp differed in the two modalities with the visual priming effect slightly larger over the right hemisphere, whereas the auditory effect was slightly larger over the left hemisphere. Holcomb and Neville concluded that there may be overlap in the priming processes that occur in each modality but that these processes are not identical. In particular, they noted that the earlier onset of the N400 in the auditory modality was consistent with the MarslenWilson (1987) view that auditory word processing can begin prior to the arrival of all of the acoustic information in a spoken word and that the time course of this processing can be influenced by semantic properties of a prior word (i.e., context).

In their second study, Holcomb and Neville's (1991) subjects listened to naturally spoken sentences that ended either anomalously or with the expected best completion final word. The ERPs to the final words were more negative in the anomalous condition and this difference started as early as 50 ms post-word-onset at posterior electrode sites. This is particularly remarkable as the average duration of final words was greater than 500 ms (for a review of the N400 literature see Pritchard, Shappell, & Brandt, 1991).

Developmental Studies

A number of studies have explored developmental changes in ERPs. Much of this work has focused on the P300 component (e.g., Brown, Marsh, & La Rue, 1983; Courchesne, 1977, 1978; Goodin, Squires, Henderson, & Starr, 1978; Holcomb, Ackerman, & Dykman, 1985; Johnson, 1989; Mul-lis, Holcomb, Diner, & Dykman, 1985; Polich, Ladish, & Burns, 1990), although a few studies have also examined earlier components as well (primarily N100 and P200-e.g., Courchesne, 1978; Friedman et al., 1985; Johnson, 1989). The most consistent finding has been a decrease in P300 latency from 5 or 6 years of age through the late teens and early twenties (Courchesne, 1978; Friedman, Boltri, Vaughan, & Erlenmeyer-Kimling, 1985; Goodin et al., 1978; Johnson, 1989; Mullis et al., 1985). This finding has generally been assumed to reflect the increased efficiency of cognitive processes that occurs with development.

A few studies have also found overall declines in P300 amplitude across age (Johnson, 1989) or changes in the distribution of the P300 across the scalp with age (Mullis et al., 1985). Age effects on the N100 and P200 components are less clear. Johnson found no effects of age on auditory N100 and P200 amplitudes or latencies, but did report a decline in visual N100 amplitude and N100 and P200 latency with increasing age (7 to 20 years). However, Courchesne (1978) and Friedman et al. (1985) found no age-related effects on the N100 or P200.

As yet, there have been no systematic studies of developmental changes in language sensitive ERPs across the childhood years.[1] However, Friedman et al., (in press) studied 82 children between 6 and 17 years of age (grouped into six 2-year intervals) and 20 adults between 18 and 39 years, in a picture, matching task. In separate blocks of trials, subjects had to determine whether two pictures had the same physical appearance, the same name, or came from the same category. Comparisons of matching (same) and nonmatching (different) pictures revealed an N400-like effect in all seven age groups. Friedman et al. referred to this as the Neg400 because they were unsure if their negativity was the same as N400 recorded to language stimuli. Although children had larger potentials than adults between 250 and 500 ms, the critical interaction between stimulus type (same/different) and age group was not significant. That is, there was no evidence that the N400-like effect was larger (or smaller) in children. Moreover, with the exception of the youngest group (6 to 7) who produced smaller negN400s at Pz and Oz, Friedman et al. reported that the scalp distribution of Neg400 was similar for children and adults. Neg400 latency on the other hand decreased across the ages, particularly for name and physical identity matches.

Current Study

In the current study, 130 subjects between 5 and 26 years of age were tested. Each subject was run through a battery of behavioral screening tests and eight ERP procedures. In this article, the findings from the procedures in which subjects read and listened to sentences are reported. The sentences were all simple declaratives and were modeled after those used by Kutas & Hillyard (1980), but with topics appropriate for readers in the second grade. There were two types of sentences, those that ended with the most expected, "best completion" word and those that ended with an "anomalous completion" word (see Method section for examples of both sentence types). The primary goal of this study was to chart developmental changes (as indexed by ERPs) in the processing of these two types of completions. Some of the questions of interest were: Are there predictable changes in the amplitude

[1]Note, however, that several studies have looked at language issues in children and infants using the ERP technique (e.g., Mills, Coffey, & Neville, 1991, in press; Molfese, 1989, 1990; Taylor, 1988).

and latency of ERPs that index contextual effects over development?; Is there evidence that similar neural systems underlie language comprehension processes in children and adults (i.e., how does the scalp distribution of language sensitive ERP components change with age?)?; and How are visual and auditory processing of language similar and different during development?

METHOD

Subjects

A total of 130 volunteers between the ages of 5 and 26 years served as subjects. They were recruited from local schools in the San Diego area and by advertisements in a university student newspaper. Subjects were paid for their participation ($40.00 to $60.00 for the entire study, depending on the number of laboratory sessions required). All were right-handed (Edinburgh Handedness Inventory; Oldfield, 1971) and were native speakers of English. The children were screened for childhood behavioral/neurological problems including: attentional deficit disorder (Conner's teacher questionnaire < 2 Sd above mean) and reading and learning disabilities (Teacher Questionnaire and WRAT Reading and Spelling Scores >_ Grade Level). All subjects were screened for a family history of alcoholism and were administered five subtests (information, arithmetic, digit span, coding, and block design) from the appropriate Wechsler intelligence test to estimate IQ; Wechsler Preschool and Primary Scale of Intelligence (WPPSI) for 5-yearolds, Wechsler Intelligence Scale for Children-Revised (WISC-R) for 6through 16-year-olds and Wechsler Adult Intelligence Scale (WAIS) for 17to 26-year-olds. Upon admittance to the study each subject was assigned to one of 10 age groups (see Table 1 for the age, gender, and IQ scores for each group).

All 10 age groups participated in the spoken sentence task, however, a significant number of the 5- and 6-year-olds were not reading at a level sufficiently high enough to comprehend the visual sentences. Therefore, only the nine oldest age groups (7 to 26 years) participated in the reading task.

Stimuli and Procedure

The stimuli for this experiment were generated from a master list of 160 highly constrained sentences (final word cloze probability > 0.8) ranging

TABLE 1 Group Composition, Gender, Age, and IQ

Age Group	*Number Males*	*Number Females*	*Mean Age*	*Mean !Q*
5-6	*5*	*6*	*5.9(.5)*	*123 (15.4)*
7-8	*6*	*5*	*8.3(.5)*	*126 (13.2)*
9-10	*9*	*7*	*10.0 (.5)*	*116 (11.2)*
11-12	*9*	*7*	*11.8(.5)*	*123 (13.9)*
13-14	*16*	*6*	*13.9(.5)*	*123(8.9)*
15-16	*9*	*5*	*16.0 (.5)*	*117(12.9)*

Note. Standard deviations are in parentheses.

from 3 to 13 words in length.[2] Four lists of 80 sentences were formed from the master list such that lists 1 and 3 contained the same sentence stems (the first 80) and list 2 and 4 contained the same (the remaining 80). In List 1, 40 of the sentences ended with a best-completion word and the other 40 ended with an anomalous-completion word.

List 1 best completions:
We saw elephants and monkeys at the *zoo*.
We bake cookies in the *oven*.

List 1 anomalous completions:
Kids learn to read and write in *finger*.
Mother wears a ring on her *school.*

Anomalous words were selected by rearranging the best completion words (between sentences) such that they no longer fit with the sentence context (e.g., *school* in the second example sentence went originally with the first example sentence). In List 3, the 40 best completions sentences from List 1 were repaired with final words that were anomalous, but which came from the same list, while the anomalies from List 1 were paired with their appropriate best completions. In this manner, List 1 and 3 contained the same root sentences and the same final words, but with a different arrangement of best completions and anomalies.

[2]The sentences used in this study were selected based on extensive testing in several San Diego area elementary schools. Before a sentence could be a candidate for inclusion in the study it had to meet two criteria. First, it had to be "readable" by greater than *97%* of second grade children *(n = 80).* Second, it had to have a cloze probability for second- and third-grade children greater than *0.8 (n = 120).* That is, greater than *8001o* of the children tested had to fill in the appropriate best completion final word when given the stem sentence ending in a blank.

List 3 best completions:
Kids learn to read and write in *school*.
Mother wears a ring on her *finger.*

List 3 anomalous completions:
We saw elephants and monkeys at the *oven*.
We bake cookies in the *zoo*.

List 2 and 4 were formed in a similar manner from the remaining 80 sentences. Each subject was presented with two of the four lists (1 and 2 or 3 and 4), one in the auditory modality and one visually. Using this procedure each sentence (and final word) occurred in all .four conditions (auditory-best completion, auditory-anomalous completion, visual-best completion, and visual-anomalous completion) across subjects, and each subject read each of the 160 sentences and final words exactly once.

For the auditory lists, each sentence was spoken by a female member of our research team at a slow speaking rate (one word per second). Sentences were first recorded on analog tape and were then digitized (16KHz, 12 bit resolution) and broken up into word-sized chunks, which were stored in separate disk files. Using this technique, the onset envelope of each word was aligned with the beginning of its digital file. Interword pauses were placed at the ends of files. During the experiment, the stimulus presentation software reassembled each sentence in real time and, simultaneous with the onset of each word, a code was output to the computer which digitized the EEG. This procedure resulted in sentences that were indistinguishable from those recorded on analog tape. Spoken sentences were presented binaurally over headphones at a comfortable listening level (60 dB SL) with a stimulus-onset-asynchrony (SOA) between words of 1000 ms.

Visual sentences were presented in a word-by-word fashion in the center of a video monitor at a comfortable illumination level. The SOA was the same as in the auditory sentences (word duration = 300 ms, interstimulus-interval = 700 ms). All first words and proper nouns began with an upper case letter and all other letters were lower case. All words were between 0.5 and 2.0 degrees of horizontal visual angle and 0.75 degrees of vertical visual angle.

The remainder of the procedure was equivalent for the two modalities. The experiment was self-paced, each trial beginning when the subject pressed a button. The outline of a white rectangle appeared on a video monitor 1.5 sec later (6 x 3 degrees). The subject was told not to move or blink during the time the rectangle was on the screen. The first word of the sentence was presented 1 sec after the onset of the rectangle. The rectangle was turned off 3 sec after the onset of the final word in the sentence and was replaced by a visual message to respond YES or NO. The subject responded by pressing a button indicating whether or not the sentence made sense. Because the response was delayed 3 sec (to prevent the motor response from contaminating the ERP to the final word), accuracy of response, rather than speed, was emphasized. Response hand was counterbalanced across subjects in each age group. Each subject engaged in 10 practice trials prior to the run of 80 experimental sentences.

ERP Recording

The EEG was recorded from 14 scalp electrodes including standard International 10-20 System locations, left and right occipital (01, 02), frontal (F7, 1[7]8) and six nonstandard locations, left and right parietal (30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz, roughly Wernicke's region), left and right temporal (33% of the interaural distance lateral to Cz), and left the right anterior temporal (onehalf of the distance between F7[8] and T3[4J). These electrodes were attached to an elastic cap (Electro-Cap) and were referenced to linked mastoids. The electro-oculogram (EOG) was recorded from electrodes beneath the left eye and lateral to the right eye (mastoid reference). All impedances were maintained below 5 Kohms. Grass 7P511 amplifiers (bandpass 0.01 to 100 Hz) were interfaced to a 16-channel, 12-bit A/D converter and the EEG was digitized on-line and stored on digital tape.

