5-1992

Event Related Potential Correlates of Picture-Word Matching

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Psyc 499 Honors Thesis

ABSTRACT

Behavioral as well as electrophysiological evidence suggests that words are processed differently than pictures in a number of tasks. We used within-form comparisons in order to control for effects of differential accessibility to separate cognitive representations by picture and word stimuli. A "same"-"different" judgement task was employed which is known to modulate certain event-related potential (ERP) measures. The purpose of the study was to identify ERP variance components that reflect comparison decisions as a function of stimulus type. Sixteen adult subjects were tested in this study. Stimuli were printed names and drawings of twelve common objects. In half of the trials, a word was followed by a drawing (W-P trials). In the other half, the reverse order was used (P-W trials). In W-P trials, subjects decided on the identity between their internal image of the drawing that was named by the word and the drawing stimulus. In P-W trials, comparisons were made on the name of the depicted object. ERPs were collected to the second stimulus. Manual RT was also recorded. Average ERPs were submitted to a Principal Components Analysis (PCA) -- Varimax Rotation procedure, followed by separate ANOVAs on the component scores.

Event Related Potential Correlates of Picture-Word Matching

Introduction and Reveiw of the Literature

Event related potentials (ERP) have successfully been used to identify language and cognitively related processes in individuals unable to respond. For example, they have been used to assess speech perception in newborn infants (Molfese & Molfese, 1979; 1985), as well as word discrimination abilities in 14-month-old infants (Molfese, Morse, & Peters, 1990). It has also proven useful to apply the technique with moderately retarded young adults who have impaired speech abilities (Molfese, Morris, & Romski, 1990). ERPs were used to demonstrate that TBI (traumatic brain injured) patients with limited output and expressive communication abilities comprehended aspects of words and sentences (Molfese, Morse, & Cornblatt, submitted).

It has proven extremely difficult to assess populations with limited communicational abilities through their behavioral output. Standard aphasia batteries typically rely on some type of behavioral (motor, manual, or verbal) information to indicate what the patient comprehends. For this reason it may not be possible to fully assess the cognitive abilities of these patients, infants, or mentally retarded people.

The basic assumptions made in interpreting an ERP component are that (1) the appearance of the component implies that, somewhere inside the head, neurons are activated synchronously; and that (2) what is observed on the scalp is the time fixed activity of some functionally unified part of the brain (Donchin, 1979).

The event-related potential (ERP) is a portion of the scalp-recorded EEG which is time-locked to some event of experimental interest. Because its voltage

amplitude is very small (usually on the order of a few microvolts) compared to the amplitude of the ongoing EEG (sometimes this amplitude ratio may be as low as 1:1000) signal averaging is used to improve the signal-to-noise ratio (McGillem & Aunon, 1987). Since the early demonstrations that the amplitude of certain portions of the ERP could be modulated by experimental manipulations designed to affect psychological variables (e.g., Sutton et al, 1965), the use of ERPs in the study of cognitive and linguistic processing has been rising rapidly. Thus, ERPs have been employed in the investigation of issues like speech-cue discrimination (Molfese, 1984; Molfese & Schmidt, 1984), processing of word meaning (Molfese, 1989; 1990), sentence processing (Kutas & Hillyard, 1980; McCallum et al, 1984; Wetzel & Molfese, 1991), and mental imagery (Farah et al, 1988; Stuss et al, 1988), among other things.

It should be stressed, however, that ERP measurements (e.g., visible deflections on the waveform, difference waves, or variance components) should by no means be identified with any specific process which fits the description of a construct defined in cognitive psychological terms. Such an assumption could be true only under ideal conditions. That is, only if (1) experimental manipulations have completely orthogonal effects on the psychological processes under investigation and, (2) ERP quantification procedures can reliably disentangle overlapping variance components which, in turn, were selectively affected by the experimental manipulations. Such an assumption, then, would be based on a principle of reductionistic isomorphism to the same extent as the postulation that any given ERP component bears a fixed correspondence to a neuroanatomically distinct intracranial generator (Fabiani et al, 1987, p.5). Rather, a clearly tentative position will be adopted here which holds that a

reliably identifiable ERP component reflects a change in the activity of some "processing unit with physical properties that allow its activity to be manifested on the scalp" (Coles, Gratton, Kramer, & Miller, 1986, p. 246).

It should also be kept in mind that what has been referred to above as an "ERP component" largely depends on many factors. It depends on the techniques used for recording the ERP over the surface of the scalp, as well as on the methods used for quantifying and establishing the component's responsivity to certain experimental manipulations. For example, placement of the reference electrodes is expected to affect the distribution of amplitude peaks over the scalp surface (Nunez, 1990). Such parameters as the time constant and/or filter settings, the resolution and speed of the analogue-to-digital converter, and the sampling rate used for digitizing the EEG signal may make important, yet not always appreciated contributions to determining the form of the extracted ERP waveform (Regan, 1989, pp.21-27).

Traditionally, it has been proposed that information processing involves the transformation of input data by processes that proceed sequentially (Sternberg, 1975). In recent years, these discrete models have been challenged by those who propose that information can be transmitted from one structure to another before the process performed by the first is completed (Miller, 1982). These continuous models imply that several processes can occur simultaneously and that a given process can operate on the partial information provided by another process. The measurements taken by cognitive psychologists (e.g., reaction time) are seriously limited in terms of their ability to test continuous theories. Changes in RT (reaction time) that result from a manipulation might be the result of many factors. In this case, psychophysiological measures may prove to be extremely useful because they can provide information about the

processes that intervene between input and behavioral output (Donchin, Karis, Bashore, Coles, and Gratton, 1986).

Responses to relevant word-picture matching manipulations are not restricted to any one single component or portion of the ERP. Studies which involve PCA, area measures, or slow wave (SW) analysis procedures identify changes in many components of the ERP. In a study done by Kok and Rooyakkers (1986), ERPs were recorded from ten male undergraduate students reacting to visual stimuli (pictures or words) presented in the left or right visual fields. All the subjects were right-handed and were screened for visual acuity and strabismus. Stimuli were selected from a pool of 30 natural concepts, e.g. dog-chair, which were presented either as words or pictures. Subjects were instructed to match these stimuli either on the basis of physical or categorical identity, with a previously presented memory list. The following experimental variables were varied: 1) Stimulus-type (Words and Pictures), 2) Visual field of presentation (LVF, RVF), 3) Match-type (Physical and Category identity) 4) Response (Match and Mismatch) 5) Sessions (Session 1 and Session 2). Each subject received 12 presentations of each trial type. The ERPs elicited by the lateral stimuli consisted of a sequence of topographically and functionally separable, negative and positive components, including N200, P300, N540, P720, and SW. Since pictures and words produced virtually identical match-mismatch results for the various ERP components, waveforms were collapsed over the two stimulus categories. It was found that mismatches were associated with much larger N540 waves than matches in physical identity trials, but not in category identity trials. A significant effect of Match-type was found for the P300 component reflecting that category-identity trials elicited larger P300 components than physical identity trials, at all lateral electrode sites. On this basis, the

authors proposed that the P300 component is a manifestation of the non-specific component of the visual evoked potential (P2).

A later study by Friedman, Sutton, Putnam, Brown, and Kimling (1988) reported similar effects in children and adults. ERPs were recorded from 2 young children and 25 adults in a modification of Posner's (1978) letter-matching paradigm that used pictorial stimuli. Subjects were required to decide whether two line drawings, presented sequentially, were the same or different on the basis of whether they were physically identical, shared the same name, or were in the same category. A prestimulus ERP recording period of 300 ms was initiated, after which the first pictorial slide (S1) was presented, followed 2000 ms later by the presentation of the second pictorial slide (S2). Exposure duration of each picture was 300 ms. The majority of the subjects were required to respond "same" with the dominant hand and "different" with the non-dominant hand. They found large, classical P300s to S1 in both children and adults which reflected the fact that S1 provided information as to what had to be matched in relation to the operative matching rule in order for S2 to be considered "same" or "different". Consistent with this interpretation was their finding that P300s to S1 were largest under category match instructions and smallest under physical match instructions, i.e., P300 was larger with the more elaborative the information processing.

The long latency components of the ERP can also serve as a sensitive indicator, systematically varying with comparison decisions. In a study by Harbin, Marsh, and Harvey (1984) twelve young (mean age = 21) and twelve elderly (mean age =71) males were presented with 5-word strings on each trial and were asked to decide whether or not the fifth word matched the other four. The first of two conditions (the "Identity" condition) consisted of four words that were identical to one another. The fifth word that was the same as the others on 15%

of the trials (match trials) and different on 85% of the trials (mismatch trials). In the second condition (the "Category" condition), the first four words were examples of a category. The fifth word was also an example of the category (i.e., a match) on 15% of the trials and was not a member on 85% of the trials (i.e., a mismatch). Subjects pressed a switch forward for matches and pulled the switch back for mismatches. The sampled EEG resulted in a total of 12 averaged ERPs per subject.

The results of this experiment indicate that the long latency components of the ERP are affected in complex ways. As expected, the mismatches in the Category condition produced a prominent negative peak at about 375 msec in young subjects and 450 msec in the elderly. They found that the LPC (late positive component) amplitude in young subjects was, in part, a function of event probability, with matches producing larger LPCs than mismatches. The latency of the LPC was greater for mismatches than for matches. For the young and old subjects, the N400 was most apparent in the Category mismatch condition.

Using such criteria as novel and familiar stimuli, other investigators have reported ERP differences to "before training" and "after training" (Ciesielske & French, 1989). They examined the neurophysiological correlates of learning in a visual template-matching task when stimuli were novel and the same task when it was overtrained to a high degree of automaticity. Eight male subjects (average age 27 years) were presented with three amoeboid patterns in vertical pairs -- either two identical or two different yielding nine combinations. The key observations in this study are that training in a visual matching task affects N2 significantly while having little impact in N1. The effect is a reduction of N2 latency and an increase of N2 amplitude.

A component of the ERP called processing negativity (PN) has also been proposed to indicate a matching or comparison process between the physical

features of a stimulus and an "attentional trace", an actively formed and maintained temporary neuronal representation of the features defining the relevant stimuli (Alho, Töttölä, Reinikainen, Sams & Näätänen, 1987). According to Näätänen (1982) the smaller the difference between the eliciting stimulus and that represented by the attentional trace, the longer the time that the stimulus is processed, and thus the larger in amplitude and longer the duration of the elicited PN. The relevant stimuli, perfectly matching with the attentional trace, and therefore eliciting the largest and longest duration PN, are selected for further processing. In the study, ten subjects (aged 20-35 years) were presented with relevant and irrelevant stimuli that differed in pitch, and the magnitude of this pitch separation was varied between different stimulus blocks. The results showed that PN is not elicited only by the relevant stimuli but even by irrelevant stimuli. Additionally, when the PN is larger in amplitude and longer in duration the more similar the irrelevant stimuli are to the relevant stimuli. This PN, however, was smaller than that to the relevant stimuli even for very small separations, reflecting high accuracy of the discrimination function of the attentional trace mechanism proposed to underlie selective listening.

The present study is a follow-up study to the one conducted by Molfese *et al*. (submitted). They recorded ERPs from the left and right hemisphere frontal, temporal, and parietal regions of 7 traumatic head injured adults while they participated in a receptive naming task. Subsequently, behavioral responses were obtained. Patients simultaneously viewed a series of pictures and listened to series of words. The words named objects, letters, or actions which either matched or did not match the computer displayed pictures. Thirty-six pictures depicting 12 letters, 12 objects, and 12 actions were selected and computer digitized from the Boston Diagnostic Aphasia Exam (BDAE), the Western Aphasia Battery (WAB), and the Peabody Picture Vocabulary Test

(PPVT). Adults were seated in front of a Macintosh computer that first displayed a picture and subsequently, within 2 to 5 seconds, an auditory stimulus. Pictures depicted either an object, letter, or action which either was named by the auditory stimulus (a match) or which did not name the picture (no-match). On half of the trials a match occurred between the name the adult heard and the picture they saw. No match occurred on the other half of the trials. Subjects were instructed to attend to the picture displayed on the computer screen and then to listen to the word presented during this time. Once the auditory stimulus was presented, they were to decide whether or not the word they heard named the picture on the screen.

Two regions of the ERPs, one bilateral and one lateralized to the right hemisphere frontal region, discriminated when a match occurred between the viewed picture and its auditory name versus those in which no-match occurred. One portion of the ERP in the region of the P300 component (a positive ERP component that reached a positive peak between 260 ms and 490 ms) discriminated between the match and no-match conditions across all stimulus conditions, electrode sites, and hemispheres. Despite the small number of subjects, PCA (principal component analysis) identified a reliable factor structure. When non-brain injured individuals were tested in a similar task, match and no-match responses were also found. The available ERP data, then, indicate that ERPs can be used effectively to discriminate between match and no-match conditions for simultaneously presented visual and auditory stimuli.

The present study examined match-mismatch effects in a non-simultaneous situation. Non-brain injured individuals were cued to think of one stimulus and then later view a picture or a word that either matched, or failed to match, that earlier cue. The study's major purpose was to identify systematic variation in the evoked potential wave forms that correlated with comparison

decisions. It was expected that matching would be reflected in a systematic way in the brain waves.

RESEARCH HYPOTHESES

1. An early component with posterior distribution was expected to reflect "match" versus "mismatch" differences in the imagery condition according to the finding of Farah et al (1988). This component would describe systematic ERP variation around the N1 deflection. The N1 deflection was expected to show increased amplitude in response to the test stimult that matched the image of the previously presented target stimuli.

2. Another component describing variability of voltage points in the next portion of the waveform was also anticipated to reflect "match"-"mismatch" differences (cf., Barret & Rugg, 1989; Farah et al, 1988). The same region centering around the P2 deflection was also likely to contain variability as a function of (test) stimulus type. However, given that opposite findings have been reported by different studies (Berman et al, 1991; Kok & Rooyakkers, 1986; Noldy et al, 1990) the direction of P2 amplitude modulation could not be predicted.

3. Further, effects of comparison decision were anticipated in the middle region of the ERP. Existing evidence from a number of studies suggested that these effects were associated with N4 (or N400) (Barrett & Rugg, 1989; 1990a; b) and P3 (or P300) (Friedman et al, 1988; Kok & Rooyakkers, 1986). Apart from peak latency, component identification was based on scalp distribution as well. Identification of the P3 component was based on the characteristic posterior maximum of component scores (e.g., Fabiani et al, 1987). Identification of the N400 component was expected to be more difficult given the reports for negative-going potentials in the same latency region that apparently show different scalp

distributions (Barrett & Rugg, 1990b, Stuss et al, 1983, Stuss, Picton, & Ceri, 1986). Frontally distributed negativities may be due to the superimposition of P300 components that show parietal maxima (Stuss, Picton, & Ceri, 1986). The presence of conditions that favour P300 components may affect the scalp distribution of late negativities revealed by analyses on component scores. for instance, under such conditions an Electrode Site main effect was suppressed (Polich, 1985, Experiment 2). Depending on the extent of spatial and functional dissociation among ERP components we considered the possibility that each might be principally represented by different variance components in the PCA. However, it was predicted that all these components (if readily identified in the ERP waveform) would generally show the same direction of amplitude modulation as a function of comparison outcome: increase positivity, or decreased negativity, in response to "matches" as compared to "mismatches".

