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# Auditory Evoked Responses Recorded from 16-Month-Old Human Infants to Words They Did and Did Not Know

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Auditory evoked responses (AERs) were recorded from the frontal, temporal, and parietal scalp regions of nine male and nine female 16-month-old infants while they listened to a series of words. The brain responses reliably discriminated between words the infants were thought to understand versus those that they did not appear to know as judged by their parents and two independent raters. Findings from this study indicated that the brain wave patterns could discriminate known from unknown words. Sex differences in the patterns of lateralized hemispheric responses to the known and unknown words were also noted. These data indicate that auditory evoked responses may be used to detect differences in word meanings in young infants. © 1990 Academic Press, Inc.

## INTRODUCTION

Language comprehension in the human infant presumes at least several important abilities: the comprehension of human speech sounds and the learning that these patterns of speech sounds are linked in an arbitrary way to referents/objects in the environment as "names." However, although research on human speech perception indicates that even young infants can discriminate between the basic sounds of human speech in a manner similar to adult listeners (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Morse, 1974; Molfese & Molfese, 1979, 1980, 1985), very little is known about the infant's beginning comprehension of "names" for objects/events. While some investigations have documented and cataloged the words first comprehended by infants, beginning around 8

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months of age (Benedict, 1979; Kamhi, 1986; Miller & Chapman, 1981; Macnamara, 1982), little is yet known about the earliest stages of the infant's learning and how particular speech sound patterns are arbitrarily associated with specific referents. In fact, only recently have investigators begun to probe the very beginning stages of the infant's ability to perceive and remember the names for objects and events (Bates, Bretherton, Snyder, Shore, & Volterra, 1980; Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Kamhi, 1986; Miller & Chapman, 1981). Moreover, virtually nothing is known about the role that the brain plays in the early acquisition of such word-meanings. It is these last two points which are of concern in the present paper.

A second area of research not addressed in the past concerns the involvement of general brain mechanisms which might underlie the initial process of language learning. While researchers have long speculated that the left hemisphere plays a major role in early language acquisition (Basser, 1962; Lenneberg, 1967; see Molfese & Segalowitz, 1988, for a review of this field), no direct assessments of early word comprehension with non-brain-damaged infants have been attempted which might indicate the role that different areas of the brain play in first word learning during early infancy.

One procedure that may be useful in studying such problems involves the recording of an auditory evoked response (AER). The evoked potential recorded from the scalp is a synchronized portion of the ongoing EEG pattern. It is usually represented as a complex waveform that reflects changes in electrical activity over time. Such waveforms are thought to reflect changes in brain activity as reflected by changes in the amplitude or height of the wave at different points in its time course (Callaway, Tueting, & Koslow, 1978). What distinguishes the evoked potential from the more traditional EGG measure is that the event-related potential (ERP) is a portion of the ongoing EEG activity of the brain that is **time-locked** to the onset of some event in the subject's environment. While the ongoing EEG activity reflects a wide range of neural activity related to the myriad of neural and body self-regulating systems as well as the various sensory and cognitive functions ongoing in the brain at that time, the AER, because of its time-locked relation to the evoking stimulus, has been shown more likely to reflect both general and specific aspects of the evoking stimulus and the infant's perceptions and decisions regarding the stimulus (Molfese, 1983; Nelson & Salapatek, 1986; Ruchkin, Sutton, Munson, Silver, & Macar, 1981). It is this time-locking feature that enables researchers to pinpoint, with some degree of certainty, portions of the electrical response that occurred while the infant's attention was focused on a discrete event. For example, there has been a great deal of research investigating the infant's perception of speech sounds using the AER procedure (Molfese, 1972; Molfese, Freeman, & Palermo, 1975; Molfese & Molfese, 1979, 1980, 1985; see also Molfese & Betz, 1988, for a review of this literature).

The ERP procedure has a number of strengths which include its ability to employ identical procedures with all participants, regardless of age or species. Consequently, direct comparisons can be made between various subject groups in terms of discrimination abilities. Although the waveshapes of the ERPs will change from infancy to adulthood and differ across different species, one can assess whether the brain responses recorded from these different populations reliably discriminate between different stimuli, subject groups, and task characteristics. Moreover, the ERP procedures can be used to obtain response information from subjects who either have difficulty in responding in a normal fashion (as in the case of individuals with brain damage) or who cannot respond because of language or maturity factors (as with young subjects and children). They also provide information concerning both between hemisphere differences as well as within hemisphere differences. Finally, the procedure provides time-related information that may provide information about the different points in time when such information is detected and processed.

There have been extensive studies of word discrimination conducted with adults (Begleiter & Platz, 1969; Brown, Marsh, & Smith, 1979; Chapman, McCrary, Bragdon, & Chapman, 1979; Molfese, 1979; Molfese, Papanicolaou, Hess, & Molfese, 1979; see also the review by Molfese, 1983, for an in-depth review of these and additional studies), but only a single study has been published that reported early word comprehension in such young infant populations (Molfese, 1989). For example, Molfese (1979) demonstrated that the AERs could successfully discriminate between meaningful words and nonsense syllables. AERs were recorded from over the left and right hemispheres of 10 adults while they listened to a series of word and nonsense consonant–vowel–consonant syllables (CVC). After hearing each stimulus the adults pressed buttons to indicate whether they had heard a word or not. Molfese identified four regions of the AER waveform which discriminated between the words and nonsense CVCs. This study and others (see Molfese, 1983, for a review of this work) indicate that the evoked potential procedures used with adults can discriminate differences in meaningful versus nonmeaningful materials (Molfese, 1979) and perhaps even between different interpretations of the same word (Molfese et al., 1979).

