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Electrophysiological Correlates of Noun–Verb Processing in Adults

DENNIS L. MOLFESE, LISA M. BURGER-JUDISCH, AND LESLIE A. GILL

Southern Illinois University at Carbondale

ROBERTA M. GOLINKOFF

University of Delaware

AND

KATHRYN A. HIRSCH-PASEK

Temple University

Auditory event related potentials (ERPs) were recorded to a series of nouns and verbs while 16 adults watched videotaped scenes. The scenes depicted an individual using objects or performing actions that were either labeled or not named by the auditorily presented nouns or verbs. Electrodes were placed over the left and right hemisphere frontal, temporal, and parietal regions of the scalp. Analyses compared ERPs elicited by words that matched or failed to match the scenes. Marked changes were noted in the ERPs recorded from electrode placements across the two hemispheres in response to words that served two different syntactic functions. This procedure is viewed as a useful technique for use with younger subject populations. © 1996 Academic Press, Inc.

INTRODUCTION

Scientists have long speculated that the two hemispheres of the brain are differentially involved in language processing. Studies have also noted that this differential hemisphere ability for language processes is established early in development, if not already established at birth (Dennis & Kohn, 1975; Dennis & Whitaker, 1976; Molfese, 1972; Molfese, Freeman, & Palermo, 1975; Molfese & Molfese, 1979, 1980, 1985). Dennis and Whitaker (1976) for example, report that children who suffered early left hemisphere lesions had reduced syntactic competencies while those children who experienced

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similar right hemisphere damage showed no reduction in syntactic abilities. Studies with split brain patients similarly note that the left hemisphere is able to demonstrate good noun and verb comprehension across tasks while the right hemisphere shows a marked decrement in performance for verb processing (Gazzaniga, 1970, p. 121; Zaidel, 1976).

Syntactic organization or structure advantages for the left hemisphere also is seen in the dichotic listening literature. In a study by Zurif and Sait (1970), 16 undergraduates were required to identify dichotically presented pairs of meaningless sequences presented in either a structured or an unstructured manner. The sequences in the structured condition were ordered such that if the nonsense stems were replaced by English stems a grammatical sentence would result. In contrast, in the unstructured sequences the same words were randomly arranged. Recognition accuracy was significantly superior in the structured condition. In addition, the laterality effect was significant only for the structured condition.

More recent evidence suggests that the systems to handle nouns and verbs are independently represented in the human brain. Caramazza and Hillis (1991), for example, reported data from two brain-damaged patients which indicate that noun and verb information may be stored separately and redundantly within different output systems. Each patient was characterized by modality-specific deficits restricted principally to verbs in their oral or written utterances. One patient, HW, was aphasic due to a stroke in the parietal region of the left hemisphere. This individual produced semantic errors in reading with more errors for verbs than nouns. No such problems were noted for writing. A second patient, SJD, who became aphasic due to a left fronto-temporal stroke, made more semantic errors during writing. While these writing errors were also more marked for verbs than for nouns, no differences were noted during reading. Caramazza and Hillis interpreted the two patients' contrasting performances to indicate that grammatical-class distinctions between nouns and verbs are redundantly represented in the phonological and orthographic output systems. What is also clear from this work is that brain mechanisms differentially support noun versus verb processing. Given the absence in the literature of such reported findings from right damaged patients, it would also appear that the left hemisphere plays a more major role in processing these different word functions.

While there is growing indirect evidence that nouns and verbs are distinct entities that are processed and possibly stored differently in the brain, there remains relatively little work in this area. Moreover, prior investigations have generally been restricted to methodologies such as the dichotic listening procedure which allow one to determine only left vs. right differences but which provide no information concerning anterior vs. posterior processing differences. Such techniques also generally fail to provide information concerning any priority that might exist in processing one syntactic function versus another. However, there are techniques such as event related potentials (ERPs) which can provide better information concerning spatial resolution beyond basic left–right differences. In addition, ERPs can also provide some information concerning the temporal order in which information is processed.

Event related potential procedures involve the recording of a portion of the ongoing EEG pattern from electrodes placed on the scalp in response to discrete stimulus events. Unlike standard EEG techniques, ERPs establish strict temporal relationships between the onset of a discrete stimulus event and changes in regions of the accompanying ERP pattern evoked by this stimulus. Because the size of the ERP is so small (5 to 15 μV) relative to background EEG and other sources of "noise," researchers usually repeat the stimulus in order to collect multiple instances of the brain response. These repeated ERPs are then averaged together in order to partial out random trial-to-trial variations while maintaining the waveform that is invariant across successive presentations. Next, a variety of different procedures are applied to these derived waveforms in order to determine whether changes in certain stimulus features produced systematic and corresponding changes in discrete spatial and/or temporal regions of the averaged ERPs.

This technique has been used successfully in a number of areas. For example, researchers, using a variety of stimuli, subject populations, and analysis procedures, have demonstrated that ERPs can be effectively used to study specific language dimensions such as speech perception and auditory discrimination (Molfese, 1978a, 1978b, 1980a, 1980b, 1984; Molfese & Hess, 1978), word meanings (Molfese, 1985; 1989, 1990; Molfese, Papanicolaou, Hess, and Molfese, 1979), lexical decisions (Kutas & Hillyard, 1980, 1984), sentence processing (Erwin, 1986; Holcomb, Coffey, & Neville, 1992; Neville, Nicol, Baress, Forester, & Garrett, 1991; Papanicolaou, 1980; Wetzel & Molfese, 1992), as well as cognitive processes (Papanicolaou & Molfese, 1978).

In relation to the current issues under study in this paper, a number of studies already have identified ERP changes that are associated, at least in part, with noun versus verb differences (Teyler, Roemer, Harrison, & Thompson, 1973; Brown, Marsh, & Smith, 1973, 1976, 1979; Brown, Lehmann, & Marsh, 1980). Teyler et al. (1973) recorded auditory ERPs to brief noun and verb phrases such as "a rock" and "to rock." In general, larger N100–P160 amplitudes were reported over the left hemisphere for both nouns and verbs although the left hemisphere response in the verb condition was approximately 15 msec faster than that produced when subjects were processing a noun phrase. Subsequent classic studies by Warren Brown and his colleagues support these earlier findings. They also noted differences in both ERP component structures and topographic distributions when adults listened to series of phrases in which the ERPs were collected to identical sounding words that served different functions within the phrase and which also differed in their lexical meaning. For example, Brown et al. (1973) recorded ERPs to an experimental stimulus set composed of phrases such as