4. Finally, on the basis of some indications pointing to the presence of a late positive deflection that may show increased amplitude following "mismatches" versus "matches" (Bentin, 1987; Harbin et al, 1984) we considered the possibility for obtaining a component with similar characteristics.

METHODS

Subjects

Sixteen adults (eight males and eight females) were tested in this study. Subjects were volunteers recruited from the Psychology Department's undergraduate psychology courses at Southern Illinois University at Carbondale. Their participation was contingent upon meeting a set of criteria evaluated in a preliminary screening. The criteria included: age between 18 and 36 years, normal vision, and a score of +45 or higher on the Edinburgh Handedness

Inventory (Oldfield, 1971; see Appendix B). The latter criterion was prompted because prior research has indicated that handedness can affect substantially the ERP waveform obtained in response to linguistic stimuli (Molfese, Linville, Wetzel, and Leight, 1985). In addition, individuals with previously sustained head injuries leading to any loss of consciousness, with reported seizure activity, drug or alcohol abuse, or any kind of learning disability, were not included in the study. Additionally, an individual was not tested if he/she reported that he/she was currently receiving, at the time of the test, medication which is known to influence central psychophysiological processes. Vision was assessed with the Rosenbaum Pocket Vision Screener (see Appendix C). All individuals had uncorrected visual acuity of 20/40 or better in both eyes. Past medical and educational history was obtained from all subjects (see Appendix C). These criteria were based on the rationale that control of the underlying variables would reduce the influence of unwanted sources of variability on the ERP data. A total of 74 individuals were screened in order to obtain 25 who met these criteria. Forty five individuals were excluded from the study because they reported having sustained some form of head injury during their lifetime. The remaining four individuals were excluded on the basis of their scores on the Edinburgh Handedness Inventory. ERP data were obtained from these twenty-five individuals. The data from nine of the twenty-five tested participants had to be excluded due to the following reasons: three subjects were excluded due to reasons not related to the experiment, one subject was excluded due to excessive artifact contaminations of the ERP records, three others were excluded due to unacceptably high electrode post-test impedances, and the remaining two -- due to a computer malfunction during data collection. Individual and group subject information is summarized in Table 9 (Appendix I).

Stimuli

Pictures, depicting twelve concrete, common concepts and their respective names, served as stimuli. Concepts were selected so that all items were: (1) "unambiguously picturable", (2) exemplars from the Battig and Montague (1969) set of category norms, and (3) concepts at the "basic level of categorization" (Rosch, 1975). Pictorial stimuli were taken from a set of 260 pictures based on standardized norms developed by Snodgrass and Wanderwart (1980).

The picture stimuli used in the present study were selected on the basis of three criteria: (1) they had single-syllable names, (2) their respective ratings for image agreement (Information Statistic H) fell below the 25th percentile of the distribution of scores for the whole set of 260 pictures, and (3) their scores on name agreement fell above the 75th percentile on the corresponding distribution for the total sample of pictures. The twelve pictures that satisfied all three criteria were used in the study. Scores on three additional measures -- visual complexity, familiarity, and Kucera and Fransis (1967) frequency of occurrence for the picture's most common name -- are also available for all 12 pictures. This information may enable the post-hoc clarification of analysis outcomes. All normative values for the stimuli employed in this study were taken from data reported by Snodgrass and Wanderwart (1980, Appendix C). Image agreement was defined by Snodgrass and Wanderwart (1980) as the degree of correspondence between the subjects' own mental image of an object formed in response to the object's most common name and the picture of that object which was subsequently presented. It was measured for each subject on a 5-point scale with a score of "1", indicating very low, and a score of "5", indicating very high image-to-picture agreement. Ratings on name agreement were obtained by instructing subjects to report the name that they first "thought about" upon

viewing a given depicted object. An information statistic (H) was preferred over another measure- the percentage of subjects responding with the most common name for any given picture. The former measure (H) takes into account the number of different names given to each picture, as well as the proportion of subjects giving each picture a different name. Familiarity and visual complexity were defined as the subjective frequency of encountering each depicted object in each subject's own experience, and the subjective estimate of the amount of detail or intricacy in each picture, respectively. Both measures were assessed by self-report ratings on two 5-point scales, with scores of 1 indicating low, and scores of 5 indicating high familiarity or complexity. Pictured objects were presented at their most frequent or "natural" orientation, whenever such an orientation existed, in order to reduce the necessity of any additional mental operations (such as mental rotation) in the matching process. Pictures were digitized, using Thunderscan Software, and stored as Mac Paint documents. Some pictures were further processed using Super Paint (v 3.0) in an effort to bring their size closer to the average size of all the drawings. All pictures were black drawings on a light gray background subtending a visual angle that ranged from 1.75° to 4.60°, vertically, and from 2.00° to 5.10°, horizontally, at a viewing distance of 90 cm (see Appendix E).

12 concrete nouns, corresponding to the most common names given by the subjects in the Snodgrass and Wanderwart (1980) study to each of the 12 selected pictures, were used as word stimuli. The latter were constructed in uppercase letters for presentation on the computer screen with Superpaint (v 3.0). They were all presented vertically along the vertical meridian subtending 1.91°to 4.51°vertical and 0.85°horizontal visual angle. A square frame made of black, nontransparent tape was attached to the center of the screen and remained there throughout the testing. The frame subtended 6.03° visual angle.

Table 8 (see Appendix F) lists the words/names of the 12 pictures with their respective scores on the five measures described above. Summary information is also presented for comparisons between the subset of 12 pictures and the total sample of 260 pictures.

Exposure duration for all stimuli was set at 1300 msec. in order to ensure ample viewing time and also avoid a situation where stimulus offset falls within the ERP-collecting epoch. All stimuli were presented centrally on the screen from a viewing distance of 90 cm. The square frame fully enclosed each individual stimulus during presentation.

Procedures

Subjects were solicited through the Introductory Psychology class subject pool of Southern Illinois University at Carbondale. Testing was completed in two parts. In part 1, individuals who were willing to participate went through a preliminary behavioral screening procedure. They were asked to sign up on a Research Participation Form if they considered themselves right handed and if they did not wear any visual aids (glasses, contact lenses). Several groups of five to twelve individuals had to be screened in order to accumulate a sufficient number of subjects who met the criteria of the study. In each behavioral screening session, individuals were first asked to sign an informed consent form (see Appendix G). The experimenter, then, briefly described the study and its purposes, making clear that only individuals who met the criteria of the study could participate in the second part which involved electrophysiological testing and was to be scheduled for a different day. Subjects were then asked to complete an Edinburgh Handedness Inventory form, and a self-report questionnaire that asked for information on past and current medical and neurological health (see Appendices B and D for copies of the two forms).

Finally, they were escorted to a different room where they were given the vision screening test individually (see Appendix C for a copy of the Rosenbaum screener).

Part 2 was scheduled for a different day. On that day, subjects were taken to a separate room for electrode application. Tin ear electrodes (ECI) filled with electrode gel (ECI), to be used as linked references (A1/A2), were first attached. Earlobes were cleaned with an alcohol prep pad (American Hospital Supply) and then scrubbed with a pumice paste (Omni-Prep) to remove oil and dead skin cells. Then, two sites, one laterally and one just below the right eye, were scrubbed. Silver eye electrodes (Beckman Model 650437) were attached over the cleaned areas with the aid of an adhesive collar. Scalp EEG was recorded using a standard electrode cap (Electro-cap International, Inc.-ECI) of the appropriate size for each individual. Electrode cap application involved taking a set of scalp measurements first. All measurements and the respective points below were in accordance with the 10/20 system of the International Federation (Jasper, 1958). (1) The distance between the nasion and the inion was measured over the vertex along the midline of the head. A water-soluble pen was used to make two marks along this line, one at a point located at 10% of the total nasion-inion distance up from the nasion (Fp), and a second at a point 50% of the same distance (Cz). (2) A measurement was taken on the coronal plane from the left to the right external meatus. Two points, located at 10% of this total distance up from each external meatus, and a third point located midpoint along this line were then marked (T3, T4, and Cz, respectively). In this way, precise alignment of the first set of measurements along the midline of the head was cross-checked by using the location of the second Cz mark on the coronal plane as reference. Whenever the two Cz marks did not overlap, an adjustment was made in the position of the cap. (3) The distance between the 10% marks

located above the external meati, via Fpz was measured; Fpz should be found in the middle of this distance. (4) The circumference of the head was measured at the horizontal plane passing through Fp, T3, and T4. Two points at 5% of the total circumference were marked on either side of Fp (Fp1, Fp2). These two marks served as fixed reference points for the placement of the front of the electrode cap. The cap was then fitted on the head by first placing the centers of the Fp1 and Fp2 electrodes on the forehead exactly above the Fp1 and Fp2 marks, respectively. The two electrodes were held in place by two adhesive, foam collars placed around them. Then, the Cz electrode was placed over the corresponding vertex mark and was held there by the experimenter while the rest of the cap was fitted on the head. An elastic strap was then attached around the subject's chest to hold the electrode cap in place. The second part of the electrode cap application involved the actual electrode site preparation. Twelve sites were gently abrased with a sterile, blunted hypodermic needle (ECI) filled with electrode gel (ECI). These sites corresponded to F3, F4, F7, F8, T3, T4, T5, T6, C3, C4, P3, and P4 scalp locations of the 10/20 System. An effort was made to have all electrode impedances below 5 KOhms, with a range of less than 1 KOhm. The range and mean values of interelectrode impedances, measured before and after the recording session, are summarized for each subject in Table 10 (Appendix K). Earlobe electrode impedances are also provided separatelly. Special care was taken to ensure that contact impedances of the two ear leads did not differ more than 1 KOhm from each other. This was believed to be very important since the consequences of obtaining scalp electrophysiological recordings, using linked reference electrodes with large and varying resistance differences within and across subjects can be rather severe. This situation might lead to one or the other reference electrode becoming the actual reference, rather than the average of the two ear electrodes (see Nunez, 1990, pp.26-8, for

a discussion on this issue). In light of this and in keeping with standard laboratory procedures, electrode impedances were measured before and after testing to ensure that impedance values were reasonably stable throughout the recording session.

During the recording session, all of the electrodes were connected to a Grass Bio-Potential isolator model IMEB2-INT 25, which was, in turn, connected to a Grass Model 12 Neurodata Acquisition System of 13 amplifiers, powered by a Grass RPS 107 Regulated Power Supply. All amplifier channels used for EEG recording had been individually calibrated prior to the study so that maximum output jitter between amplifiers did not exceed 0.5 μV. As an àdditional precaution, the order of electrode input into the amplifiers was counterbalanced across subjects using the Latin Square method to control for possible differences in signal processing characteristics between recording channels. Gain settings were at 20,000 for scalp and ear channels, and at 5,000 for the eye channel. Amplifier filters were set at 0.1 Hz and 30 Hz corresponding to 50% (3db) low- and high-frequency cutoff points, respectively. The 60 Hz notch filter was also engaged. The amplified signal was then sent to a 12-bit analog-to-digital (ATD) device (Metaresearch Benchtop, Model 2048). Next, the digitized signal was input to a Macintosh SE microcomputer for further analysis and storage. A modified 8-channel Tektronix 511A Storage Oscilloscope was used to monitor all channels of ongoing EEG and EOG activity during the test session. The digitized visual stimuli were presented on the 9" screen of a Macintosh SE/30 microcomputer. The same program that delivered the stimuli to the subject, also generated a 1.650 V square wave signal, that triggered the Macintosh SE to start collecting an EEG epoch 100 msec. before each stimulus onset.

When the electrode application was completed, the subject was escorted to a small, sound attenuated testing room and seated in a comfortable armchair

in front of the Macintosh SE/30 microcomputer. The center of the screen was at the same level with the subject's eyes. Electrophysiological testing was conducted individually and was completed on a single day. After reading the instructions to the subject, the testing-room illumination was reduced to a low and constant level that was maintained throughout the testing session. These manipulations were intended to reduce the likelihood of blinking, and help subjects focus on the screen.

Next, a series of 8 practice trials was given to the subject, which consisted of the presentation of one stimulus pair in each of the four combinations of the stimulus conditions. The four different words and the four different pictures that were presented in the practice session were not used in any of the subsequent experimental sessions. Experimental trials were given in two sessions of 96 trials each. Each session included a single type of stimulus pair (either Word-Picture, or Picture-Word). Further, different instructions were given to subjects in each session: a Naming instruction was always given for Picture-Word trials, whereas an Imaging instruction was always used in the Word-Picture session (see Appendix H for a copy of the instruction sheet that was read to subjects).

Four blocks of 24 trials each were given in both sessions. Each block contained an equal number of trials with respect to Comparison Outcome (Match or Mismatch trials) and repetition of individual stimuli (either pictures or words) either as S1, or S2. Specifically, there were 12 Match and 12 Mismatch trials in each block. Further, within each block, each concept was repeated with an equal frequency: (1) as a picture and a word, (2) as S1 and S2, and (3) as a matching and non-matching S2. That is, each concept appeared two times as S1 and two times as S2, once ending as a match to S1 and once ending as a mismatch to S1. The order of pairs was randomized within blocks and a different random sequence was employed for each block. The order of experimental sessions was

counterbalanced across subjects. Thus, Comparison Outcome conditions were balanced with respect to the repetition rate of individual items (pictures and words), as well as to the repetition rate of different stimulus pairs. Instruction conditions were matched using the same criteria, but this time applied to stimulus concepts (either pictures or words). This step was taken in order to control for the possibility that ERP differences between conditions might arise from item-specific (e.g. perceptual) characteristics.

In addition, non-matching pairs were based on independent random pairings of the experimental items for each subject. This step was taken in order to control for possible confounding effects arising from any systematic pairing of items across subjects. It was anticipated that with this manipulation such biases would be randomly distributed across subjects and thus eliminated through group averaging. Finally, for each individual the same non-matching pairs were used across all blocks of trials. For example, for a given subject "fork" (either as a picture or as a word) always followed "pear" (word or picture) in "mismatch" trials.

Throughout the testing session, the Macintosh Computer keyboard rested on the subject's lap. Subjects were told to rest their left index finger on the key labeled "z", and their right index finger on the key labeled "/". Half of the subjects were instructed to respond with their right hand whenever they detected a Match and with their left hand to the Mismatch trials; the reverse held for the other half of the subjects.