In the only published electrophysiological study of word meanings in young infants, Molfese (1989) noted that the brain responses of young infants can also provide information concerning word understanding. In this study, Molf..s recorded auditory evoked responses from frontal, temporal, and parietal scalp locations over the left and right hemispheres of 10 infants who listened to a series of words, half of which were determined to be known to the infants (based on behavioral testing and parental report) and half of which were believed not to be known to the infant. Analyses of the AER data isolated three regions of the evoked potential waveform that discriminated known from unknown words in this population. Initially, AER activity between 30 and 220 msec following stimulus onset discriminated between known and unknown words. This effect could be seen as a positive peak for the known words and a negative peak in this same region for the unknown words. This activity was followed shortly by a large positive to negative change in amplitude between 270 and 380 msec across all electrode sites for both the left and right hemispheres that was larger for the known than for the unknown words. Finally, a late negative peak between 380 and 500 msec that was detected only by electrodes placed over the left and right parietal regions was larger for the known than for the unknown words. These results support the notion that AERs can be used to successfully discriminate between words that infants do and do not understand.

The present investigation was designed to determine whether the electrophysiological procedures outlined by Molfese (1989) could reliably discriminate between the known and unknown words presented to an older group of infants in order to assess the reliability of the procedure. Moreover, it was hoped that since electrodes could be placed over various areas of the brain, some information could be gathered concerning changes in general brain organization during early word discrimination. Given previous findings concerning sex-related hemisphere differences (Witelson, 1987; Witelson & Kigar, 1988), a group of nine male and nine female infants were selected for testing in order to further evaluate such relationships.

## METHODS

*Subjects.* Names of infants whose birth dates would place them at approximately 16 months of age when testing was to be scheduled were obtained from county birth records. Letters were sent to the parents describing the research project and requesting their participation. After sufficient time had elapsed for delivery of the letters, a research assistant contacted the parents by telephone. At this time, parents were provided with more details about the project and were asked if they would allow their infant to participate.

*Subject characteristics.* Eighteen infants, nine females and nine males, participated in the present experiment. The mean age of the female infants was 16.57 months ($SD = 0.6$ months, range = 15.37–17.5 months) and the mean age for the male infants was 16.42 months ($SD = 0.58$ months, range = 15.08–17.03 months). Both groups were also matched on the basis of parental hand preferences using the Edinburgh Handedness Inventory (Oldfield, 1971). This step was taken in order to document the direction of lateralization in the infant's immediate family. Given the consistent correlations for familial handedness factors, the use of parental handedness measures was felt justified (Bryden, 1982; Annett, 1985). The Edinburgh Handedness Inventory is a standardized and normalized handedness test that yields laterality quotients between −1.00 (which indicates a strong and consistent left hand preference) and +1.00 (which indicates a strong and consistent right hand preference). Responses to this questionnaire indicated that the parents as a group were right handed (mean Laterality Quotient = +.69, $SD = .47$). An examination of the individual data indicated that for the females, the mother's mean LQ was .84 ($SD = .22$) and the father's was +.50 ($SD = .73$). The mean LQ for the parents of the male infants was +.67 ($SD = .55$) for the mothers and +.76 ($SD = .14$) for the fathers. $t$ tests indicated no differences in hand preferences between the mothers and fathers, $t(16) = .537$, $p > .10$. In addition, no hand preference differences were noted between the mothers of the two groups of infants ($t = .86$, $p > .10$) or between the fathers ($t = 1.05$, $p > .10$). Likewise, no differences in hand preferences were noted between the fathers and mothers for either the male infants ($t = .476$, $p > .10$) or the female infants ($t = 1.3$, $p > .10$).



*Stimuli.* Because the stimulus tapes were to be constructed for each infant before the test session and these tapes could only be produced at another institution some distance away, it was necessary to identify possible stimulus words, edit them, and generate computerized stimulus tapes prior to contacting any of the parents for this study. In order to limit the number of tapes that would have to be generated and to increase the likelihood of identifying young infants with vocabularies that included the words that we had previously prepared, a search of the research literature on infant early word comprehension was conducted. This search identified a series of words which appeared to characterize the early vocabularies of many of the infants who had previously been studied and who overlapped in age the infants targeted by the present study (Benedict, 1978, 1979; Nelson, 1973; Oviatt, 1980). From this initial word list, a final set of words were selected if they met several criterion: the word must begin with an initial stop consonant, the initial consonant must be followed by a vowel sound, the word must identify an object, and the words were to be no longer than two syllables in length. These criterion were used in order to control for stimulus onset and rise time characteristics which might otherwise contribute to differences in the resulting AERs. Ten words were identified in this manner: "bottle," "book," "cookie," "key," "kitty," "ball," "dog," "baby," "duck," and "cat." Each word was then recorded while spoken by an adult female speaker using a flat intonation. The words were subsequently edited to an average duration of 474 msec (range 420–494 msec). Peak stimulus intensities were matched and the stimuli stored for later tape construction. Stimulus tapes were constructed for each infant, based upon the parental ratings obtained during the telephone interview. Each tape for each infant contained stimulus repetitions of two words: one word rated by the parent as KNOWN by the infant and a second word that the parent rated as not KNOWN by the infant. These words were arranged on the tape in a block random order, with 54 occurrences of each. In all, then, each infant heard a total of 108 stimuli. The interstimulus interval between words varied randomly between 2.5 and 4.0 sec.