Off-line, separate ERPs (100-ms, prestimulus baseline) were averaged for each subject at each electrode site from trials free of EOG and movement artifact.[3] Separate averages were made for final words of both sentence types (best completions and anomalous completions). Only trials on which the subject responded correctly were included.

The ERPs to the final words were quantified in several ways. First, the peak latency and amplitude of the P100 (0 to 100 ms, except 0 to 200 ms occipital sites visual ERPs), N100 (50 to 200 ms, except 100 to 250-ms occipital sites, visual ERPs), and P200 (100 to 300 ms, except 200 to 400-ms occipital sites, visual ERPs) components were measured using a standard computer algorithm (i.e., the largest value in a latency window relative to the average of the prestimulus baseline).

Second, the average amplitudes between 300 and 500 ms and between 500 and 800 ms were calculated (relative to the average prestimulus baseline). These values were then normalized using the formula recommended by McCarthy and Wood (1985):

(Score - Minimum Score)/(Maximum Score - Minimum Score),

where score is an ERP average amplitude value (one for each condition and scalp site). This procedure, which eliminates the main effect of age group

[3]The EOG channels of each subject's raw data were searched (via a software routine) on a trial-by-trial basis for high amplitude activity and these trials were automatically rejected by the averaging program. The criteria for rejection was titrated individually for each subject based on inspection of the eye channels after averaging, and the relative amplitude of the ERPs for that subject (range 50 to 100 NV peak to peak).

(but not legitimate interactions between age group and other variables), was deemed appropriate because it is clear that the ERPs from younger children were of considerably larger overall amplitude than were ERPs from the older groups. Larger amplitudes in children may be attributable to increases in skull thickness with age (Pfefferbaum & Rosenbloom, 1987) or to the marked diminution in the number of synapses that occurs from 2 years of age until the late teens (Huttenlocher, 1979) or to other such general factors. However, because some differences between the best completions and anomalous completions may also be larger, in younger subjects as a consequence of their overall larger amplitude ERPs, overall age effects must be eliminated in order to assess changes in the magnitude of sentence-type effects (i.e., priming) across the ages.

Finally, in order to better isolate the effects of priming and to facilitate between-modality comparisons of the N400, "difference waves" were computed by subtracting the final word ERPs in the best-completion sentences from those in the anomalous-completion sentences. The peak latency of the N400 (200- to 900-ms window) was calculated from the difference waves. Also the mean amplitudes between 300 and 600 ms and between 600 and 900 ms were computed and these values were normalized as just described.

Mixed design analyses of variance (ANOVAs - BMDP2V) were used to analyze all measures. Repeated measures variables included: electrode site (frontal vs. anterior temporal vs. temporal vs. parietal vs. occipital), hemisphere (right vs. left) and, with the exception of difference waves, sentence Type (best completions vs. anomalous completions). The correction recommended by Geisser and Greenhouse (1959) was applied to all repeated measures variables with more than two levels (reported as corrected p values). There was also a single between-subject variable of age group (7 to 8, 9 to 10, 11 to 12; 13 to 14, 15 to 16, 17 to 18, 19 to 20, 21 to 22, and 23 to 26 years, also 5 to 6 for auditory). The ANOVAs on the difference wave measures also included a within-subject variable of modality. However, because they did not participate in the visual reading task, the 5- to 6-year-old group was excluded from the cross-modality analyses. The standard parametric model for analysis of unequal n designs was used (Herr, 1986) for between-subject comparisons.

RESULTS

Behavioral Data

The number of best completion and anomalous completion errors for each group are reported in Table 2. Younger subjects made more errors than older subjects in both modalities, but this effect was equivalent for the two

TABLE 2

Percent Correct by Age Group

	Ages									
	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-26
Visual										
Best										
completion	-	97.27	97.19	98.28	98.85	98.39	99.32	98.33	99.32	98.33
Anomalous										
completion	-	98.41	96.88	97.97	99.09	99.81	99.09	98.33	98.18	99.58
Auditory										
Best										
completion	95.74	96.82	98.44	97.81	98.75	98.93	98.18	98.82	98.64	99.17
Anomalous										
completion	95.55	96.80	97.03	97.94	98.52	98.21	98.41	99.38	98.86	100.00

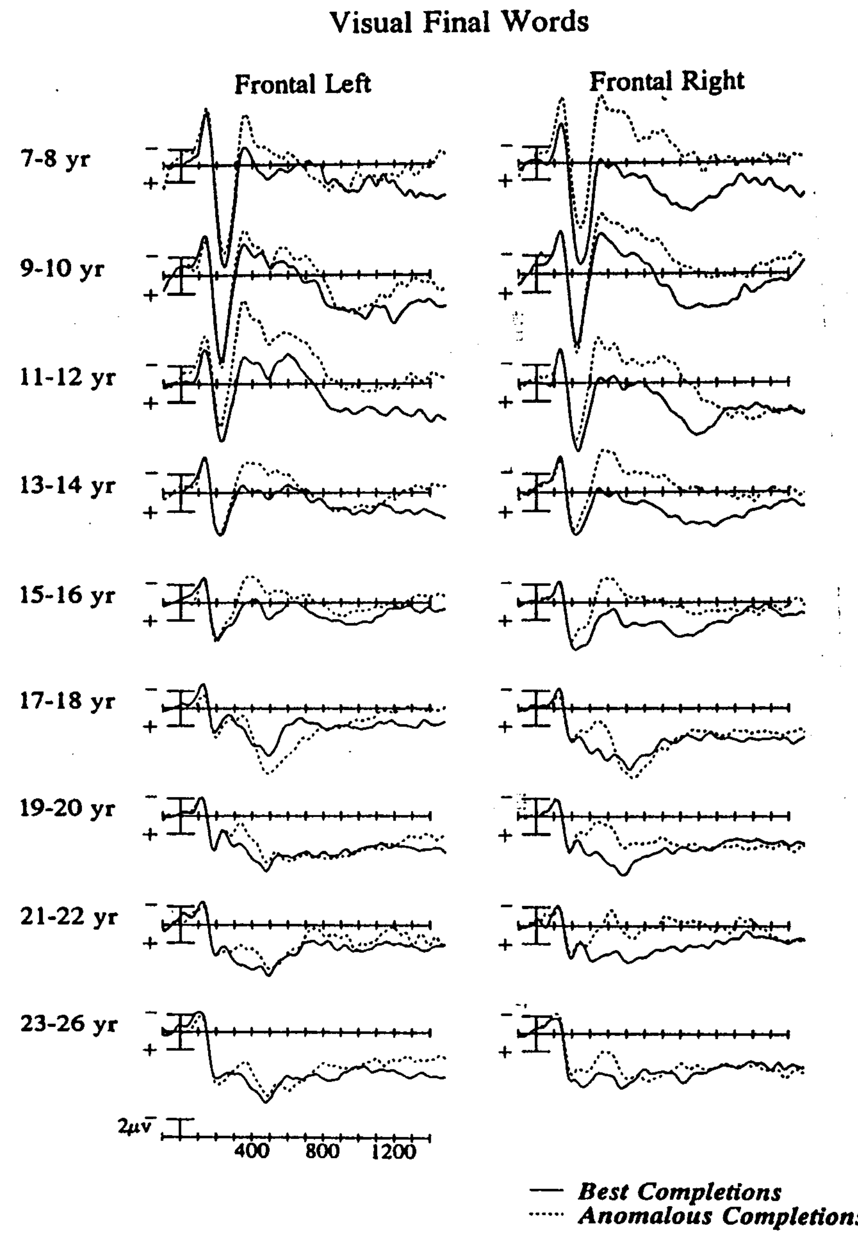
sentence types; main effect of age group, visual, $F(1, 110) = 2.2$, $p < .01$; auditory $F(1\ 120) = 3.53$, $p < .001$.

Visual Sentences

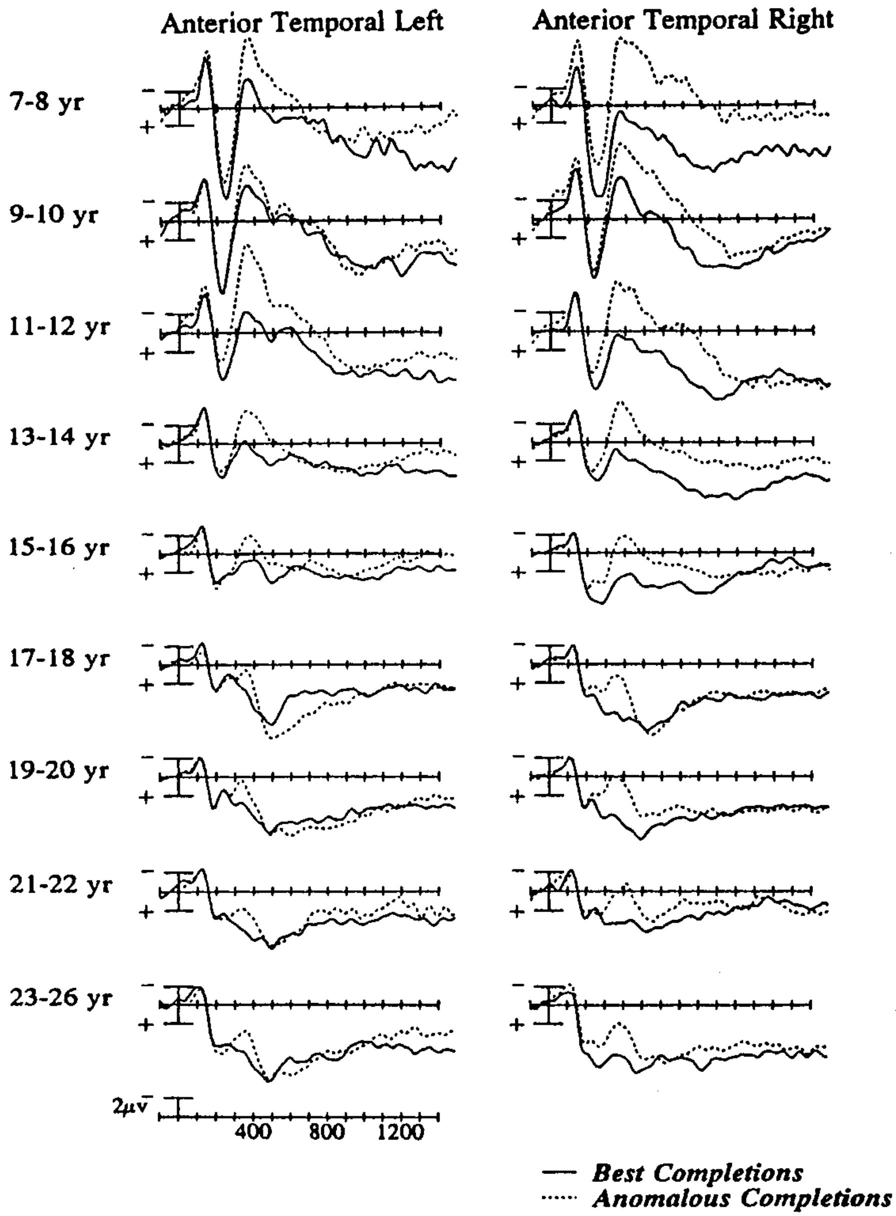
Early Peak Analyses

Sites anterior to the occiput. Figure 1 (a to e) presents the ERPs for the two sentence types for each age group at five pairs of lateral electrode sites in the visual sentence task. Across the age groups the sites anterior to the occipital region were characterized by an early negativity which peaked between 100 and 200 ms (N 100). The N100 increased in amplitude and peaked later moving from the parietal to more anterior electrode sites; electrode site, amplitude, $F(3, 24) = 36.4$, $p < .0005$; latency, $F(3, 330) = 10.4$, $p < .0005$. N100 was also larger and later in younger than older subjects; age group, amplitude, $F(8, 110) = 7.3$, $p < .0005$; latency, $F(8, 110) = 4.4$, $p < .0005$. In addition, as in previous studies of language processing, the amplitude of N100 was larger from the left than from the right hemisphere. However, whereas in the four oldest groups the asymmetry was confined to parietal sites, in younger subjects it was evident over both anterior and parietal regions; Hemisphere x Electrode Site x Age Group, $F(24, 330) = 1.9$, $p< .05$. There were no systematic effects of sentence type on visual N100 amplitude.