After the practice session, the subject began the experimental trials by pressing the "Return" key. Each trial started with the presentation of a short message in the center of the screen, prompting the subject to initiate a trial by pressing the "<return> key when ready". Immediately after pressing the <return> key a blank screen appeared for a randomly varying interval of 5 to 6 sec. Given that trials were subject-initiated, this period essentially corresponded to a

counterbalanced across subjects. Thus, Comparison Outcome conditions were balanced with respect to the repetition rate of individual items (pictures and words), as well as to the repetition rate of different stimulus pairs. Instruction conditions were matched using the same criteria, but this time applied to stimulus concepts (either pictures or words). This step was taken in order to control for the possibility that ERP differences between conditions might arise from item-specific (e.g. perceptual) characteristics.

In addition, non-matching pairs were based on independent random pairings of the experimental items for each subject. This step was taken in order to control for possible confounding effects arising from any systematic pairing of items across subjects. It was anticipated that with this manipulation such biases would be randomly distributed across subjects and thus eliminated through group averaging. Finally, for each individual the same non-matching pairs were used across all blocks of trials. For example, for a given subject "fork" (either as a picture or as a word) always followed "pear" (word or picture) in "mismatch" trials.

Throughout the testing session, the Macintosh Computer keyboard rested on the subject's lap. Subjects were told to rest their left index finger on the key labeled "z", and their right index finger on the key labeled "/". Half of the subjects were instructed to respond with their right hand whenever they detected a Match and with their left hand to the Mismatch trials; the reverse held for the other half of the subjects.

After the practice session, the subject began the experimental trials by pressing the "Return" key. Each trial started with the presentation of a short message in the center of the screen, prompting the subject to initiate a trial by pressing the "<return> key when ready". Immediately after pressing the <return> key a blank screen appeared for a randomly varying interval of 5 to 6 sec. Given that trials were subject-initiated, this period essentially corresponded to a

minimum ITI. Then, the blank screen was replaced by the target stimulus screen that stayed on for 1300 msec. It was followed by a second blank screen occupying the whole length of the ISI that lasted for 5-6 sec. Finally, the test stimulus was presented for 1300 msec. and 1 sec later followed by the same message that prompted the individual to initiate the next trial.

During stimulus presentation the rectangular frame remained at the center of the screen, marking where stimuli were to appear. The frame aided subjects in maintaining their fixation on the center of the screen throughout the testing session. Before the Imaging-instruction session subjects were given hard copies of the Picture stimuli and told to look through them carefully, trying to remember how these particular drawings of the objects looked because they would be asked to draw them after the session. Next, the sequence of events during that session was described to them. They were instructed to form the image of the object which was named by the word they saw on the screen (as the target stimulus), and, upon presentation of S2, they were to decide whether their image matched the object whose picture then appeared on the screen (as the test stimulus). They were also told that their images had to be clear and vivid, resembling the drawings they had just seen as much as possible. They were also asked to project their image within the rectangular frame on the center of the screen. After the end of that session, the subject was given a note pad and was asked to draw the objects he/she had just seen as he/she remembered them. In the Naming-instruction session, subjects were asked to covertly name the object whose picture appeared on the screen, keep that name in their mind, and, upon presentation of the word-test stimulus, decide if the two names matched or not. It was also stressed to all subjects that trial order was completely random, thus they should not make attempts to predict what the next trial would be in terms of either Match/Mismatch or Word/Picture order. Subjects were finally asked to

make their response as fast as they could immediately after the S2 appeared on the screen, but without compromising with response accuracy. After the 96th trial a screen message informed the subject of the end of the first session, telling him/her to wait for further instructions.

Subjects were asked to relax their jaw and face muscles, not move their eyes when a stimulus was on the screen, and try to keep their eyes in the center of the square frame. They were also asked to avoid blinking between the presentation of the first stimulus and before the beginning of the next trial. Subjects were told that they could stop the experimental session at any point and for any reason by not pressing the <return> key to begin a new trial. Total testing time, including practice, was approximately 60 minutes.

The program that controlled stimulus delivery was set to consider any trial in which a key-pressing response had occurred before S2 onset or after S2 offset as a no-response trial. Double responses were also discarded. The same program also collected the subject's behavioral responses and created a report with accuracy and reaction time data for each trial, as well as individual summary statistics (Mean, SD) for all trials in which a valid response was made.

ANALYSES

ELECTROPHYSIOLOGICAL DATA

Individual ERPs were digitized online at 5 msec. intervals (sampling rate = 200 Hz), with sampling beginning 100 msec. before the onset of S2, and continuing for 1200 msec. following onset. This interval and sampling rate were selected on the basis of prior published work, indicating that the most significant phasic variability in the brainwaves of adult subjects in related tasks occurs within

this time window (Barrett & Rugg, 1990b; Kok & Rooyakers, 1986; Molfese, Morse, & Cornblatt, in press). The 100 msec. (20 data points) of prestimulus EEG activity was used to obtain baseline estimates across all ERPs. All digitized values were stored using the EPACS software package (Molfese, 1988) on a Macintosh SE microcomputer.

After testing, individual trials for which either an incorrect key-pressing response was given, or response latency did not fall into a prespecified interval (130 to 800 msec.), were manually rejected for any given subject. The interval was set on the basis of the range of reaction time performance of five subjects during pilot testing for the present study. The remaining single-trial ERPs were submitted to a two-step artifact rejection procedure: first, trials on which the peak amplitude value in the eye channel exceeded 48 μV were rejected manually; second, the eye-artifact free trials were subjected to an EPACS routine in order to further clear the data from large myogenic-artifact contamination. If such an artifact (operationally defined as a peak-to-peak voltage level larger than 100 μV) occurred in any one electrode channel during the 1200 msec. poststimulus period, all of the ERPs collected across all the electrode sites for that trial were discarded automatically. The percentage of trials that had to be excluded following these criteria ranged from 12% to 49.5% across subjects (for details see Table 11, Appendix L). Data from subjects with overall rejection rates larger than 50% were not included in further analyses. As Table 11 shows, the mean number of single-trial ERPs that was included in each subject-average was essentially equal across experimental conditions. Balanced average ERPs, with respect to the number of single-trial ERPs comprising the average, ensured comparable signal-to-noise ratios for the different experimental conditions. Overall, each average ERP was computed from 33 single-trial ERPs (range: 19-45), a number which can be considered sufficiently large to keep the reliability of

the obtained component structure high by reducing the amount of autocorrelated noise present in the individual average ERPs (Fabiani et al, 1987, pp. 39-40, 48).

Following artifact rejection, single-trial data were averaged separately for each of the 12 electrode sites and each of the 4 stimulus/trial conditions. In this manner, 48 averages were obtained for each subject, resulting in 768 averaged ERPs for all 16 subjects. Each average contained 240 time points (representing 1200 msec. of poststimulus recorded activity). The number of time-points per ERP was subsequently reduced to 120 by sampling every other point. In this way the ratio of averaged ERPs to time points was 6.23. This is close to the ratios suggested for PCAs when applied to ERP data (Picton & Stuss, 1980). One additional procedure was employed in order to further "clean" the data from the effects of unwanted sources of variability. Data were submitted to a program routine designed to adjust for possible baseline shifts among recording channels. This was conducted separately for each ERP, and across all subjects in an effort to reduce this source of error variance.

Data were then submitted to a two step analysis procedure which involved the use of a Principal Components Analysis (PCA), first, followed by univariate ANOVAs, conducted separately on the component scores calculated for each Principal Component. The basic logic behind the use of PCA on ERP data rests on the idea that when voltage amplitudes of two or more time-points covary substantially across subjects and experimental conditions, there is an increased likelihood that these points are influenced by a common process. It follows, then, that if one obtained the variance-covariance matrix of all time-points that make up the ERP waveforms, points sharing a large enough amount of variance would be clustered into more or less discrete groups, each describing an independent component (Wastell, 1981). Although there are a variety of different analysis procedures which could be used to analyze ERP data (see for example, Coles,

Gratton, Kramer, & Miller, 1986, pp. 196-8), a decision was made to utilize a multivariate approach that has produced consistent results in programmatic research across a number of laboratories (Brown, Marsh, & Smith, 1979; Chapman, McCrary, Bragdon, & Chapman, 1979; Donchin, Teuting, Ritter, Kutas, & Heffley, 1975; Gelfer, 1987; Molfese & Molfese, 1979, 1980, 1985; Ruchkin, Sutton, Munson, Silver, & Macar, 1981). Such studies indicate that the PCA procedure has proven successful in identifying regions of the ERP that account for most of the variability that occurs across subjects and ERPs. In this way PCA offers a more parsimonious description of the data by reducing the original set of measures (ERP time points) to a limited set of more "meaningful" and informative principal components. Among the advantages of the PCA procedure is the fact that it is not based on any assumptions regarding ERP waveshape, and consequently, it does not impose any preselected criteria on the ERP component/wave latency. The PCA procedure itself is blind to experimental conditions and generates the same solutions regardless of the order in which the ERPs are entered. Moreover, PCA can identify overlapping variance components, although some reservations have been stated on the ability of the method to reliably associate effects of different experimental manipulations to these components (Wood and McCarthy, 1984; Möcks & Verleger, 1986; Hunt, 1985). From a computational standpoint, PCA differs from the Principal Axes Factoring (PAF) method in that communality values (i.e., the entries in the main diagonal of the original association matrix) are not estimated, as in the latter method, but rather set to unity (Gorsuch, 1974. p. 90). Consequently, total variance present in the data set is analyzed with the PCA method in contrast to the PAF method in which only common variance is factored. The option of a correlation matrix was selected for the PCA routine. Under this method, grand-average (or centroid) amplitude values for each time-point are first subtracted

from corresponding values of each average ERP. Deviation scores of each time-point are then normalized by being divided by their respective standard deviation. Thus, variability due to differences between time-points with respect to mean amplitude, as well as variance, is removed when the correlation matrix is computed (Donchin & Heffley, 1978).

BEHAVIORAL DATA

Given the simplicity of the task, accuracy data were expected to approach ceiling levels for most subjects. Therefore, they served primarily to indicate possible "bad" trials that may have been due to temporary shifts in arousal and/or attention. As such, these trials were rejected from further analyses.

As a function of experimental manipulations, Reaction Time was expected to be more useful as a behavioral indicator of possible variations in the processing characteristics demonstrated by subjects in responding to the second stimulus of each pair. A single ANOVA with Comparison Outcome(2) x Type of Stimulus Pair(2), with repeated measures for all factors, was applied to the individual RT data. Analyses were performed using the SuperANOVA program for the Macintosh microcomputer (Abacus Concepts, Inc., Berkeley, CA, 1989). Only effects beyond the .01 level were considered significant.

RESULTS

ERP DATA

The averaged, baseline adjusted ERPs to the test stimuli formed the input matrix for the PCA using the Factor Analysis program from the SPSS v. 4.0 package (SPSS Inc. 1990). Preliminary analyses, where all 120 ERP time points (excluding those from the prestimulus period) served as the dependent variables in the PCA, did not reveal any experimental effects beyond 760 msec. poststimulus. A second set of analyses was performed on the first 760 msec. (76 time points) of the ERP epoch. This initially resulted in a number of variance components equal to the number of the input variables. Correlations were computed over 768 average ERPs or cases (i.e., 10.1 cases per variable). The Cattell Scree Test (Cattell, 1965) was then used to isolate six components that accounted for 84.76% of the total variance in the data set. Residual variance was considered as error variance during ERP data analyses (Rosler and Manzey, 1981). The selected components were then rotated using the normalized varimax criterion (Kaiser, 1958). The aim of the Varimax rotation was to limit the number of time points with high loadings, while increasing the number of time points with negligible loadings on any particular component. This step improved component distinctiveness while preserving their orthogonality. Despite some arguments raised against the appropriateness of (Varimax) rotation when analyzing ERP data (Rösler & Manzey, 1981), it appears that this step is necessary in order to attain a simple structure and reduce component overlap (Wood & McCarthy, 1984). Following rotation, the program calculated component loadings that reflected the relation between rotated components and time points, and also component scores or weights for each of the 768 averaged ERPs for each of these components. Given the orthogonality of the components,

these component loadings were equal to the correlations between components and individual time points. The squares of these correlations were used as an index of the amount of variance shared between a component and a given time-point. They reflected the contribution of components to the amplitude of the ERP waveform at any point of time during the ERP recording epoch. Component scores, on the other hand, reflected the amount of variability accounted for by any one component in an individual averaged ERP. The temporal extent of these components according to a component loading cutoff of 0.35 is given in the second column of Table 12. Plots of the component waveforms derived by the PCA are presented in Figure 1. The centroid waveform which represents activity common to all ERPs appears at the top. Figure 1 also shows the percentage of the total variance in the data set accounted for by each of the components. This measure was derived by computing the sum of the squared loadings of each time-point on the individual components (eigenvalue). The sum was then divided by the number of time-points and multiplied by 100 in order to convert it into a percentage (Stevens, 1986). As Figure 1 shows, the early portion of the centroid was characterized by a series of small deflections: N50, P90, N125, P155, and N185, with peaks at 50, 90, 125, 155, and 185 msec. poststimulus onset, respectively. Next, there was a prominent positive-going deflection with a peak latency of 255 msec. (P255). The small negative-going deflection that followed at 345 msec. (N345) reflected the merging of a negative-going wave, that characterized the Mismatch condition, with a positive-going wave that was elicited in the Match condition at the same latency (see Figure 2). Given the fact that a single PCA component reflected variability associated with both deflections (Component 3), this region of the ERP will be referred to as the NP345 complex. Next, there was a positive-going deflection at 390 msec. (P390) which, as Figure 2 shows, marked the peak of the voltage recovery slope following N345 in the

Mismatch condition. The rest of the waveform was characterized by the slow recovery of the preceding positivity that lasted until the end of the 760-msec. epoch. The return to baseline activity levels was only interupted by a small notch at 505 msec. which reflected the contribution of a positive-going deflection (P505) that was evident in the Mismatch waveform only.

A series of ANOVAs was then performed on the component scores, separately for each principal component. The ANOVAs were used to determine whether the variability reflected in the component scores, assigned for each component to each average ERP, differed systematically as a function of the experimental manipulations. This procedure directly addressed the question of whether the ERP waveshapes in the region, characterized by the most variability for any one component, changed systematically as a function of Comparison Outcome (Match or Mismatch) and Type of Stimulus Pair (Picture-Word or Word-Picture) recorded from the different electrode sites over each hemisphere. The design was thus in the form of a 2(Comparison Outcome) x 2(Type of Stimulus-Pair) x 6(Electrode Site) x 2(Hemisphere) ANOVA, with repeated measures for all factors. All factors were treated as fixed in the computation of expected mean squares. Since the order of trials was randomized across subjects, the risk of Type I error in statistical tests due to systematic covariation among conditions was expected to be reduced. However, only effects beyond the .01 level were considered significant. This decision was made as a precaution against the likelihood of inflated Type I error that has been suggested by some authors (Hunt, 1985; Wood & McCarthy, 1984) as the result of spurious distribution of variance across principal components.