*Choice of stimulus items for each infant.* Once parents agreed to have their infant participate in the study, they were asked about the infant's knowledge regarding ten words: "bottle," "book," "cookie," "key," "kitty," "ball," "dog," "baby," "duck," and "cat." Parents were instructed to decide whether or not the infant understood the word when it was spoken to them. Next, the parents were asked to rate their confidence of that decision along a 5-point scale. Parents were told that a rating of "5" indicated that they were "very confident" that their infant did or did not know the word, while a rating of "1" signified that the parents were "not confident at all" about the decision. Following the interview, these ratings were converted to a range from "1" to "10," to establish a continuum from KNOWN to UNKNOWN words with "1" signifying high confidence that the infant did not know the word and "10" signifying high confidence that the infant knew the word. The stimuli which were later used as the KNOWN words in the present study were all rated at 10 during the telephone interview. That is, all of the parents were highly confident that their infants did know certain words. The average rating for the words the parents believed were not KNOWN to their infants was 2.1 ($SD = 1.5$). Parents, then, were fairly confident that their infants did not know a different set of words. At the end of this interview the parents were instructed not to train the infant on any of the 10 words prior to the evoked potential test session that was scheduled within 2 weeks following this interview.

*Behavioral testing.* For an infant to be included in the present study, both the parents and raters had to agree on which words were KNOWN and which were not KNOWN to the infant. To accomplish this, parents were again administered a questionnaire identical to the one presented to them earlier during the initial telephone contact. This test occurred immediately prior to the electrophysiological test session. Parents were given the list of 10 words and asked to rate the infant's knowledge of the words. For the female infants, this session resulted in a mean parental rating of 10.0 ($SD$ = 0.0) for the KNOWN words and 3.3 ($SD$ = 1.36) for the UNKNOWN words. The ratings for the males infants were 10.0 ($SD$ = 0) for the KNOWN words and 2.56 ($SD$ = 1.77) for the UNKNOWN words. No differences in ratings were found between these groups. Immediately following the completion of this questionnaire, a behavioral test involving two independent raters was performed with the infant. Both KNOWN and UNKNOWN words, as determined by parental ratings, received four behavioral trials each, with two independent observers rating whether or not the infant knew the word presented. In order to assess the infant's comprehension, the object representing the KNOWN or the UNKNOWN word (as appropriate) was placed in one of the four compartments of a test box. One of the compartments was empty. The remaining two compartments of the test box each contained distracter items randomly selected for each trial from a sack of toys. The parent then instructed the infant to look at or retrieve the various toys using instructions to the infant such as "Go get the book" or "Look at the duck." The compartments that contained the test object, the empty space, and the distracters were randomized for each trial for each infant based on a randomly generated list derived by computer prior to the test session. On each trial the raters had to determine whether they believed that the infant responded to the instructions correctly. They also recorded their own confidence in these judgements on a 5-point scale identical to that previously used by the parents. For the female infants, the mean rating for the KNOWN words (combined raters) was 9.38 ($SD$ = .63); for the UNKNOWN words, it was 3.03 ($SD$ = 1.6). For the male infants the ratings were 9.91 ($SD$ = .103) for the KNOWN words and 1.59 ($SD$ = .9) for the UNKNOWN words.

*Electrophysiological testing.* This testing occurred within 30 min following the conclusion of the behavioral testing. While one parent and a researcher entertained the infant with various toys and pictures, two other assistants applied the electrodes to the infant's scalp. To accomplish this, the head of each infant was first measured to identify where electrodes were to be placed. A mark was placed on the scalp immediately anterior to each position using a water soluble marker pen. Next, each area was rubbed with a pumice solution to lower skin resistances. The area was then cleaned and the residual paste removed. Grass electrode paste (EC-2), a conductive gel, was then rubbed into the scalp at this location. This paste was also placed in the cup of the electrode that was then placed on the scalp. The conductive paste was also placed on a folded square of gauze which was placed over the back of the electrode. A 1-inch strip of surgical tape was then placed over the back of the electrode and gauze as a further means of holding the electrode to the scalp. Six silver cup scalp electrodes were placed over the left and right sides of each infant's head. These placements included two electrodes placed, respectively, over the left (T3) and right (T4) temporal areas of the 10–20 system (Jasper, 1958); a third electrode placed at FL, a point midway between the external meatus of the left ear and Fz; a fourth electrode placed at FR, a position midway between the right external meatus and Fz; a fifth electrode placed at PL, a point midway between the left external meatus and Pz; and a sixth electrode placed at PR, a point on the right side of the head midway between the right ear's external meatus and Pz. The frontal and parietal electrode positions were chosen over the conventional 10–20 electrode placement system commonly used with adults for two reasons. First, extensive pilot work in our lab consistently indicated that these positions could be measured and electrodes placed in less than half of the time usually required for 10–20 positions such as F3/F4 or P3/P4. This time savings was believed important for reducing subject attrition due to long electrode preparation times. Second, it was not clear that the standard adult 10–20 system bore any systematic relationship to underlying infant brain regions. While the adult 10–20 system was based on at least some empirical work to determine what general brain regions lay beneath the proportional measures identified by Jasper and others, no such systematic work with a sizeable population has been conducted with infants of various ages. Consequently, little if anything is known concerning the identity of the brain topography that lays immediately below the 10–20 scalp positions of young infants. The electrode placements used in the present study were over the left frontal (FL), temporal (T3), and parietal (PL) areas of the brain and the corresponding areas of the right hemisphere (FR, T4, and PR, respectively). Such placements, it was hoped, would provide information concerning not only left versus right hemisphere responses to the KNOWN and UNKNOWN words but, in addition, information within each hemisphere from frontal and parietal regions concerning general language perception areas commonly thought to be localized to the left temporal and parietal regions of the brain as well as language production areas of the frontal lobe. The electrical activity recorded from these scalp electrode positions was referred to electrodes placed on each earlobe and linked together (A1, A2). Electrode impedances were under 5 kohm and did not vary more than 1 kohm between electrode sites on the scalp, as indicated by measurements before and after the test session. The infant was seated in a parent's lap throughout the test session. The stimuli, which consisted of the KNOWN word and the UNKNOWN word, were presented through a speaker positioned approximately 1 m over the midline of the infant's head. Stimulus presentation was at 80 dB SPL (A) as measured at the infant's ears. Stimulus presentation occurred when the infant was in a quiet awake state. Continuous monitoring of the infant's ongoing EEG and EMG, as well as behavioral observation, were used to determine when stimulus presentation should occur. During periods of motor activity, stimulus presentation was suspended and the infant was then shown various toys and pictures until quieting. Testing was later resumed when the infant's motor activity declined to an acceptable level.