Following the N100, there was a positive-going wave that peaked between 200 and 300 ms (P250). As with the N100, P250 was larger (i.e., more positive) in younger than older subjects; age group, $F(8, 110) = 4.8$, $p < .0005$. The P250 also tended to be larger and peak later over the right hemisphere; hemisphere, amplitude, $F(I, 110) = 15.6$, $p < .0005$; latency, $F(1, 110) = 24.9$, $p < .0005$. The amplitude asymmetry was greater at the more posterior sites; Hemisphere x Electrode Site, $F(3, 330) = 34.5$,



Visual Final Words



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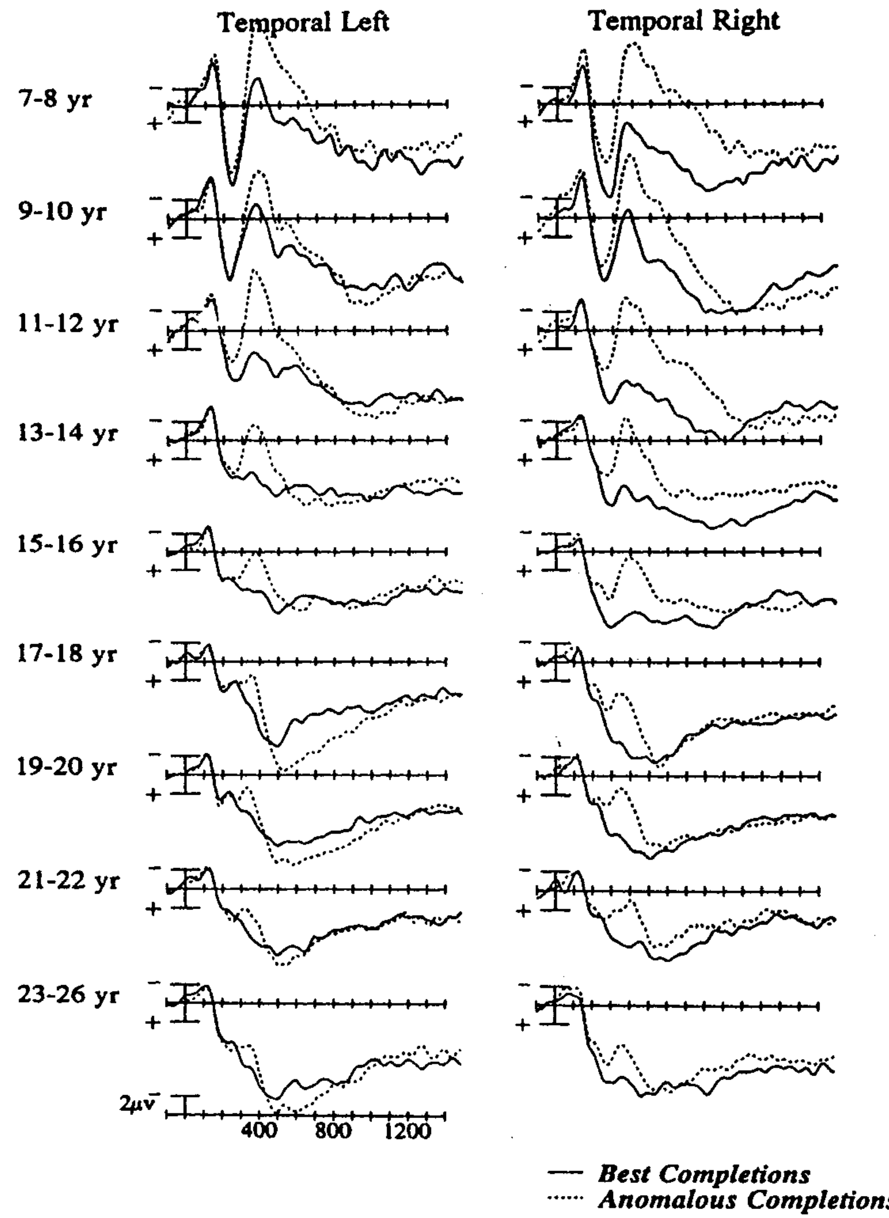
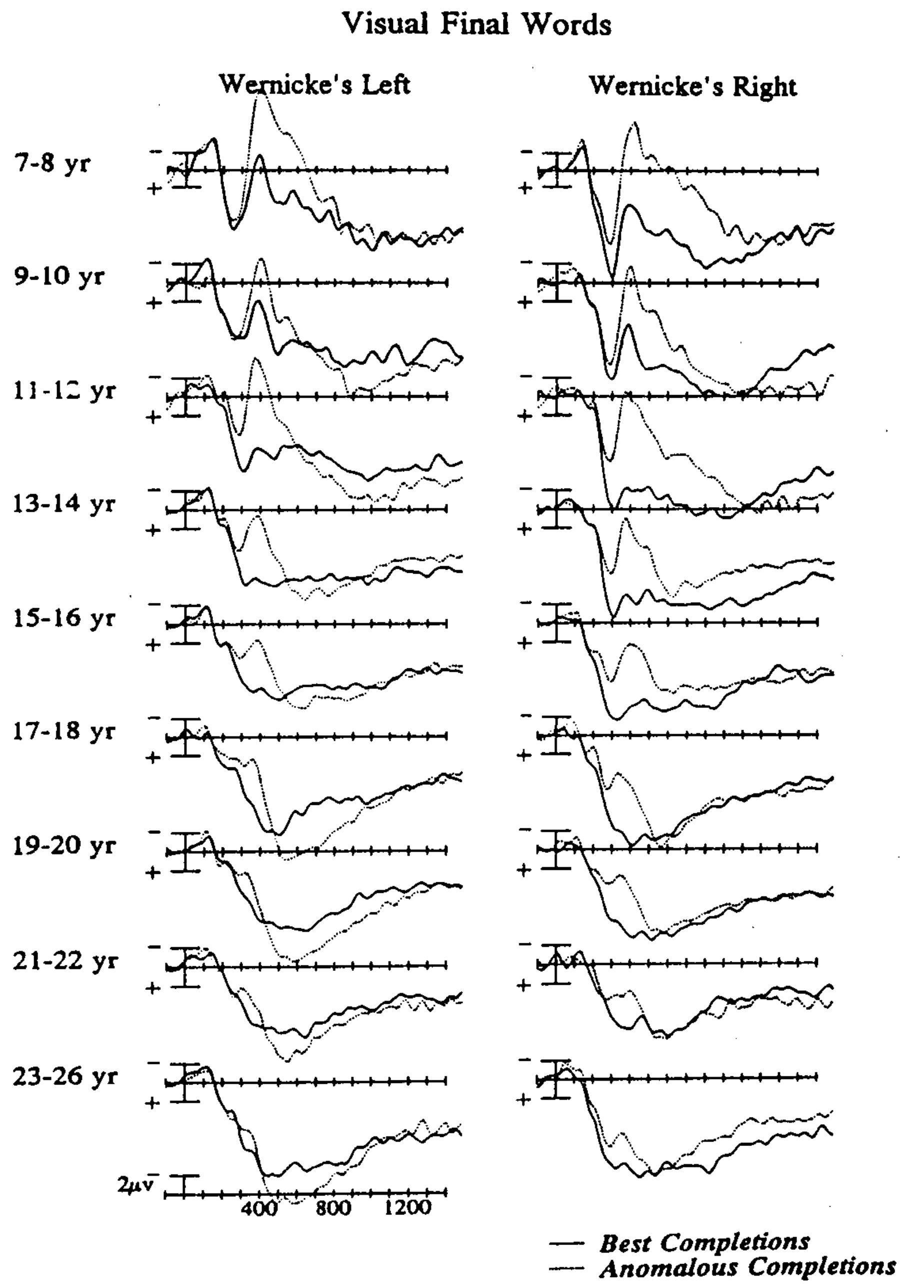




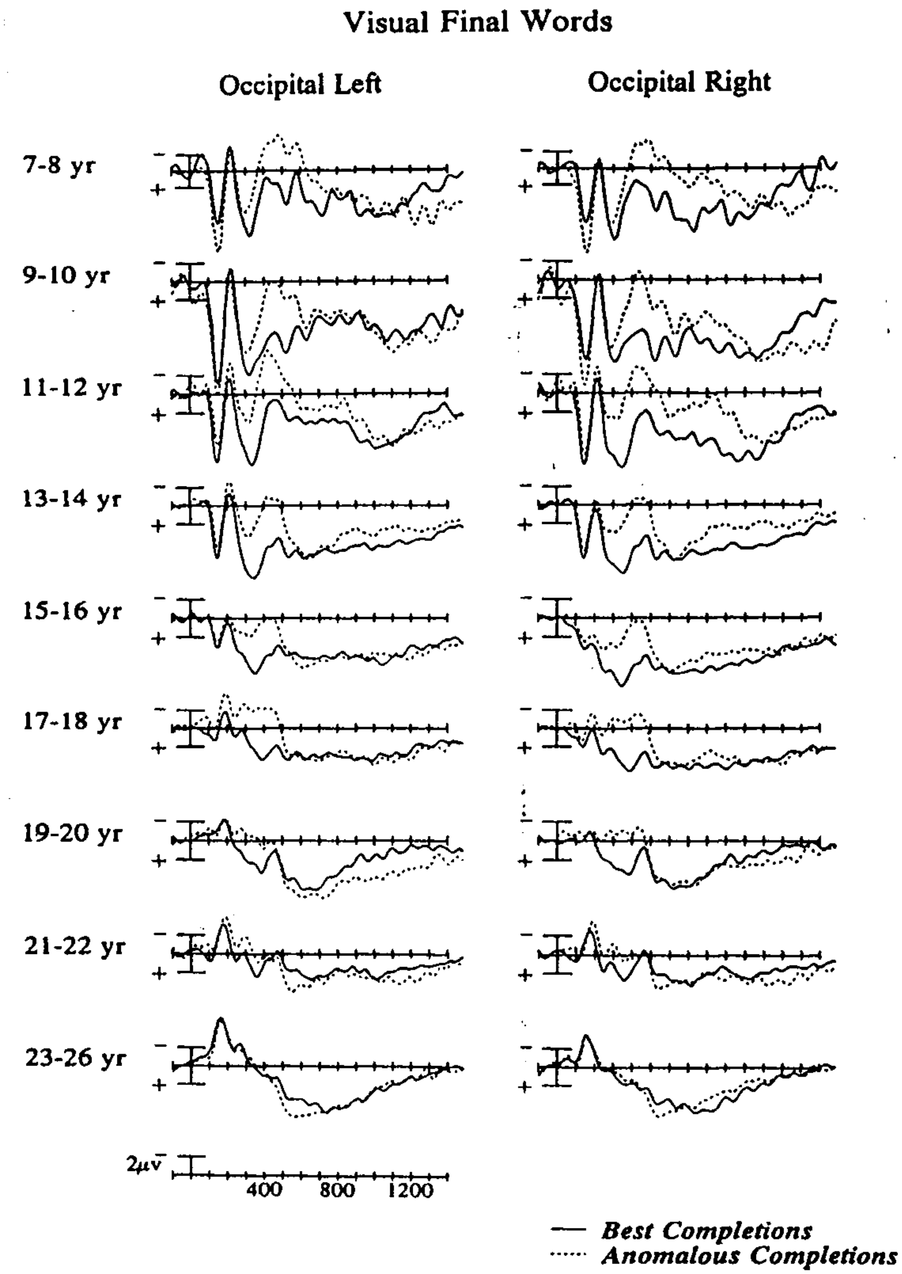


FIGURE 1 (a–e) ERPs to best completion and anomalous final words of visual sentences, averaged across all subjects in each age group. From left and right (a) frontal, (b) anterior temporal, (c) temporal, (d) parietal (Wernicke's), and (e) occipital sites. Stimulus onset is the vertical calibration bar.