All main effects and interactions in the main ANOVAs were evaluated using the Box method (Box, 1954; Geisser & Greenhouse, 1959). According to this procedure, F-ratios were tested against epsilon-corrected degrees of

freedom, with epsilon reflecting the estimated degree of inhomogeneity of variances and covariances between pairs of treatments. This step has been widely recommended as a countermeasure against violations of the assumption of sphericity (see, for instance, Jennings & Wood, 1976; Myers, 1979, pp.165-174; Keppel, 1991, pp.351-353). Significant interactions were evaluated by pairwise means comparisons (i.e., single-df contrasts; Keppel, 1991, pp. 115-120). Given the fact that the number of means comparisons that had to be performed in order to evaluate a given interaction was quite large (especially for interactions involving the Electrode Site factor), alpha levels for individual comparisons were adjusted using the Bonferonni method (Keppel, 1990, p). According to this method, the maximum acceptable Type I error rate for a given family of contrasts (in this case .01) was divided by the total number of comparisons actually performed to analyse the significant interaction effect from the main ANOVA. This procedure was chosen over the more conservative Scheffé method because it provides sufficient protection against the risk of inflated familywise Type I error rates based only on those contrasts that are directly relevant to the experimental hypotheses. The Scheffé method, on the other hand, uses the total number of possible pairwise contrasts in a given interaction for computing adjusted critical F-values. In this way, the latter method results in unnecessary reduction of statistical power. All statistical analyses mentioned above were performed using the SuperANOVA program for the Macintosh microcomputer (Abacus Concepts, Inc., Berkeley, CA, 1989).

Component 1 was characterized by a main effect for Comparison Outcome, $F(1,15)=13.651$, $p=.0022$, a Type of Stimulus Pair by Comparison Outcome interaction, $F(1,15)=15.944$, $p=.0012$, as well as a Comparison Outcome by Hemisphere interaction, $F(1,15)=8.922$, $p=.0092$. Examination of the area of the ERP contained within the rectangle labeled "b" in Figure 2 shows

that the late positive-going deflection that peaks at approximately 505 msec. in the Mismatch condition (P505) is virtually absent in the Match condition. This finding is in clear agreement with Hypothesis 4. Means comparisons performed to assess the interactions, revealed that the difference between Match and Mismatch conditions was significant only for the ERPs elicited by Words (Picture-Word pairs), $F(1,15)=27.383$, $p=.0001$, and were recorded over the left hemisphere, $F(1,15)=46.879$, $p=.0001$. As Figure 3 shows, the area of the difference between the Match and Mismatch traces (shaded area) is larger for the Picture-Word than for Word-Picture condition.

The latter interaction was due to the fact that only ERPs recorded over left hemisphere locations made a significant contribution to the Match versus Mismatch difference, $F(1,15)=46.879$, $p=.0001$. Inspection of the portion of the waveform enclosed in the rectangle in Figure 4 shows that P505 displays larger peak amplitude over the left versus the right hemisphere. As a result the area of the difference between the Match and the Mismatch waveforms is larger over the left than over the right hemisphere.

The Type of Stimulus Pair by Comparison Outcome interaction was also due to the fact that the effect of the Type of Stimulus Pair was significant only in the Mismatch condition, $F(1,15)=27.039$, $p=.0001$. Inspection of the waveforms displayed in Figure 5 indicates that the ERP is molulated in different ways in the two Outcome conditions. The difference in the Match conditions appears in the form of increased positivity in response to pictures. In the Mismatch condition, an initial increasein positivity in response to pictures is replaced at approximately 520 msec. by a slow negativity. In addition, the effect of the Type of Stimulus Pair interacted with Electrode Site, $F(5,75)=15.906$, $p=.0001$, as well as with the combination of Electrode Site and Hemispheres, $F(5,75)=7.823$, $p=.0003$. Pairwise contrasts showed that this region of the ERP discriminated between

Picture-Word and Word-Picture conditions over left and right central locations, $F(1,15)=53.305$, $p=.0001$ and $F(1,15)=41.507$, $p=.0001$, respectively, over left and right parietal regions, $F(1,15)=57.879$, $p=.0001$ and $F(1,15)=39.113$, $p=.0001$, respectively, as well as over the right temporoparietal region, $F(1,15)=36.687$, $p=.0001$. Figure 7 shows the divergence between the waveforms elicited by words and pictures that starts within the latency range of Component 1 and is more pronounced over centro-parietal locations. A main effect of Electrode Site was also noted for Component 1, $F(5,75)=10.201$, $p=.0001$.

Component 2 was characterized by a Comparison Outcome by Electrode Site by Hemisphere interaction, $F(1,15)=4.249$, $p=.0087$. Pairwise contrasts showed that only the left temporal and left parietal regions discriminated between the Match and Mismatch conditions, $F(1,15)=19.475$, $p=.0001$, and $F(1,15)=24.143$, $p=.0001$, respectively.

A Comparison by Electrode Site interaction, $F(5,75)=30.556$, $p=.0001$, as well as a Comparison by Electrode Site by Hemisphere interaction, $F(5,75)=21.468$, $p=.0001$, were noted for Component 3. Means comparisons, performed to assess the former interaction, indicated that the difference between Match and Mismatch conditions was significant over medial frontal, $F(1,75)=48.411$, $p=.0001$, temporal, $F(1,75)=43.166$, $p=.0001$, central, $F(1,75)=22.306$, $p=.0014$, and parietal locations, $F(1,75)=28.796$, $p=.0005$. The latter interaction was due to the fact that although the difference between Match and Mismatch conditions was significant at every electrode site over both hemispheres, the amount of difference varied slightly among recording locations. Hypothesis 3 is supported by this finding. Examination of the portion of the ERP enclosed within the rectangle labeled "a" in Figure 2 reveals that P345, which is characteristic of the Match waveform, is replaced by a negative-going wave that

peaks at roughly the same latency (N345). Figure 6 displays the group averaged ERPs for the two Outcome conditions for each electrode site and reveals the broad scalp distribution of the effect. A main effect for Electrode Site, $F(5,75)=6.935$, $p=.0006$, and an Electrode Site by Hemisphere interaction, $F(5,75)=6.226$, $p=.003$, were also found to contribute to the variability represented by Component 3.

Component 4 was characterized by a Comparison by Electrode Site by Hemisphere interaction, $F(5,75)=6.299$, $p=.0014$. Means comparisons indicated that the ERP recorded over the right temporoparietal region discriminated between Comparison Outcome conditions, $F(1,75)=11.169$, $p=.0001$. A Type of Stimulus Pair by Electrode Site interaction, $F(5,75)=5.541$, $p=.0036$, was also found for Component 4. However, none of the pairwise contrasts that were computed in order to assess differences between Picture-Word and Word-Picture condition means were significant at the .0017 level (determined by the Bonferonni method). Finally, a main effect for Electrode Site was also noted, $F(5,75)=5.812$, $p=.0065$.

The ANOVA performed on the component scores for Component 5 did not reveal any significant effects at the .01 level as the SuperANOVA effects table in Appendix N shows.

Finally, the ANOVA on Component 6 scores revealed a Comparison Outcome by Electrode Site by Hemisphere interaction, $F(5,75)=5.563$, $p=.0048$, as well as a main effect for Electrode Site, $F(5,75)=4.958$, $p=.0089$, and an Electrode Site by Hemisphere interaction, $F(5,75)=6.533$, $p=.001$. Pairwise contrasts indicated that the former interaction was due to a Match-Mismatch difference in the ERP recorded over the right temporoparietal region only, $F(5,75)=44.153$, $p=.0001$. Inspection of the waveforms displayed in Figure 6 shows that this effect was probably due to the increased amplitude of the N1

deflection recorded over the T6 location in association with the Match condition. This effect was found across Type of Stimulus Pair conditions and therefore it does not lend direct support to Hypothesis 1.

BEHAVIORAL DATA

As expected, response error rates were very low. As Table 13 shows, group mean percent correct ranged from 94.06% to 97.38% across conditions. Individual accuracy rates ranged from 100% to 73% correct.

DISCUSSION

The present investigation attempted to identify reliable patterns of changes in the ERP waveform associated with: (1.) the outcome (either "match" or "mismatch") of cognitive comparisons between internally represented concepts and visual stimuli, and (2.) the type of representational code (verbal or imaginal) that was intentionally employed by the individual in the comparison decision. Several design characteristics were employed in order to control for possible confounding influences. Thus, stimulus parameters such as word and image agreement were controlled on the basis of previously published normative data. In addition, although the same stimuli were used across all experimental conditions, different pairings of stimulus items were used across subjects. This manipulation was anticipated to reduce the likelihood that differences between experimental conditions could be due to systematic confounding differences in either physical stimulus parameters or in the relation among members of the

stimulus pairs. Furthermore, the pairing of stimulus items was kept constant across all "mismatch" trials for a given stimulus-trial list. In this way, there were only two possible S2 items to be presented following a given S1 item. Thereby, it was anticipated that the amount of uncertainty reduction triggered by the test stimuli should be kept constant between matching and non-matching events. Finally, the low cutoff filter setting used for ERP recording was set to a value that was expected to allow for faster ERP components to make a substantial contribution to the overall waveform variability.

The effects of comparison outcome proved to be very strong, and widely distributed along the ERP epoch. The earliest time-point that appeared to be reliably influenced by "match"/"mismatch" decisions occurred at 130 msec. poststimulus and the latest at 760 msec. Two ERP variance components were found to be strongly influenced by the outcome of comparison decisions. Modulation of Component 1 scores, which mostly reflected variability between 400 and 670 msec., by comparison outcome varied as a function of the representational code that mediated the comparison. Thus, in Mismatch trials a late slow positive wave (P505) was larger in the Picture-Word compared to the Word-Picture condition. In addition, the P345 deflection that characterized the Match condition showed a faster recovery rate in response to Words than in response to Pictures. As a result, the area of the difference between the Match and the Mismatch waves was larger in the Picture-Word condition. Hypothesis 4 was clearly supported by this finding. A number of studies report a similar direction of modulation of the late portion of the ERP by matching versus nonmatching events in a variety of tasks. Task manipulations were found by Kramer and Donchin (1987) to affect a late variance component that followed N350 in a word-matching paradigm. The amplitude of a co-occurring positive deflection was larger in the rhyme-compared to the visual-match condition. That

deflection showed larger base-to-peak amplitude in response to nonmatching versus matching word pairs. The authors identified this deflection with a P300 component. The broad scalp distribution of the experiment-related variance associated with the NP345 component in the present data does not allow topography-based characterization.

The appearance of a distinct negative going peak in the Mismatch condition is consistent with the notion (Kutas et al, 1984) that an N400-like component will occur whenever a word (or picture) is presented in the absence of a predictive context. It is possible that predictability of nonmatching trials was not fully equated among matching and nonmatching pairs despite the construction of stimulus pairs in such a way that only two equally probable items could follow a given S1 stimulus. It should be emphasized that subjects were instructed to actively rehearse a representation of the first concept in each pair while they waited for the second item. Therefore, the design of this study was appropriate for controlling the differences among the two types of trials with respect to the predictability of S2 but not with respect to active expectancy regarding the identity of the second stimulus. The fact that repetition of nonmatching pairs during the testing session did not eliminate the NP345 effect suggests that this component may also be an index of automatic mismatch detection. It was found to persist despite high levels of familiarization with a limited set of nonmatching alternatives through repetition across trials. A similar finding has been reported by Fischler et al (1985) in a sentence verification task. In that study it was found that giving subjects repeated exposure to a number of short statements, that were either true or false, during the EEG recording session did not affect the magnitude of the NP320 effect. A safer way to ensure that matching and nonmathing items would receive equal amounts of priming associated with the formation of active expectancies would be to present subjects before the actual test with a list of item

pairs to be used in nonmatching trials with the instruction to try to memorize them. Thus at least two task-related factors apparently contributed to experimental variance reflected in Component 4 scores: (1) confirmation of active expectancies held by the subjects regarding the identity of the second item in each pair, and (2) detection of a mismatch between an intentionally maintained internal representation and a subsequently presented visual stimulus.

Furthermore, the scalp distribution of the Match-Mismatch effect showed a complex temporal pattern. In the initial portion of the ERP, the effect was restricted to the right temporoparietal region. Hypothesis 1 predicted that the early portion of the waveform would be modulated by comparison outcome when the comparison is based on an imaginal representation. The visual similarity between the intentionally retained image and the test stimulus would enhance the N1 deflection of the Visual Evoked Response to S2 (Farah et al, 1988). Although the N1 amplitude modulation was in the expected direction (Figure 6), the effect occurred also in the Picture-Word as well as in the Word-Picture condition. Two possibilities may help account for this discrepancy. First, it is possible that ERP variability in this portion of the waveform was not solely determined by modality-specific activity that originates in visual cortical areas and gives rise to the N1 deflection. There are several reports of similar ERP modulation by the outcome of decisions in tasks that did not require or emphasize stimulus processing based on visual characteristics (Boddy & Weinberg, 1981). However, the regional specificity of the response in the present investigation makes this interpretation less likely. Another possibility is that subjects employed a visual instead of a phonological code in order to carry out comparisons in Picture-Word trials as well as in Word-Picture trials. This code could probably take the form of an orthographic representation of the name of the preceding object-drawing.

Then, between 280 and 670 msec., all scalp locations made a substantial contribution to the ERP modulation by comparison outcome. However, when the Match-Mismatch difference was evaluated at each hemisphere separately, it was found to be significant only over the left hemisphere regions in the 400 to 670 msec. latency range. This finding was unpredictable given the lack of data on consistent hemispheric asymmetries displayed by Match-Mismatch differences in explicit paired comparison tasks. Finally, towards the end of the 760 msec. epoch, a significant effect of Comparison Outcome was found only for temporal and parietal regions of the left hemisphere.

The narrow scalp distribution of many of the effects reported above, especially of those associated with the later portion of the waveform (Match versus Mismatch), and also with word-picture differences, may have resulted from the use of conservative alpha levels for testing means comparisons. However, given that the main purpose of this study was identify reliable ERP correlates of certain experimental events, we preferred to sacrifice some statistical power over a higher risk for Type I error.

Two further steps can be taken in future research to further address the reliability issue. First, the across-sample stability of the observed effects can be assessed by performing the same analysis sequence, as described in the Methods section, on multiple independent samples extracted from the present group in the form of split-halves. Second, analyses on single-trial data are necessary for determining whether the effects reported above reflect changes (in terms of both amplitude and latency) that occur systematically across repeated occurrences of the experimental events. This finding would ensure that effects derived from group data are not simply a quasi-artifactual generalization that results from the averaging process, but that, instead, they reflect over-the-scalp estimates of relative stable neurophysiological phenomena.

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APPENDIX B

EDINBURGH HANDEDNESS INVENTORY

Surname _____ Given Name _____

Date of Birth _____ Sex _____

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in brackets.