*Analyses.* Individual auditory evoked responses were initially digitized at 5-msec intervals for a 800-msec period. The digitized signal included a prestimulus period of 100 msec and a 700-msec period following stimulus onset. These digitized values were stored on-line during the data recording session by a DEC PDP 11/34 minicomputer. Subsequent analyses were performed off-line after the testing session had been completed. Artifact rejection was carried out on the AER data for each electrode to eliminate from further analyses the AERs contaminated by motor movements. If an artifact (operationally defined as a shift in the voltage level in excess of 40 $\mu$V) occurred on any one electrode channel during the 100-msec pre- or 700-msec poststimulus period, all of the AERs collected across all of the electrode sites for that trial were discarded from subsequent analyses. This procedure, which was based on the peak-to-peak amplitudes of single trial responses, resulted in an average of 7% of the trials being rejected for each infant ($SD$ = 3.4%). Rejection rates were comparable across the two stimulus conditions. Following artifact rejection, the single trial data were then averaged separately for each electrode site and stimulus condition. In this manner, 216 averaged AERs were obtained for the 18 infants. Based on a pilot study with a similar age population, 70 data points over a 700-msec period beginning with stimulus onset were selected from each AER for further analyses (Molfese, Wetzel, Linnville, Imbasciate, Leicht, Courtney, Baldwin, & Adams, 1985). This period was selected because most of the synchronized activity of the AER elicited by the meaningful and nonmeaningful stimuli had concluded at the end of the 700-msec poststimulus onset period. In addition, since no differences were found in the pilot study between the AERs when digitized at 5-msec intervals versus those digitized at 10-msec intervals over the same 700-msec period, the decision was made to use the longer 10-msec sampling rate.

The final data set to be used in the subsequent analyses described below, then, consisted of 216 averaged AERs. These 216 averaged waveforms were obtained from the 18 infants for each of the two words (KNOWN, UNKNOWN), for each of the three electrode sites (Frontal, Temporal, and Parietal), for each of the two hemispheres (Left and Right). On the basis of pilot testing and related work (Molfese, 1989; Molfese & Molfese, 1979, 1985), a subset of the original digitized data points were selected for subsequent analyses. The points selected began with stimulus onset and continued at 10-msec intervals through 700-msec poststimulus onset. Earlier work in this area had suggested that most of the organized AER activity was completed by 700-msec post-stimulus onset. Each averaged AER consisted of 70 data points beginning at stimulus onset and continuing at 10-msec intervals for 700 msec. For each infant, 12 averages were obtained. These included averages for the KNOWN and UNKNOWN words for each of the six electrode sites. While there are a variety of different analysis procedures which could be used to analyze the AER data, a decision was made to utilize a multivariate approach which has produced consistent results in programmatic research across a number of laboratories (Brown et al., 1979; Chapman et al., 1979; Donchin, Tueting, Ritter, Kutas, & Heffley, 1975; Gelfer, 1987; Molfese, 1978a,b; Molfese & Molfese, 1979, 1980, 1985; Ruchkin et al., 1981). For example, Molfese, in a series of papers investigating speech perception cues such as Voice Onset Time and Place of Articulation, has noted consistent systematic effects across studies for each cue (Molfese, 1978a,b; 1980, 1984; Molfese & Schmidt, 1983). Moreover, these effects have also been independently replicated using comparable analysis procedures involving the principal components analysis—ANOVA sequence (Gelfer, 1987; Segalowitz & Cohen, 1989).

The average AERs obtained in the present study were submitted to a two-step analysis procedure which first involved the use of a Principal Components Analysis (PCA) and then an Analysis of Variance. The rationale for the use of this procedure is that it has proven successful in first identifying regions of the AER where most of the variability occurred across AERs and subjects and, second, in then determining if the variability characterized by the different factors were due to systematic changes in the independent variables under investigation. The PCA procedure behaves somewhat similar to a factor analysis with the exception that it constructs the factors on the basis of variances instead of correlations (Rockstroh, Elbert, Birbaumer, & Lutzenberger, 1982, p. 63). The PCA procedure itself is blind to individual experimental conditions and generates the same solution regardless of the order in which the AERs are entered. Once the PCA identifies where within the AERs most of the variability occurred, the ANOVA was used to identify the cause of this variability. The Analysis of Variance accomplishes this task by determining whether the variability reflected in the factor scores assigned for each factor to each averaged AER differed as a function of changes in the independent variables. This procedure directly addresses the question of whether the AER waveshapes in the region characterized by the most variability for any one factor changed systematically in response to the KNOWN versus the UNKNOWN words recorded from the different electrode sites over each hemisphere.