$p < .0005$. P250 peaked earlier in response to anomalous completions, especially in the right hemisphere; Sentence Type x Hemisphere, $F(1, 110) = 8.0$, $p < .005$ and in the younger age groups; Sentence Type x Age Group, $F(8, 110) = 3.2$, $p < .005$. The P250 was larger for best completions than anomalous completions (i.e., ERPs to Anomalous sentences were more negative) over temporal and parietal sites in the right hemisphere Sentence Type x Hemisphere x Electrode Site, $F(3, 330) = 4.3$, $p < .01$.

Occipital sites. The morphology of the early part of the ERPs at the occipital electrodes differed from that of the other sites. In children up to 14 years of age there was a large symmetrical positivity that peaked between 100 and 200 ms (occipital P150). The occipital P150 decreased in amplitude and latency with increasing age; age group, amplitude, $F(8, 110) = 12.1$, $p < .0005$, latency, $F(8, 110) = 6.6$, $p < .0005$. P 150 was larger and later to anomalous completions in the youngest two groups, but did not vary with sentence type in the older groups; Sentence Type x Age Group, amplitude, $F(8, 110) = 3.3$, $p < .00.1$; latency, $F(8, 110) = 2.2$, $p < .05$.

Following the occipital P150, there was a negative-going wave that peaked between 150 and 225 ms (occipital N200). In the older groups (ages 19 to 26) this was the first visible peak. The occipital N200 was larger over the left hemisphere; hemisphere, $F(1, 110) = 12.3$, $p < .001$ and decreased in latency from the youngest to the oldest age groups; Age Group, $F(8, 110)=2.8, p<.01$.

The occipital N200 was followed by a positivity (occipital P250) in all but the oldest age group. Like the occipital N200, this wave was larger in the youngest groups, and declined with increasing age; age group, $F(8, 110) = 4.3$, $p < .0005$. Anomalous completions had a smaller (more negative) and earlier P250 than best completions; sentence type, amplitude, $F(1, 110) = 46.4$, $p < .0005$; latency, $F(l, 110) = 9.3$, $p < .005$.

N400

At all electrode sites, P250 was followed by a negative-going component that peaked between 300 and 500 ms (N400), but which continued for some groups and sites for several hundred ms (see Figure 1 (a to e]). The older age groups (15 to 26 years) tended to show a peaked negativity only in the anomalous completion sentences, while the younger groups (7 to 12 years) revealed a peaked negativity for best completions as well. That is, the younger subjects seemed to show an N400-like response to both sentence types, albeit a larger one to anomalous completions.

The raw area measures between 300 and 500 ms and between 500 and 800 ms displayed significant main effects of group indicating that the ERPs of younger children were significantly more negative than were those of older subjects (range -0.92 NV to 5.7 uV for area 300 to 500 ms) and this

effect interacted with sentence type, hemisphere, and electrode site. Therefore, the following analyses were performed on normalized values

Normalized mean amplitude (300 to 500 ms). Across all groups the responses to anomalous completions were more negative than to best completions; sentence type, $F(1, 110) = 122.0$, $p < .0005$ especially over parietal and temporal regions of the right hemisphere; Sentence Type x Hemisphere x Electrode Site, $F(4, 440) = 11.9$, $p < .0005$.

There were age group differences in the distribution of the *overall amplitude* (i.e., across sentence type) of the mean amplitude between 300 and 500 ms: In the four oldest groups this measure was more negative from the occipital regions, but in the five youngest groups it was most negative from the anterior temporal and frontal regions Electrode Site x Age Group, $F(32, 440) = 5.1$, $p < .0005$ (see Figure 2[4]). This effect on overall amplitude is in contrast to the Sentence Type x Electrode Site x Age Group interaction; $F(32, 440) = 2.0$, $p < .01$, which indicated that, over parietal regions only, the sentence type effect was larger for younger than older subjects. This is because of a decrease with age in the negativity to anomalous completions (see Figure 3). This suggests that the negative mean amplitude between 300 and 500 ms and its modulation by the sentence type variable are generated by different ERP sources that are differentially affected by development. The overall negative mean amplitude also displayed different hemispheric asymmetries across ages-it tended to be larger from the left hemisphere in the younger groups, but from the right hemisphere in the older groups; Hemisphere x Age Group, $F(32, 440) = 1.67$, $p < .05$.

Normalized mean amplitude (500 to 800 ms). This time window displayed a sentence type effect (anomalous completions more negative than best completions) that was largest over the right hemisphere; Sentence Type x Hemisphere: $F(1, 110) = 85.4$, $p < .0005$. However, in contrast to the earlier measure, this effect were largest over anterior regions of the right hemisphere; Sentence Type x Electrode Site x Hemisphere, $F(4, 440) = 19.0$, $p < .0005$. Moreover, this later measure of sentence type effects displayed significant changes with age. Indeed the ERPs to the anomalous completion sentences were more negative than those of the best completion sentences only in subjects 16 years of age or younger and only at sites over the right hemisphere, anterior to the occipital region; Sentence Type x Age Group x Hemisphere x Electrode Site, $F(32, 440) = 1.7$, $p < .05$ (see Figure 4)..

[4]The normalization procedure scales the raw ERP data between 0 and 1.0 such that negative ERP measures have values closer to 0 and positive measures have values closer to 1.0. Therefore, in graphs of interactions involving normalized data, values approaching 1.0 (positive-going) are plotted in the downward direction and values approach 0 (negative-going) are plotted in the upward direction.

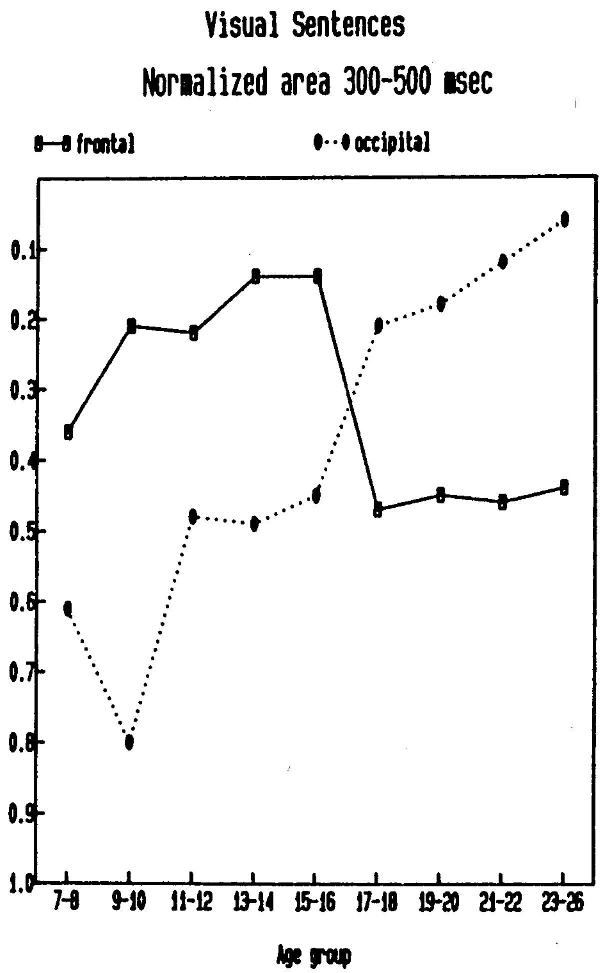


FIGURE 2 Normalized area 300 to 500 ms, from ERPs to visual sentences averaged across sentence type (negative-going is plotted up as in the ERP figures). Note that frontal sites become less negative and occipital sites become more negative with increasing age.

Auditory Sentences

Early Peak Analyses

In Figure 5 (a to e) ERPs for the two sentence types for each age group at the five pairs of lateral electrode sites in the auditory sentence task can be seen. The first component visible in these waveforms was a widely distributed positivity that peaked around 50 ms (P50). The P50 was largest at the three most anterior sites and smallest at the occipital sites; electrode site,

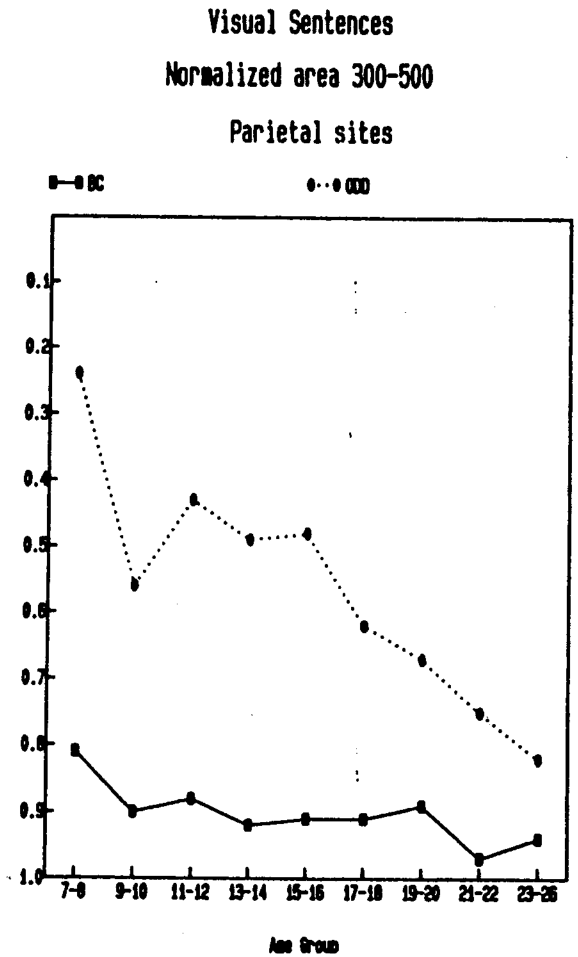


FIGURE 3 Normalized area 300 to 500 ms from best and anomalous completion sentences from parietal (Wernicke's area) sites (negative-going is plotted up). The best completion response changes only slightly over age while the response to anomalous completions become less negative.

$F(4, 480) = 13.6$, $p < .0005$ and was slightly larger over the right than left hemisphere; hemisphere, $F(1, 120) = 4.0$, $p < .05$. The peak of the P50 was larger and later in younger than older subjects; age group, amplitude, $F(9, 120) = 16.5$, $p < .0005$; latency, $F(9, 120) = 9.6$, $p < .0005$. Over occipital sites the P50 to anomalous completions occurred earlier than P50 to best completions; Sentence Type x Electrode Site, $F(4, 480) = 4.4$, $p < .005$.