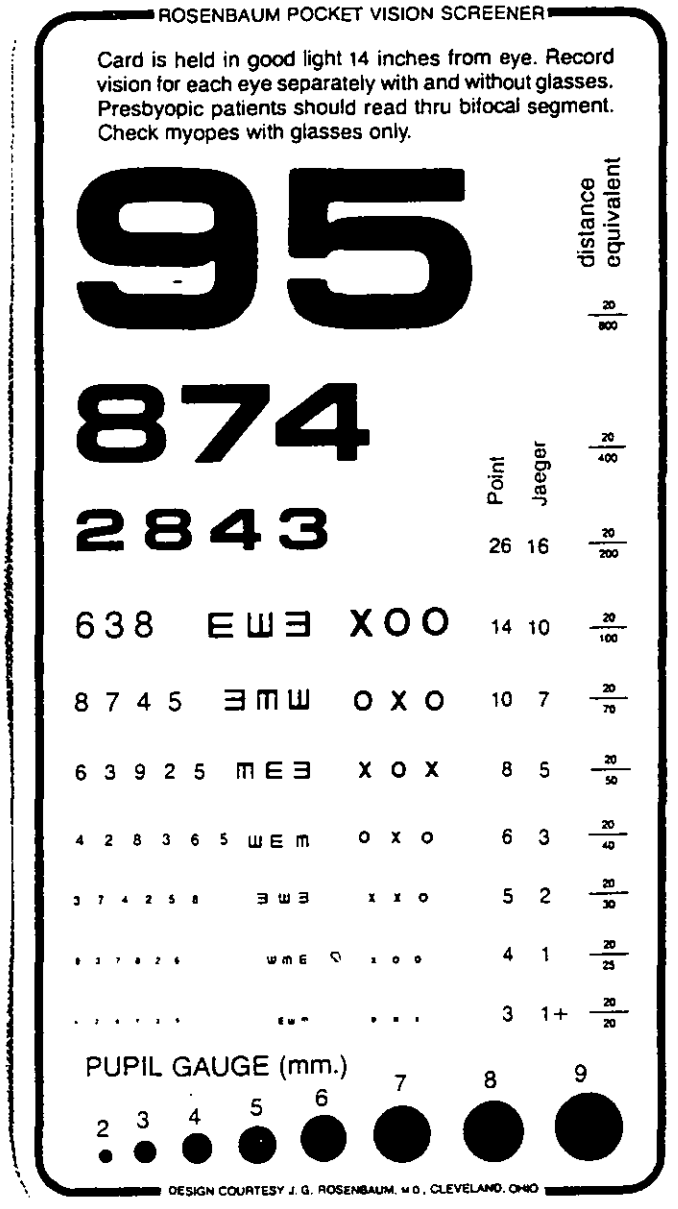
Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

		Left	Right
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom (upper hand)		
9	Striking Match		
10	Opening Box (lid)		
i	Which foot do you prefer to kick with?		
ii	Which eye do you use when using only one?		

L.Q. _____ Leave these spaces blank.

DECIBLE	

APPENDIX C


ROSENBAUM POCKET VISION SCREENER
Card is held in good light 14 inches from eye. Record vision for each eye separately with and without glasses. Presbyopic patients should read thru bifocal segment. Check myopes with glasses only.
95
874
2843
Point
Jaeger
distance equivalent
638
26 16
8745
14 10
63925
10 7
42836 5
8 5
37425 8
6 3
5 2
4 1
3 1+
PUPIL GAUGE (mm.)
2 3 4 5 6 7 8 9
DESIGN COURTESY J. G. ROSENBAUM, M.D., CLEVELAND, OHIO

APPENDIX D

NEUROLOGICAL SCREEENING FORM

Your name will not appear on this form. Your privacy will not be breeched in any manner. What you say will be held in strictest confidence. The following questions will only be used to determine whether you fit the profile for the testing to be conducted. You are not required to respond to any of these questions. However, if you choose not to answer any of these questions, we will not be able to use you in this study.

1.Have you ever been retained in any grade in school?_____

---

2. Do you have any history of learning disabilities?_____

---

3. Have you ever been seen by a neurologist?_____

---

4. Do you have any history of central nervous system disease?

---

5. Have you ever had a high fever that led to a seizure?

---

6. Do you have a history of seizures? _____

---

7. Have you ever hit or injured your head?_____

If so, did you:

_____ lose consciousness

_____ feel dizziness leading to nausea or

disorientation?

_____ have a persistent headache?

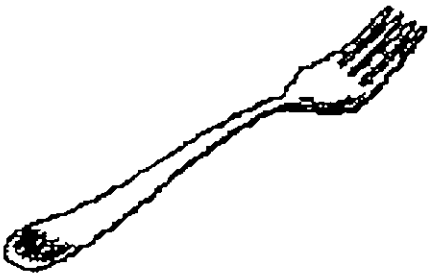
_____ seek medical attention?

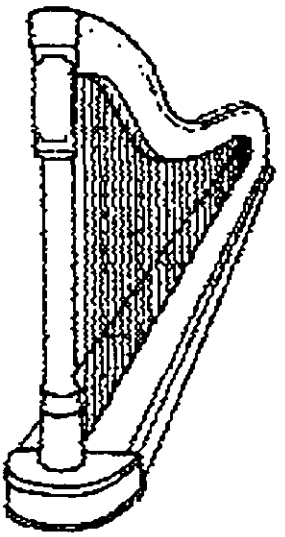
8. Have you ever lost consciousness due to a seizure or a drug reaction?_____
___
_____
___
9. Are you a recovering alcoholic?_____
10. Are you a recovering drug user?_____
11. Are you taking prescription drugs or any other kind of drugs or medication?_____
__
_____
___
10. Do you currently have any minor and/or major health problems?
_____
___
_____
___

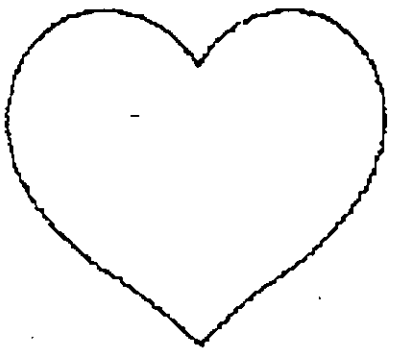
DO NOT WRITE BELOW THIS LINE
Comments:

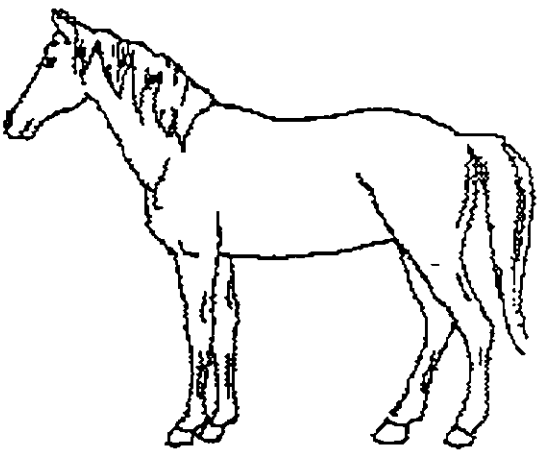
Experimenter's initials:_____
Date:_____
Criterion met?_____
Study Code:_____

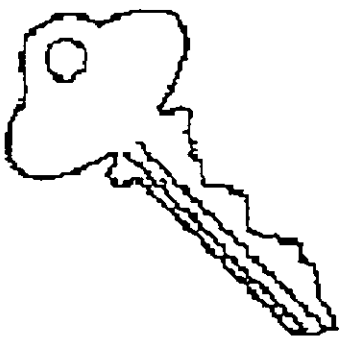
APPENDIX E



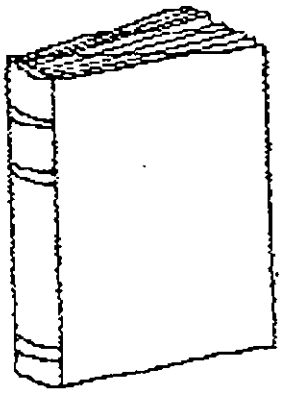


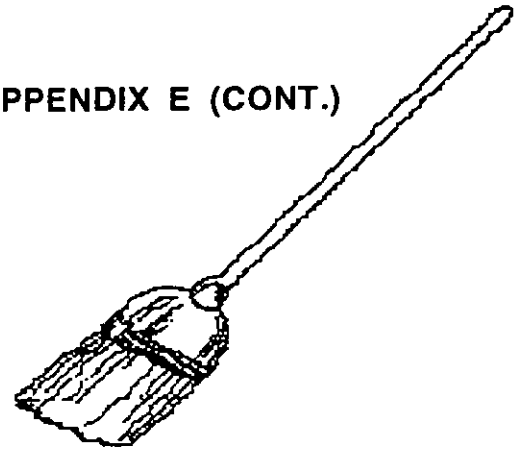


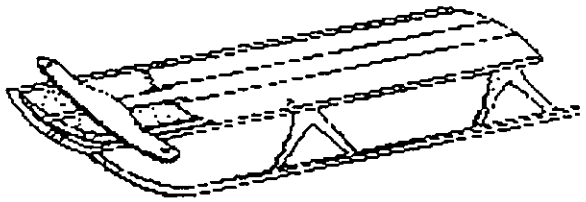


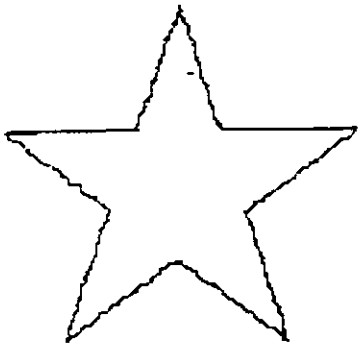


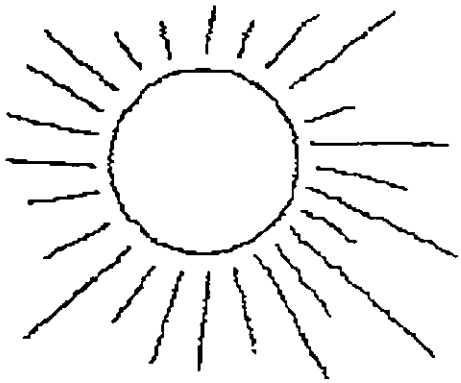
APPENDIX E (CONT.)

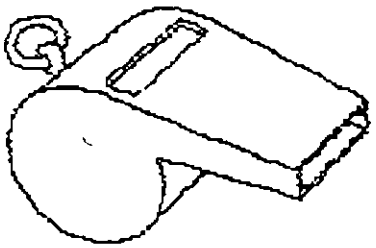


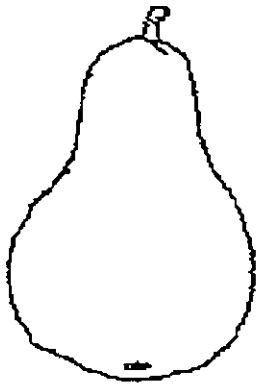












APPENDIX F

Table 8

	Concept	IA	H	F	VC	K-F
1.	Book	4.33	.00	4.75	2.10	193
2.	Broom	4.35	.00	3.42	2.42	2
3.	Fork	4.15	.00	4.78	2.62	14
4.	Harp	4.28	.00	1.88	4.05	1
5.	Heart	4.49	.00	3.72	1.00	173
6.	Horse	4.20	.00	3.55	3.82	117
7.	Key	4.58	.00	4.85	1.92	88
8.	Pear	4.62	.00	3.55	1.15	6
9.	Sled	4.49	.00	2.80	3.05	0
10.	Star	4.41	.00	3.35	1.05	25
11.	Sun	4.22	.00	4.90	1.20	112
12.	Whistle	4.55	.00	2.45	2.55	4
	Mean(N=12)	4.39	.00	3.67	2.44	6.13
	SD(N=12)	.58	.00	1.00	1.10	7.20
	Mean(N=26)	3.69	.558	3.29	2.96	37.86
	SD(N=260)	.585	.526	.956	.897	88.09

Table 1. Mean ratings for the 12 pictures on five measures: Image Agreement (IA), Information Statistic (H), Familiarity (F), Visual Complexity (VC), Kucera and Fransis counts (K-F). Means and Standard Deviations for the subset of 12 pictures, and for the total sample of 260 pictures. The most common name for each picture is given in the first column.

APPENDIX G

match/mismatch study
EP testing

INFORMED CONSENT FORM

This study is conducted under the direction of Dr. Dennis Molfese of Southern Illinois University in collaboration with Panagiotis Simos, and Ketty Russeva. It uses brain-waves recorded from the scalp to investigate how the human brain comes up with decisions of match or mismatch between words and pictures or images. This will involve first measuring your head to determine where recording monitors will be placed. Next, a standard electrode cap will be placed on your head, and twelve small areas about 1/4" in diameter will be gently rubbed with a blunted hypodermic needle. A small amount of water soluble conductive gel will be placed on each of these areas. One monitor will be attached to each ear lobe, and a second pair of monitors will be placed above and an inch or so to the right of your right eye. Once the monitors are all in place, you will be asked to be seated in a chair facing the screen of a microcomputer. You are, then, going to watch a series of picture and word pairs on the screen. In each case you will have to form an image of the object named by the word, or depicted in the picture, you just saw. Then, you will have to decide whether this image matches or not with the word/picture that comes after, and press a button located in front of you to indicate your decision. After the testing is over, the electrode cap and the four additional monitors will be removed from your head and any gel that remains will be cleaned. The gel is readily removed with warm water so this process should not take more than a few minutes. In all, the entire testing may last approximately 2 hours.

This study has been reviewed and approved by the Carbondale Committee for Research Involving Human Subjects Institutional Review Board. There are no risks to you as a function of participation in this project. All equipment is checked regularly to insure that it is in safe operating order. Once all of the data have been collected and analyzed from all of the participants in this study, we will send you a report of our findings for the entire group, if you wish. However, since information collected from any one

person will be coded so as to insure absolute anonymity, we will not be able to provide you with any results specific to you.

Your participation in this project is completely voluntary. You can choose to not participate at this time or at any time during the testing session. If you do want to stop the testing, simply say so. There are, of course, no penalties for stopping the testing at any time. If you should have questions about any of the procedures, please feel free to ask any staff present with you, or call one of the following: Dennis L. Molfese, Ph. D., Panagiotis G. Simos, or Kevin B. Clark [phone number: (618) 453-3510].

All information that you provide during this study will be kept confidential. With the exception of the consent form, no names are placed on any of the data sheets or questionnaires. These sheets will be kept separate from your answers, so that once you leave this room, no one will be able to connect your name with the records in our files. Furthermore, all data will be kept in a locked file cabinet with access restricted to only Dr. Molfese and his research assistants.