"Sit by the fire" and "Ready, aim, fire." In these cases, ERPs to the word "fire" were compared. A control stimulus set contained these same homophones but at the beginning position in a sentence such as "Fire the gun." In both conditions, ERPs were recorded to exactly the same stimulus word token that was simply spliced into each of the different phrases. Brown et al. found that left hemisphere ERP responses discriminated between the same word when it served as a noun versus a verb. In a subsequent study, Brown et al. (1976) recorded auditory ERPs from over left and right hemisphere frontal and temporal recording sites to the last word of the phrase, "It was led." On half of the trials, the phrase was preceded by instructions to think of the stimulus word as either a noun or a verb. Analyses identified the later portions of the ERP recorded over the left hemisphere anterior region at 390 and 500 msec and at the posterior temporal site at 258 and 305 msec as discriminating the noun and verb interpretations, respectively. A reanalysis of these data by Brown et al. (1979) using a principal components analysis modeled after that used by Molfese (1978) noted three regions of the ERP that discriminated nouns from verbs. These included the rising portion of the waveform following the initial large negative peak in the region of N150 that was larger over the left hemisphere posterior lead for nouns than for verbs, a positive peak that rose after 230 msec in which the response was larger to nouns than verbs at the posterior sites across both hemispheres, and, finally, a negative peak centered around 370 msec that characterized responses to nouns over the left hemisphere anterior and right hemisphere posterior sites. These anterior–posterior polarity reversals for nouns were also noted by Brown et al. (1980) who studied these effects across English and Swiss–German language users. They also used phrases containing homophones that served different syntactic functions within the stimulus phrases. Adults listened to sentences or sentence fragments such as, "A boatman rose" and "A pretty rose." In the first case, the word "rose" described an action and served as the simple predicate while in the second sentence, "rose" referred to a flower. As in the earlier Brown studies, anterior effects were found for nouns that had an anterior advantage while verbs had a more posterior effect. These studies and others (Molfese, 1983) indicate that the evoked potential procedures can discriminate between meaningful versus nonmeaningful materials (Molfese, 1979) and at least the syntactic categories of noun and verb as cued by context or the functions of the words as action and object (Brown et al. 1976).

The purpose of the present study was to assess the utility of a new technique for testing syntactic category comprehension during ERP recording procedures. A modification of the procedure first employed by Golinkoff, Hirsh-Pasek, Cauley, and Gordon (1987) was used. In their procedure, an infant observed two simultaneously presented video events presented side-by-side, while the infant listened to an audio message which matched one or the other of the displayed scenes. The audio message was played through a speaker placed midway between the two video screens while the infant's looking time at each monitor was videotaped. Analyses from this and later studies have noted that children under three years of age prefer to watch the screen that matches the linguistic stimulus more than the screen which does not match it. Such effects have been noted for studies of lexical and syntactic comprehension (Golinkoff et al., 1987; see Hirsch-Pasek & Golinkoff, 1993, for a review). In our ERP test procedure, however, only a single video monitor was used. During the presentation of the video scene, an audio message was presented that either matched the depicted scene or did not match it. ERPs were recorded from scalp locations over different regions of the left and right hemispheres during the audio presentation of various nouns and verbs. Each video scene depicted an adult manipulating an object. In half of the trials, the action was labeled with a verb as in "pour" or the object was named with a noun as in "milk." On half of the trials the labels were incorrectly assigned (as in the verb "bouncing" applied to the action of pouring or the noun "shoe" for the glass of milk).

In addition, this study used a match–mismatch task in order to test for differences in the processing of nouns and verbs. Such tasks have been used effectively in ERP studies and appear to note changes in ERP components across the time span of the ERP, but especially during its middle and later portions. For example, Posner et al. (1973) found that N1–P2 and P2–N2 amplitude differences decreased during match judgments when subjects viewed a series of uppercase single letters. A somewhat later occurring effect was noted by Thatcher (1977) who used *t* tests to compare amplitudes of individual data points along the ERPs across conditions and electrode sites. Thatcher found increased positivity in the 350- to 399-msec region for match vs. no match ERPs. Other researchers also noted effects in this region. For example, Friedman, Sutton, Putnam, Brown, and Erlenmeyer-Kimling (1988) found changes in the N400 component of the ERPs as a function of match vs. mismatch when subjects were required to make judgments on the basis of category, name, or physical identity. Bentin (1987) found similar amplitude differences in the ERP data with a reduction occurring in the region of the N400 following a matching event, while Harbin, March, and Harvey (1984) reported similar effects in the middle and later peak ERP regions for these conditions. An even later ERP effect was noted by Sanquist, Rohrbaugh, Syndulko, and Lindsley (1980) who required subjects to match words on the basis of phonological, semantic, or orthographic information and found a component centered around 500 msec that discriminated match from mismatch conditions, while a peak in the region of 300 msec discriminated the orthographic from the phonemic and semantic comparisons. Kok and Rooyakkers (1986) also reported a late ERP effect during a match vs. no match task. The N540 peak was noted as larger in the match than in the no match condition when subjects were asked to make judgments about physical comparisons. This effect was more negative over the frontal electrode sites and more positive at posterior sites. Thus, as noted here, a series of studies have noted that the ERP is sensitive to match vs. mismatch effects. In general, it appears that these effects are centered on the ERP in the region from 300 until 550 msec poststimulus onset.

The following hypotheses were tested. First, it was anticipated that the ERPs would change based on the word's syntactic category (noun versus verb) and that this change would occur over the left hemisphere. Second, it was anticipated that the ERPs would discriminate match from mismatch trials. Based on previous research with adults, children, and infants, it was expected that specific regions such as the P300 and N400 complex would vary in amplitude during the match and mismatch trials.

METHODS

Subjects. Eight female and eight male undergraduate adults (mean age = 23.8 years; range, 19–46 years; SD = 6.78 years) volunteered to participate in this study following approval by the University's Institutional Human Subjects Review Committee. All participants were native American English speakers. Handedness measures using the Edinburgh Handedness Inventory (Oldfield, 1971) were obtained for all subjects. Handedness laterality quotients ranged from −.29 to +1.0 with a mean of +.63 (SD = .37). Visual acuity was measured using a Rosenbaum pocket vision screener placed 14" in front of the subject. All subjects had normal or corrected vision of 20/30 or better in both eyes. Hearing was evaluated using a Zenith ZA-112A audiometer with Telephonics TDH 39-10 earphones. Each ear was tested separately using standard procedures to determine air condition thresholds across the frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 8 kHz. Hearing thresholds for all individuals were well within normal range (i.e., 20 dB SPL or less) across these frequencies. Mean ear difference scores ranged from 0 dB SPL to 6.7 dB SPL (mean = 1.82 dB SPL, SD = 1.95). All but two subjects had mean ear difference scores of 3.3 dB SPL or less. The higher mean ear air conduction threshold difference scores for these two subjects were due to elevated thresholds for their left ear at 4 kHz.

Stimuli. The visual and auditory stimuli consisted of videotaped presentations of actions performed with various objects (e.g., bouncing a ball) and a recorded voice saying one of four nouns or one of four verbs. Thus, every visual scene was accompanied by an auditory presentation of a noun or a verb (presented twice within the scene). Each auditory word either named the action or object depicted in the scene (match) or did not (mismatch). The visual scenes and the auditory stimuli for the Match and Mismatch conditions are presented in Table 1.

Constructing the videotape at Southern Illinois University–Carbondale first involved recording eight separate visual scenes. These scenes consisted of a female adult actor eating a cookie, pouring milk, pushing a toy car, patting a toy dog, bouncing a small ball, dropping a toy baby bottle, rocking a doll, and drinking from a cup. All scenes were uniform in terms of background (plain white) and camera distance from location of the action being recorded (5'). Once recorded, the eight scenes were edited to 5 sec in length. The intervals between scenes varied randomly from 3 to 4 sec. Each scene was presented twice within a block for a total of 16 randomly ordered scenes per block. Thus, each event occurred an equal number of times. Six different random block orders were then generated to yield 96 separate stimulus presentations.