Following the P50, there was a negative-going potential, also broadly distributed, which peaked between 90 and 200 ms (N100). The N100 was larger and had a later peak at more posterior sites; electrode site, amplitude,

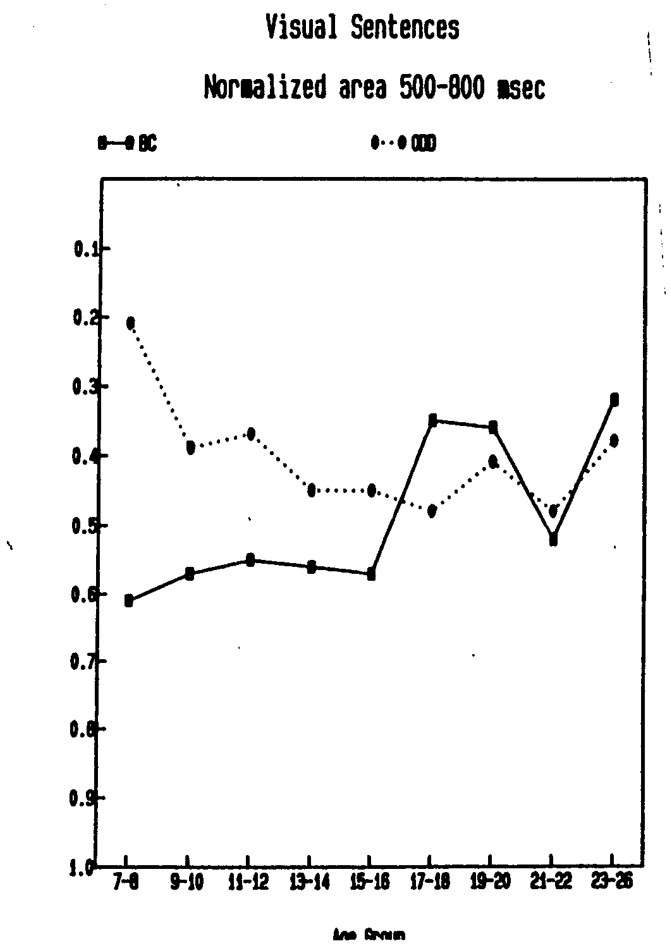
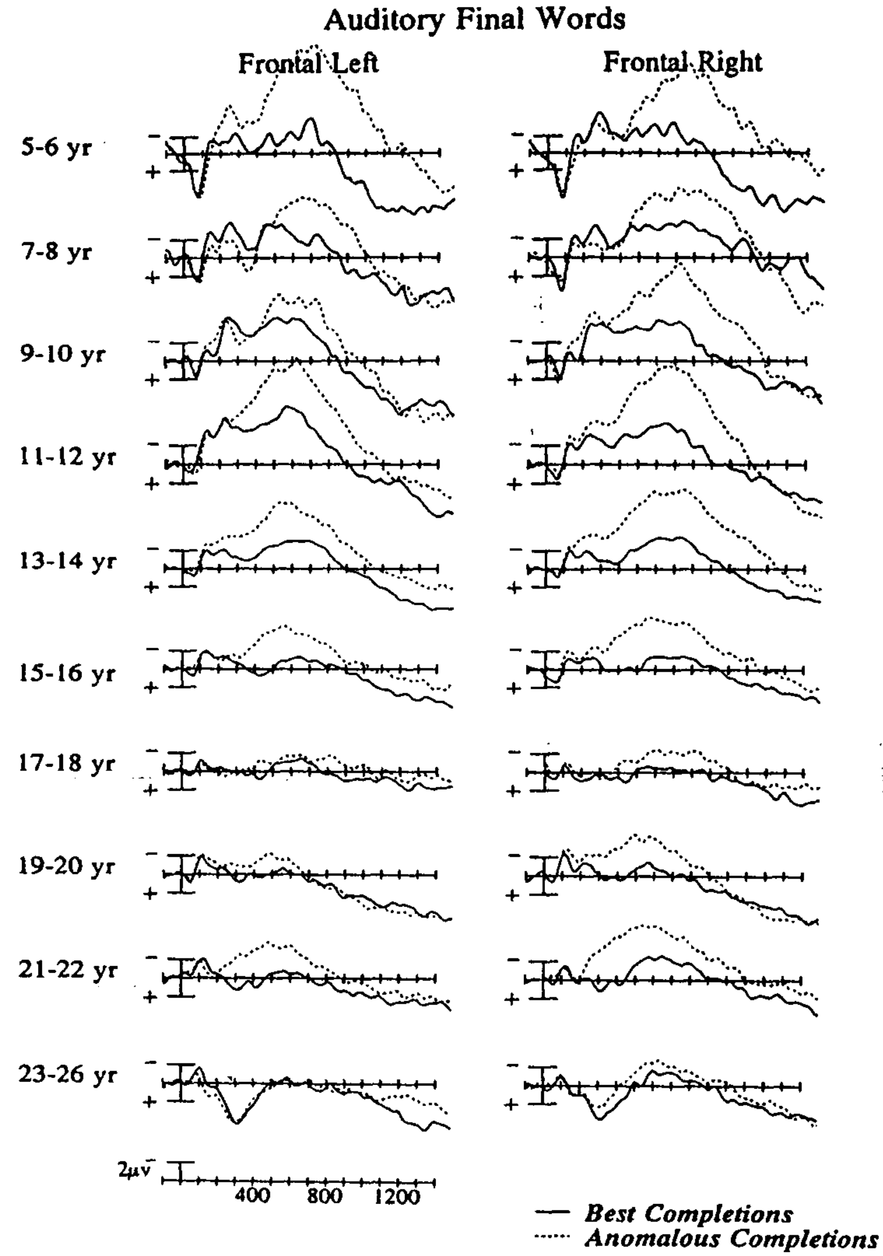
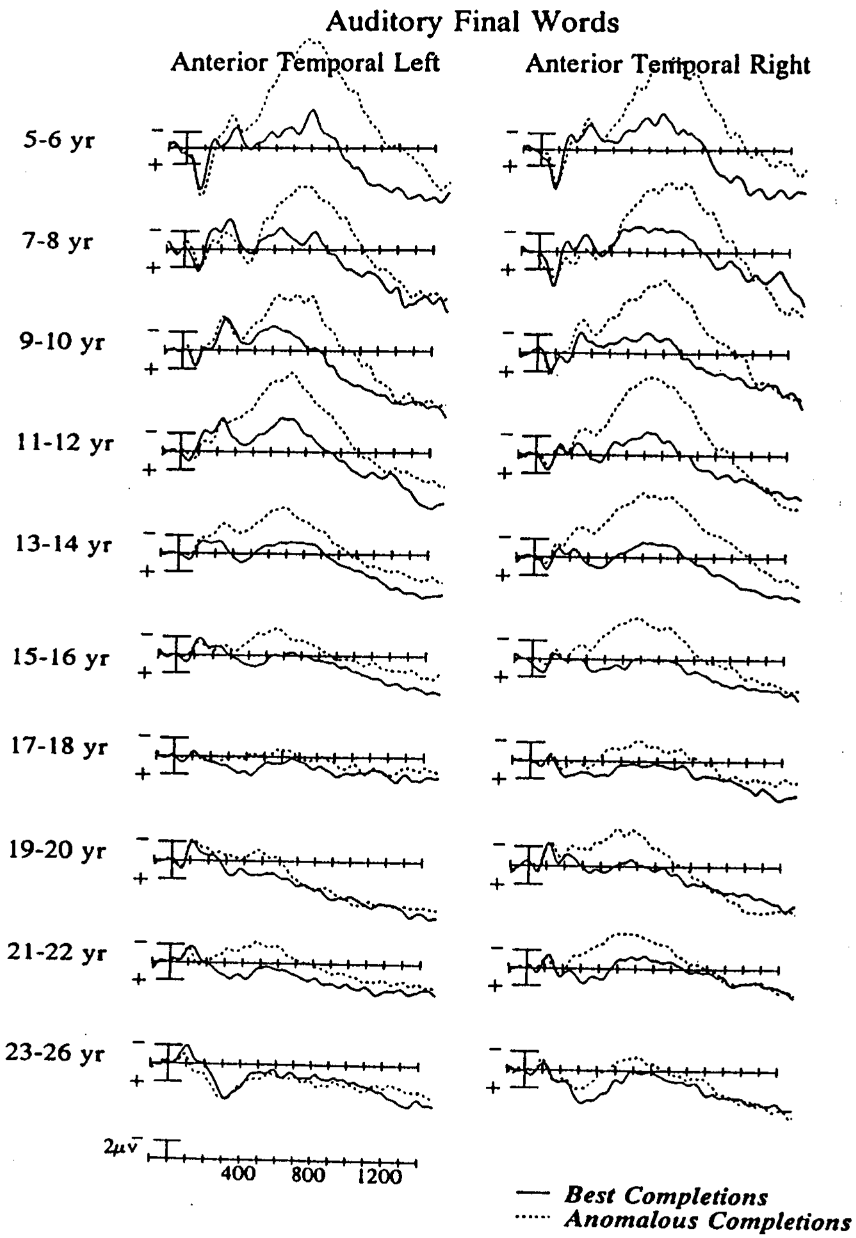
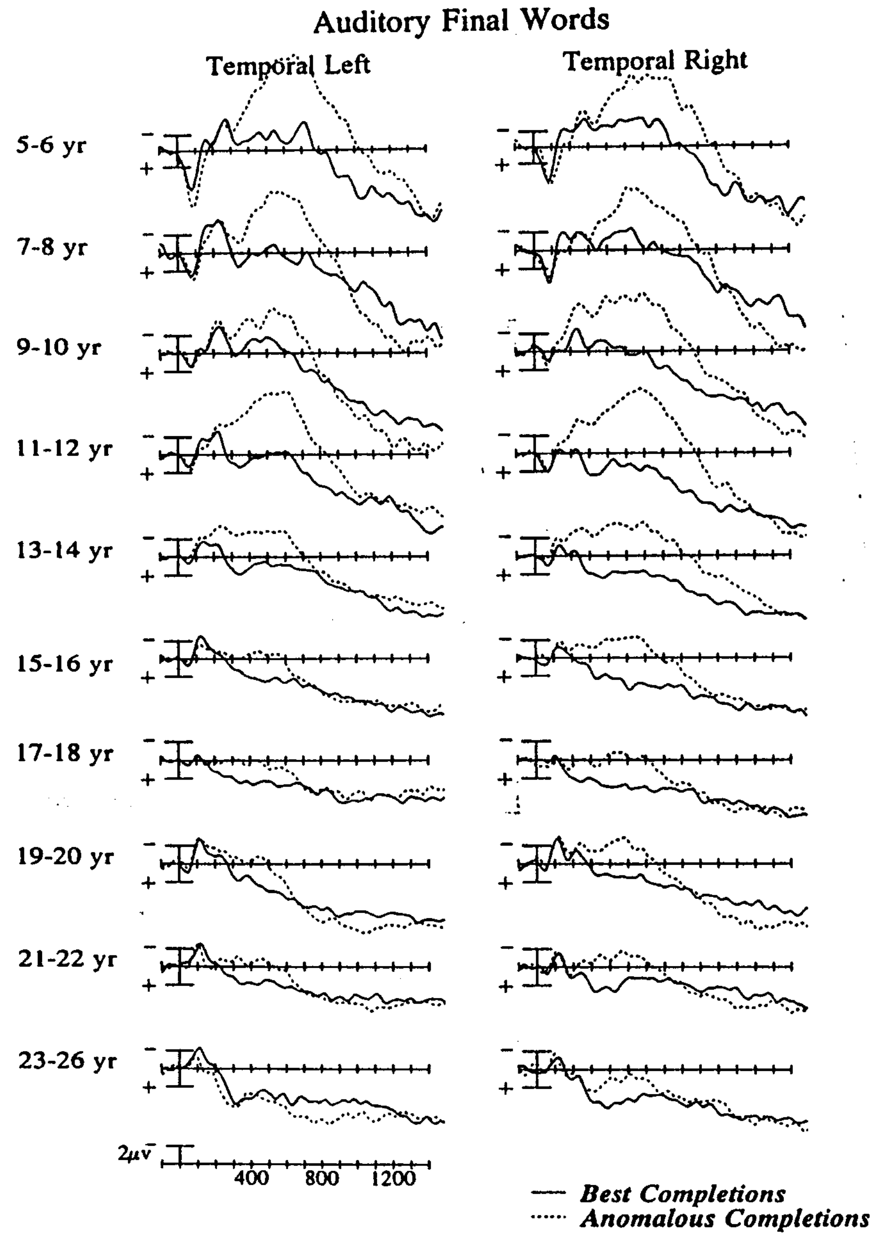


