Word and Picture Processing in Children: An Event-Related Potential Study

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In an investigation of the N400 component, event-related potentials (ERPs) elicited by 4 types of word stimuli (real words, pseudowords, random letter strings, and false fonts) and 3 types of picture stimuli (real pictures, pseudopictures, and picture parts) presented in separate lists were recorded from 10- and 11-year-old children. All types of word stimuli elicited an anteriorly distributed negativity peaking at about 400 msec (antN400). Words and pseudowords elicited similar ERPs, whereas ERPs to letter strings differed from those to both pseudowords and false fonts. All types of picture stimuli elicited dual anterior negativities (N350 and N430). Real pictures and pseudopictures elicited similar ERPs, whereas pseudopictures and picture parts elicited asymmetrical processing. The results are discussed in terms of increased sensitivity to and dependence on context in children.

Language has long been a topic of study within various disciplines: Cognitive psychologists have focused on language as one of the most elaborate mental behaviors of humans; linguists have investigated the structure and function of language within and across cultures; neuroscientists have known for at least a century that neurological specializations, primarily involving the cerebral cortex, are at the basis of language; and the development of language skills has always been integral to

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the educational process. Despite the breadth of disciplines engaged in language study, relatively little is known about what occurs in the brain as language skills, and specifically comprehension skills in written language, develop. This current lack of a thorough understanding of the complex neurocognitive processes involved in language skills development is due in part to a paucity of adequate methodologies for exploring online, real-time language processing in the brain (Osterhout & Holcomb, 1995), especially methods that can be used with children.

The electrophysiological recording of event-related potentials (ERPs) of the brain is one of the few online methods that is both usable with children and relatively well suited to the investigation of real-time language processing in the brain. Scalp-recorded ERPs reflect the stimulus-locked information-processing activities in terms of net electrical fields, or large assemblies of neurons in different areas of the brain (e.g., see Coles & Rugg, 1995); this provides tentative information about localization and lateralization of brain activity. Further, the individual components that constitute the ERP waveform index particular types of information processing, allowing for investigation of specific brain-behavior relationships.

Fortunately for researchers interested in language, the N400 component of the ERP waveform is consistently elicited in linguistic contexts and appears to be sensitive to aspects of language comprehension; it may also be sensitive to aspects of picture processing. Unfortunately for researchers interested in cognitive development as reflected in picture processing and reading skills, few studies have specifically investigated the developmental course of the N400 component. The present study is an attempt to begin to fill this knowledge gap.

ERPs and Word Processing

The N400 component was introduced in a seminal article in which it was reported that semantically incongruent terminal words of visually presented sentences, as compared to semantically congruent terminal words, elicited a negative-going deflection, with peak latency near 400 msec-an N400 (Kutas & Hillyard, 1980). Related research indicated that the amplitude of the N400 elicited by a sentence terminal word was an inverse function of the cloze probability of that word in context: The more related and predictable the word, the less the amplitude of the N400 (Holcomb & Neville, 1991; Kutas, Lindamood, & Hillyard, 1984). Subsequently, researchers demonstrated that an N400 was not only elicited by unexpected, anomalous sentence-ending words, but also by anomalous words in the middle of sentences (Kutas & Hillyard, 1983; Kutas & Van Petten, 1988, 1994); moreover, similar effects were apparent in different languages (Besson & Macar, 1987) and modalities (Holcomb & Neville, 1991). Investigators also found that an N400 could be elicited in the context of words presented in pairs and by words presented in lists (Bentin, 1987; Bentin, McCarthy, & Wood, 1985; Harbin, Marsh, & Harvey, 1984;

Holcomb, 1988; Holcomb & Neville, 1990; Nobre & McCarthy, 1994; Rugg, 1985). However, no N400 was evident to physically incongruous words (Kutas & Hillyard, 1980), grammatical errors (Kutas & Hillyard, 1983; Osterhout & Holcomb, 1995), or geometric or musical incongruities (Besson & Macar, 1987).

This accumulative pattern of results has suggested that the N400 is sensitive to semantic aspects of language. Numerous studies with adults have now replicated the basic finding that N400 amplitude to a target word is attenuated by prior exposure to a semantically related prime word, or words (e.g., Bentin, 1987; Bentin et al., 1985; Holcomb, 1988; Holcomb & Neville, 1990; Kutas et al., 1984; Neville, 1985). The "N400 semantic priming effect"-the difference between N400s to primed and unprimed words-onsets at 200-250 msec and peaks at 400 msec, is usually slightly larger over the right hemisphere in sentence contexts, and is usually largest at central and posterior lateral electrode sites, such as those over Wernicke's area (e.g., Holcomb, 1988; Kutas et al., 1984; Kutas, Van Petten, & Besson, 1988; Nobre & McCarthy, 1994). Based on these findings, some researchers have hypothesized that the N400 might be an index of lexically based semantic processes, such as lexical search and access resulting from spreading activation within a semantic network (e.g., Fischler & Raney, 1991). In this view, the N400 is smaller to primed targets because spreading activation has already partially activated the representation of the target on exposure to the prime, and the N400 is larger to unprimed targets because such activation is not present and relatively more resources are required for activation of the representation of the target (i.e., word recognition).

Another possibility consistent with the extant data is that the N400 may reflect some aspect of postlexical semantic processing, such as a high-level integrative process [Brown & Hagoort, 1993; Holcomb, 1993; Osterhout & Holcomb, 1995; Rugg, 1990; Rugg, Furda, & Lorist, 1988). In this view, the amplitude of the N400 reflects "the ease with which various knowledge sources [e.g., lexical, syntactic and semantic] are used to form an integrated discourse representation; the more difficult it is to integrate a given piece of information into the ongoing representation, the larger the N400 effect elicited by that information" (Holcomb, 1993, p. 48). Theoretically, when a word is unprimed, the integration of its meaning with its context requires greater resources, and this is indexed by a larger N400 (as compared to a primed word; Rugg et al., 1988).

Consistent with this integrative hypothesis, nonwords (unpronounceable permutations of orthographically legal letters) do not elicit N400s, whereas pseudowords (pronounceable nonwords that follow the rules of English orthography and phonology) do elicit marked N400s (e.g., Bentin, 1987; Bentin et al., 1985; Holcomb, 1988, 1993; Holcomb & Neville, 1990; Nobre & McCarthy, 1994; Rugg, 1984, 1990; Rugg & Nagy, 1987). These findings are compatible with the contention that the N400 reflects some sort of higher level process that builds, from the products of lower order processes, the representation(s) that provide the basis for comprehension (Holcomb, 1988): Such a process is not possible with nonwords because lower

level phonological processing cannot be completed and no semantic processes are activated, making an integration process impossible. However, such a process is possible with pseudowords because early phonological and orthographic processing can be completed, although semantic processes may be only partially activated representations of similar real words may be activated, whereas no direct conceptual match is possible-making an integration process attemptable but extremely difficult. These findings suggest that semantic analysis in context may always be attempted on orthographically legal, pronounceable letter strings (Rugg, 1984). In this sense, the N400 appears to be a "default response to words" (Kutas & Van Petten, 1994, p. 104) or potential words, possibly reflecting the activation of an integrator whenever groups of words are expected or comprehension of words is required (Holcomb, 1988).

ERPs and Picture Processing

The apparent sensitivity of the N400 to language and meaning and the possibility of the existence of a general, unitary, amodal, semantic system accessible to both images and words (e.g., Kroll & Potter, 1984) have prompted investigation of the N400 in picture-processing paradigms. Barrett and Rugg (1990) reported that ERPs to the second pictures in nonassociated picture pairs were more negative-going than ERPs to the second pictures in associated picture pairs, mirroring the pattern found in word-priming studies. The observed differences were the result of both a frontally distributed N300 and a more widely distributed N450; the authors suggested that the latter was a late N400, evidence that the N400 was "sensitive to semantic relationships between nonverbal stimuli" (Barrett & Rugg, 1990, p. 201). Nigam, Hoffman, and Simons (1992) came to a similar conclusion based on results of a sentence-reading study in which the terminal word of the sentences was either a word or a picture (line drawing), because they found that pictures and words in sentence-terminal position elicited identical N400s in terms of amplitude, scalp distribution, and latency. However, in a comparable sentence reading study, Ganis, Kutas, and Sereno (1996) found that the N400 congruity effect for words was largest at posterior sites, whereas the N400 congruity effect for pictures was largest at anterior sites.

A similar difference in N400 scalp distribution for picture processing versus word processing has been reported in a number of other studies. Stuss, Picton, and Cerri (1986) found that unexpected pictures in a picture-naming task elicited an N417 that was more negative over anterior sites than the N400 associated with words. Likewise, Holcomb and McPherson (1994) reported a larger frontally distributed N400 for unrelated than related target pictures in a picture-priming task; this N400 was larger over the left hemisphere, and virtually no priming effect was visible at occipital sites. In addition, Stuss, Picton, Cerri, Leech, and Stethem

(1992) reported an N400 maximal over the frontocentral scalp in response to incomplete pictures. Such distributional differences between the N400 evoked by words and the N400-like effect elicited by pictures, in addition to the N300 observed in some picture-processing paradigms (Barrett & Rugg, 1990; Holcomb & McPherson, 1994; McPherson & Holcomb, 1999), suggest that semantic analysis of words and pictures may involve different, at least partially nonoverlapping (Ganis et al., 1996), neural systems.