The auditory portion of the videotape involved the recorded voice of a female adult speaker saying one of the following four nouns (i.e., "cookie, baby, bottle, doggie") or one of the following four verbs (i.e., "bouncing, pushing, pouring, drinking") in an exaggerated motherese fashion with a rising inflection on the first syllable and a falling one on the second. After editing using MacRecorder (Farallon) on a Macintosh SE30 computer, the resulting mean

TABLE 1
List of Stimulus Sequences Used

Video scene	Match: Noun	Match: Verb	No match: Noun	No match: Verb
Patting dog	Doggie			Pouring
Pushing car		Pushing	Cookie	
Eating cookie	Cookie			Bouncing
Pouring milk		Pouring	Doggie	
Bouncing ball		Bouncing	Bottle	
Dropping bottle	Bottle			Pushing
Rocking baby	Baby			Drinking
Drinking from cup		Drinking	Baby	

Note. An adult female performed the visual action in each scene and the auditory stimuli were spoken by an adult female.

duration for each word was 1276.6 msec for the verbs (SD = 30.97) and 1201.9 msec, (SD = 61.59) for the nouns. A t test for independent samples indicated no difference in word length between the two word types, $t(6) = 2.17, p < .073$. Peak amplitudes and stresses were also identical for the two word types. Individual edited words were then recorded onto the left channel of the stereo audio track of the videotape which contained the prior recorded visual scenes. Words either matched or did not match the visual scene. No scene was used on different trials to depict a match for both a noun and a verb (as illustrated in Table 1). For each visual scene, the word paired with that scene was presented twice with an interword interval that varied randomly between 2.0 to 2.5 sec. The first word of each pair occurred approximately 1 sec after onset of the visual scene. The right channel of the audio track of the videotape contained a square wave trigger pulse that was time locked to occur 100 msec prior to the onset of the word recorded on the left channel.

Procedures. Six silver-cup scalp electrodes (Grass E5S) were placed over left and right frontal, temporal, and parietal areas. Temporal electrodes were placed at T3 and T4 according to the Jasper 10–20 system (Jasper, 1958). Frontal and parietal electrodes were placed over the left and right sides of the head at 50% of the distance between the external auditory meatus and Fz and Pz, respectively. Linked ear electrodes (A1, A2; Jasper, 1958) were used as the reference. Eye movements were recorded from electrodes placed supraorbital and canthal to the right eye. Impedances for all electrodes including the ear references were within 1 kOhm of each other. Average pretest mean impedance across all sites was 1.76 (SD = .63) and the average post-test mean impedance was 1.78 (SD = .66). A schematic illustrating the electrode locations is presented in Fig. 1.

The videotapes were played through a Philips VHS cassette recorder (model VR6585) and presented via a Magnavox stereo television (Model RK4490 AK01) with a 25″ screen. The screen was centered 26″ in front of each subject. Auditory stimuli were presented at 75 dB SPL(A) peak intensity level. Participants were told that they would watch video scenes and hear pairs of words that either matched or did not match the video scenes. The subjects was instructed to indicate their match or mismatch decision by pressing the appropriate button on a decision box as soon as possible after hearing each word. The hands used to signal match and mismatch responses were counterbalanced across subjects. Prior to testing, all participants were given practice trials to accustom them to the procedure. The lights in the room were turned off so that only the TV screen was seen and then the test session began. The videotape presentation lasted approximately 20 min for each participant.

Auditory evoked potentials were recorded to each word presentation at a sampling rate of 5 msec for a duration of 1 sec using the EPACS program for the Macintosh. Therefore, a

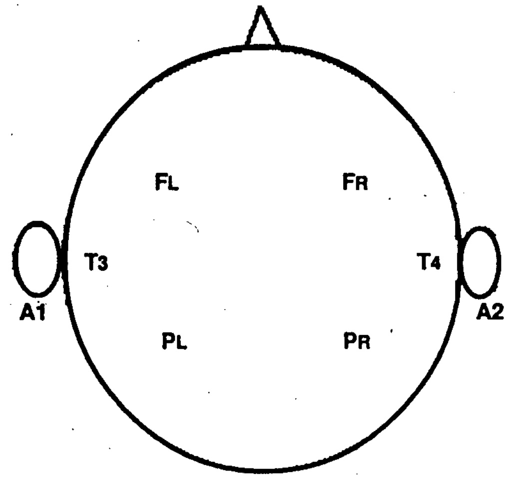

FIG. 1. Schematic representation of electrode locations used in the present study.

total of 200 data points were obtained for each ERP. Tektronix differential amplifiers (Tektronix Model AM502) were set at a gain of 20 K with filters set flat between .1 and 30 Hz. Once collected, the ERPs were subjected to an artifact rejection procedure. Scalp lead artifacts were defined as single trial voltage shifts in excess of 70 μV peak-to-peak. Data collected from the eye leads were examined to determine if additional trials should be rejected based on eye movement artifact. Eye movement artifact was defined as a voltage shift in excess of approximately 50 μV. This procedure did not result in any additional trials being rejected based on eye artifact for any subject. The percentage of trials rejected ranged from 1.04 to 22.39% with a mean of 11.16% (SD = 7.94). The percentage of rejection was approximately equal across conditions.

RESULTS

Behavioral responses collected during the testing session indicated that participants readily and appropriately identified match and mismatch trials. Error rates across subjects were less than 1%.

Following completion of the study, the averaged ERPs from the 16 subjects were submitted to two different analysis procedures. The first utilized a two-step process which involved the use of a principal components analysis (PCA) using the BMDP4M program followed by an analysis of variance, BMDP8V (Dixon, 1987). The second approach calculated a baseline-to-peak amplitude measure for each ERP. Those results were then input to a repeated measures ANOVA. A Greenhouse–Geisser correction factor was used.

Analysis 1: Principal Components Analysis–ANOVA

This analysis sequence followed the procedures outlined and used successfully in previous studies which have produced consistent and replicable results in programmatic research across a number of laboratories (Brown et al., 1979; Chapman, McCrary, Bragdon, & Chapman, 1979; Donchin, Tueting, Ritter, Kutas, & Heffley, 1975; Gelfer, 1987; Molfese, 1978a, 1978b; Molfese & Molfese, 1979, 1980, 1985; Ruchkin, Sutton, Munson, Silver, & Macar, 1981; Segalowitz & Cohen, 1989). For example, Molfese, in a series of papers investigating speech perception cues such as voice onset time and place of articulation, noted consistent systematic effects across studies for each cue (Molfese, 1978a, 1978b, 1980, 1984; Molfese & Schmidt, 1983). These findings have been independently replicated (Gelfer, 1987; Segalowitz & Cohen, 1989).

Once the PCA identified regions within the ERPs where most of the variability occurred, the ANOVA was used to identify the source of this variability. The analysis of variance accomplished this task by determining whether the variability reflected in the factor scores assigned for each factor to each averaged ERP differed as a function of changes in the independent variables. This procedure directly addressed the question of whether the ERP waveshapes in the region characterized by the most variability for any one factor changed systematically in response to the noun versus verb conditions and the match versus mismatch conditions recorded from the different electrode sites over each hemisphere.