## RESULTS

The 216 averaged auditory evoked responses obtained from the 18 infants each consisted of 70 data points. These AERs formed the input matrix for the PCA using the BMDP4M program from the BMDP86 package (Dixon, 1986). This program first transformed the data into a covariance matrix and then applied the PCA to this matrix. Five factors accounting for 74.33% of the total variance were selected for further analyses based on the Cattell Scree Test (Cattell, 1966). These factors were then rotated using the normalized varimax criterion (Kaiser, 1958)



which preserved the orthogonality among the factors while improving their distinctiveness. This analysis generated factor scores or weights for each of the 216 averaged AERs for each of the five rotated factors. The variance isolated by the PCA was characterized by the five factors (factor loadings). The peak for each factor and the area immediately surrounding it in time indicates that this region of the brain wave changed in amplitude or slope across some proportion of the AERs in the present data. For the purposes of the present study, factor loadings with values above .4 are used to identify major regions of variability in each of the factors. Factor 1, for example, accounted for 28.68% of the total variance in the data set. The factor loadings for this factor indicated that this region of variability began to increase immediately following stimulus onset, peaked at 50 msec, and ended approximately 200 msec following stimulus onset. Factor 2, which accounted for 13.77% of the total variance, reflected an increase in waveshape variability beginning at 310 msec and peaking approximately 410 msec following stimulus onset and a decline by 490 msec. Factor 3 (12.52% of the total variance) reflected waveform variability beginning 450 msec after stimulus onset which peaked at 520 msec and then diminished by 600 msec. Factor 4 (10.86% of the total variance) characterized a region of variability in the AERs between 180 and 340 msec, with the peak region of variability at 270 msec. The region of variability in the AER waveforms between 580 and 700 msec (with a peak at 650 msec) characterized Factor 5 (8.50% of the total variance).

The PCA, as noted above, generated a set of factor scores for each averaged AER for each factor. Consequently, 216 factor scores were generated for Factor 1 which reflected the variability across each of the averaged AERs for the two words, six electrode sites, and 18 infants. A second set of factor scores were generated for Factor 2, which identified variability in a different region of the averaged AERs, etc. These factor scores, which reflected the amount of variability for that factor in an individual AER, constituted the dependent variables in a series of five independent analyses of variance using the BMDP8V statistical package (Dixon, 1986). The separate ANOVAs conducted for each factor were appropriate because the factors derived by the PCA were orthogonal to each other. The ANOVAs were based on the design of Sex (2) × Subjects (9) × Word Understanding (2) × Electrode Sites Within Hemispheres (3) × Hemispheres (2). These ANOVAs were conducted to determine if any of the regions of the AERs identified by the factors varied systematically as a function of the specific levels of the independent variables in this study. To decrease the possibility of a Type 1 error, only factor effects beyond the .01 level are reported. While this criterion may appear overly strict and place the study at greater risk for Type 2 errors, when a test for experiment familywise error rate is calculated to determine the risk of a type I error, a new $p$ level of .039 is calculated (Keppel, 1982). In cases where post hoc analyses were conducted, the conservative Scheffe Critical F test procedure was used (Scheffe, 1959). For the purposes of the present report, the word-related effects are reported in the order in which they occurred in the AER waveform. Next, effects are reported for sex, electrode, and hemisphere effects which did not interact with the word effects.

A Sex × Word × Electrode × Hemisphere effect, $F(2, 32) = 5.65$, $p < .0079$, was found for Factor 4. Scheffe tests of this interaction indicated that one scalp region of female infants differentiated between the KNOWN and UNKNOWN words while three regions of the males' brain responses made this same discrimination. More specifically, the one region of AER activity found to differentiate between the KNOWN and UNKNOWN words occurred at the left temporal (T3) hemisphere site of the female infants, $F(1, 32) = 22.29$, $p < .0001$. The three scalp regions of the male infants that differentiated KNOWN from UNKNOWN words occurred at the left hemisphere frontal, $F(1, 32) = 5.36$, $p < .0256$, and temporal, $F(1, 32) = 4.49$, $p < .0396$ sites, and at the right hemisphere frontal site, $F(1, 32) = 8.77$, $p < .0058$.

The sex-related effects described above can be seen in Figs. 1 and 2

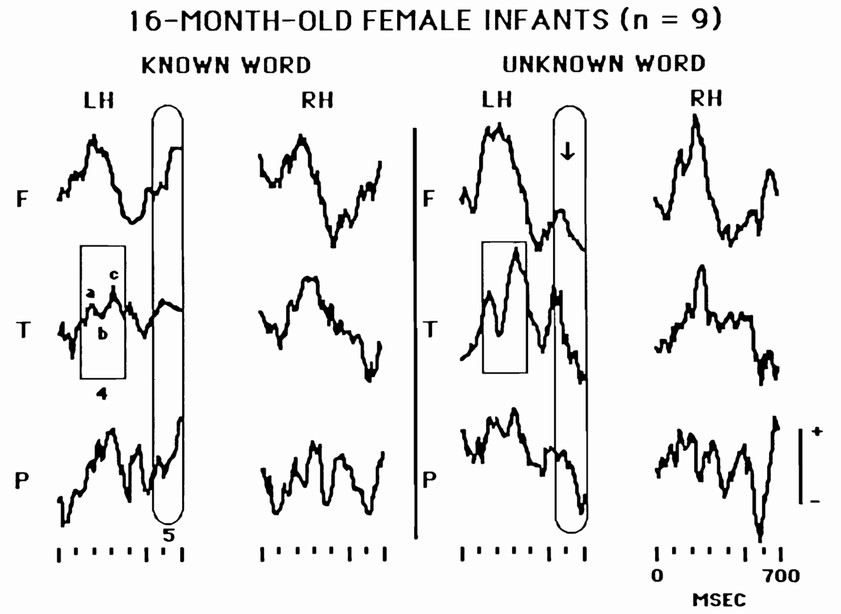


FIG. 1. The group averaged AERs recorded from the nine female infants. The AERs were recorded from the left and right frontal, temporal, and parietal electrode sites in response to KNOWN and UNKNOWN words. Positivity is up. The calibration marker is 10 μV. AER duration is 700 msec.