The Department of Health and Human Services requires that you be advised as to the availability of medical treatment if a physical injury should result from any research procedures. No special medical arrangements have been made regarding your participation in this project. If you are a registered student at SIUC, you are eligible to receive medical treatment at the University Health Service. If you are not a registered student at the University, immediate treatment is available at usual and customary fees at the Carbondale Memorial Hospital. In the event that you believe that you have suffered any injury as a result of participation in the research program, please contact the Chairperson of the SIUC Institutional Review Board [phone number: (618) 536-2301, (618) 453-4531, or (618) 453-4533]. The Chairperson will review the matter with you and identify any other resources that may be available to you.

I, _____ , have read the material above, and any questions I asked have been answered to my satisfaction. I agree to participate in this activity, realizing that I may withdraw without prejudice at any time.

Participant _____
Date_____

Witness _____
Date_____

APPENDIX H

MATCH/MISMATCH STUDY: INSTRUCTIONS

Word-Picture session

In this part of the experiment you will be presented with a series of trials. You will initiate each trial by pressing the <return> key. In each trial, you will see a word followed, a few seconds later, by a picture that will be one of the drawings on the sheet that you have just looked at. When you see the word try to form an image in your mind of the drawn object that the word names. Project your image on the space within the square frame. It is very important that your image is clear and that it resembles the particular drawing of the object that you have seen on the sheet. Also keep the image in your mind until the picture is presented and then decide whether they match or not. If they match, press the "__" key with your _____ index finger; if they do not match press the "__" key with your _____ finger. You should respond as fast as you can while the picture is still on the screen.

During a trial, it is very important that you do not blink after a word is presented and until you see a message on the screen telling you to start a new trial. Otherwise, blinks can wipe out the recording of your brain response to the stimuli. You should keep your eyes on the center of the square frame during a trial. Also, be sure to keep your feet flat on the floor. This part of the experiment will last about 30 min.

Picture-Word session

In this part of the experiment you will be presented with a series of trials. You will initiate each trial by pressing the <return> key. In each trial, you will see a picture followed, a few seconds later, by a word. The picture will be one of the drawings on the sheet that you have just looked at. When you see the picture bring in your mind the name of the drawn object. Keep that name in your mind until the word is presented and then decide whether they match or not. If they match, press the "__" key with your ____ index finger; if they do not match press the "__" key with your ____ finger. You should respond as fast as you can while the word is still on the screen.

During a trial, it is very important that you do not blink after a word is presented and until you see a message on the screen telling you to start a new trial. Otherwise, blinks can wipe out the recording of your brain response to the stimuli. You should keep your eyes on the center of the square frame during a trial. Also, be sure to keep your feet flat on the floor. This part of the experiment will last about 30 min.

APPENDIX I
Table 9

TABLE : SUBJECT INFORMATION *

SUBJECT ID	SEX	AGE	LQ	VISION
1	F	19	1.00	20/20-20/30
2	F	20	1.00	20/30-20/30
3	M	19	.73	20/25-20/25
4	F	23	.83	20/20-20/25
5	F	20	.67	20/25-20/30
6	M	33	.90	20/30-20/25
7	M	28	.89	20/20-20/20
8	F	22	.84	20/25-20/30
9	F	20	.86	20/20-20/20
10	F	20	1.00	20/20-20/20
11	M	29	1.00	20/30-20/30
12	M	21	.46	20/20-20/20
13	F	19	1.00	20/25-20/25
14	M	23	.91	20/30-20/30
15	M	20	.91	20/25-20/25
16	M	36	.67	20/25-20/20
MEAN	--	23.25	.85	--
SD	--	5.34	.15	--

* In addition, none of the subjects responded "yes" to any of the items on the Neurological Screening Form (Appendix).

APPENDIX K
Table 10

ELECTRODE IMPEDANCES

SUBJECT ID	RANGE / PRE-TEST	RANGE / POST-TEST	MEAN (SD) / PRE- TEST	MEAN (SD) / POST- TEST	A1 / A2 PRE-TEST	A1 / A2 POST-TEST
1	1.1-4.2	0.9-5.0	2.03 (0.79)	2.03 (1.51)	1.2-1.5	1.3-1.4
2	1.3-3.9	1.0-3.5	2.67 (0.80)	2.45 (0.79)	1.0-1.8	1.0-1.6
3	1.0-4.0	0.8-4.0	2.73 (1.05)	2.60 (1.18)	1.3-3.3	1.3-3.3
4	0.7-3.2	0.4-3.0	2.16 (0.73)	1.79 (0.61)	1.8-3.2	2.0-3.5
5	0.7-3.9	0.8-4.0	2.41 (1.00)	2.04 (0.94)	0.7-1.4	0.8-1.8
6	0.8-3.6	0.7-3.2	1.98 (0.94)	1.96 (0.87)	1.0-1.6	2.7-1.8
7	0.9-3.5	0.7-3.0	1.94 (0.88)	1.71 (0.75)	0.7-2.0	0.8-2.5
8	0.9-3.2	0.7-3.0	2.03 (0.75)	1.64 (0.62)	1.2-2.5	1.2-3.5
9	1.4-2.4	0.9-1.8	1.95 (0.41)	1.54 (0.29)	1.4-1.0	1.7-1.3
10	0.9-2.5	0.9-3.7	1.69 (0.49)	1.50 (0.45)	1.7-3.0	2.3-3.7
11	0.8-2.6	0.8-2.3	1.73 (0.59)	1.49 (0.45)	0.9-2.2	1.2-1.9
12	1.0-2.5	0.9-2.1	1.94 (0.49)	1.68 (0.39)	1.5-1.3	1.6-1.3
13	1.3-3.1	1.1-2.6	2.06 (0.47)	1.78 (0.40)	1.9-3.0	2.0-2.6
14	3.7-5.0	3.3-5.0	4.77 (0.83)	4.53 (0.74)	3.9-5.5	5.4-4.2
15	0.9-2.5	0.8-3.3	1.85 (0.46)	1.70 (0.60)	2.5-1.2	3.0-1.2
16	1.5-3.2	1.3-3.3	2.29 (0.42)	1.72 (0.51)	2.6-2.2	3.3-2.5
MEAN	1.81-3.33	1.00-3.30	2.26	2.01	1.58-2.29	1.98-2.38
SD	0.72-0.75	0.64-0.90	0.73	0.74	0.84-1.13	1.20-1.00

APPENDIX L
Table 11

ELECTROPHYSIOLOGICAL TESTING INFORMATION

							NUMBER OF ERPs PER AVERAGE			
SUBJECT ID	DATE TESTED	PARM FILE *	CONDITION ORDER	ELEC-TRODE ORDER	RESPO-NDING HAND (M-MM)	% REJE-CTION	WORD-PICTURE/ MATCH	WORD-PICTURE MMATCH	WORD-PICTURE/ MATCH	WORD-PICTURE/ MMATCH
1	11/13/92	M1	W-P/P-W	F8	L - R	36.45	30	26	33	33
2	11/16/92	M1	W-P/P-W	F3	R - L	46.40	19	23	30	31
3	12/2/92	M2	P-W/W-P	T5	R - L	27.30	44	37	32	27
4	12/4/92	M2	P-W/W-P	T6	L - R	42.20	22	21	36	32
5	2/4/93	M3	W-P/P-W	C3	L - R	33.90	32	33	35	27
6	2/24/93	M3	W-P/P-W	P3	R - L	40.10	39	30	23	23
7	2/26/93	M4	P-W/W-P	P4	R - L	39.00	36	29	34	28
8	3/3/93	M4	P-W/W-P	F2	L - R	21.90	44	37	34	33
9	3/7/93	M5	W-P/P-W	F7	L - R	19.80	38	45	38	33
10	3/10/93	M5	W-P/P-W	F8	R - L	31.25	35	36	30	31
11	3/14/93	M6	P-W/W-P	F3	L - R	22.40	36	42	36	35
12	3/24/93	M6	P-W/W-P	F4	R - L	15.62	35	41	42	44
13	3/26/93	M7	W-P/P-W	T3	L - R	49.50	22	23	26	25
14	3/28/93	M7	W-P/P-W	T4	R - L	12.00	41	41	42	45
15	3/29/93	M8	P-W/W/P	T5	L - R	36.97	34	28	28	31
16	4/4/93	M8	P-W/W/P	C3	R - L	26.04	27	39	39	36
MEAN						31.3	33.38	33.19	33.63	32.13
SD						11.08	7.64	7.63	5.38	6.0

* Each parameter file defines a different order of Match/Mismatch trials and also a different set of (12) nonmatching pairs.

APPENDIX M
Table 12

TABLE : EXPERIMENTAL EFFECTS (ERP DATA)

			MEANS COMPARISONS	
COMPO-NENT #	LATENCY *	MAIN ANOVA EFFECT **	CONDITION EFFECT ***	SCALP LOCATION
1	400-670	COMPARISON	M≠MM	ALL SITES
		COMPARISON x ORDER	M≠MM for P-W TRIALS; P-W≠W-P FOR MM TRIALS (.0025)	ALL SITES
		ORDER x ELECTRODE SITE	W-P≠PW (.0017)	CENTRAL, & PARIETAL
		ORDER x ELECTRODE SITE x HEMISPHERE	W-P≠PW (.0008)	C3, C4, T6, P3, & P4
		COMPARISON x HEMISPHERE	M≠MM (.005)	LEFT HEMISPHERE
2	540-760	COMPARISON x ELECTRODE SITE x HEMISPHERE	M≠MM (.0008)	T3, & P3
3	280-480	COMPARISON x ELECTRODE SITE	M≠MM (.0017)	ALL SITES EXCEPT POSTERIOR TEMPORAL
		COMPARISON x ELECTRODE SITE x HEMISPHERE,	M≠MM (.0008)	ALL SITES
4	200-320	ORDER x ELECTRODE SITE	-- ***	--
		COMPARISON x ELECTRODE SITE x HEMISPHERE	M≠MM (.0008)	T6
5	1-140	--	--	--
6	130-230	COMPARISON x ELECTRODE SITE x HEMISPHERE	M≠MM (.0008)	T6

* In ms poststimulus, according to a 0.35 component loading cutoff.
** All effects reported were found significant at the .01 level (see Table for details).
*** In parentheses the significance level used for all the comparisons under a particular ANOVA effect determined according to the Bonferoni method (see Method Section).

APPENDIX N

COMPONENT 1. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	171.067	11.404			
ORDER	1	16.544	16.544	4.732	.0460	.0460
ORDER * Subject	15	52.445	3.496			
COMP	1	17.005	17.005	13.651	.0022	.0022
COMP * Subject	15	18.686	1.246			
SITES	5	50.788	10.158	10.201	.0001	.0001
SITES * Subject	75	74.683	.996			
HEM	1	2.401	2.401	5.754	.0299	.0299
HEM * Subject	15	6.258	.417			
ORDER * COMP	1	23.352	23.352	15.944	.0012	.0012
ORDER * COMP * Subject	15	21.970	1.465			
ORDER * SITES	5	22.259	4.452	15.906	.0001	.0001
ORDER * SITES * Subject	75	20.991	.280			
COMP * SITES	5	2.423	.485	1.316	.2666	.2829
COMP * SITES * Subject	75	27.621	.368			
ORDER * HEM	1	.333	.333	.391	.5410	.5410
ORDER * HEM * Subject	15	12.748	.850			
COMP * HEM	1	3.384	3.384	8.922	.0092	.0092
COMP * HEM * Subject	15	5.689	.379			
SITES * HEM	5	17.071	3.414	3.430	.0076	.0348
SITES * HEM * Subject	75	74.657	.995			
ORDER * COMP * SITES	5	6.184	1.237	1.789	.1255	.1975
ORDER * COMP * SITE...	75	51.860	.691			
ORDER * COMP * HEM	1	.139	.139	.561	.4656	.4656
ORDER * COMP * HEM...	15	3.725	.248			
ORDER * SITES * HEM	5	7.715	1.543	7.823	.0001	.0003
ORDER * SITES * HEM ...	75	14.793	.197			
COMP * SITES * HEM	5	.694	.139	.721	.6098	.5302
COMP * SITES * HEM *...	75	14.440	.193			
ORDER * COMP * SITE...	5	2.374	.475	1.564	.1806	.2239
ORDER * COMP * SITE...	75	22.767	.304			

Dependent: SCORES 1

APPENDIX N

COMPONENT 2. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	254.818	16.988			
ORDR	1	7.332	7.332	2.257	.1537	.1537
ORDR * Subject	15	48.720	3.248			
COMP	1	5.437	5.437	8.670	.0100	.0100
COMP * Subject	15	9.406	.627			
SITES	5	11.675	2.335	1.422	.2261	.2574
SITES * Subject	75	123.133	1.642			
HEM	1	1.892	1.892	8.692	.0100	.0100
HEM * Subject	15	3.265	.218			
ORDR * COMP	1	2.256	2.256	.991	.3352	.3352
ORDR * COMP * Subject	15	34.125	2.275			
ORDR * SITES	5	5.906	1.181	1.760	.1315	.1863
ORDR * SITES * Subject	75	50.335	.671			
COMP * SITES	5	1.542	.308	.727	.6054	.5043
COMP * SITES * Subject	75	31.818	.424			
ORDR * HEM	1	.004	.004	.017	.8991	.8991
ORDR * HEM * Subject	15	3.314	.221			
COMP * HEM	1	2.473	2.473	6.518	.0221	.0221
COMP * HEM * Subject	15	5.691	.379			
SITES * HEM	5	10.907	2.181	2.715	.0261	.0859
SITES * HEM * Subject	75	60.262	.803			
ORDR * COMP * SITES	5	5.667	1.133	3.305	.0094	.0377
ORDR * COMP * SITES ...	75	25.721	.343			
ORDR * COMP * HEM	1	1.693	1.693	3.965	.0650	.0650
ORDR * COMP * HEM ...	15	6.405	.427			
ORDR * SITES * HEM	5	3.863	.773	2.449	.0413	.0800
ORDR * SITES * HEM *...	75	23.666	.316			
COMP * SITES * HEM	5	2.138	.428	4.249	.0019	.0087
COMP * SITES * HEM *...	75	7.548	.101			
ORDR * COMP * SITES ...	5	.858	.172	.852	.5174	.4384
ORDR * COMP * SITES ...	75	15.109	.201			