Input to the PCA included 384 averaged ERPs with 24 ERPs obtained from each of the 16 subjects. The 24 ERPs were obtained from each electrode site (3) over each hemisphere (2), in response to each of the Match and Mismatch conditions (2), for nouns and verbs (2). The ERPs input to the PCA were composed of 100 time points that were sampled at 5-msec intervals beginning at word onset and continuing for the next 500 msec. The choice of the 500-msec window was based on two factors: (1) the standard deviation of the ERP centroid or grand average was noted to decrease markedly after 500 msec, indicating less variability in the ERP waveform after this point and, (2) preliminary analyses of pilot data based on the 500-msec window identified more systematic ERP changes than those using either a 700- or a 900-msec window. The PCA first transformed the data into a covariance matrix and then extracted seven factors which described distinct major patterns of variation in the data set. These factors, which accounted for 85.26% of the total variance in the entire data set, were chosen based on the Cattell Scree Test criterion (Cattell, 1966). The factors were then rotated using the varimax method. The centroid and the seven factors are plotted in Fig. 2.

As depicted by the topmost waveform in this figure, the centroid was characterized by a number of peaks throughout its time course. The first major peak encountered in the centroid was positive, with a peak latency of 65 msec. This peak was followed by a negative deflection whose greatest amplitude was attained at 125 msec and a positive deflection, which rose from the preceding negative peak to reach its greatest positive value at 215 msec. This in turn was followed by a gradual negative going peak which peaked at 310 msec. The remaining portion of the centroid was characterized by an alternating series of small positive and negative deflections occurring at 360, 395, 440, 465, and 490 msec, respectively.

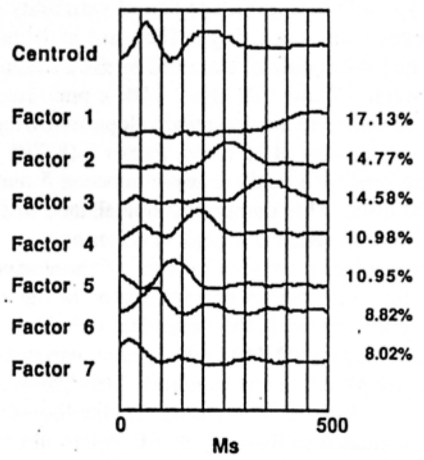

FIG. 2. The centroid and the seven factors identified by the PCA for the ERP data set. Positivity is up. ERP duration is 500 msec. The percentage of total variance accounted for by each factor is displayed to the right of that factor.

The seven factors identified by the PCA are represented by the seven lower waveforms in Fig. 2. These waveforms are for the most part characterized by a single discrete peak that characterizes the region of variability in the ERP waveforms reflected by that factor. For the purpose of identifying the contributions of the factors to the original waveforms, the factor loadings must rise above .30. Factor 1, which accounted for 17.13% of the total variance in the entire data set, was characterized by variability which began at approximately 350 msec after stimulus onset, reached a maximum at 445 msec, and ended at 500 msec. This factor appears to have contributed to the late positivity in the centroid. Factor 2 (14.77% of the total variance) was marked by a variation in the ERP waveform that occurred between 210 and 345 msec poststimulus onset, with a peak at 265 msec. This variability seems to be related to the amplitude of the large positive–negative peak sequence between 215 and 330 msec. The third factor extracted by the PCA characterized variability in the ERP waveform that occurred between 285 and 445 msec, which reached a maximum value at 355 msec. Factor 3 accounted for 14.58% of the total variance among all of the ERPs. This factor corresponds to the series of small negative–positive–negative deflections in the centroid. Factor 4, which accounted for 10.98% of the total variance, was characterized by variability between 150 and 245 msec, reaching a maximum value at 195 msec. This factor characterized the variability of the large positive wave that reached the peak at 215 msec. Factor 5 (10.95% of the total variance) was marked by variations in the ERP waveform between 95 and 185 msec (peak latency = 135 msec). This region of variability corresponds with the early large negative peak occurring at 125 msec in the centroid. The sixth factor (8.82% of the total variance) extracted by the PCA isolated variability that occurred between 45 and 120 msec, with a peak latency at 85 msec. This variability contributed to the downward slope following the initial small positive wave of the centroid at 65 msec. Factor 7 (8.02% of the total variance) was characterized by a positive wave between 5 and 75 msec with a peak latency of 30 msec. This component contributed to the initial portion of the positive wave that reached a peak at 65 msec.

The PCA generated factor weights for each of these seven factors. These weights reflected the contribution of each factor to the original averaged ERPs and subsequently served as the dependent variables in seven independent analyses of variance (ANOVA) with repeated measures for Word Function conditions (2) by Match (2) by Electrode Sites (3) by Hemispheres (2). As a conservative measure for decreasing the likelihood of Type 1 error, only effects with a chance probability of .01 or less are reported. Scheffe Critical F tests were used to test interactions. Table 2 provides a summary of the latencies, significant main effects, interactions, and comparisons associated with each factor. In the presentation that follows, the ERP effects are reported first for Word Function (Noun vs. Verb), then for Match vs. Mismatch, and then for Hemispheres (Left vs. Right) and Electrode Sites (Frontal, Temporal, and Parietal).

Noun vs. Verb effects. The ANOVA test of the factor scores for Factor 2 identified a main effect for Word Function, $F(1, 15) = 11.17$, $p = .0045$. As illustrated in the group grand averaged ERPs for nouns and verbs presented in Fig. 3, the positive peak (the second positive peak in the ERP waveform, P2) enclosed by the rectangle labeled "Factor 2" between 210 and 345 msec following word onset and centered around 230 msec was larger in response to presentations of the verb (dashed line) than in response to the noun stimuli (solid line).

Two interactions, a Match by Function, $F(1, 15) = 11.39$, $p = .0042$, and a Match by Function by Hemisphere, $F(1, 15) = 18.44$, $p = .0006$, were found for Factor 3. The latter interaction is illustrated in the graph of the factor scores for the left hemisphere (LH) responses to nouns and verbs during the Match and Mismatch conditions in Fig. 4 and the graph of the right hemisphere (RH) responses in Fig. 5. Here, the left hemisphere sites discriminated between the Noun and the Verb conditions for both the Match, $F(1, 15) = 92.687$, $p < .00001$, and the Mismatch conditions, $F(1, 15) = 24.063$, $p < .0004$, between 285 and 445 msec. The right hemisphere sites, however, were able to discriminate only between Verbs and Nouns in the Match condition $F(1, 15) = 13.674$, $p < .0024$. Additionally, the left and right hemispheres differed in the manner in which they responded to Verbs in the Match condition, $F(1, 15) = 23.839$, $p < .0004$. These effects are illustrated in the group averaged ERPs depicted in Fig. 6. For the Match condition, both the LH and the RH responses to the verb stimuli (dashed line) produced larger slow positive waves during this interval (as illustrated within the first two rectangles to the left of the figure) and appear well above the ERP response to the nouns (solid line). For the Mismatch condition, however, the LH ERP to the verb was characterized by a more negative wave and dropped below the ERP response to the nouns during this time interval. This is illustrated within the third rectangle on the left side of the figure. The RH response to the nouns and verbs do not appear to differ, as indicated by the closeness of the solid and dashed lines within this same interval. These effects can also be seen in the group averaged ERPs to all stimulus conditions across the six electrode sites as depicted in Fig. 7. Overall, during the Match condition on the left side of the figure, the ERP amplitudes elicited in response to the verb stimuli (dashed line) appear consistently larger than for the nouns (solid lines). During the Mismatch condition, however, the overlap between the ERPs for nouns and verbs is much greater.