ERPs and Development

There have been few studies of normal developmental changes across childhood in ERPs related to word-processing (although several ERP studies have looked at language in infants and children; e.g., Mills, Coffey-Corina, & Neville, 1993; Molfese, 1983; Molfese & Betz, 1988; Taylor, 1989). In one developmental, cross-sectional sentence-reading study, Holcomb, Coffey, and Neville (1992) visually presented sentences with either congruous or incongruous terminal words to 7- to 26-year-olds and found that the N400 decreased in both amplitude and latency with increasing age. Further, they reported that an N400 was evident to both best completions and anomalous terminal words in 7- to 12-year-olds. The authors suggested that these results indicated an overall declining responsiveness to context with age, reflecting a greater role for sentence-level contextual factors during language comprehension for children as compared to adults. In another developmental, longitudinal word-list reading study, Licht and colleagues did not observe an N400; instead, they reported that the amplitude of a temporal N530 decreased as a function of grade whereas the amplitude of a temporoparietal N360 increased as a function of grade, from first to third grade (Licht, Bakker, Kok, & Bouma, 1988, 1992). These authors suggested that this pattern represented a shift from a slower, more controlled stage of processing (N530) to a faster, more automatic stage of processing (N360) for word recognition over time (Licht et a1., 1992).

In addition to these language studies, at least two studies of picture processing have reported a negative-going wave peaking at about 500 msec in young children (Kok & Rooijakkers, 1985; Symmes & Eisengart, 1971), and one has reported an anterior N350 that is larger to pictures than to words for 7- to 10-year-old children, but not for adolescents or adults (Berman, Friedman, & Cramer, 1990). Further, Friedman and colleagues have extensively investigated a negative-going component with latency 400 msec elicited in children (and adults) that is greater to the second pictures in nonmatching picture pairs than in matching picture pairs (when the match is in terms of physical appearance, name, or semantic category, e.g., Friedman, Putnam, Hamberger, & Berman, 1992; Friedman, Putnam, & Sutton, 1989,1990; Friedman, Sutton, & Putnam, 1987; Friedman, Sutton, Putnam, Brown, & Erlenmeyer-Kimling, 1988). They termed this component

"Neg400," as they were unsure if the negativity was the same as the N400 elicited by language stimuli. Neg400 has a frontocentral scalp topography for both children and adults, and its amplitude evidences no changes with age (from 7 years old to old age), whereas its latency decreases with increasing age.

The Present Study

Developmental, cognitive psychologists and educators interested in language comprehension have established that the early stages of learning to read are primarily concerned with lower level processes, such as analysis of visual word features (orthography) and an evolving understanding of grapheme-to-phoneme correspondences (phonology; e.g., Adams, 1990; Barron, 1986; Fletcher & Satz, 1980; Fletcher, Satz, & Scholes, 1981; Stanovich, 1980; Wagner & Torgesen, 1987). As the process of learning to read progresses, knowledge of the visual characteristics of words expands and orthographic and phonological information begin to be integrated (e.g., Bakker, 1981; Knight & Fischer, 1992), allowing higher-level processes such as word recognition and identification to become increasingly automatic (i.e., fast, obligatory, autonomous, and requiring limited use of cognitive resources; Wolf, 1991). This developing ability to read words quickly, accurately, and effortlessly is critical to skillful reading comprehension (Adams, 1990) because it frees cognitive resources to allow for the integration of words and their context, which leads to an understanding of the meaning of texts (e.g., Stanovich, 1980).

Although the developmental process of integration is known to be essential to efficient reading behaviorally, little is known about how the developing brain processes or integrates linguistic information. Because the N400 is hypothesized to be an index of a higher order process of integration within the language comprehension system (Brown & Hagoort, 1993; Holcomb, 1988, 1993; Osterhout & Holcomb, 1995; Rugg, 1990), as well as, by some accounts, involved in picture comprehension (Barrett & Rugg, 1990; Nigam et al., 1992), it would seem a promising approach to focus on this aspect of the ERP waveform in order to explore the development of neural conceptual systems. Therefore, the present study was designed as a developmental investigation of the N400 and the neurocognitive process(es) that it might represent, in terms of both word processing and picture processing.

Behavioral research has indicated that the abilities to use orthographic structure and phonology develop gradually and systematically during the early elementary school years, reaching adult levels by the third or fourth grade (e.g., see review in Adams, 1990). The present study was an attempt to discover if electrophysiological results-especially in terms of the N400 and related components-might corroborate such behavioral findings. Ten- and I 1-year-old children read different types of words and looked at different types of pictures, both presented (separately) in list form. The types of stimuli were designed to detect fine-tuning in

conceptual processing in terms known to be relevant to the N400: Real words were meaningful and followed the orthographic and phonological rules of English; pseudowords were meaningless but followed orthographic and phonological rules; letter strings were meaningless and broke word-level orthographic rules and phonological rules; and false fonts were meaningless and broke both word- and feature-level orthographic rules as well as phonological rules. In parallel, real pictures were meaningful closed-object images; pseudopictures were meaningless closed-object images; picture parts were meaningless open images of jumbles of closed-object parts; and flashes were meaningless images.

Because negativities with approximate latencies of 400 msec have been elicited in children and adults in response to words (e.g., Holcomb et al., 1992) and pictures (e.g., Friedman et al., 1992), it was expected that the words and pictures in this study would elicit negativities similar to those previously observed. In contrast to the classic N400 effect observed in sentence and priming paradigms, the N400 elicited in word-list tasks without priming has a more anterior distribution, is largest at central and frontal locations (especially along the midline), and is slightly larger over the left hemisphere early in its course (Nobre & McCarthy, 1994). In the present word-list task without priming, a similar anteriorly distributed N400 was anticipated. Despite the distributional difference, the anterior N400 is thought to be closely related to the classic N400 and probably reflects similar cognitive processes (Nobre & McCarthy, 1994).

The primary purpose of the present study was to investigate the N400 elicited by pictures and words in a group of children. Specifically, we looked at whether or not the types of word stimuli and the types of picture stimuli would be differentiated from one another and, if so, how they would be processed relative to each other, and relative to the N400 findings from previous studies with adults. Would the previously observed pattern of words and pseudowords but not letter strings eliciting N400s (e.g., see Kutas & Van Petten, 1994) be evident in children? How might false fonts be processed-similar to other word stimuli or as a distinctive category of their own? Would real pictures elicit the N300 and N450 complex seen in some previous studies with adults (Barrett & Rugg, 1990; Holcomb & McPherson, 1994; McPherson & Holcomb, 1999)? Would pseudopictures and picture parts elicit waveforms similar to those elicited by pictures?

METHODS

Subjects

The full sample included 20 ten- and 11-year-old children, 10 girls and 10 boys. All participants were right-handed, native monolingual English speakers, with normal or

corrected-to-normal vision, and were reported to be at or above grade level in reading by a parent. Participants were paid from $10 to $25. Data for 6 participants did not meet criteria for inclusion (described later); the final sample used for analyses (ages 10;9-11;11, average 11;4) included 7 boys (ages 10;911;11, average 11;4) and 7 girls (ages 11;1-11;9, average 11;5).

Stimuli

Stimuli were presented in separate lists. Each list consisted of 200 different word stimuli or 200 different picture stimuli, with each type of stimulus (five types per list, described later) occurring 40 times in pseudorandom order. Lists were formed such that real objects in Picture List 1 had lexical equivalents in Word List 1, and real objects in Picture List 2 had lexical equivalents in Word List 2. Half of the subjects were presented with Picture List 1 and Word List 2, and the other half received Picture List 2 and Word List 1; presentation and order of lists were counterbalanced across all participants.