Dependent: SCORES 2

APPENDIX N

COMPONENT 3. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	107.109	7.141			
ORDR	1	.183	.183	.037	.8498	.8498
ORDR * Subject	15	74.035	4.936			
COMP	1	5.350	5.350	6.909	.0190	.0190
COMP * Subject	15	11.615	.774			
SITES	5	43.435	8.687	6.935	.0001	.0006
SITES * Subject	75	93.952	1.253			
HEM	1	1.144	1.144	2.907	.1088	.1088
HEM * Subject	15	5.902	.393			
ORDR * COMP	1	2.710	2.710	1.509	.2383	.2383
ORDR * COMP * Subject	15	26.945	1.796			
ORDR * SITES	5	3.701	.740	1.372	.2445	.2690
ORDR * SITES * Subject	75	40.458	.539			
COMP * SITES	5	73.851	14.770	30.556	.0001	.0001
COMP * SITES * Subject	75	36.254	.483			
ORDR * HEM	1	.099	.099	.375	.5495	.5495
ORDR * HEM * Subject	15	3.962	.264			
COMP * HEM	1	.332	.332	.842	.3735	.3735
COMP * HEM * Subject	15	5.912	.394			
SITES * HEM	5	40.619	8.124	6.226	.0001	.0030
SITES * HEM * Subject	75	97.867	1.305			
ORDR * COMP * SITES	5	.529	.106	.448	.8137	.7240
ORDR * COMP * SITES ...	75	17.723	.236			
ORDR * COMP * HEM	1	.161	.161	.248	.6255	.6255
ORDR * COMP * HEM ...	15	9.727	.648			
ORDR * SITES * HEM	5	1.551	.310	1.951	.0959	.1449
ORDR * SITES * HEM *...	75	11.924	.159			
COMP * SITES * HEM	5	19.502	3.900	21.468	.0001	.0001
COMP * SITES * HEM *...	75	13.626	.182			
ORDR * COMP * SITES ...	5	3.735	.747	4.314	.0017	.0126
ORDR * COMP * SITES ...	75	12.984	.173			

Dependent: SCORES3

APPENDIX N

COMPONENT 4. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	304.968	20.331			
ORDR	1	1.427	1.427	.398	.5379	.5379
ORDR * Subject	15	53.828	3.589			
COMP	1	1.460	1.460	2.201	.1586	.1586
COMP * Subject	15	9.948	.663			
SITES	5	37.577	7.515	5.812	.0001	.0065
SITES * Subject	75	96.976	1.293			
HEM	1	2.755E-4	2.755E-4	.001	.9784	.9784
HEM * Subject	15	5.462	.364			
ORDR * COMP	1	.248	.248	.207	.6553	.6553
ORDR * COMP * Subject	15	17.930	1.195			
ORDR * SITES	5	12.715	2.543	5.541	.0002	.0036
ORDR * SITES * Subject	75	34.422	.459			
COMP * SITES	5	2.683	.537	1.575	.1775	.2284
COMP * SITES * Subject	75	25.553	.341			
ORDR * HEM	1	1.910	1.910	7.505	.0152	.0152
ORDR * HEM * Subject	15	3.817	.254			
COMP * HEM	1	.969	.969	5.222	.0373	.0373
COMP * HEM * Subject	15	2.783	.186			
SITES * HEM	5	8.693	1.739	2.206	.0624	.1099
SITES * HEM * Subject	75	59.106	.788			
ORDR * COMP * SITES	5	1.218	.244	.668	.6488	.4940
ORDR * COMP * SITES ...	75	27.341	.365			
ORDR * COMP * HEM	1	.007	.007	.021	.8861	.8861
ORDR * COMP * HEM ...	15	5.123	.342			
ORDR * SITES * HEM	5	1.621	.324	1.333	.2595	.2763
ORDR * SITES * HEM *...	75	18.234	.243			
COMP * SITES * HEM	5	2.729	.546	6.299	.0001	.0014
COMP * SITES * HEM *...	75	6.499	.087			
ORDR * COMP * SITES ...	5	5.327	1.065	4.822	.0007	.0158
ORDR * COMP * SITES ...	75	16.573	.221			

Dependent: SCORES 4

APPENDIX N

COMPONENT 5. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	145.307	9.687			
ORDR	1	.263	.263	.088	.7713	.7713
ORDR * Subject	15	45.036	3.002			
COMP	1	3.963	3.963	1.838	.1952	.1952
COMP * Subject	15	32.336	2.156			
SITES	5	3.473	.695	1.343	.2556	.2733
SITES * Subject	75	38.790	.517			
HEM	1	.372	.372	1.966	.1812	.1812
HEM * Subject	15	2.840	.189			
ORDR * COMP	1	.019	.019	.011	.9185	.9185
ORDR * COMP * Subject	15	25.659	1.711			
ORDR * SITES	5	1.059	.212	.339	.8877	.7683
ORDR * SITES * Subject	75	46.849	.625			
COMP * SITES	5	15.400	3.080	1.671	.1519	.2149
COMP * SITES * Subject	75	138.205	1.843			
ORDR * HEM	1	.179	.179	.207	.6556	.6556
ORDR * HEM * Subject	15	12.937	.862			
COMP * HEM	1	1.236	1.236	.492	.4939	.4939
COMP * HEM * Subject	15	37.710	2.514			
SITES * HEM	5	3.929	.786	1.661	.1546	.2016
SITES * HEM * Subject	75	35.484	.473			
ORDR * COMP * SITES	5	2.323	.465	.585	.7115	.5469
ORDR * COMP * SITES ...	75	59.579	.794			
ORDR * COMP * HEM	1	5.023	5.023	6.811	.0197	.0197
ORDR * COMP * HEM ...	15	11.062	.737			
ORDR * SITES * HEM	5	2.368	.474	1.343	.2558	.2737
ORDR * SITES * HEM *...	75	26.454	.353			
COMP * SITES * HEM	5	2.155	.431	1.133	.3502	.3316
COMP * SITES * HEM *...	75	28.519	.380			
ORDR * COMP * SITES ...	5	1.979	.396	.811	.5452	.4557
ORDR * COMP * SITES ...	75	36.577	.488			

Dependent: SCORES 5

APPENDIX N

COMPONENT 6. ANOVA TABLE

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	G-G
Subject	15	261.976	17.465			
ORDR	1	.060	.060	.026	.8732	.8732
ORDR * Subject	15	34.050	2.270			
COMP	1	.338	.338	.627	.4408	.4408
COMP * Subject	15	8.095	.540			
SITES	5	42.773	8.555	4.958	.0006	.0089
SITES * Subject	75	129.420	1.726			
HEM	1	1.418	1.418	4.674	.0472	.0472
HEM * Subject	15	4.551	.303			
ORDR * COMP	1	.428	.428	.211	.6525	.6525
ORDR * COMP * Subject	15	30.444	2.030			
ORDR * SITES	5	6.731	1.346	2.262	.0568	.1242
ORDR * SITES * Subject	75	44.642	.595			
COMP * SITES	5	1.612	.322	1.292	.2762	.2897
COMP * SITES * Subject	75	18.714	.250			
ORDR * HEM	1	.003	.003	.005	.9425	.9425
ORDR * HEM * Subject	15	8.179	.545			
COMP * HEM	1	.008	.008	.027	.8724	.8724
COMP * HEM * Subject	15	4.499	.300			
SITES * HEM	5	29.124	5.825	6.533	.0001	.0010
SITES * HEM * Subject	75	66.873	.892			
ORDR * COMP * SITES	5	3.793	.759	2.128	.0713	.1355
ORDR * COMP * SITES ...	75	26.742	.357			
ORDR * COMP * HEM	1	.356	.356	1.995	.1782	.1782
ORDR * COMP * HEM ...	15	2.678	.179			
ORDR * SITES * HEM	5	.491	.098	.616	.6880	.5702
ORDR * SITES * HEM *...	75	11.966	.160			
COMP * SITES * HEM	5	1.848	.370	5.563	.0002	.0048
COMP * SITES * HEM *...	75	4.982	.066			
ORDR * COMP * SITES ...	5	3.033	.607	2.653	.0291	.0678
ORDR * COMP * SITES ...	75	17.144	.229			

Dependent: SCORES 6

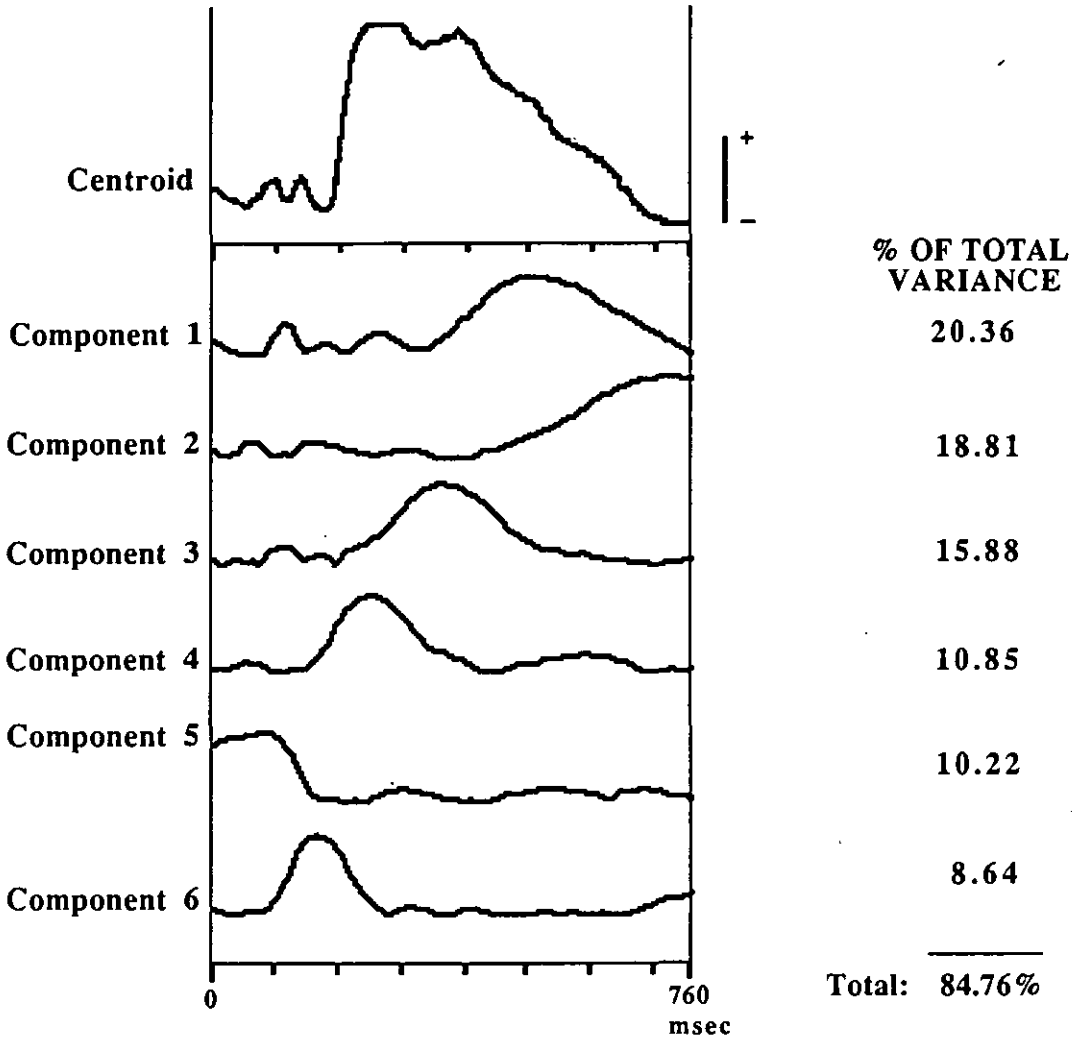


Figure 1. The centroid and the six components identified by the PCA. The ERP epoch is 760 msec. For the centoid, positivity is up. The percentage of total variance in the data set accounted for by each component is displayed to the right of that component.

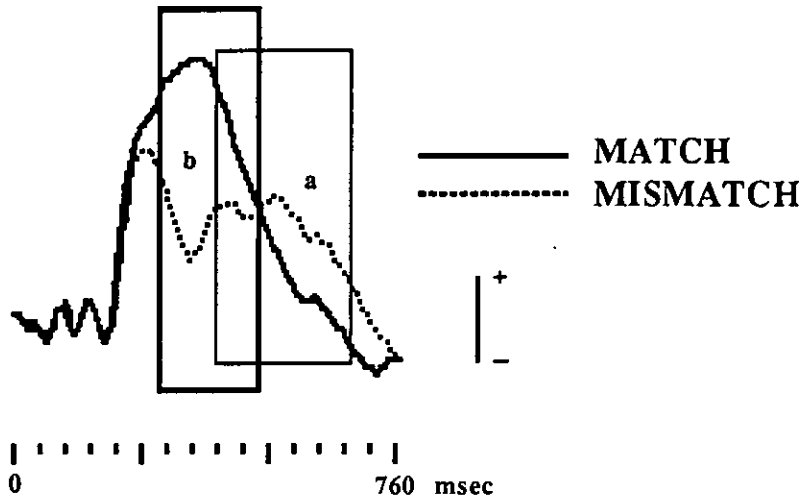


Figure 2. The group average ERP waveforms for the match and mismatch conditions. The ERP region labeled "a" (P505) discriminated between matching and nonmatching events as a function of the Type of Stimulus Pair. The portion of the ERP labeled "b" (NP345) varied as a function of Comparison Outcome independent of the Type of Stimulus Pair across all recording locations. Stimulus onset was at 0 msec. Positivity is up.

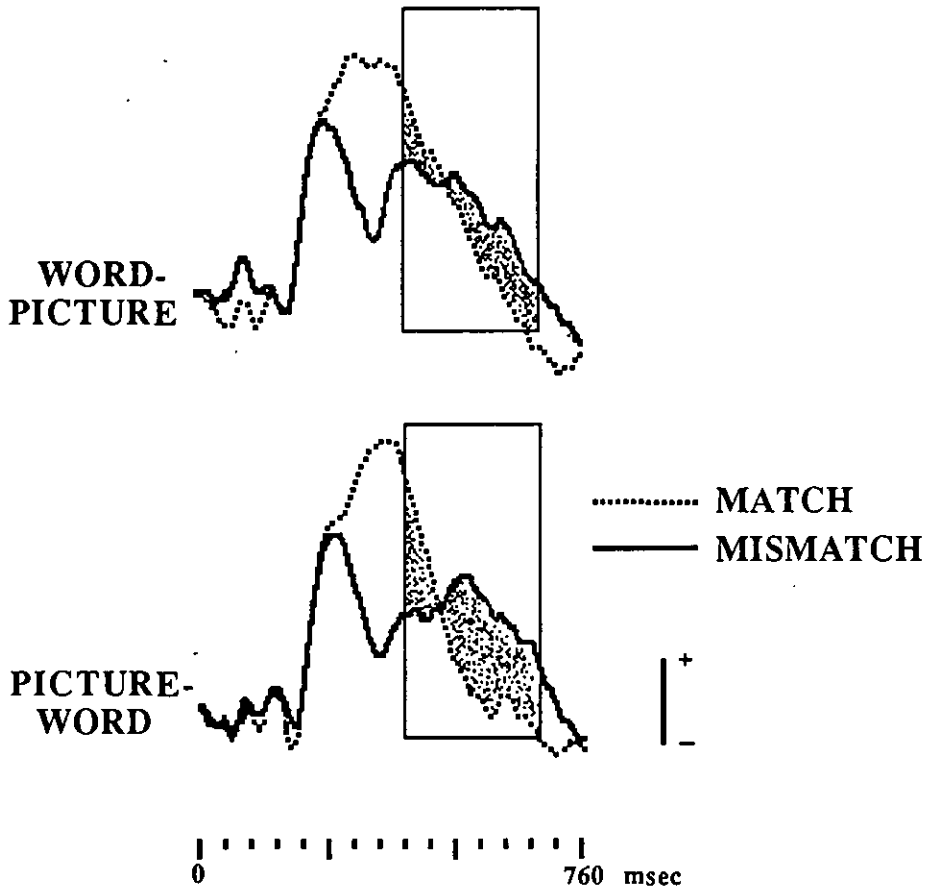


Figure 3. The group average waveforms that represent the Type of Stimulus Pair by Comparison Outcome interaction noted for Component 1. The area of the difference between Match and Mismatch waveforms in the 400 to 670 msec. region is larger for the Picture-Word than for the Word-Picture condition.