TABLE 2
A Summary of the Significant Main Effects and Interactions Associated with Each Factor Obtained through the PCA-ANOVA Approach

Factor	Main effects and interactions	Comparison	Peak latency (msec)
1	Match		445
	Match × Electrode	F: M ≠ MM	
		T: M ≠ MM	
		P: M ≠ MM	
		M: F ≠ P	
		MM: F ≠ P, T ≠ P	
2	Function		265
	Match		
	Electrodes	F ≠ P	
3	Match × Function		355
	Match × Function × Hemisphere	LH (M): N ≠ V	
		LH (MM): N ≠ V	
		RH (M): N ≠ V	
		V (M): LH ≠ RH	
4	Match × Hemisphere	M: LH ≠ RH	195
5	Electrodes	F ≠ T, T ≠ P	135
6	Electrodes	F ≠ T ≠ P	85
7	Electrodes × Hemispheres	LH: F ≠ P, T ≠ P	30
		RH: F ≠ P, T ≠ P	

Note. LH, left hemisphere; RH, right hemisphere; F, frontal; T, temporal; P, parietal; M, match; MM, mismatch; N, noun; V, verb.

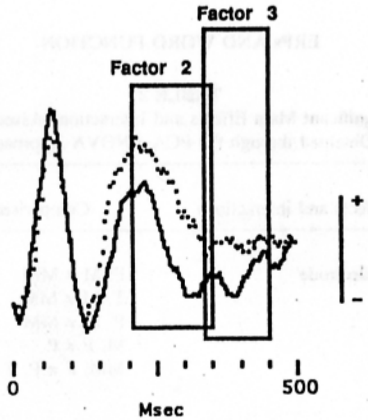

FIG. 3. The group grand averaged ERPs elicited in response to the auditory presentations of the nouns and verbs while individuals watched the videotaped scenes. The region of the ERP characterized by Factor 2 is demarcated by the rectangle labeled Factor 2,'' while that region characterized by Factor 3 is labeled accordingly. Stimulus onset began at 0 msec. Sampling continued throughout the 500-msec poststimulus onset period. Positivity is up. The calibration marker is 10 μV.

Match vs. Mismatch effects. A main effect for Match, $F(1, 15) = 14.95$, $p < .0015$, and a Match by Electrode interaction, $F(2, 30) = 11.62$, $p < .0002$, were noted for Factor 1. This factor, as noted earlier, characterized variability in the final portion of the ERP between 365 and 500 msec following stimulus onset. Post hoc Scheffe tests of the Match by Electrode interaction indicated that the Match and Mismatch responses differed at frontal, $F(1, 30) = 8.698$, $p < .0062$, temporal, $F(1, 30) = 8.018$, $p < .0081$, and parietal sites, $F(1, 30) = 77.354$, $p < .00001$. Additionally, the frontal response was different from the parietal response in both the Mismatch, $F(1, 30) = 10.670$, $p < .003$, and Match conditions, $F(1, 30) = 6.653$, $p < .014$. The temporal response was different from the parietal response in the Mismatch condition, $F(1, 30) = 14.825$, $p < .0009$. Group average ERPs illustrate this in Fig. 6. In general, the final portion of the ERP decreases in amplitude for the Match condition while it shows a more marked increase in positivity (an upward movement) for the Mismatch condition at the end of the waveform.

In addition to the Word Function effect already noted above, a main effect for Match, $F(1, 15) = 49.61$, $p < .00001$, was also identified for Factor 2.

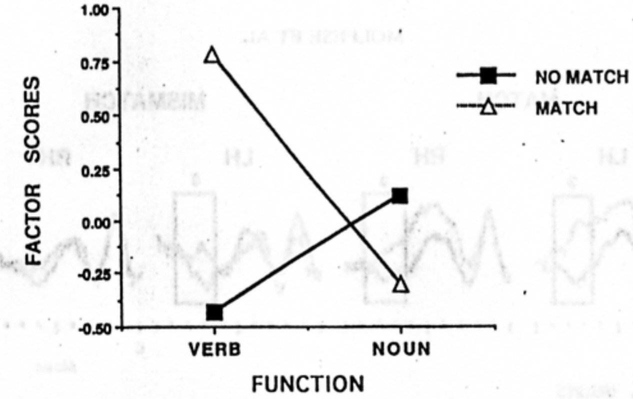

FIG. 4. The graphic representation of the Match by Function by Hemisphere interaction found for Factor 3 for the left hemisphere. Here, the ERPs recorded from over the left hemisphere sites discriminated between the Noun and the Verb conditions for both the Match and the Mismatch conditions between 295 and 430 msec. The factor scores or weights that served as the dependent variables in the analyses are the metric depicted along the ordinate of the graph.

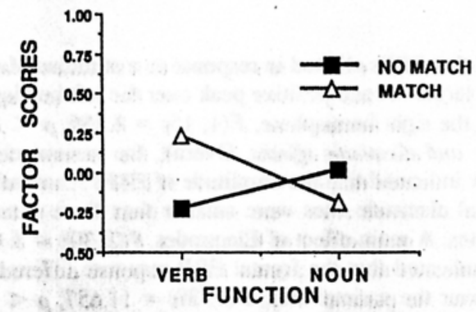

FIG. 5. The graphic representation of the Match by Function by Hemisphere, found for Factor 3 for the right hemisphere. The right hemisphere sites, were able to discriminate only between Verbs and Nouns in the Match condition. The factor scores or weights that served as the dependent variables in the analyses are the metric depicted along the ordinate of the graph.

This peak was larger in amplitude between 215 and 330 msec in the Match condition than in the Mismatch response. This contributes to a larger P2 response for the Match than for the Mismatch conditions. Variations in the P2 component are also reflected by the Match by Hemisphere interaction, $F(1, 15) = 8.70$, $p < .01$, which characterized the ERP activity which occurred between 155 and 235 sec as reflected by Factor 4. Post hoc Scheffe

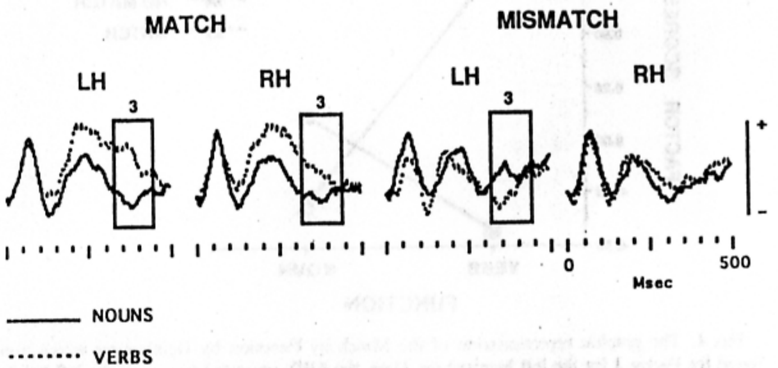

FIG. 6. The group averaged ERPs recorded from the left (LH) and right (RH) hemisphere electrode sites and elicited in response to noun and verb presentations during the Match and the Mismatch conditions. The region characterized by Factor 3 is labeled "3." Stimulus onset began at 0 msec. Sampling continued throughout the 500-msec poststimulus onset period. Positivity is up. The calibration marker is 10 µV.

tests indicated that ERPs elicited in response to a stimulus Match were characterized by a larger second positive peak over the left hemisphere than that recorded over the right hemisphere, $F(1, 15) = 8.196, p < .0115$.