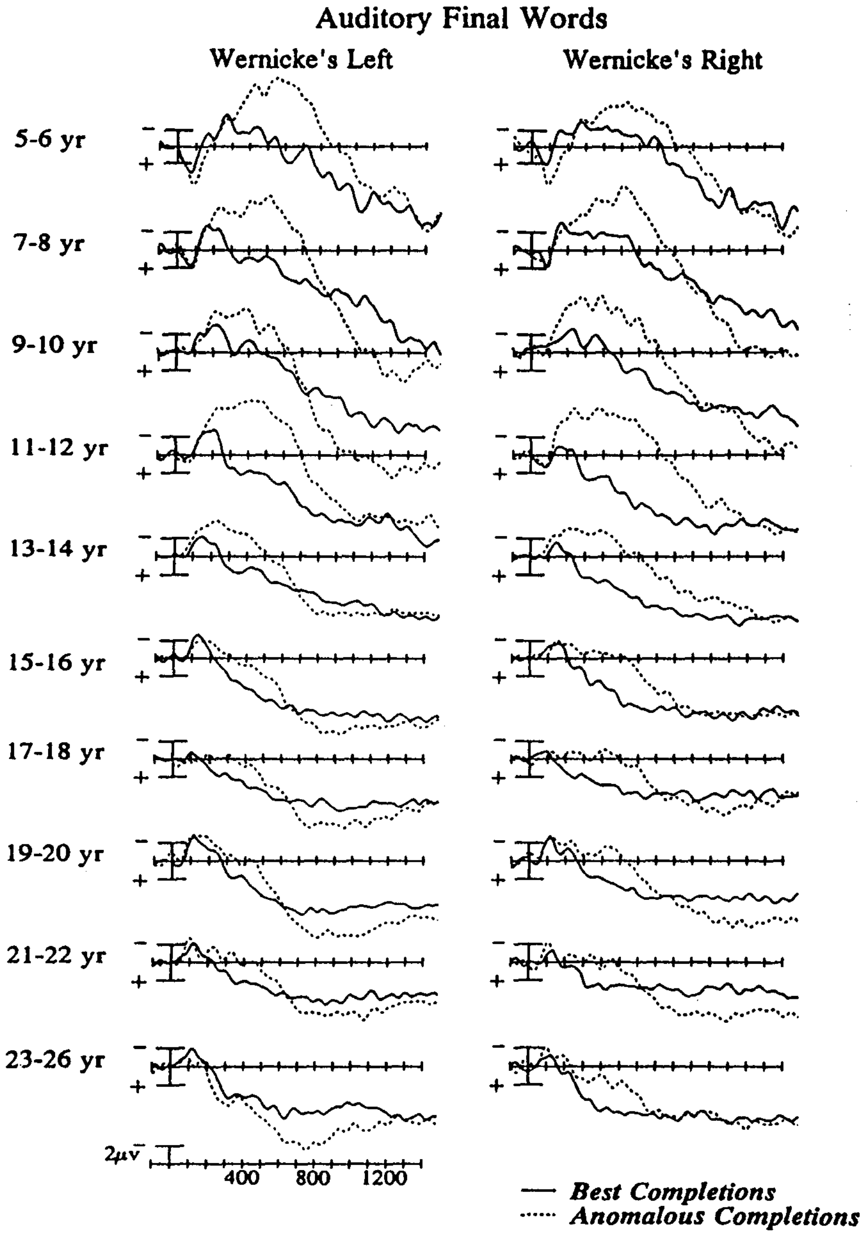
FIGURE 4-Normalized area 500 to 800 ms to final words of visual sentences (averaged across all electrode sites-negative-going is plotted up). The ERPs to Anomalous endings are more negative than those to best completions only in subjects 16 years of age or younger.

F(4, 480) = 9.4, $p < .0005$, latency, F(4, 480) = 3.2, $p < .05$. N 100 was also larger and later over the left than right hemisphere; hemisphere, amplitude, *F(l,* 120) = 5.8, $p < .05$; latency, F(1, 120) = 3.7, $p < .06$, and the latency asymmetry increased with age; Hemisphere x Age Group, *F(1, 120) = 2.0,* $p < .05$. N100 latency also declined with age especially over anterior regions; Electrode Site x Age Group, F(36, 480) = 2.9, $p < .0005$. Over the occipital sites, the N100 to anomalous completions was slightly more negative than that to the best completions; marginal Sentence Type x Electrode Site, F(4, 480) = 2.3, $p < .10$. Follow-up analyses at the occipital sites re-




Auditory Final Words
Anterior Temporal Left
Anterior Temporal Right
5-6 yr
7-8 yr
9-10 yr
11-12 yr
13-14 yr
15-16 yr
17-18 yr
19-20 yr
21-22 yr
23-26 yr
2µv
400
800
1200
Best Completions
Anomalous Completions


Auditory Final Words
Temporal Left
Temporal Right
5-6 yr
7-8 yr
9-10 yr
11-12 yr
13-14 yr
15-16 yr
17-18 yr
19-20 yr
21-22 yr
23-26 yr
2µv
400
800
1200
Best Completions
Anomalous Completions



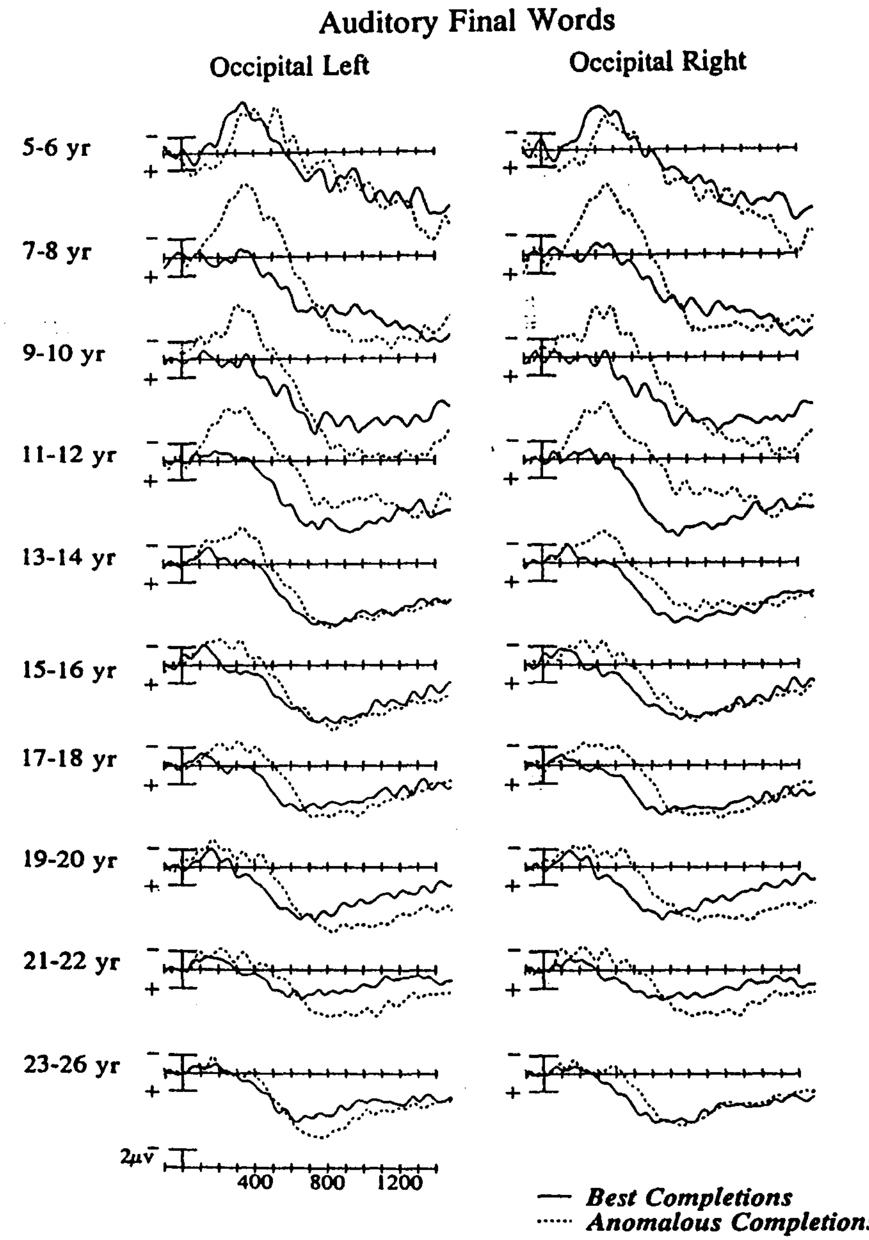


FIGURE 5 (a–e) ERPs to best completion and anomalous final words of auditory sentences, averaged across all subjects in each age group. From left and right (a) frontal, (b) anterior temporal, (c) temporal, (d) parietal (Wernicke's), and (e) occipital sites.

vealed that this trend was significant over the left hemisphere; Sentence Type x Hemisphere, $F(1, 120) = 5.7$, $p < .05$. N100 responses to best completions occurred earlier than those to anomalous completions especially over occipital and parietal sites; Sentence Type x Electrode Site, $F(4, 480) = 4.0$, $p < .01$. But this pattern held only for younger subjects, as older subjects produced later N100s to best completions; Sentence Type x Age Group, $F(9, 120) = 2.4$, $p < .05$.

Unlike the visual sentences, the positivity (P250) following the auditory N100 was only clearly visible (and was only measured) between 200 and 500 ms over the temporal and anterior temporal sites. P250 latency was earlier from the right hemisphere; hemisphere, $F(1, 120) = 7.6$, $p < .005$. P250 amplitude was larger over anterior temporal than temporal sites in older subjects; in younger subjects they were equivalent; Electrode Site x Age Group, $F(9, 120) = 1.9$, $p < .05$. The P250 was earlier and less positive (i.e., more negative) for anomalous than best completions; sentence type, latency, $F(1, 120) = 22.5$, $p < .0005$; amplitude $F(1, 120) = 51.2$, $p < .0005$. Over anterior temporal regions the amplitude difference between the sentence types was larger in subjects younger than 13 years; Sentence Type x Electrode Site x Age Group, $F(9, 120) = 2.1$, $p < .05$.