Each of the two picture lists contained 40 of each of the following types of stimuli: animal pictures (20 pictures, each presented twice), real pictures, pseudopictures, picture parts, and flashes (see Fig. 1). All pictures (except flashes) were presented as white line drawings on a uniform black background and subtended less than 3 deg of visual angle. Animal pictures, which served as targets,
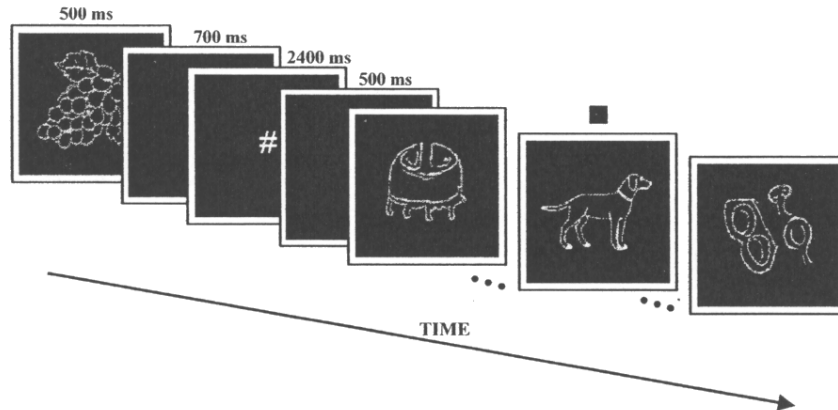

FIGURE 1 Picture- and word-list stimuli were presented in list form; picture-list stimuli included real pictures, pseudopictures, animal pictures, and picture parts (illustrated respectively from left to right). Animal pictures served as targets for a button-press response (). Each stimulus was presented for a duration of 500 msec. Stimulus presentation was followed by a blank screen (700 msec duration), a hash mark symbol (#) indicating an appropriate time to blink (2,400 msec duration), and another blank screen (500 msec duration).

and pictures of real objects were adapted from black-and-white line drawings from Snodgrass and Vanderwart (1980) and were chosen based on the regularity, syllabic length, and frequency of their lexical representation. Pseudopictures consisted of nonobjects adapted from Kroll and Potter (1984) and were "line drawings of closed figures with an object-like appearance, created by tracing parts of drawings of real objects and regularizing the results" (p. 41). Picture parts consisted of three to five randomly arranged component parts from the Kroll and Potter (1984) pseudopictures, clustered together to form an image of comparable size to the real pictures and pseudopictures. Flashes were flashes of light subtending a visual angle of 6 x 5 deg and were not included in analyses (in part because these stimuli tended to elicit eye and movement artifacts and in part because these stimuli were not well matched with the other types of picture stimuli, in that they were substantially larger and brighter than any other stimulus type and did not consist of white lines on a black background).

In parallel, each of the two word lists contained 40 of each of the following types of stimuli: animal names (20 names, each presented twice), real words, pseudowords, random letter strings, and false fonts. All word stimuli (except false fonts) were composed of lowercase white letters presented on a uniform black background and were single syllables, three to six letters in length. Animal names, which served as targets, were lexical equivalents of the animal pictures (e.g., dog). Real words were lexical equivalents of the real pictures (e.g., *grapes)*. The mean word frequency of animal names was 19.7; the mean word frequency of real words was 62.4 (based on Kucera & Francis, 1967). Pseudowords were nonwords that conformed to the orthographic and phonological rules of English, formed by changing one or two letters of a real word (e.g., chour). Letter strings followed the letter-level orthographic rules of English (in that they consisted of legal letters), but violated word-level orthographic rules (in that they consisted of illegal letter combinations), and also violated phonological rules. Letter strings were formed by randomly rearranging letters from real words to form nonpronounceable units (e.g., *bnra).* False font stimuli were comprised of characters based on real letters (from the pseudowords) that were systematically altered by a font editor such that no character resembled any letter in the English alphabet. (Cf. Petersen, Fox, Snyder, & Raichle, 1990, for a similar set of word stimuli in a PET study.)

Animal names and pictures of animals served as targets that required a simple button-press response and were used to maintain engagement and to ensure that stimuli were processed to a "deep" semantic level (e.g., see discussion in Rugg et al., 1988). ERP results regarding these stimulus categories will not be reported herein.

Stimuli were presented sequentially in list form; subjects were simply asked to look at the pictures or read the words as they were presented on the screen and press a button whenever a picture (picture list) or name (word list) of an animal appeared. Stimuli were presented for a duration of 500 msec, after which a blank screen was

presented for 700 msec, followed by the hatch mark symbol (#), which appeared on the screen for 2,400 msec in order to indicate that eye movement was acceptable at that time;' 500 msec prior to presentation of the next stimulus, the screen was again blanked to prepare subjects for the upcoming stimulus (see Fig.1)

Procedure

Subjects were given a brief tour of the laboratory and then seated in a comfortable chair in a sound-attenuated room and fitted with an electrode cap (described later). Following electrode placement, pictures and words were displayed on a 16-in. Goldstar monitor 57 in. from the subject. Subjects were informed that they would see different kinds of pictures (or words) come up on the screen and were given the instructions to sit as still and relaxed as possible; to focus their eyes on the pictures (or words) and try not to blink until a hatch mark (#) appeared on the screen, and then to press the "yes" button of a response box on their laps with their right hand when a picture of an animal (or name of an animal) appeared on the screen.

Prior to the presentation of each list, a practice list of 20 similar stimuli was run. None of the practice stimuli (except flashes) were included in the actual experiment. Breaks were given after the presentation of 50 stimuli (three times per each list) and between picture lists and word lists.

EEG/ERP Recording

An EEG was recorded from 13 active electrodes in an electrode cap (Electro-Cap International). Seven standard 10-20 system sites were used: left and right occipital (O1, 02); left and right frontal (F7, F8); and midline (Fz, Cz, Pz). In addition, six nonstandard sites typical of ERP language studies were used (because they overlie brain regions known to be involved in language-processing): Wernicke's area and its right hemisphere homologue (WL, WR; 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz); left and

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[1]One disadvantage of the ERP method is a problem with artifact; that is, extraneous electrical response generated by a variety of sources, primarily muscle movement. Participants must be instructed to sit as still as possible and not blink while stimuli are presented, because any muscle movement, including eye blinks, involves an outburst of electrical activity that effectively "drowns out" the desired neurophysiological recording. Research design allows for controlled eye blinks by interspersing a symbol such as a hatch mark (#, used in the present study) indicating an appropriate time to blink. ERPs are time-locked to the presentation of a stimulus; therefore, this has no effect on the ERP waveform because the portions of the EEG that reflect these controlled eye blinks are simply never used in further analyses.

right temporal regions (TL, TR; 33% of the interaural distance lateral to Cz); and left and right anterior temporal regions (ATL, ATR; 50% of the distance between standard T3[4] and F7[8]). The EEG was amplified by a Grass Model 12 Neurodata Acquisition system (-3dB cutoffs of 0.01 and 100 Hz) and was continuously digitized online at 200 Hz by an IBM PC compatible microcomputer; raw EEG was stored on the hard drive of this computer.

To monitor eye blinks, the electrooculogram (EOG) was recorded from an electrode placed below the left eye, and an electrode placed at the outer canthus of the right eye recorded horizontal eye movements. All electrodes were referenced to the left mastoid; recordings were also taken at the right mastoid to test the assumption of neutral electrical activity between the mastoids. All scalp and reference electrode impedances were maintained below 5 KOhm; eye electrodes were maintained below 10 KOhm.

Because children's ERPS were likely to be contaminated by blinks and movement, a minimum criterion for subject inclusion often viable trails for each category of word stimulus and picture stimulus was established; 6 participants did not meet this criterion and were not included in further analyses. No participant was excluded on the basis of an inability to perform the task; rather, the ERPs of the excluded subjects were contaminated by excessive blinking or movement. Table 1 provides a summary of the number of trials included in each individual participant's average for each stimulus category for the 14 subjects included in the analyses.

Data Analysis

Offline, EEG epochs were averaged for each subject at each electrode site to form separate ERPS for each word-list and picture-list condition. Only epochs free of artifact were included in data analyses. The EOG channels of each participant's raw data were searched (via a software routine) on a trial-by-trial basis for high amplitude activity (>60 uV), and trials contaminated by such activity were automatically rejected by the averaging program. Based on inspection of the eye channels after averaging and the relative amplitude of ERPS for that participant, participant inclusion was determined on an individual basis.

The ERPs for individual subjects were subsequently averaged to form grand average ERPs for four word-list conditions (real words, pseudowords, letter strings, and false fonts) and three picture-list conditions (real pictures, pseudopictures, and picture parts). Each participant's ERPs were quantified by calculating mean amplitudes (using a 100-msec pre-stimulus baseline) within three latency windows: 200-400 msec, 300-500 msec, and 400-650 msec. The 300-500-msec epoch was used as a direct measure of the (ant)N400, whereas epochs of 200-400 and 400-650 msec were used to capture the early and late aspects of the (ant)N400, respectively. Note that when mean amplitudes are reported across a

TABLE 1
Summary of Individual Trials per Average by Stimulus Category for Each Subject

			Word-Stimulus Categories					Picture-Stimulus Categories				
Subject	Age	Sex	Animal Names$	Real Words	Pseudo Words	Letter Strings	False Fonts	Animal Pictures$	Real Pictures	Pseudo- Pictures	Picture Parts	Flashes$
Ol	11;5	F	27	30	27	31	30	22	28	25	30	33
02	11;5	F	19	24	23	24	20	24	29	26	28	32
03	11;7	F	33	34	36	36	32	17	26	23	34	29
04	11;8	F	33	35	36	34	32	31	32	32	32	28
05	11;1	F	20	15	19	21	14	18	29	28	24	26
06	11;3	F	30	19	25	28	29	10	18	11	15	15
07	11;9	F	28	29	28	26	24	32	33	34	39	33
08	11;1	M	16	24	25	22	20	17	17	18	23	16
09	11;7	M	27	28	35	35	35	17	26	19	21	27
10	10;9	M	24	21	19	18	17	22	23	21	21	27
11,	11;4	M	33	37	33	37	36	29	33	35	37	38
12	11;4	M	22	28	25	25	25	20	23	21	18	19
13	11;8	M	16	15	15	17	21	10	15	12	18	16
14	11;11	M	23	26	27	24	21	26	26	27	22	24
		Minimum	16	15	15	17	14	10	15	11	15	15
		Maximum	33	37	36	37	36	32	33	35	39	38
		M	25.07	26.07	26.64	27.00	25.43	21.07	25.57	23.71	25.86	25.93

Maximum number of trials per average for each stimulus category is 40.
Stimulus category not used in further data analysis.

latency range, "positive" and "negative" are relative terms; the classic N400 and the anterior N400 (antN400) overall are both negative-going deflections in the ERP waveform. All ERP waveforms are plotted "negative-up."