Hemisphere and electrode effects. Overall, the various electrode effects outlined below indicated that the amplitude of ERPs recorded from over the lateral temporal electrode sites were smaller than those noted over frontal and parietal sites. A main effect of Electrodes, $F(2, 30) = 6.12, p < .0059$, for Factor 2 indicated that the frontal ERP response differed from that recorded from over the parietal area, $F(1, 30) = 11.657, p < .0022$. In Fig. 3, this effect is illustrated by somewhat larger positive–negative shifts in this region for the parietal than for the frontal recorded ERPs. There were also main effects of Electrodes for Factor 5, $F(2, 30) = 9.42, p < .0007$, and Factor 6, $F(2, 30) = 22.02, p < .00001$. Further post hoc Scheffe analyses for Factor 5 indicated that the frontal and temporal responses differed, $F(1, 30) = 11.368, p < .0024$, and the temporal response differed from the parietal, $F(1, 30) = 16.418, p < .0006$. In both cases, the negative–positive shift that occurred in the region of the N100 peak to the following P200 peak was larger for the frontal and parietal electrodes than for the temporal electrodes. Post hoc Scheffe analyses for the Electrode main effect of Factor 6 indicated that ERPs recorded over all three electrode sites differed from each other. Frontal recorded ERPs differed from temporal ERPs, $F(1, 30) = 43.875, p < .00001$, temporal ERPs differed from parietal ERPs, $F(1, 30) = 13.399, p < .0013$, and frontal recorded ERPs differed from parietal ERPs, $F(1, 30)$

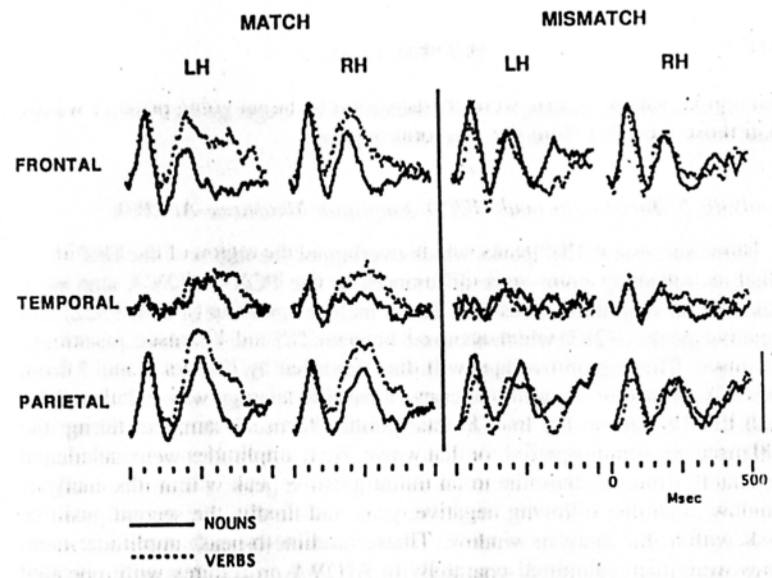

FIG. 7. The group averaged ERP waveforms from the 16 adults that were collected during the ERP test session. The ERPs were recorded from the frontal, temporal, and parietal regions of both the left (LH) and the right (RH) hemispheres in response to presentations of the auditory tokens while individuals watched the videotaped scenes. Stimulus onset began at 0 msec. Sampling continued throughout the 500-msec poststimulus onset period. Positivity is up. The calibration marker is 10 µV.

$= 8.781, p < .006$. In this case, as illustrated in Fig. 3, the positive–negative shift from the region of the P60 peak to the following N100 peak was largest for the frontal electrode sites, significantly smaller at the parietal electrode sites, and smallest at the temporal sites.

Finally, an Electrode by Hemisphere interaction was identified for Factor 7, $F(2, 30) = 5.85, p < .0071$. Post hoc Scheffe tests revealed that within the left hemisphere both ERPs recorded from the frontal site, $F(1, 30) = 23.940, p < .0001$, and the temporal site, $F(1, 30) = 8.219, p < .0075$, differed from ERPs recorded at the parietal electrode site. ERPs recorded at the frontal sites differed from those recorded at the temporal sites, $F(1, 30) = 7.925, p < .0084$, and the temporal ERP recordings differed from the parietal ERPs, $F(1, 30) = 27.967, p < .0001$, within the right hemisphere. As illustrated by the group ERPs in Fig. 3, this effect behaved in a similar fashion to that identified by Factor 6 in that the initial portion of the ERPs recorded from the frontal region were characterized by a larger positive going wave during the first 70 msec of the ERP than those recorded from the parietal region, which, in turn, were characterized by larger going positive waves than those recorded from the temporal region.

Analysis 2: Baseline-to-peak (BTP) Amplitude Measures–ANOVA

Three successive ERP peaks which overlapped the region of the ERP identified as reflecting noun–verb differences by the PCA–ANOVA step were selected for amplitude measures. These included positive (P254, P352) and negative peaks (N283) which occurred between 215 and 430 msec poststimulus onset. This region overlaps with that described by Factors 2 and 3 from the PCA procedure. In all three cases, a baseline average was calculated for each ERP based on the first 18 data points (90 msec) sampled during the 100 msec prestimulus period for that wave. Next, amplitudes were calculated separately from this baseline to an initial positive peak within this analysis window, then the following negative peak, and finally, the second positive peak within the analysis window. These baseline-to-peak amplitude measures were then submitted separately to ANOVA procedures with repeated measures for Match (2), Function (2), Electrode Sites (3), and Hemispheres (2). A Means Comparison procedure was used to test interactions (see Table 3).

First baseline-to-positive peak (P254). The peak latency for the first positive peak within the window of 215 to 330 msec poststimulus onset was 253.65 msec. Main effects were noted for Match, $F(1, 15) = 16.57$, $p < .001$, and Word Function, $F(1, 15) = 13.0$, $p < .0026$. Baseline-to-positive peak amplitudes were nearly twice as large for the match than for the mismatch condition while those elicited in response to verbs were approximately 50% larger than those elicited during the noun condition. In addition, a Match × Function interaction, $F(1, 15) = 9.27$, $p < .008$, and a Match × Function × Hemisphere interaction, $F(1, 15) = 5.335$, $p < .0355$, were noted. Means comparisons of the latter interaction indicated that the left hemisphere electrode sites discriminated between nouns and verbs during the Match condition, $F(1, 15) = 62.3$, $p < .0001$. The right hemisphere responded in a similar fashion, $F(1, 15) = 31.9$, $p < .0001$. Both hemispheres readily discriminated between verbs in the match vs. mismatch conditions, $F(1, 15) = 74.99$, $p < .0001$, and $F(1, 15) = 57.1$, $p < .0001$, for the left and right hemispheres, respectively. However, only the right hemisphere discriminated between the match and mismatch conditions when nouns occurred, $F(1, 15) = 9.99$, $p < .006$.