N400

Following the N100-P250 complex, the ERPs were dominated by a large negative component (N400) which was of maximum amplitude between 200 and 900 ms. As can be seen in Figure 5 (a to e) and as in the visual modality, whereas the older age groups (15 to 26 years) tended to show a peaked N400 only in the anomalous completion sentences, the younger groups (5 to 14 years) revealed an N400-like negativity for best completions as well, particularly at the more anterior sites.

The amplitude of the N400 (i.e., maximum negativity between 200 and 900) and the mean areas from 300 to 500 and 500 to 800 ms, all diminished considerably, in ERPs to both sentence types, with age. These age group differences also interacted with the electrode site, sentence type, and hemisphere variables. Thus, for the reasons discussed above, only the normalized results are considered here.

Normalized mean amplitude (300 to 500 ms). The normalized area was significantly more negative in ERPs to anomalous than best completion endings especially over temporal and parietal regions and over the right hemisphere; Sentence Type x Hemisphere, $F(1, 120) = 5.8$, $p < .01$; Sentence Type x Electrode Site, $F(4, 480) = 4.4$, $p < .05$. These effects displayed significant shifts between and within the hemispheres as a function of age. The negativity to the anomalous completions diminished with age over parietal and temporal regions, whereas this area in ERPs to the best completions displayed fewer changes over age. Thus, the difference between the sentence types diminished with age over these regions; Age Group x Sentence Type x Electrode Site, $F(36, 480) = 2.2$, $p < .01$ (see Figure 6). In addition, whereas responses to best completions tended to be symmetrical in this time window, responses to the anomalous completions were consistently more negative from the right hemisphere. However, this asymmetry was only present in subjects 13 years and older; Age Group x Sentence Type x Hemisphere, $F(9, 120) = 3.0$, $p < .005$.

Normalized mean amplitude (500 to 800 ms). This area also was considerably more negative to anomalous completions, and this effect was again largest from the right hemisphere. However, whereas the earlier (300 to 500 ms) difference between sentence types was largest over parietal and temporal regions, this later effect, and the asymmetry it displayed, were largest from the anterior electrodes; Sentence Type x Hemisphere, $F(1, 120) = 11.5$, $p < .001$; Sentence Type x Electrode Site, $F(4, 480) = 10.5$, $p < .0005$. The ERPs to the anomalous completions diminished with age, whereas responses to best completions were similar across age groups; Sentence Type x Age Group, $F(9, 120) = 2.3$, $p < .05$ (see Figure 7). Additionally, the asymmetry in response to anomalous completions (right hemisphere more negative) increased with age; Sentence Type x Hemisphere x Age Group, $F(9, 120) = 2.4$, $p < .01$.

Difference Waves

Peak Latency (200 to 900 ms)

The overall mean latency of the negative peak (N400) in the visual difference waves was 475 ms. The peak was later from frontal than from other sites; Electrode Site, $F(4, 440) = 7.4$, $p < .0005$ and from the right than the left hemisphere; hemisphere, $F(1, 110) = 18.5$, $p < .0005$. The peak latency decreased until 19 years and then increased in the 19- to 23-year-old groups; age group, $F(8, 110) = 2.5$, $p < .05$.

The latency of the N400 in the auditory difference waves was 525 ms. The peak was earlier from posterior (470 ms) than anterior (580 ms) electrodes; electrode site, $F(4, 480) = 29.1$, $p < .0005$. The peak latency decreased from 5 years of age (619 ms) until 13 years of age (498 ms) after which it was stable; age group, $F(1, 120) = 2.7$, $p < .005$.

In between modality comparisons, the peak of N400 was earlier in the visual than auditory modality, but only over temporal, anterior temporal and frontal sites. The earliest peak in the visual modality was over parietal and temporal sites, in the auditory modality it was over parietal and occipital sites; Electrode Site x Modality, $F(4, 440) = 7.3$, $p < .0005$. The peak was asymmetric (right hemisphere later) only in the visual modality; Hemisphere x Modality, $F(1, 110) = 6.1$, $p < .01$.

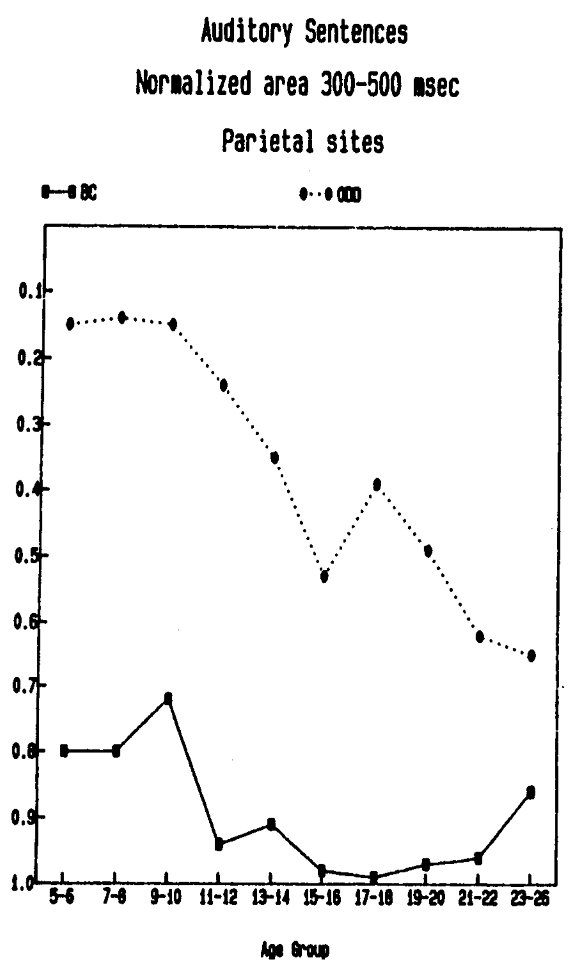


FIGURE 6 Normalized area 300 to 500 ms from ERPs to best completions and anomalous completions in auditory sentences (negative-going is plotted up). Over parietal sites the response to best completions becomes less negative until I I to 12 years; the negativity to anomalous completions declines across all ages.

Normalized mean amplitude (300 to 600 ms). This analysis of the difference waves from both modalities together produced a strong overall hemispheric asymmetry, especially over parietal and temporal regions; Hemisphere x Electrode Site, $F(4, 440) = 9.5$, $p < .0005$. In addition, the change in intrahemispheric distribution with age of the priming effect was apparent. Across both modalities, younger subjects tended to have larger effects from parietal than anterior regions, whereas anterior effects were larger in the older subjects (see Figure 8). The only significant effect of modality was a Hemisphere x Electrode Site x Modality interaction; $F(4,$

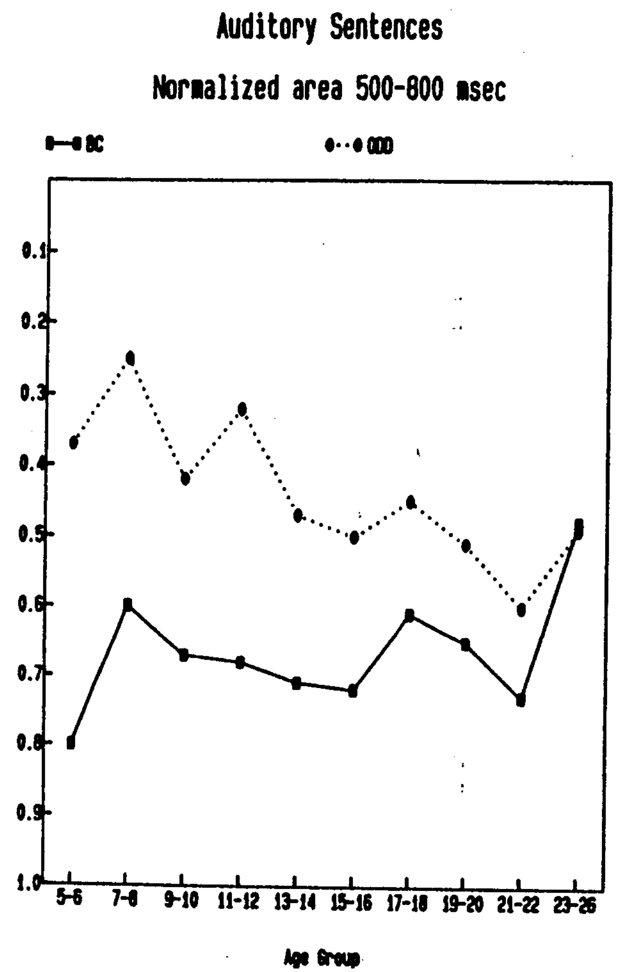


FIGURE 7 Normalized area 500 to 800 in ERPs to best completions and anomalous completions (negative-going is plotted up). This measure of the difference between sentence types also declines across ages, due to a decrease in negativity to anomalous completions (ODD).

$440) = 2.7$, $p < .05$ indicating that although both the visual and auditory effects were larger from the right hemisphere, this asymmetry over parietal and temporal regions was larger in the visual than the auditory modality. This was because of the auditory effect being larger than the visual effect over the parietal and temporal regions of the left hemisphere.

Normalized mean amplitude (600 to 900 ms). This later measure was also largest over the right hemisphere across both modalities, and also displayed a frontal distribution across modalities; hemisphere, F(1,

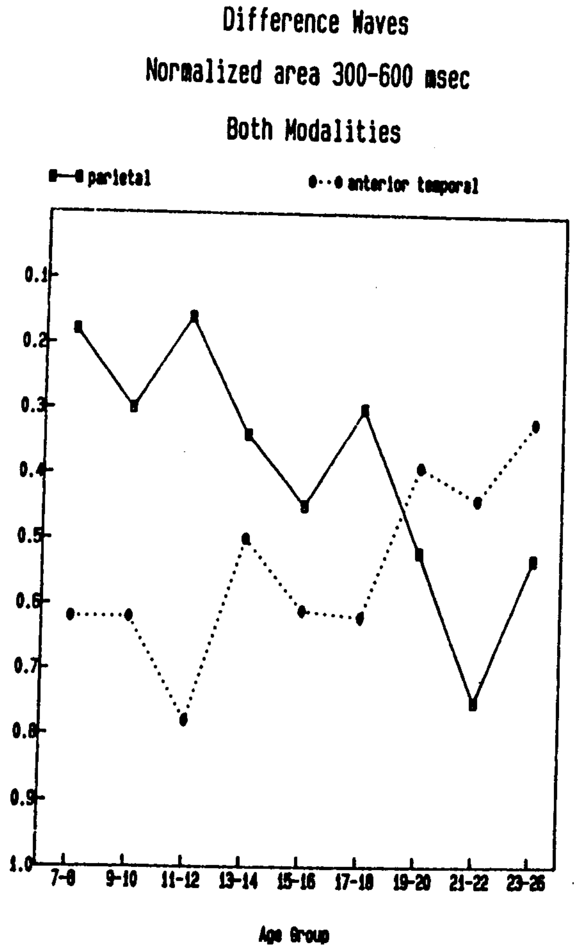


FIGURE 8 Normalized area 3170 to 600 ms in difference waves (formed by subtracting ERPs to best completions from ERPs to anomalous completions). Across both modalities this difference (i.e., the priming effect) declines with age over parietal areas and increases with age over anterior areas (negative-going is plotted up).