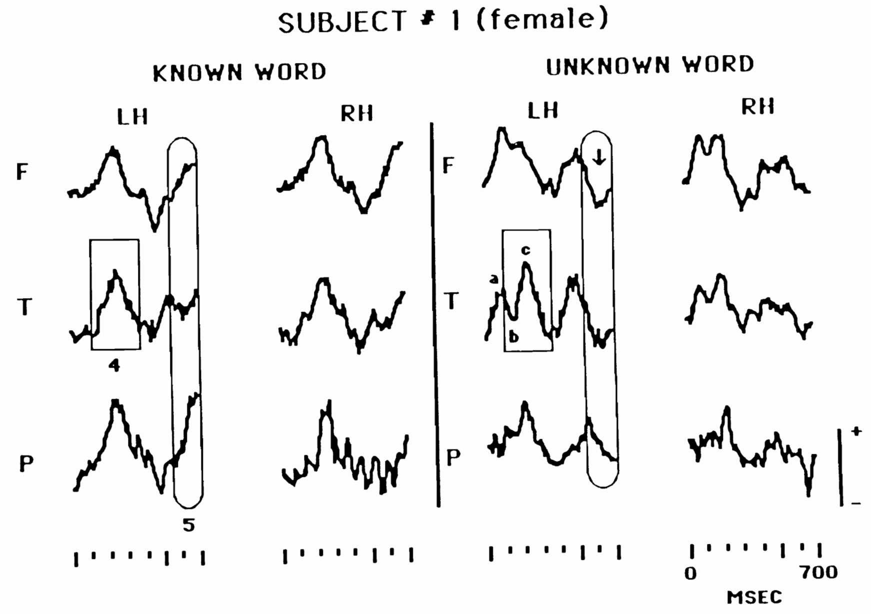


FIG. 2. The averaged AERs from female infant No. 1 recorded from the left and right frontal, temporal, and parietal electrode sites in response to KNOWN and UNKNOWN words. Positivity is up. The calibration marker is 10 μV. AER duration is 700 msec.

for the female infants and in Figs. 3 and 4 for the male infants. The region of the AER waveform where the effects for Factor 4 occurred are contained within the rectangle labeled "4." These effects appear to be reflected by changes in the combined amplitudes of three peaks within this rectangle for each wave. For example, the AERs elicited by the KNOWN words from the female infants (see Figs. 1 and 2) were characterized by larger amplitude peaks for the UNKNOWN than for the KNOWN stimuli. In the present case, the vertical amplitude as measured from the positive peak labeled "a" to the negative peak identified as "b" and back to a second positive peak marked "c" is clearly larger for the left hemisphere (LH) temporal (T) site for the UNKNOWN word condition. This is true for both the female infant group averaged data as illustrated in Fig. 1 and for plots of an individual female infant's data as illustrated in Fig. 2.

The group averaged male infant data and that for a single male infant are presented in Figs. 3 and 4. As noted above, the left frontal and temporal areas as well as the right frontal area discriminated between the KNOWN and UNKNOWN words for the male infants. Within the rectangle labeled "4" the peak-to-peak amplitudes from points "a" to "b" and "b" to "c" are larger for these three sites in response to the UNKNOWN than to the KNOWN words. This effect can be viewed in

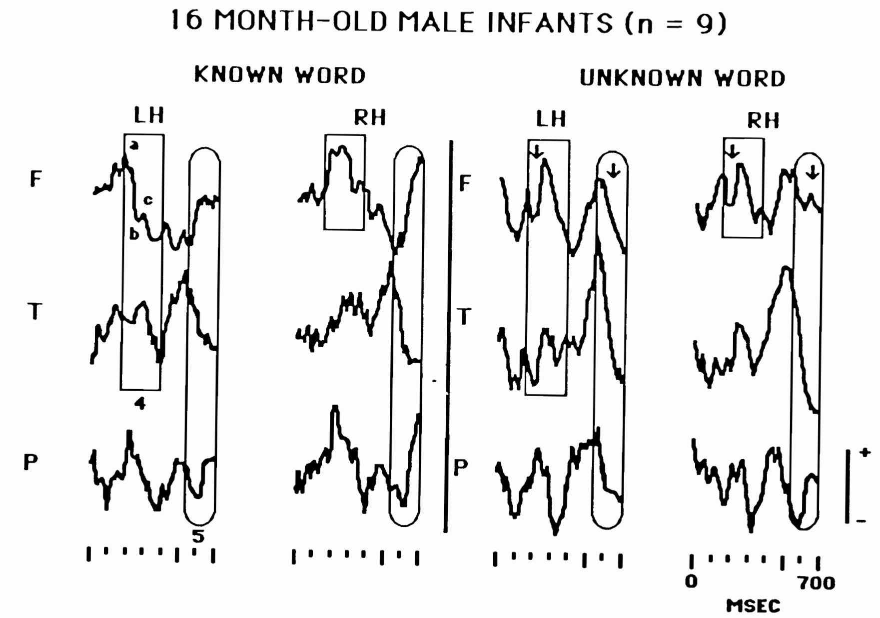


FIG. 3. The group averaged AERs recorded from nine male infants. The AERs were recorded from the left and right frontal, temporal, and parietal electrode sites in response to KNOWN and UNKNOWN words. Positivity is up. The calibration marker is 10 $\mu$V. AER duration is 700 msec.