Omnibus analyses of variance (ANOVAs-BM DP2V) were used to analyze the amplitude data. Repeated measures variables included four levels of word-list stimuli (words vs. pseudowords vs. letter strings vs. false fonts) or three levels of picture-list stimuli (pictures vs. pseudopictures vs. picture parts) and either three levels of electrode site (midline: Fz vs. Cz vs. Pz) or five levels of electrode site (lateral: frontal vs. anterior temporal vs. temporal vs. Wernicke's vs. occipital) and two levels of hemisphere (left vs. right, for lateral sites only). An alpha level of .05 was used for all initial ANOVAs, and the Greenhouse-Geisser correction was applied to repeated measures variables with more than two levels. In cases in which an ANOVA indicated that a main effect or interaction involving the word stimuli or picture stimuli was significant, planned comparisons between word-list conditions (words vs. pseudowords, pseudowords vs. letter strings, letter strings vs. false fonts) or picture-list conditions (pictures vs. pseudopictures, pseudopictures vs. picture parts) were performed. For significant interactions involving electrode site, follow-up t tests were conducted at each electrode site, collapsed across the hemisphere. For all comparisons, alpha values were corrected for the number of comparisons conducted (Bonferroni correction for multiple comparisons) in order to reduce the risk of Type 1 error. For the three word-list comparisons, corrected alpha levels were .017 for the main effect of word type, .0033 for word type by lateral site interaction effects, and .0055 for word type by midline site interaction effects. For the two picture-list comparisons, corrected alpha levels were .025 for the main effect of picture type, .005 for picture type by lateral site-interaction effects, and .008 for picture site by midline site-interaction effects.

RESULTS

Word-List Stimuli

Visual inspection.   The grand average ERP waveforms (see Fig. 2) indicate that all word-list stimuli elicited an early, anteriorly distributed, negative-going component peaking at approximately 125 msec (N1), followed by a positive-going component peaking at approximately 240 msec (P2), also most apparent at anterior sites. The P2 to false fonts at frontal, anterior temporal, central, and temporal sites appeared smaller in amplitude than the P2 to other word stimuli. At occipital sites, a positivity peaking at approximately 125 msec (Occipital P 1) was apparent, followed by a negative-going component peaking at approximately 200 msec (Occipital N1).
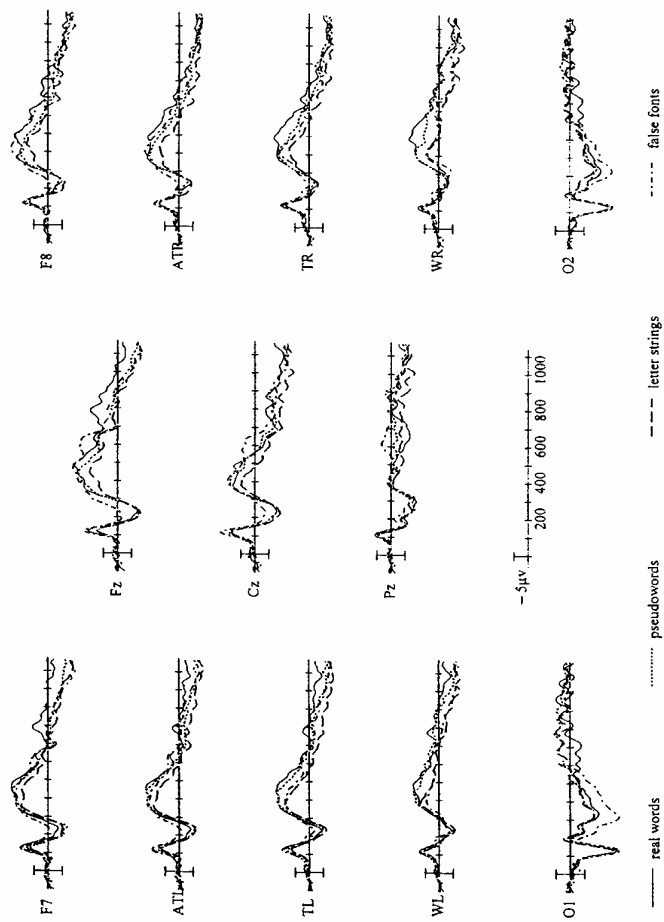
F7 ATL TL WL O1

Fz Cz Pz

F8 ATR TR WR O2

$-5\mu v$ 200 400 600 800 1000

—— real words

········ pseudowords

— — letter strings

- - - - false fonts

FIGURE 2 Children's grand average ERP waveforms to words (solid line), pseudowords (short dashes), letter strings (long dashes), and false fonts (alternating short and long dashes). Stimulus onset is the vertical calibration bar, and negative is plotted up. Left hemisphere sites are on the left side of the figure, right hemisphere sites are on the right side, and midline sites are down the middle; more anterior sites are toward the top, and more posterior sites are toward the bottom.

Following the typical N1-P2 complex, a negative-going, anteriorly maximal but widely distributed component peaking between 300 and 500 msec was evident; this will be referred to as the antN400 in order to distinguish it from the more posteriorly distributed classic N400 (e.g., see Kutas & Van Petten, 1988, 1994). The amplitude of the antN400 appeared to be similar for words, pseudowords, and false fonts, with a slightly smaller amplitude to letter strings, especially at frontal sites; however, this pattern was evident at anterior temporal, temporal, and Wernicke's sites. The antN400 seemed to be comprised of two peaks, which appeared to vary across the scalp: the early peak occurred at about 360 msec at frontal and anterior temporal sites, and at about 400 msec at the Wernicke's and temporal sites. The later peak occurred at about 460 msec over the left hemisphere and 490 msec over the right hemisphere. This dual-peak response was most evident for words and less clear for pseudowords; for letter strings, it was apparent only at frontal and anterior temporal sites. At the temporal and Wernicke's sites, letter strings elicited only a single negative peak at about 400 msec, a pattern seen for false fonts across the scalp anterior to the occipital sites. There was evidence of a dual-peak antN400 in only a few individual subjects' waveforms, suggesting that the appearance of dual peaks in the grand average waveforms might be an artifact of latency jitter across subjects. In addition to the antN400, particularly at midline sites, false fonts elicited an N600.

At posterior sites (01, 02), a positive-going component peaking at approximately 330 msec (P330) was evident, especially to false fonts, but also marked for real words, pseudowords, and letter strings.

Analyses of ERP epochs.   Table 2 contains a summary of the ANOVAs performed on the word-stimuli data from lateral and midline sites for all three epochs. Table 3 summarizes the results of the planned comparisons for the Wordstimuli data at lateral and midline sites for all three epochs; results of contrasts at each electrode site are reported in the text. A more explicit description of the significant results by epoch follows.

200-400 msec.   The main effect of word type at midline sites, $F(3, 36)$ _ 3.59, $p <$ .0339, reflects the result that ERPS to letter strings were least negative, followed by pseudowords, words, and then false fonts; however, this effect varied across the midline scalp: Word Type x Electrode Site, $F(6, 72) = 3.51, p < .0230$. In addition, processing of the types of word stimuli differed across the lateral scalp: Word Type x Electrode Site, $F(12, 144) = 7.66, p < .0005$. Planned comparisons indicated that false fonts were more negative than letter strings at midline sites, $F(1, 12) = 11.61, p < .0052$, but this effect varied across the midline: word type x electrode site, $F(2, 24) = 10.66, p < .001$ 7, and lateral scalp: Word Type x Electrode Site, $F(4, 48) = 15.79, p < .0006$. Follow-up contrasts by electrode site indicated that false fonts were more negative than letter strings at the frontal, $t(13) = 3.778, p < .002$, anterior temporal, $t(13) = 3.564, p < .003$, and Fz sites, $t(l3) = 5.633,$

TABLE 2

Summary of ANOVAs for Word Stimuli at Lateral   and Midline Sites[1]

| | *Epochs* | | | | | |
| | *200-400 ms* | | *300-500 ms* | | *400-650 ms* | |
Source	*df*	*F*	*df*	*F*	*df*	*F*
Lateral sites						
Word type	3	0.82	3	3.51 *	3	4.31
Electrode site	4	12.72**	4	26.02**	4	16.47**
Hemisphere	1	0.18	1	1.30	1	0.54
Word Type x Electrode Site	12	7.66**	12	5.95**	12	3.35*
Word Type x Hemisphere	3	0.54	3	1.24	3	1.93
Word Type x Electrode Site x Hemisphere	12	1.75	12	1.22	12	1.06
Midline sites						
Word type	3	3.59*	3	2.19	3	3.30*
Electrode site	2	14.70**	2	26.58**	2	25.05**
Word Type x Electrode Site	6	3.51 *	6	2.30	6	1.36

*p<.05. **p<.01.

p < .0001, but less negative than letter strings at occipital sites, t(13) =-3.612, p < .003. Thus, false fonts were more positive than letter strings at occipital sites and more negative than letter strings at anterior sites (see Fig. 3a).