Baseline-to-negative peak (N283). The peak latency for the negative peak within the window of 215 to 330 msec poststimulus onset was 283.05 msec. Main effects were noted for Match, $F(1, 15) = 37.59$, $p < .0001$, and Word Function, $F(1, 15) = 17.87$, $p < .0007$. The baseline-to-peak amplitudes for this negative peak were larger for the mismatch condition and for nouns. In

TABLE 3
A Summary of the Significant Main Effects and Interactions Associated with Each Factor Obtained through the Baseline-to-Peak Analysis Approach

BTP	Main effects and interactions	Comparison	Peak latency (msec)
Positive 1	Match		253.65
	Function		
	Match × Function		
	Match × Function × Hemisphere	LH (M): N ≠ V	
		RH (M): N ≠ V	
		LH (V): M ≠ MM	
		RH (N): M ≠ MM	
		RH (V): M ≠ MM	
Negative 1	Match		283.05
	Function		
	Match × Function		
	Match × Function × Hemisphere	LH (M): N ≠ V	
		RH (M): N ≠ V	
		LH (MM): N ≠ V	
		RH (MM): N ≠ V	
	Function × Electrodes × Hemisphere	LH (F, P): N ≠ V	
		RH (F, T, P): N ≠ V	
Positive 2	Function		352.5
	Function × Electrodes × Hemisphere	LH (F, T, P): N ≠ V	
		RH (T, P): N ≠ V	

Note. BTP, baseline-to-peak; LH, left hemisphere; RH, right hemisphere; F, frontal; T, temporal; P, parietal; M, match; MM, mismatch; N, noun; V, verb.

addition, a Match × Function interaction, $F(1, 15) = 7.19$, $p < .017$, and a Match × Function × Hemisphere interaction, $F(1, 15) = 8.02$, $p < .013$, were noted. A Function × Electrode × Hemisphere interaction, $F(2, 30) = 5.82$, $p < .008$, was also found. Means comparisons for the Match × Function × Hemisphere interaction indicated that the two hemispheres, for both the nouns and verbs could discriminate between the match and mismatch conditions. The Function × Electrode × Hemisphere interaction noted that all electrode sites except the left temporal region generated different ERP responses to the noun and verb conditions.

Second baseline-to-positive peak (P352). The peak latency for the positive component within the window of 295 and 430 msec poststimulus onset was 352.5 msec. Analyses of variance of the baseline-to-peak amplitude measures identified a main effect for Function, $F(1, 15) = 7.68$, $p < .014$, and a Function × Electrode × Hemisphere interaction, $F(2, 30) = 6.02$, $p < .014$. The latter interaction indicated that all electrode sites except the right hemisphere frontal one generated larger ERP responses to verbs than nouns. This latter effect is illustrated in Fig. 8.

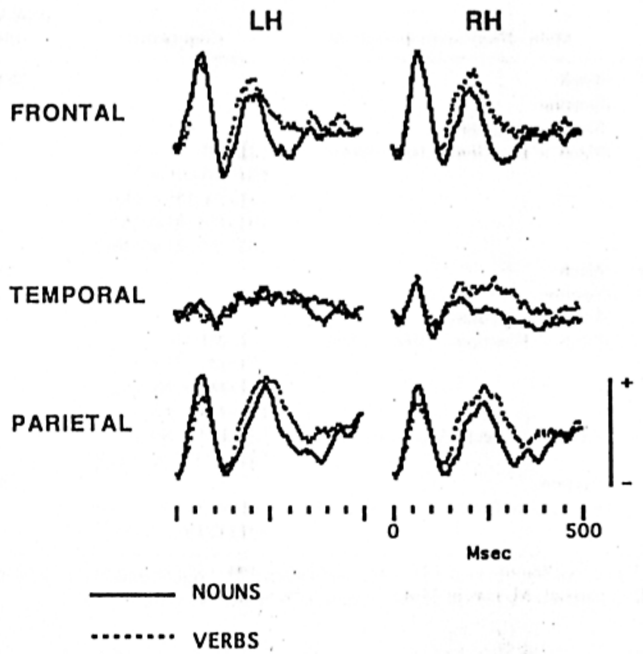

FIG. 8. The group averaged ERP waveforms from the 16 adults averaged for Hemispheres, Electrode Sites, and Word Functions. Stimulus onset began at 0 msec. Positivity is up. The calibration marker is 10 μV.

DISCUSSION

Both analysis approaches clearly indicate that different portions of the ERPs could discriminate between noun and verb processing during this experiment. The data, in fact, offer partial support the first hypothesis that ERPs would change based on the word's grammatical category and that this change would occur over the left hemisphere. Qualified support for hypothesis 1 comes from both analyses—those involving the PCA and those involving the more traditional baseline-to-peak amplitude measures. The P3 component (as indicated by the Match by Function by Hemisphere interaction that peaked at 355 msec for Factor 3 of the PCA) noted that the left hemisphere differentiated verbs from nouns, regardless of whether the distinction was made in the Match or the Mismatch condition. This would appear to support hypothesis 1. However, contrary to the hypothesis, the right hemisphere was also able to distinguish nouns from verbs although only for the Match condition. The BTP analysis of P3 also found that the left hemisphere could discriminate nouns from verbs under all conditions but noted that the right hemisphere frontal region could not. In addition, the P2 component which characterized a region of variability nearly 100 msec earlier (as indicated by the main effect for Function for Factor 2 in the PCA analysis), discriminated nouns from verbs across conditions and was carried out by both hemispheres across all electrode sites. Analyses of P2 and N2 using the BTP measures reinforce this point. Thus, both hemispheres initially appear to discriminate nouns from verbs but somewhat later in time may work separately to process them. While these differences in lateral patterns of responding are at variance with what was initially hypothesized, they may in fact provide important information regarding the dynamic temporal processing changes across successive time intervals which occurred rapidly within the brain while individuals were engaged in this task. It appears that both hemispheres in this task possess similar abilities to discriminate nouns from verbs, at least at one point in time. It will be interesting to follow up this work to determine what is the basis for these shifting patterns of lateralized and bilateral responses.

These patterns of results reflecting left and right hemisphere in noun–verb discriminations are somewhat similar to those reported earlier by Brown and his colleagues (Brown et al., 1973, 1976, 1979, 1980). Brown et al. (1976), who used left and right hemisphere frontal and temporal recording sites, noted left frontal and temporal differences which discriminated nouns from verbs. The left anterior site discriminated between nouns and verbs best at 390 and 500 msec, while the left posterior temporal site discriminated best at 258 and 305 msec. A later reanalysis of these data by Brown et al. (1979) using a principal components analysis noted three regions of the ERP that discriminated nouns from verbs. These included the rising portion of the waveform following the initial large negative peak in the region of N150 that was larger over the left hemisphere posterior lead for nouns than for verbs, a positive peak that rose after 230 msec in which the response was larger to nouns than verbs at the posterior sites across both hemispheres, and, finally, a negative peak centered around 370 msec that characterized responses to nouns over the left hemisphere anterior and right hemisphere posterior sites. These anterior–posterior polarity reversals for nouns were also noted by Brown et al. (1980). Both the present study and the series conducted by Brown and his colleagues point to the involvement of both hemispheres in discriminating nouns from verbs. Moreover, the latencies for these differences across both sets of studies occur during the central portion of the ERP, between 200 and 500 msec poststimulus onset.