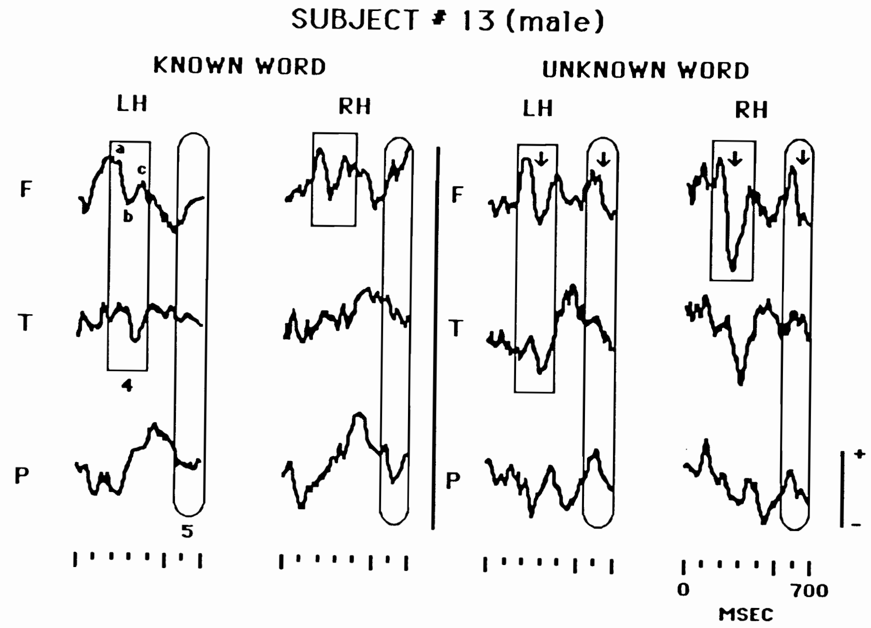


FIG. 4. The averaged AERs from male infant No. 13 recorded from the left and right frontal, temporal, and parietal electrode sites in response to KNOWN and UNKNOWN words. Positivity is up. The calibration marker is 10 $\mu$V. AER duration is 700 msec.





the male group averaged data displayed in Fig. 3 and in the individual male infant's responses depicted in Fig. 4.

A Sex × Word × Hemisphere effect was found for Factor 5, $F(1, 16) = 17.19$, $p < .0008$. Scheffe tests of this interaction revealed that evoked potential activity that occurred in the female infants between 570 and 700 msec over all of the left hemisphere electrode sites differentiated between the KNOWN and UNKNOWN words, $F(1, 16) = 23.29$, $p < .0004$. A similar left hemisphere effect was also noted for the male infants, $F(1, 16) = 7.07$, $p < .0164$. However, in addition, all of the right hemisphere electrode sites of the male infants also discriminated between the KNOWN and UNKNOWN words, $F(1, 16) = 51.69$, $p < .00001$. These effects can also be identified in the waveforms depicted in Figs. 1 through 4. Across all figures the region of variability identified by Factor 5 is contained within the circled area labeled "5." For both the female group plots and the plots for the individual female infant (No. 1), the downward pointing arrow identifies a larger negative going wave for the UNKNOWN word than for the KNOWN word stimuli across all of the left hemisphere electrode sites. For the KNOWN word, this same region is either characterized by a positive going wave or a negative slope that is much smaller in amplitude than that noted for the UNKNOWN words. A similar difference can be noted across both the left hemisphere electrode sites in Figs. 3 and 4 for the male group data and for the individual male subject's (No. 13) data. However, in addition, the right hemisphere electrode sites are also characterized by more negative going waves for the UNKNOWN than for the KNOWN words. As in the case of the female data, the downward pointing arrows mark the regions where the negative portions of the wave are more pronounced for the UNKNOWN than for the KNOWN words.

Other effects were also noted which did not vary as a function of word meaning. A main effect for Electrodes was found for Factor 2, $F(1, 32) = 16.73$, $p < .0001$. In this case, Scheffe tests indicated that activity recorded from the frontal sites differed from the temporal sites between 310 and 490 msec, $F(1, 32) = 33.16$, $p < .0001$, and differed between the frontal and parietal sites, $F(1, 32) = 11.35$, $p < .0023$, and between the temporal and parietal sites, $F(1, 32) = 5.71$, $p < .0217$. Finally, a main effect for Electrodes, $F(1, 32) = 30.21$, $p < .0001$, was noted for Factor 5. This effect identified differences in activity recorded from the frontal and temporal sites, $F(1, 32) = 23.62$, $p < .0001$, and between the temporal and parietal sites, $F(1, 32) = 66.91$, $p < .00001$. No other main effects or interactions were noted.

## DISCUSSION

*AERs and meaning.* These results indicate that the AERs can successfully discriminate between words that parents and independent raters believe 16-month-old infants know from those that the infants appear not to understand. Moreover, as in the findings of Molfese (1989) with a group of 14-month-old infants, the process of word comprehension seems to be a dynamic one in the sense that different regions of the brain respond differently over time following the onset of the word that is known to the infant. However, the latencies of the evoked potential components in these 16-month-old infants that discriminated between the known and unknown words differed from those found for the 14-month-old infants reported by Molfese (1989), although the polarity of the peaks that did discriminate were comparable. In both that study and in the present one, the responses to the unknown words were characterized by larger negative peaks than those elicited by the known words. In the present study, differential electrical activity began approximately 180 msec following the onset of a word and continued for approximately 160 msec over the temporal region of the left hemisphere for both male and female infants. In addition, the left and right hemisphere frontal regions of the male infants also discriminated between the KNOWN and UNKNOWN words. This response was followed after nearly a 240-msec period by a second shift in the evoked potential waveform which also discriminated between the KNOWN and UNKNOWN words. As was the case with the first portion of the waveform, the word discrimination response occurred in a more restricted region of the left hemisphere of the females. In contrast, the male responses that differentiated between KNOWN and UNKNOWN words spread out to include the different regions of the right as well as the left hemisphere.