300-500 msec.   Although there were no significant word-type effects at midline sites, the main effect of word type at lateral sites, F(3, 39) = 3.51, p < .0296, reflects the result that ERPs to letter strings were least negative, followed by false fonts, pseudowords, and then words; however, this effect varied across the lateral scalp: Word Type x Electrode Site, F(12, 156) = 5.95, p < .0019. Planned comparisons indicated that pseudowords were more negative than letter strings overall, F(l, 13) = 7.44, p <.0173, a borderline effect not significant during the 200-400 msec epoch, which suggests a relatively late differentiation between these stimulus categories (see Fig. 3b). Follow-up contrasts at each electrode site indicated no differences in pseudoword and letter string processing. Planned comparisons also indicated that letter strings differed from false fonts across the lateral scalp: Word Type x Electrode Site, F(4, 52) = 14.20, p <.0003, but follow-up contrasts at each electrode. site across hemispheres indicated no differences between false fonts and letter strings.

400-650 msec.   The main effect of word type at midline sites, F(3, 36) = 3.30, p < .0450, reflects the result that ERPs to letter strings were least negative, followed by words, pseudowords, and then false fonts, whereas the main effect of

TABLE 3

Summary of Planned Contrast Results for Word Stimuli at Lateral and Midline Sites

| | Epochs | | | | | |
| | 200-400 ms | | 300-500 ms | | 400-650 ms | |
Planned Contrast	*df*	*F*	*df*	*F*	*d/*	*F*
Lateral sites						
Words *vs.* pseudowords						
Word type	1	0.26	1	0.31	1	1.66
Word Type x Electrode Site	4	0.98	4	1.89	4	3.26
Word Type x Hemisphere	1	0.42	1	0.48	1	4.70
Word Type *x* Electrode Site x Hemisphere	4	0.33	4	0.10	4	0.30
Pseudowords *vs.* letter strings						
Word type	1	1.56	1	7.44*	1	8.23*
Word Type x Electrode Site	4	2.54	4	2.66	4	1.99
Word Type x Hemisphere	1	2.36	1	0.18	1	0.41
Word Type x Electrode Site x Hemisphere	4	2.73	4	1.46	4	0.48
Letter strings *vs.* false fonts						
Word type	1	1.95	1	0.11	1	1.73
Word Type *x* Electrode Site	4	15.79*	4	14.20*	4	7.22*
Word Type x Hemisphere	1	2.03	1	2.87	1	0.71
Word Type x Electrode Site x Hemisphere	4	2.01	4	2.06	4	1.40
Midline sites						
Words vs. pseudowords						
Word type	I	0.19			1	0.01
Word Type x Electrode Site	2	0.76			2	3.00
Pseudowords *vs.* letter strings						
Word type	1	1.10			1	2.88
Word Type *x* Electrode Site	2	0.76			2	0.58
Letter strings vs. false fonts						
Word type	1	11.61 *			1	7.11
Word Type x Electrode Site	2	10.66*			2	2.23

*Significant at the corrected a level.

word type at lateral sites, $F(3, 36) = 4.31$, $p < .0213$, was such that letter strings were least negative, followed by false fonts, pseudowords, and then words; however, this latter effect varied across the lateral scalp: Word Type x Electrode Site, $F(12, 144) = 3.35$, $p < .0449$. Planned contrasts indicated that pseudowords were more negative than letter strings overall at lateral sites, $F(l, 12) = 8.23$, $p < .0141$, as was tentatively the case from 300-500 msec (see Figure 3c). Follow-up contrasts at each electrode site across hemispheres indicated that pseudowords were more negative than letter strings at temporal sites, $t(13) = <3.830$, $p < .0020$. Planned comparisons also indicated that letter strings and false fonts differed across the
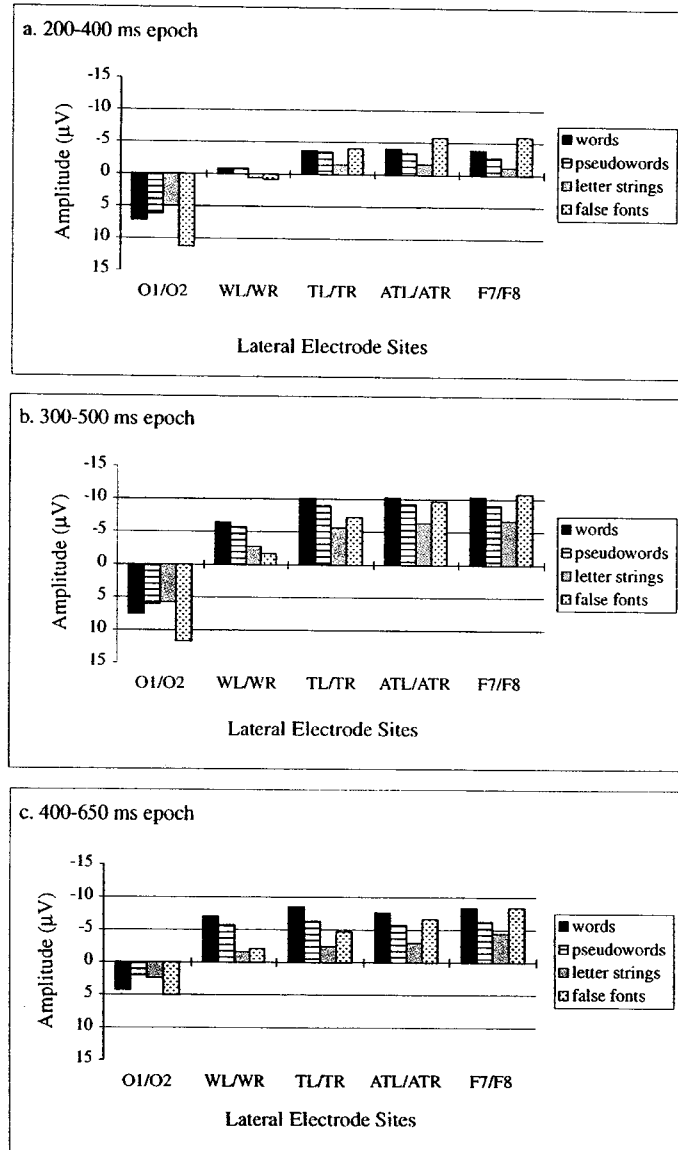
FIGURE 3 An illustration of word-processing results at lateral electrode sites, collapsed across hemisphere. More posterior sites are toward the left, and more anterior sites are toward the right; negative is plotted up. (a) During the 200–400-msec epoch, false fonts were more positive than letter strings at occipital sites and more negative than letter strings at anterior sites. (b) During the 300–500-msec epoch, pseudowords were tentatively more negative than letter strings overall. (c) During the 400–650-msec epoch, pseudowords were clearly more negative than letter strings overall.

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lateral scalp: Word Type x Electrode Site, $F(4, 48) = 7.22$, $p < .0068$, although follow-up contrasts at each electrode site across hemispheres were not significant.

Summary of word-list results.   The ERP waveforms elicited by word stimuli in children (see Fig. 2) were characterized by an N400 maximal at anterior locations but widely distributed (antN400), which was elicited by all types of word stimuli. Across all three epochs, words were statistically indistinguishable from pseudowords. Pseudowords were tentatively more negative overall than letter strings during the middle epoch and clearly more negative during the late epoch. Letter strings differed from false fonts during the first epoch such that false fonts were more positive than letter strings at occipital sites and more negative than letter strings at anterior sites (see Fig. 3).

Picture-List Stimuli

Visual inspection.   The grand average ERP waveforms (see Fig. 4) indicate that all picture-list stimuli elicited a complex of early components similar to wordlist stimuli (NI-P2 at anterior sites; Occipital PI-Occipital N1 at occipital sites). At the most anterior sites (F7, F8, Fz, ATL, and ATR), the N1-P2 complex was followed by two overlapping negativities, the first peaking at approximately 350 msec (N350) and the second at about 440 msec over the left hemisphere and midline but at about 420 msec over the right hemisphere (N430). In individual participants' waveforms, dual negativities within the 300-500 msec epoch were clearly evident at anterior sites for 12 of the 14 total participants, and were suggested but less clear in 2 of the 14 participants, indicating that these picture stimuli do elicit an anterior dual-peak response in children. At the Cz, Pz, temporal, and Wernicke's sites, a negative-going wave peaking at approximately 425 msec (N425) was evident to all picture stimuli. At many electrode sites, a negative-going wave peaking at about 540 msec (N540) was evident exclusively to pseudopictures. At occipital sites and Pz, a positivity peaking at about 310 msec (P310) was evident to all picture stimuli.