Such similarities are especially interesting in spite of the marked differences in the procedures employed across these different studies. Brown et al. (1980) used more electrodes across the scalp while the present study used only three over each hemisphere. Brown noted anterior effects at electrode sites more laterally placed than the more midline frontal locations employed in the present study. In addition, the present study used a match/mismatch task while the series of studies by Brown *et al.* did not. Finally, auditory contextual cues were employed by Brown to establish interpretation of the target nouns and verbs while the present study used a videotaped scene with the evoking auditory words presented twice during the occurrence of each scene. Nevertheless, both the work by Brown and the present study identify consistent differences in ERPs elicited by nouns versus verbs.

Support for hypothesis 2 regarding sensitivity of the ERPs to match versus mismatch differences is based on the findings that several components of the ERP did discriminate match from mismatch conditions. Factors 4, 2, and 1 all indicated that the regions between 150–245 msec, 210–345 msec, and 350–500 msec, respectively, changed as a function of match or mismatch with a larger negative wave in the N1–P2 region as well as late in the waveform for the mismatch condition. The findings of the baseline-to-peak analyses also note amplitude differences at P254 (a P2 response) and N283 (an N2 response) as a function of matching. Posner et al. reported reduced P2–N2 amplitudes to matches at Cz. This is similar to the response noted in the present study as reflected by Factor 2. In terms of the scalp topography, the larger late negative peaks occurred over parietal regions, with somewhat smaller peaks noted over frontal and then temporal regions. Overall, as indicated by the Match × Electrode interaction, this effect was more pronounced for more midline leads (frontal, parietal) than for the more laterally located temporal leads.

Results related to simple topographic or electrode site differences characterized the first 200 msec of the ERP waveform (Factors 7, 6, and 5). For the most part, these differences reflected amplitude differences between the larger ERPs recorded from the more midline electrode sites (frontal and parietal) and the smaller ERPs recorded from the more lateral temporal sites (Factor 5). Additional amplitude differences reflected in the analyses showed larger responses recorded from frontal than parietal sites (Factors 2 and 6) and between the frontal, temporal, and parietal sites (Factor 2).

If one examines the general time course of the ERPs recorded during a trial, the earliest portions of the ERPs appear sensitive to simple ERP topographic differences in which the midline amplitudes are larger than those recorded over the lateral electrode sites and the frontally recorded ERP responses are larger than those recorded at the more posterior electrode sites. Subsequent to these early portions of the wave, the later ERP components appear to reflect cognitive decisions regarding matching and the more linguistic decisions concerning word type. Match related effects clearly can be seen throughout the waveform, beginning after the initial 150 msec following stimulus onset until the end of the ERP sampled period at 500 msec. Linguistic decisions regarding word type, however, appear more focused on the middle of the ERP, from 215 msec until 450 msec, with the left hemisphere lateralized effects most prominent between 295 and 430 msec, the period characterized by Factor 3 and the late positive peak identified through the BTP analysis at 350 msec.

Given the overall duration of the visual scenes (5 sec) and the auditory words (nearly 1.3 sec), the ERPs are clearly able to accurately and reliably detect differences between match and mismatch events and between nouns and verbs considerably before the end of both the visual scene and the auditory stimulus presented on each trial. These effects are consistent with findings from a number of other studies which indicate that brain responses discriminating events can be identified prior to completion of the evoking stimuli (Molfese, 1979). Clearly, individuals are able to rapidly perceive, process, and utilize brief and perhaps incomplete segments of information during sensory input to make accurate decisions some time prior to the end of a stimulus event. This underscores the rapidity with which linguistic and cognitive processing occurs and reinforces the view that such processing occurs during and not exclusively after even very brief (i.e., a second or less) events.

While the results as described above suggest strong support for the notion that ERPs can discriminate grammatical classes, some questions can be raised concerning possible confounds between these two stimulus classes. One marked difference that occurred between the nouns and verbs used in the present study was the presence of the inflection "ing" in the verbs which signaled their identity as verbs. An alternative explanation to that offered above is that the present results are due simply to the presence of this inflection. Another alternative explanation for the present findings is that these effects could be due to the acoustic differences between the nouns (which vary somewhat in their endings) and the verbs (which always end in "ing"). Two factors, however, argue against these alternative explanations. First, the differential ERP responses to Word Function differences occur long before the final "ing" of the verbs. While verb stimulus duration exceeded 1200 msec, all of the noun vs. verb effects noted in both analyses occurred between 200 and approximately 500 msec. Thus, the determining factor which provoked the differential ERP responses had to occur long before the final inflection. This is still possible because the verb roots (e.g., "bounce," "push," etc.) that overlap at least in part the ERP effects all characterize actions. Thus, the participants would in that first half-second hear enough of the stimulus to identify it as a noun or a verb. In fact, subject choice responses obtained during the testing session indicate flawless agreement with the investigators' assessment of correct responses. Thus, the presence or absence of the "ing" inflection can be dismissed as a confounding factor. A second point which also supports this conclusion comes from the findings of Brown and his associates. The latency of the components identified in the present study as discriminating between noun and verb events are comparable to those reported by Brown. As the reader will recall, Brown's studies utilized homophones which were cued to be perceived as either nouns or verbs. Nevertheless, portions of the ERPs recorded to the same auditory stimulus changed as a function of whether the word was identified as a noun or a verb by the subject. Given these points, the differential ERP response to nouns and verbs prior to the "ing" inflection and the similarities between the present findings and those of Brown, it appears that the ERP responses identified must, in fact, reflect grammatical class.

In summary, the present study clearly demonstrates that ERPs can be effectively used to discriminate nouns from verbs within a match/no match task. ERP responses recorded from over both hemispheres differentiate between nouns and verbs, although the advantage that one hemisphere has over the other (as defined by more areas which discriminate nouns from verbs) clearly changes across time, as suggested by both analysis procedures.

Given these results, it appears that the ERP procedure offers a means of studying when infants and young children first come to distinguish between nouns and verbs as syntactic classes. Alternatively, the ERP procedure may detect when the participant is involved in action versus object labeling. Theories of language acquisition are currently divided on whether infants begin the task of acquisition equipped with these universal categories (e.g., Pinker, 1984) or whether they construct these categories through their experience with the language (e.g., Bates & MacWhinney, 1987; Boom, 1991). Should ERPs recorded from young children be distinctly different for nouns versus verbs prior to the time that the infants produce many of each kind, it would suggest that these children are already categorizing the words that they know along these lines. Of course, a range of nouns (actors and non-actors) as well as a range of verbs (actions and nonactions) would need to be tested in order to rule out the presence of exclusively semantic categories.

Previous attempts to assess early infant cognitive and linguistic abilities have been limited, given the inability of young infants to perform reliably in overt motor tasks and tasks requiring verbal responses. ERP procedures, since they require no overt response from the subject, provide an ideal method of probing the earliest stages of infant syntactic categorization. Some success has already been made in using ERP procedures to augment our knowledge of the early development of speech perception (Molfese & Molfese, 1979, 1980, 1985), infant word acquisition (Molfese, 1989, 1990; Molfese, Morse, & Peters, 1990), and the presence of laterality in preterm and newborn infants (Molfese, 1972; Molfese & Molfese, 1979, 1980). The application of these procedures to the study of word functions, given the results of the present study, may provide new insights into other aspects of early language development.

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