110) $= 20.9$, $p < .0005$; electrode site, $F(4, 440) = 9.6$, $p < .0005$. There were no interactions with age on this measure. However, this late effect was considerably larger in the auditory than visual modality; Modality, $F(1, 110) = 62.4$, $p < .0005$. The effect also displayed different distributions in the two modalities. In the auditory modality it was largest from anterior regions, whereas in the visual modality it was large from frontal and parietal regions; Modality x Electrode Site, $F(4, 440) = 7.4$, $p < .0005$ (see Figure 9). However, the asymmetry of the effect was largest over occipital regions in the auditory modality and over anterior temporal regions in the visual

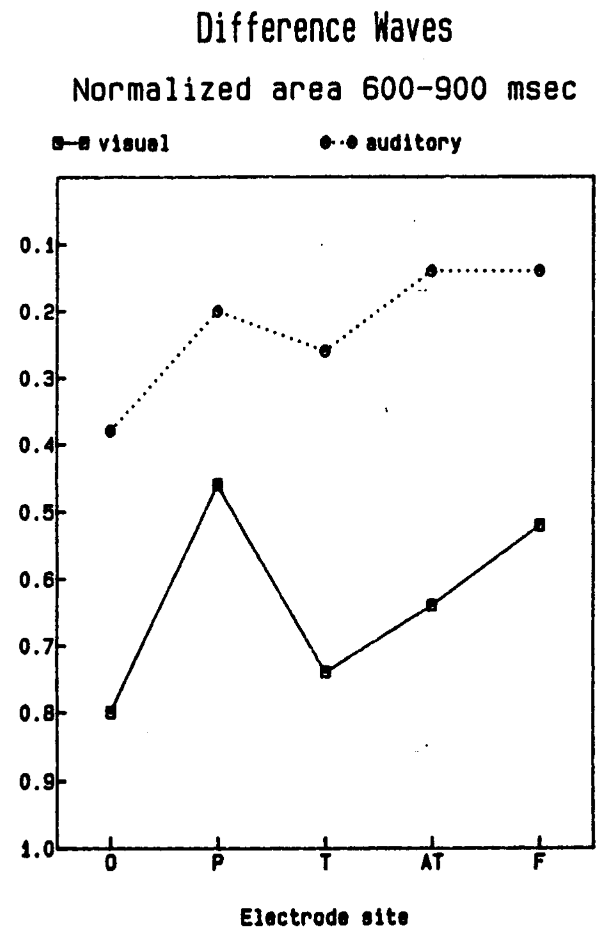


FIGURE 9 Normalized area 600 to 900 ms indifference waves for visual and auditory modalities over occipital (O), parietal (P), temporal (T), anterior temporal (AT), and frontal (F) regions (negative-going is plotted up).

modality; Electrode Site x Modality x Hemisphere, $F(4, 440) = 9.4$, $p < .0005$.

DISCUSSION

Summary of Findings

Children, like the adults in this and numerous previous studies (e.g., Holcomb & Neville, in press; Kutas & Hillyard, *1980),* produced larger *N400s* to anomalous words than to appropriate words occurring at the ends of contextually constraining sentences. This effect was present during both reading (ages 7 and 26 years) and listening (ages 5 to 26 years). The distribution and developmental time course of the priming effect was different for the two modalities, following a discussion of more general effects.

Overall Effects of Age

There were several overall effects of age on the ERPs. Both the early sensory components and the later components including the N400 displayed marked reductions in latency and marked decreases in amplitude with age. In general, these changes occurred linearly from 5 until 15 to 16 years of age and then were stable. These results are therefore consistent with a diverse literature showing that most every aspect of human brain development, including neuronal density, synapse formation, dendritic branching, continues to mature until the mid-teen years (Conel, 1939-1963; Huttenlocher, 1979; Huttenlocher et al., 1982).

Also consistent with large clinical, behavioral, and ERP literatures are the results showing asymmetries in the amplitudes of different ERP components. As in previous language studies (e.g., Neville, Kutas, Chesney, & Schmidt, 1986), the left hemisphere typically displayed greater negative potentials than the right, except in response to semantically anomalous information, in which case the asymmetry was reversed. In this study, most of the asymmetries displayed clear increases with age. Indeed, robust asymmetries were often not present until 13 years of age and thereafter. These results are in line with some clinical studies, and a small behavioral literature that suggests hemispheric specialization becomes established in the peri-pubertal time period (Carey & Diamond, 1980; Smith, 1981). On the other hand, there is also a large literature demonstrating asymmetries of cortical anatomy, ERPs, and behavior in very young infants (Entus, 1977; Molfese, Freeman, & Palermo, 1975; Witelson & Pallie, 1973). Robust ERP asymmetries have also been observed in 20-month-old infants listening to words whose meaning is comprehended (Mills, Coffey, & Neville, in press). However, it is likely that the specific language-relevant brain areas that are active depend on the task demands and capabilities of the subjects. Sentence processing is arguably a task of sufficient complexity that it may draw upon neural systems that display clear functional specialization only later in development.

Age and Context Interactions

As noted, there were clear effects of contextual priming on the ERPs for all ages in both modalities. Because the negative area that was modulated by sentence type displayed large reduction in voltage with age, it was necessary to normalize these measures separately for each group, in order to assess

the magnitude of the effect of the context manipulation independently of the main effect of age. The results point to the intriguing possibility that the negative area between 300 and 500 ms and the contextual priming effect that modulates this negative area are not generated by the same neural systems. In younger children the negative area was larger from anterior brain areas, but the priming effect (i.e., the differences between sentence types) was largest from posterior parietal areas. Older subjects displayed a trend in the opposite direction. The 300- to 500-ms measure displayed greater priming effects in younger children over parietal regions only.

One possibility for this pattern of effects is that the larger anterior negative area in children may reflect activity of a second ERP component-one that, because of similar temporal dynamics, summates with the N400 at the scalp. The presentation of novel stimuli has been reported to produce a developmentally sensitive component with a frontal distribution (referred to by Courchesne, 1978, as the Nc component; also see Holcomb et al., 1985). In the few studies where it has been identified, the Nc has been demonstrated to be large in amplitude in children (6 to 13 years), but virtually absent in adults over 18 years of age (Courchesne, 1978). Although the functional significance of this late negativity is unclear, Courchesne (1978) speculated that it may reflect the perceptual operations involved in processing attention getting novel stimuli. The two types of final words in this study could be characterized as attention getting (they were the most salient words for the assigned task) and novel (in the sense that no final word was presented more than once), and therefore may have produced an Nc-like response.

The later measure (i.e., from 500 to 800 ms) also showed larger context effects in younger children over all electrode sites. Indeed, context effects in this time window were only observed in subjects less than 16 years of age. These developmental data, together with the data showing a different distribution of the 300 to 500 ms and the 500 to 800 ms effects, argue that nonidentical sources generate the early and late contextual priming effects. One possibility is that the later sentence type effect reflects the additional contextual processes required by less skilled readers.

The current data also suggest that contextual priming effects begin to operate very early in the younger subjects. The Sentence type effects on P150 and N100 indicate that both early and later priming processes may be larger in younger than older children. However, further research is required to determine what functional characteristics, if any, distinguish the priming effects at different latencies.

Modality Effects

Sentence context effects were large in the auditory modality for all age groups-indeed, they were significantly larger than for visual sentences.

Moreover, the auditory context effects were greater for younger than older children. Like the visual results this effect of age occurred on the 300- to 500-ms measure over parietal regions only and on the 500- to 800-ms effect at all electrode locations. These findings replicate, and extend to children, recent work showing large effects of sentence and single word contexts during speech perception (e.g., Holcomb & Neville, 1990, 1991; McCallum et al., 1984).

Interactive-Compensatory Model

The nature of the change with age in the priming effect was that although the negativity to the best completions decreased only slightly and only in the youngest age groups, the N400 to the anomalous completions decreased markedly and linearly with age in both modalities. One interpretation of this finding is that with age and/or experience anomalous sentence endings produce more primed responses or require less integration. By this account, sentence context is less effective in older subjects because anomalous endings are more expected. But this could only be true in a very general because for the entire category of anomalous completions, as there was no way that subjects could have predicted the specific anomalous final words.

A second possibility is that the decline in the N400 to anomalous completions with advancing years reflects a relative decrease in the reliance on sentence context in more skilled language users. This position is in agreement with previous suggestions, based on behavioral data, that sentence level contextual factors during language comprehension play a greater role in children. More specifically, these data appear to be consistent with Stanovich's interactive compensatory model (Stanovich, 1980, 1984) in which younger unskilled readers are said to compensate for less well developed bottom-up word recognition skills through slower reading (which allows more time for spreading activation to occur) and by engaging higher strategic processes (which rely on contextual information). The finding of a later peak latency and longer duration N400 effect in younger subjects argues that context has more time to affect children's comprehension processes. And the larger N400 effects in children support the interactive compensatory prediction that context effects are greater in younger subjects. However, the degree to which the strategic or automatic compensatory processes are mediating the N400 amplitude differences between the ages is unclear, as a neutral context against which the relative contributions of each can be judged was not employed in this study. In a previous study of word-pair priming in adults, Holcomb (1988) reported that the N400 was sensitive to both types of influences.

Another finding that does not appear to be consistent with the interactive compensatory model is the presence of a similar developmental trend in the auditory N400 data. Although this model was formulated to account for larger context effects during the acquisition of reading skills, it would not appear to predict similarly large developmental trends in speech comprehension, as this skill does not as clearly differentiate children and adults.

There are at least three possibilities for reconciling the interactive compensatory model with the similar pattern of N400 developmental trends for the visual and auditory modalities found in this study. First, it may be that developmental differences in the effects of context are not specifically a function of reading skill as assumed by Stanovich's model, but rather are a reflection of a more general language or semantic proficiency that is tapped by language tasks in both modalities. In other words, children may be more sensitive to contextual information in general. Second, it is possible that the larger auditory context effects in children may be the result of their limited experience with reading. That is, learning to read may in some way alter the young child's approach to speech perception-for example, making them more attuned to context. There is some evidence that learning to read does change both adults' and children's abilities to segment speech sounds (e.g., Bentin, Hammer, & Cahan, 1991; Morals, Bertelson, Cary, & Alegria, 1986). Learning to read might affect other auditory language processes as well. However, the large N400 effects seen for the 5- to 6-year-old group, who had not yet learned to read, casts some doubt on this hypothesis. It seems unlikely that the limited experience with reading that these youngest children had received could have produced such a robust N400 effect.

A final possibility is that the aspect of context that mediated the N400 effect in this study was not the same aspect that affected RT in the studies reported by Stanovich and colleagues. Stanovich et al. (1985) emphasized that their model applies primarily to word recognition processes. Holcomb (in press) demonstrated a dissociation between reaction time (RT) and N400 semantic priming effects in a word-pair task using visually degraded stimuli. He argued that although RT is sensitive to processes associated with word recognition, N400 amplitude appears to be more sensitive to postrecognition integrative processes (i.e., those important in forming a discourse representation from lower information sources). Auditory and visual sentences may not have produced the same pattern of developmental context effects if a measure more sensitive to word recognition processes (e.g., final word pronunciation speed) had been used. This hypothesis will have to await further behavioral work using spoken sentences.

Conclusions and Future Directions

Most generally these results show that, in both the auditory and the visual modalities, responsiveness to context declines with age. These shifts occur amidst massive changes in cerebral organization including increasing functional specificity and decreasing response times that occur at least into the middle teen years. The results also indicate that there are probably two or three different effects of contextual priming, each occurring at different times and displaying different distributions over the scalp, and different age-related changes. It will be important to utilize the combined behavioralelect rophysiological approach to determine the different functional characteristics of these effects.

ACKNOWLEDGEMENT

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