Analyses of ERP epochs.   Table 4 contains a summary of the ANOVAs performed on the picture-stimuli data from lateral and midline sites for all three epochs. Table 5 summarizes the results of the planned comparisons for the picture-stimuli data at lateral and midline sites for all three epochs; results of contrasts at each electrode site are reported in the text. A more explicit description of the significant results by epoch follows.

200-400 msec.   Although there were no significant picture-type effects at midline sites, the effect of picture type varied across the lateral scalp: Picture
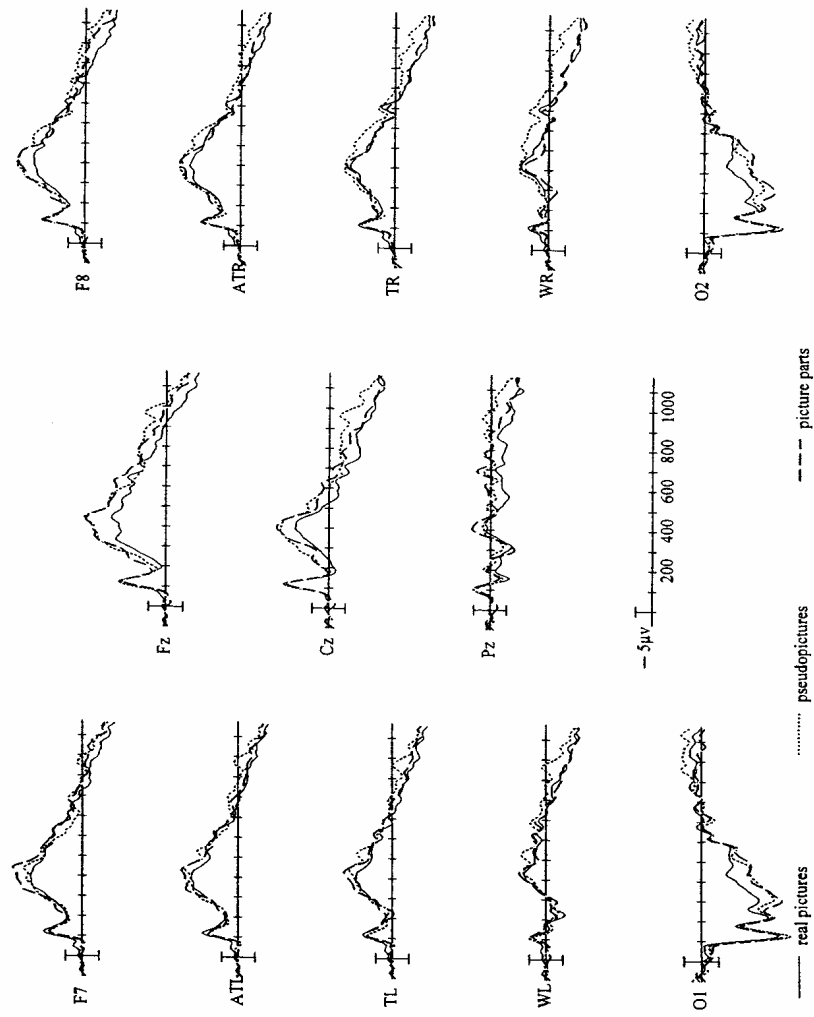
FIGURE 4 Children's grand average ERP waveforms to pictures (solid line), pseudopictures (short dashes), and picture parts (long dashes). All else as in Figure 2.

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TABLE 4

Summary of ANOVAs for Picture Stimuli at Lateral   and Midline Sites

| | | Epochs | | | | |
| | | 200-400 ms | | 300-500 ms | | 400-650 ms | |
Source		*4j*	*F*	*41*	*F*	*4f*	*F*
Lateral sites							
Picture type		2	0.11	2	0.16	2	0.70
Electrode site		4	54.38**	4	60.50**	4	45.46**
Hemisphere		1	9.72**	1	3.00	1	3.31
Picture Type x Electrode Site		8	5.18*	8	6.60**	8	2.48
Picture Type x Hemisphere		2	2.56	2	4.84*	2	5.75**
Picture Type x Electrode Site	Hemisphere	8	1.40	8	3.03	8	0.89
Midline sites							
Picture type		2	2.49	2	2.62	2	2.86
Electrode site		2	37.45**	2	66.04**	2	75.84**
Picture Type x Electrode Site		4	2.81	4	5.20**	4	0.47

*p<.05. **p<.01.

Type x Electrode Site, $F(8,96) = 5.18$, $p < .0137$. Planned comparisons indicated a tentative difference between pictures and pseudopictures across the lateral scalp: Picture Type x Electrode Site, $F(4,48) = 4.88$, $p < .0275$, but follow-up comparisons at each electrode site across hemispheres revealed no differences. In addition, the main effect of hemisphere was significant, $F(1, 12) = 9.72$, $p < .0089$, with the right hemisphere more negative than the left hemisphere. Planned comparisons indicated that pseudopictures and picture parts differed between hemispheres: Picture Type x Hemisphere, $F(1, 12) = 17.08$, $p < .0014$, such that pseudopictures were slightly less negative then picture parts over the left hemisphere, but more negative than picture parts over the right hemisphere (see Fig. 5a).

300-500 msec.   The effect of picture type varied across the midline: Picture Type x Electrode Site, $F(4, 52) = 5.20$, $p < .0057$, and lateral: Picture Type x Electrode Site, $F(8, 104) = 6.60$, $p < .0055$, scalp, as well as between hemispheres: Picture Type x Hemisphere, $F(2, 26) = 4.84$, $p < .0279$. Planned comparisons indicated that pseudopictures differed from picture parts between hemispheres: Picture Type x Hemisphere, $F(1, 13) = 22.66$, $p < .0004$, evidencing the same pattern seen during the 200-400-msec epoch (see Fig. 5b). Planned comparisons also indicated that pictures differed from pseudopictures across the lateral: Picture Type x Electrode Site, $F(4, 52) = 9.88$, $p < .0015$, and midline scalp: Picture Type x Electrode Site, $F(2, 26) = 9.71$, $p < .0020$. Follow-up contrasts at each electrode site indicated that pictures were more negative than pseudopictures

TABLE 5
Summary of Planned Contrast Results for Picture Stimuli at Lateral and Midline Sites

Planned Contrast	200-400 ms df F		300-500 ms df F		400-650 ms df F	
Lateral sites						
Pictures vs. pseudopictures						
Picture type	1	0.22	1	0.27	I	0.85
Picture Type x Electrode Site	4	4.88*	4	9.88*	4	2.97
Picture Type x Hemisphere	1	2.46	1	2.53	1	3.97
Picture Type x Electrode Site x Hemisphere	4	0.49	4	0.58	4	0.73
Pseudopictures vs. picture parts						
Picture type	I	0.10	1	0.14	1	1.43
Picture Type x Electrode Site	4	1.02	4	0.65	4	0.74
Picture Type x Hemisphere	1	17.08*	1	22.66*	1	13.32*
Picture Type x Electrode Site x Hemisphere	4	1.80	4	1.53	4	1.59
Midline sites						
Pictures vs. pseudopictures						
Picture type			1	2.75		
Picture Type x Electrode Site			2	9.71*		
Pseudopictures vs. picture parts						
Picture type			1	0.01		
Picture Type x Electrode Site			2	0.44		

*Significant at the corrected α level.

at occipital sites, $t(13) = -4.562$, $p < .001$, and less negative than pseudopictures at Fz, $t(13) = 3.111$, $p < .008$.

400-650 msec.   Although there were no significant picture-type effects at midline sites, the picture type by hemisphere interaction was significant, $F(2, 24) = 5.75$, $p < .0105$. Planned contrasts indicated that pseudopictures and picture parts differed between hemispheres: Picture Type x Hemisphere, $F(1, 12) = 13.32$, $p < .0033$, following the trend evident in the two earlier epochs, primarily due to pseudopictures being more negative over the right hemisphere (see Fig. 5c).