*General vs. specific meaning reflected by the AERs.* The results outlined above, while indicating that the AER measure can detect differences in the meaningfulness of the words to the infant, clearly do not reveal specific information concerning the different word meanings. In fact, since different words were meaningful or not meaningful to the different infants in the study, one would expect that any AER features reflecting such individual meanings would be obscured by analyzing across the different words. Consequently, the two AER features related to word meaning noted here necessarily may reflect very general "word meaning" components.

*Laterality and meaning.* Although there is a general belief that language perception is carried out by mechanisms within the left hemisphere (Lenneberg, 1967), the word-related effects identified in the present study with young infants were exclusively restricted to the left hemisphere for only the female infants. For males, only the initial AER region (as characterized by Factor 4) displayed a slight lateralized effect in favor of the left hemisphere. The second region of the males' evoked potential response discriminated between word meaning differences across all sites over the left and right hemispheres. These sex differences could reflect differences in maturation between the male and female infants as Witelson and others have argued (Witelson, 1987; Best, 1988). Perhaps the responses of the female infants reflect a more mature type of response while the responses of the male infants reflect an earlier stage of development due to a slower level of maturation. Alternately, one could argue that the responses of the female infants reflect a more lateralized system and the males for some reason are characterized by a more bilateral processing of meaningful material.

*Meaningfulness vs. familiarity.* While the AER responses reported in the present study appeared to have successfully discriminated between the stimuli based on their meaningfulness to the infants, it is possible that such differences resulted from the infants' reactions to familiar versus unfamiliar sound sequences. In this respect, words known to an infant would also be expected to be experienced more frequently by that infant than words that it did not understand. Consequently, the findings of the present study could reflect the ability of the AER to detect differences in familiarity, not meaning. In fact, Nelson and Salapatek (1986) in a study with infants 6 months of age have reported that the evoked potential response in young infants is sensitive to familiar versus novel (or frequent vs. infrequent) events. In their second experiment of a series of three studies which attempted to study the effects of novel versus familiar visual stimuli (faces), they noted that the responses recorded over a midline electrode position (Cz) to the novel event were significantly more positive than responses to a familiar event during the interval between 551 and 700 msec following stimulus onset. However, this same research report indicates that such familiarity effects are not found when stimuli are presented equally often. In Experiment 3 of their study, Nelson and Salapatek found no evidence of differences between stimuli when all had been presented an equal number of times. The data of Nelson and Salapatek illustrate one major difference between the paradigm in which such attentional differences have been demonstrated and the procedures of the present study. Traditionally such familiarity or attentional effects as demonstrated by Nelson and Salapatek occur to infrequently occurring stimuli *within the actual testing situation* when the subject is specifically instructed to attend to the infrequent event (see also Courchesne, Ganz, & Norcia, 1981, and Courchesne, Hillyard, & Galambos, 1975). In the present study, however, both the known and the unknown words occurred with equal frequency. Under such conditions, the evoked potential peak differences reported by Nelson and Salapatek that result from frequency differences would not be expected to appear. Consequently, the effects reported in the present paper may not be attributable to frequency or attentional effects.

There are other data available that suggest that infants may be capable of discriminating meaningful material independent of their familiarity with that material. In the same study in which he addressed 14-month-old infant response differences to known and unknown words, Molfese (1989) also reported results on familiarity effects. In that experiment (Experiment 2), Molfese tested whether an infant's level of experience with a sequence of sounds would generate brain response differences similar to those noted for differences in word meaning. In this experiment, infants first listened to a nonsense CVCV over a 2-day period. Then, on the 3rd day, AERs were recorded to this now familiar CVCV and a novel CVCV. Molfese reasoned that if the latencies of the brain wave AER components and their scalp distributions were similar for the known/unknown words and the familiar/novel experiments, then the results would have to be interpreted to indicate that the AERs were detecting familiarity and not meaning differences. However, if different results should be found from the two studies, these results would support the view that AERs can detect differences in the meaningfulness of words in young infants. In fact, Molfese found that AERs could discriminate between familiar and unfamiliar auditory stimuli and that this discrimination appeared to occur bilaterally over the frontal regions of the brain approximately 360 msec following stimulus onset. This effect differed both in terms of sites for the discrimination as well as the peak latency in the waveform at which the discrimination took place than that found for the known–unknown word effects. Consequently, the familiarity/novel effect and the known/unknown effect differed from each other. Thus, the earlier word-related effects appear in fact to reflect meaning differences rather than familiarity differences.

## CONCLUSIONS

Given the earlier findings reported by Molfese (1989) and those of the present study, it appears that electrophysiological measures involving the auditory event related potential can be used successfully to identify the words that are known to an infant versus the words that are unknown. These procedures open up a number of possibilities, both for exploring further the semantic development of the young infant and for detecting developmental problems in children who for one reason or another are slow in acquiring their first words. Perhaps such procedures could be used to determine more accurately the size of an infant's receptive vocabulary at an earlier point in development than is now possible using conventional behavioral assessment techniques. It is also possible that these procedures could be expected eventually to address the specific meanings that young infants have for certain words. While there remains a great deal of work to be performed to assess the usefulness, reliability, and the power of AER techniques for studying the emergence of early word meanings in young infants, the present work and that of Molfese (1989) mark a beginning.



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