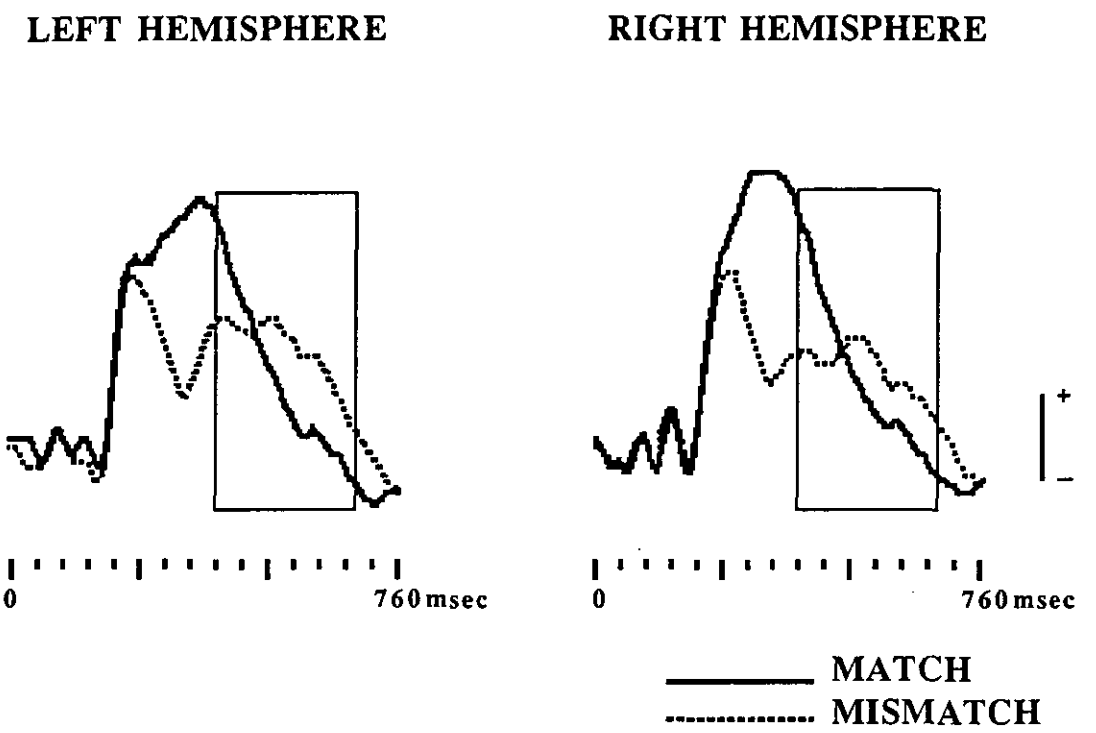


Figure 4. The group average ERP waveforms for the Comparison Outcome by Hemisphere interaction noted for Component 1. The rectangle marks the region of maximum activity for Component 1. Notice that the area of the difference between the Match and the Mismatch waves is larger for the left hemisphere recordings. Positivity is up.

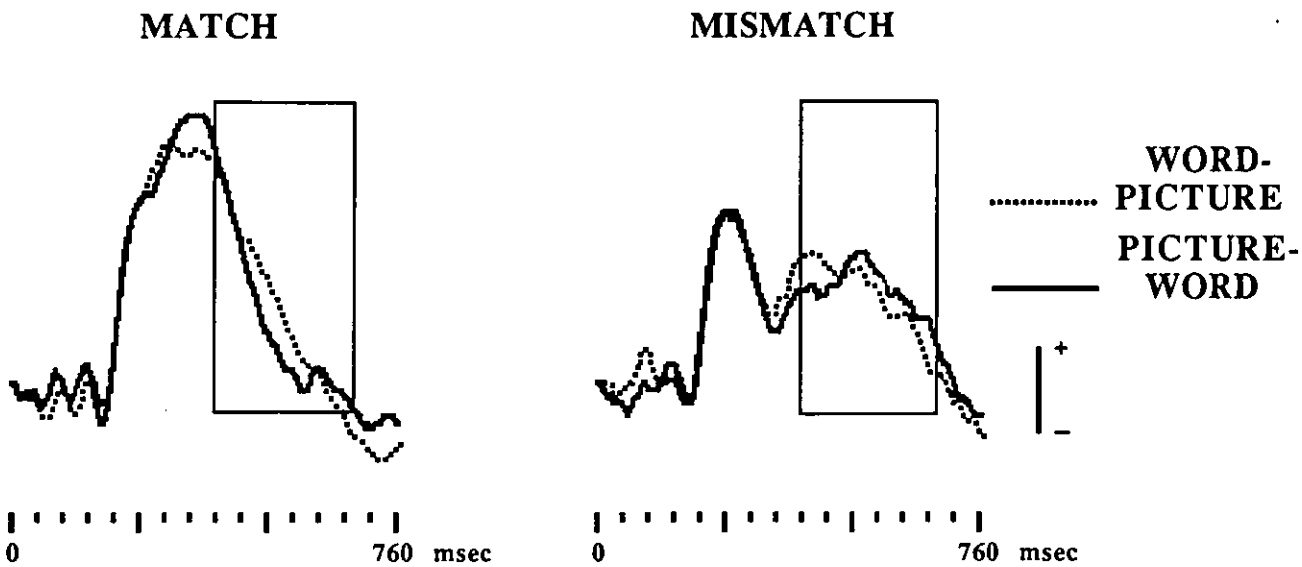


Figure 5. The group average ERP waveforms that display the Type of Stimulus Pair by Comparison Outcome interaction noted for Component 1. The ERP is modulated differently by Type of Stimulus Pair as a function of Comparison Outcome in the region between 400 and 670 msec. The Word-Picture versus Picture-Word difference was significant in the Mismatch condition only. Positivity is up.

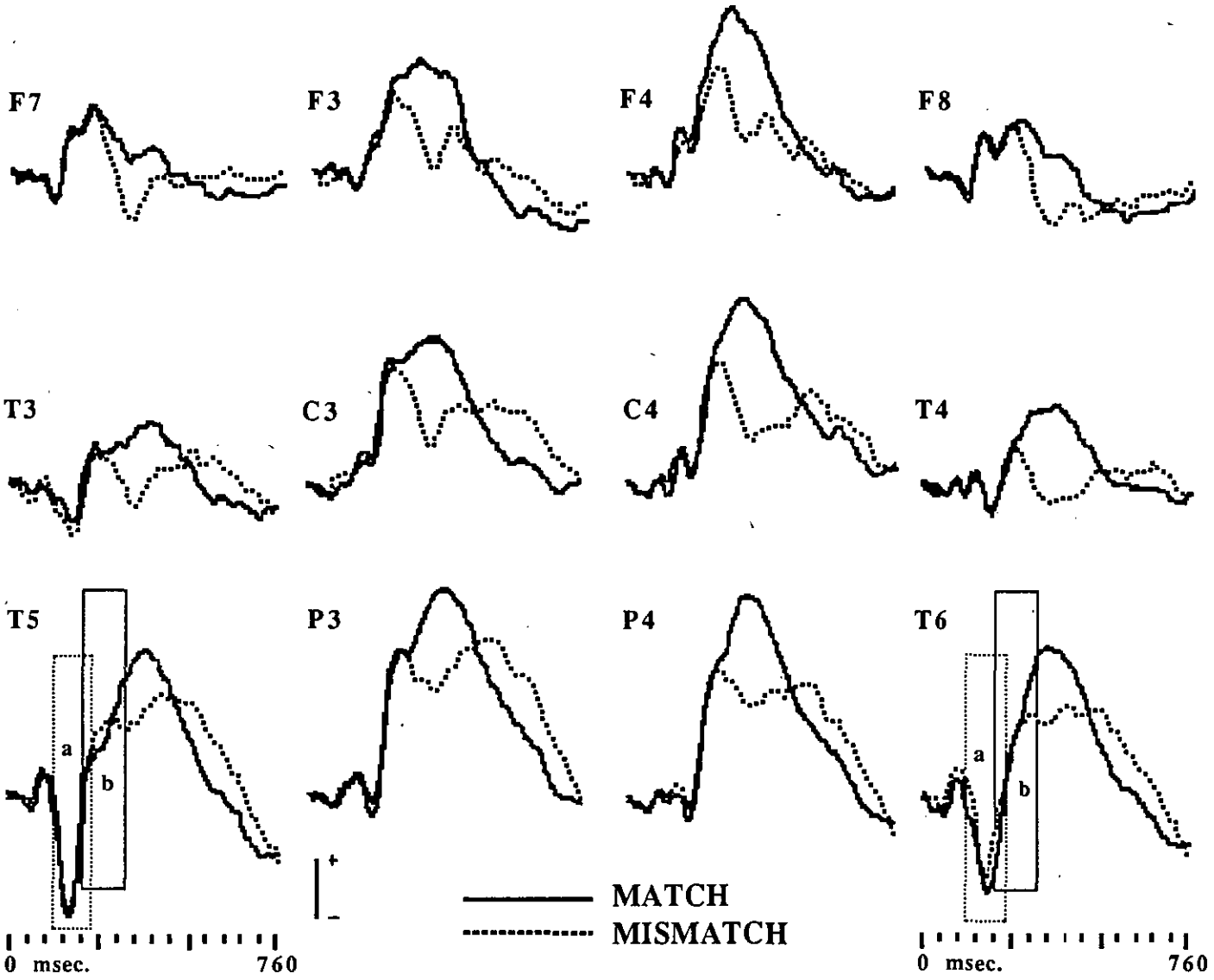


Figure 6. The group averaged ERP waveforms for the two Comparison Outcome conditions for each recording site. The regions between 400 and 670, and 280 and 480 msec. discriminated between Match and Mismatch decisions across all locations. The early portion of the ERP marked by rectangles "a" and "b" (130-230, and 200-320 msec.) varied as a function of Comparison Outcome over T6 only. Stimulus onset is at 0.

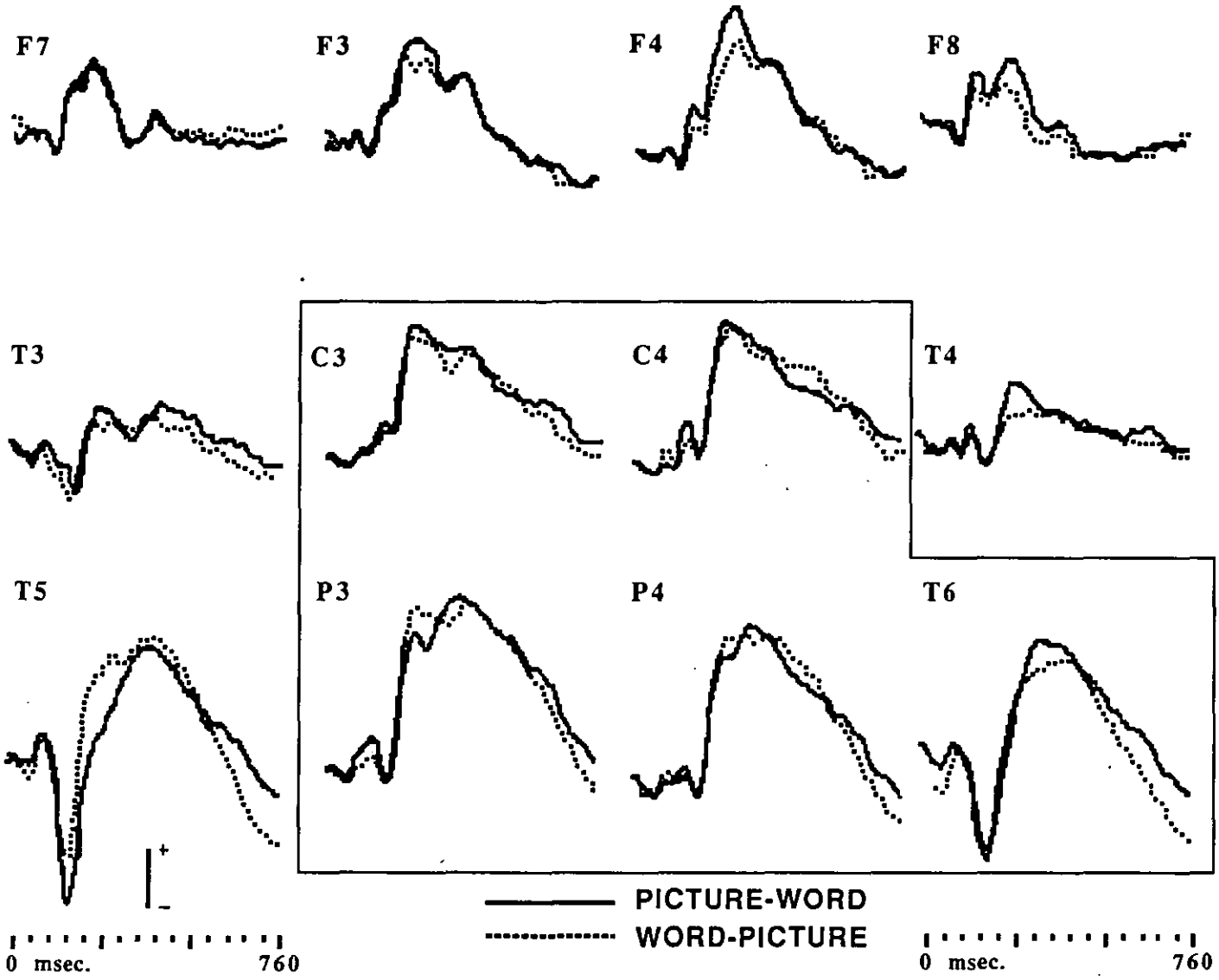


Figure 7.

Figure 7. The group averaged ERP waveforms for the two Type of Stimulus Pair conditions for each recording site. The region between 400 and 670 msec. discriminated between Picture-Word and Word-Picture pairs at central and parietal locations. Stimulus onset is at 0.