Summary of picture-list results.   The ERP waveforms elicited by picture stimuli (see Fig. 4) were characterized by two overlapping negative-- going peaks at anterior sites: N350 and N430. Pictures were distinguished from pseudopictures only at Fz and occipital sites in analyses by electrode site during the 300-500-msec time window. Pseudopictures were distinguished
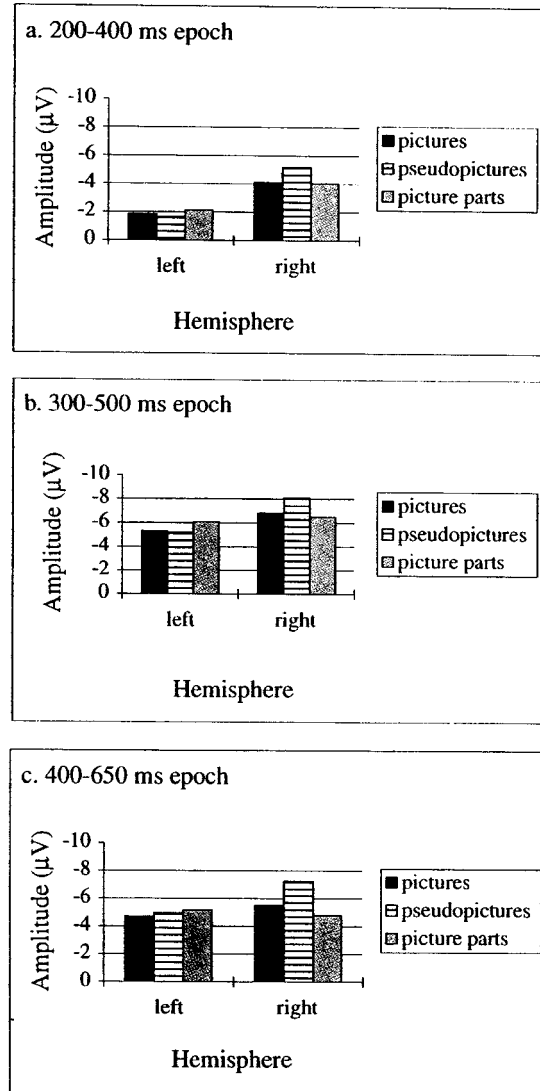
FIGURE 5 An illustration of picture-processing results between hemispheres; negative is plotted up. (a) During the 200–400-msec epoch, the right hemisphere was more negative than the left hemisphere overall, and pseudopictures were less negative than picture parts over the left hemisphere, but more negative than picture parts over the right hemisphere. (b) During the 300–500-msec epoch, pseudopictures were again less negative than picture parts over the left hemisphere, but more negative than picture parts over the right hemisphere. (c) During the 400–650-msec epoch, pseudopictures remained slightly less negative than picture parts over the left hemisphere, but were markedly more negative than picture parts over the right hemisphere.

from picture parts by hemisphere during all three epochs due to pseudopictures being more negative over the right hemisphere and less negative over the left hemisphere (see Fig. 5).

DISCUSSION

Previously, negative-going ERP components with approximate latencies of 400 msec have been elicited in adults in response to both words (e.g., Bentin et al., 1985; Kutas et al., 1984; Nobre & McCarthy, 1994) and pictures (e.g., Holcomb & McPherson, 1994). In the present study, pictures and words presented in separate lists to 10- and 11-year-old children also elicited negativities peaking near 400 msec; these negativities were maximal at anterior sites. Prior studies have shown that stimuli presented in list form tend to elicit such anteriorly distributed negativities (e.g., Nobre & McCarthy, 1994), whereas the more posteriorly distributed classic N400 and N400 effects are most clear in priming (e.g., Holcomb, 1988) and repetition (e.g., Rugg, 1985) paradigms. These anterior negativities may or may not be direct manifestations of the classic N400 (e.g., Kutas & Hillyard, 1980) hypothesized to be an index of a higher order process of integration within the language comprehension system (e.g., Brown & Hagoort, 1993; Holcomb, 1988,1993; Osterhout & Holcomb, 1995; Rugg, 1990) and involved in picture comprehension (e.g., Barrett & Rugg, 1990; Nigam et al., 1992). However, considering the similarities in morphology, latency, and conditions of elicitation, it is likely that the anterior negativities share some subset of the neural generators of the classic N400 and therefore most likely belong in an extended "N400 family" of components.

Word Processing

The most obvious feature of the ERPs to all types of word stimuli is an anteriorly maximal negativity with latency about 400 msec that extends back across temporoparietal sites. Here we refer to this as the antN400 in order to distinguish it from the classic N400 and N400 effect, which have a more posterior distribution. Previous authors have reported anterior negativities to words and pseudowords, but not to letter strings, presented in list form to adults (e.g., Bentin et. al, 1985; Nobre & McCarthy, 1994). Bentin and Colleagues (1985) presented words and pseudowords in a semantic priming paradigm requiring lexical decisions, whereas Nobre and McCarthy (1994) used a category detection task with word and pseudoword stimuli similar to those used in the present study, However, some of their words and pseudowords were more than one syllable, their letter strings were "mainly

consonants," rather than permutations of real words, and they employed an additional category of function words rather than the false fonts used here. Despite these methodological differences, as would be expected based on the consistent results across paradigms used with adults, words and pseudowords did elicit antN400s in the present study. However, contrary to expectations based on the pattern of findings with adults, letter strings and false fonts also elicited substantial antN400s.

Words and pseudowords elicited similar substantial antN400s; in fact, words were statistically indistinguishable from pseudowords during all three epochs at both lateral and midline sites. The lack of differences between ERPs elicited by pseudowords and words suggests that children may have processed pseudowords as not-yet-learned real words. Behavioral data from lexical decision tasks with young children evidence a similar "humility bias" for pseudowords: Children tend to treat pseudowords as possible words that are simply outside their vocabulary (Henderson & Chard, 1980). Just such a developmental course could be expected, considering the wider exposure to real words that accompanies increasing age: Having been exposed to more words, one might become better able to differentiate actual from possible words (although pseudowords elicit N400s in college students as well; Nobre & McCarthy, 1994). The pseudoword effect in the present study could also be influenced by the context of the actual words and animal names included in the list; within the context of real words, children may have attempted to process pseudowords as such.

Unexpectedly, ERPs to letter strings were not significantly different than ERPs to pseudowords during the early (200-400 msec) epoch. This finding is inconsistent with the previous finding that ERPs to pseudowords and letter strings presented in list form differ by 288 msec after stimulus presentation in adults (Nobre & McCarthy, 1994) and may be related to the composition of the letter string stimuli, which were primarily consonants in Nobre and McCarthy (1994) but included vowels here. Also inconsistent with previous findings with adults, letter strings elicited marked antN400s in children in the present study. That electrophysiological differentiation of the two types of stimuli occurs later and that letter strings elicit antN400s in children would seem to suggest that children are less efficient at distinguishing, in terms of ERPs, legal from illegal strings of letters. However, pseudowords were more negative overall than letter strings at lateral sites tentatively during the middle epoch and clearly during the late epoch, indicating that children's ERPs do eventually differentiate between these stimulus types. Although letter strings do not elicit anterior negativities in adults, these results parallel the general adult pattern that illegal strings bilaterally elicit more positivity than legal strings (Nobre & McCarthy, 1994).

One explanation for this unexpected pattern of results with letter strings-both the elicitation of antN400s and the lack of early differentiation from pseudowords might involve children's increased sensitivity to context in comparison to adults (e.g., Stanovich, 1980). Based on an overdependence on a context including real words, letter strings may partially activate real items (e.g., real words beginning with the same

letter) before being recognized as noncontenders for the word-processing system. Behavioral studies indicate that, with increasing age, the "concept of word-likeness becomes more refined" (Henderson & Chard, 1980, p. 101) and less influenced by immediate context (Stanovich, 1980). The present electrophysiological findings regarding both pseudowords and letter strings are consistent with such findings.

Also unexpectedly, false fonts elicited substantial antN400s in the present study. In fact, ERPs to false fonts were actually more negative than ERPs to letter strings at anterior sites during the first epoch; that is, the early aspect of the antN400 was larger to false fonts than to letter strings. This might suggest that the influence of the word-list context on children was so strong that children initially attempted to comprehend these strings of letter-like symbols as legitimate letters composing possible real words. According to this interpretation, the larger, early antN400 to false fonts as compared to letter strings might reflect the greater effort necessary to attempt to fit these illegal linguistic stimuli into an ongoing context-biased, real-word-based mental model for comprehension, a model theoretically established both by the instructions to children that they would see different kinds of words appear on the screen, and by the presence of real words, animal names, and pseudowords in the list. That letter strings and false fonts were not differentiated, specifically at anterior sites, during the middle and late epochs implies that children did eventually process the illegal word-stimuli similarly, and differently from the legal word-stimuli, regardless of orthography. However, all types of word stimuli did elicit antN400s, suggesting that children were attempting to integrate all stimuli into the ongoing context.

An alternate possible explanation for the unexpected antN400s to letter strings and false fonts in children in the present study is that this developmental difference is due not to the antN400 itself, but to the influence of another component, such as Nc (Courchesne, 1990). Because false fonts and letter strings might be considered the sort of novel or surprising events known to elicit this frontally distributed negativity, it is possible that Nc could have contributed to the anterior negativities elicited by these stimuli. However, it seems unlikely that letter strings and false fonts, which were presented with the same probability as other word stimuli, would remain surprising or particularly interesting throughout the presentation of all 200 stimuli in the word list; Nc may have overlapped antN400 on a few early letter string and false font trials, but probably not overall. Although there has been little systematic investigation of possible variables affecting Nc amplitude, making interpretations of functional significance across paradigms difficult, an explanation of the antN400s to letter strings and false fonts as due to the influence of an overlapping Nc appears to be inadequate. Conversely, interpretation of the results of the present study in terms of increased context dependency in children is consistent not only across the word-processing data, but also across the picture-processing data.

Picture Processing

All picture stimuli elicited an anterior dual-peak negative response consisting of an early N350 and a late N420 over the right hemisphere or N440 over the left hemisphere and midline (N430). This anterior dual-peak response appears to be similar to the frontally distributed N300 and the more widely distributed but Fz maximal N450 elicited by pictures in priming paradigms with adults (Barrett & Rugg, 1990; Holcomb & McPherson, 1994). Barrett and Rugg (1990) presented pictures similar to those used here in pairs in a relatedness judgment task requiring overt semantic comparison, whereas Holcomb and McPherson (1994) used the same pictures and pseudopictures used here in an object decision task in which stimuli were presented in pairs. The latter investigators reported that the left hemisphere was more negative than the right in their adult participants (Holcomb & McPherson, 1994), but the opposite asymmetry was observed in the present study: The right hemisphere was more negative than the left-but only during the early (200-400 msec) epoch. These results might suggest differently lateralized picture-processing systems in children and adults, and perhaps a developmental trend from a more bilateral to a more lateralized picture-processing system accompanied by increasing specialization in visual image processing.

One way that the meaningfulness of a given picture might be determined is through the integration of various salient aspects of the picture, existing picture knowledge, and the present picture context. Accordingly, it might be hypothesized that the greater the ease with which all of the available elements fit together, the less the effort required to make meaning out of the picture. The anterior negativities could perhaps index this imagistic integration process, such that the less the effort required for integration, the smaller the anterior negativities elicited. This speculation is constructed in parallel to the interpretation of the N400 as an index of a highlevel, postlexical linguistic integration process (e.g., Holcomb, 1988; Rugg et al., 1988). If picture stimuli do undergo neurocognitive processing analogous to that for words, it would be expected that pictures (analogues of words) and pseudopictures (analogues of pseudowords) would elicit marked anterior negativities, as full or partial integration of pictorial elements is possible with these stimuli, whereas random arrangements of picture parts (analogues of random strings of letters) would not, as integration of pictorial elements is not possible for these stimuli.

Indeed, in the present study, pictures and pseudopictures both elicited marked anterior negativities. While Holcomb and McPherson (1994) reported that their picture equivalent to pseudowords ("nonobjects") elicited larger negativities than real objects in a picture-priming paradigm (see also McPherson & Holcomb, 1999), the same pseudopictures and real pictures in the present study elicited very similar ERPS. In analyses by electrode site, pseudopictures were distinguished from pictures only in being more negative at Fz and more positive at occipital sites during the 300-500 msec

epoch. This pattern of results might suggest that individual parts of the integrated pseudopictures may be able to partially access some aspects of some meaningful real picture representations (or reactivate parts of pseudopicture representations created in the short-term context of the picture list). Overall, the similarity of the processing of pictures and pseudopictures mirrors the similarity in the processing of words and pseudowords.

In contrast to the picture and pseudopicture findings, the expectation that random arrangements of picture parts (analogous to random letter strings) would not elicit anterior negativities was not confirmed by the data: Picture parts elicited large anterior negativities; in fact, there were no differences between pseudopictures and picture parts specifically at anterior sites. However, picture parts and pseudopictures did elicit differential asymmetric processing across all three epochs, with picture parts eliciting slightly more negativity over the left hemisphere, but markedly less negativity over the right hemisphere. This hemispheric asymmetry might reflect an attempt to perhaps serially construct a meaningful image out of the picture parts (left hemisphere) versus an attempt to holistically process the more integrated pseudopictures (right hemisphere). In any case, this pattern of results implies that differently localized neurocognitive systems-or perhaps the same system to a different extent between hemispheres-are engaged in processing these stimuli. This is consistent with the previous suggestion of a bilateral picture-processing system in children.

The N400 Component: Word Processing and Picture Processing

It is difficult to statistically compare word processing and picture processing, given the physical differences between stimulus types and the differing morphologies of the ERP waveforms elicited by the stimulus types. In the present study, the most obvious difference in ERP morphology between conditions was that only picture stimuli elicited an N350, whereas the most striking similarity between conditions was that both word stimuli and picture stimuli elicited an anterior negativity with latency near 400 msec. This pattern suggests that the earlier anterior component in picture processing may be specific to image processing (McPherson & Holcomb, 1999), whereas the N400 is specific neither to words nor to pictures. Previous authors have claimed that the negativity peaking at about 400 msec in picture-processing para-digms is equivalent to the word-N400 (Barrett & Rugg, 1990; McPherson & Holcomb, 1999), although others have been more cautious in claiming homology (e.g., "Neg400," Friedman et al., 1988, 1992). Hypothesizing the conceptual equivalence of the word-N400 and the second anterior picture-processing peak, the present results are consistent with an interpretation of the N400 as an index of amodal semantic processing (McPherson & Holcomb, 1999; Pratarelli, 1994).

Like the antN400 elicited by all types of word stimuli, the N430 elicited by all types of picture stimuli can be interpreted in terms of children's strong reliance on context. Although

picture stimuli were presented in list form and were outwardly semantically unrelated, children may have attempted to integrate the current picture stimulus with previously presented picture stimuli. If the N400 reflects an amodal semantic integration process and the amplitude of the N400 reflects the ease of this process (e.g., Holcomb, 1988), the large N430s to all picture stimuli could be interpreted as reflecting the difficulty children had in attempting to make sense of a given picture stimulus in the context of all previously observed picture stimuli, and the large antN400s to all word stimuli could be interpreted as reflecting the difficulty children had in attempting to make sense of a given word stimulus in the context of all previously observed word stimuli. Because nothing within each stimulus list fit together meaningfully (by design), large N400s were observed for all types of stimuli.

Thus, the similarities across word processing and picture processing suggest a general trend in children's conceptual processing. It has been shown in numerous behavioral studies that children are more sensitive to and dependent on contextual factors and that contextual facilitation decreases with increasing fluency in reading (e.g., see Stanovich, 1980, for a review). In the present study, children's sensitivity to and over reliance on the meaningful aspects of the context (real pictures and real words) may have biased interpretation of all stimuli toward meaningfulness, thus all stimuli-regardless of actual semantic content-underwent some degree of integrative semantic processing, and all stimuli to some degree elicited N400s. The present findings suggest that children may depend more heavily on context as a broad and general comprehension strategy, even when the context provides no useful or usable information, as in this study.

Summary and Conclusion   As expected, real pictures, pseudopictures, real words, and pseudowords all elicited anterior negativities, whereas picture parts, letter strings, and false fonts also-unexpectedly-elicited robust anterior negativities in children. That legal as well as illegal word stimuli elicited an anterior N400 suggests that the word-processing system in 10- and 11-year-old children is more sensitive to linguistic context, more open to linguistic possibility, and less accurate at initial or early selection of potentially meaningful strings as candidates for word processing (cf. Nobre & McCarthy, 1994). It is largely assumed, primarily based on behavioral data (e.g., see Adams, 1990), that children of this age are virtually fluent with reading the types of simple (decontextualized) words used in the present stimulus list. The results of this ERP study are somewhat contrary to these claims of fluency and seem to suggest that the level of automaticity attained by children at this age may be less consolidated than previously believed. The finding that real pictures, pseudopictures, and picture parts all elicited anterior negativities can also be interpreted in terms of less specificity in processing and increased context reliance in children.

As is typical of much exploratory research, more questions have been raised than answered by the present study. Among these are questions concerning the nature of

the antN400, the neurocognitive processes that it represents, and its relationship to the classic N400. In addition, questions concerning the natures of the dual peaks elicited during picture processing, and their relationships to the classic N400 and antN400, have been introduced. Further investigation of the developmental issues raised by these data is also necessary; expanding the present paradigm to include younger and older participants will clarify the developmental course of word processing and picture processing. In addition, the question of the developmental significance of context in ERP studies needs further investigation. For example, modifying the instructions to explicitly state that some stimuli will be nonsense pictures and words might affect context dependency. Presenting stimulus lists with different constitutions might also provide further insight; if a word list consisted only of letter strings and false fonts, the context-dependency interpretation (if immediate context is considered exclusively) would predict that no antN400s would be elicited. Whether this is or is not the case remains to be determined by future study.

An eventual understanding of change over time in neurocognitive processing, as reflected in ERPs, will have multidisciplinary value. As children grow up in a symbol-based society, almost constantly surrounded by meaningful language and images, interactions with the environment help to shape the developing brain, establishing and fine-tuning neural connections (e.g., Buchwald, Guthrie, Schwafel, Erwin, & Van Lancker, 1994; Fischer & Rose, 1994; Kurtzberg et al., 1984; Mills, Coffey-Corina, & Neville, 1993; Neville, 1995). A more comprehensive understanding of the brain-behavior relationships underlying this developmental process has relevance for educators teaching all kinds of children to read, for cognitive psychologists and linguists theorizing about the processes involved in image comprehension and species-specific language abilities, and for neuroscientists attempting to map those processes onto the brain.

ACKNOWLEDGEMENTS

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