ELSEVIER

Electroencephalography and clinical Neurophysiology 102 (1997) 200–215

Visual object priming differs from visual word priming: an ERP study

Xiao Lei Zhang[a,b], Henri Begleiter[b,*], Bernice Porjesz[b], Ann Litke[b]

[a]*Institute of Mental Health, Beijing Medical University, Beijing 100083, China*
[b]*Department of Psychiatry, State University of New York, Health Science Center at Brooklyn, 450 Clarkson Avenue, New York 11203, USA*

Received 18 October 1995; revised version received 18 September 1996; accepted for publication: 22 September 1996

Abstract

Implicit memory is inferred from repetition priming effects in tasks such as word identification, word fragment completion, and perceptual recognition with masking or brief exposures. In this experiment, we explored whether the visual word and object repetition priming effects can be reflected by features of ERP and whether visual word repetition priming differs from visual object repetition priming. We have observed that (1) pre-exposure to recognizable stimuli (both word and object picture) shortened the response time in identifying their repetitions; (2) repetition of unrecognized scrambles of words or object pictures did not show any effects on ERP patterns; (3) ERPs distinguished recognizable from unrecognizable stimuli; and, (4) repetitions of both words and pictures strongly influenced the patterns of ERPs, though the ERPs to word stimuli differed from the ERPs to picture stimuli. © 1997 Elsevier Science Ireland Ltd.

Keywords: Memory; Working memory; Implicit memory; Repetition priming; Event related potential; Word; Object picture

1. Introduction

It is now well established that there is a distinction in memory, most frequently referred to as explicit and implicit memory (Graf and Schacter, 1985; Schacter, 1987; Schacter et al., 1993). Explicit memory reflects intentional or conscious recollection of facts or events, while implicit memory denotes a facilitation or change in test performance that is attributable to information or skills acquired during a prior study episode, even though subjects are not required to, and may even be unable to recollect the study episode. Three converging lines of evidence suggest that implicit memory differs fundamentally from explicit memory. First, performance on implicit and explicit memory tasks is affected differentially by a variety of experimental manipulations (Graf et al., 1982; Graf and Mandler, 1984; Jacoby and Dallas, 1981; Tulving et al., 1982; Graf and Schacter, 1987; Hertz et al., 1994). Second, performance on tests of implicit memory has been shown to be statistically independent of recognition performance (Eich, 1984; Tulving et al., 1982). Third, patients with organic amnesia, who are severely impaired on explicit memory tests, are less impaired, or even normal on various implicit tasks (Graf et al., 1984a,b; Schacter et al., 1984; Schacter, 1985; Squire, 1992). It has been postulated that explicit and implicit memory reflect the operation of different brain systems (Squire et al., 1985).

Facilitation in performance for previously presented material relative to novel material has been referred to as repetition or direct priming and is known to be supported by implicit memory. Visual word and object repetition priming phenomena are being extensively studied. Stem completion, fragment completion, word or perceptual identification, and lexical decision are major methods in the investigation of visual word repetition priming, while picture naming, picture fragment completion, object decision, and dot pattern identification are the methods mainly used in the study of visual object decisions with repetition priming. Priming is indicated when subjects complete, identify or show greater accuracy or reduced response time for previously experienced items than for novel items.

Recent studies on implicit memory have shown that visual word and object repetition priming effects bear many similarities. For instance, word repetition effects have been shown to be independent of semantic priming effects (Musen and Treisman, 1990), and repetition prim-

---

* Corresponding author. Tel.: +1 718 2702024; fax: +1 718 2704081; e-mail: hb@sv2.neurodyn.hscbklyn.edu.

0013-4694/97/$17.00 © 1997 Elsevier Science Ireland Ltd. All rights reserved
PII S0921-884X(96)95172-3

ing of visual objects can be observed for novel information that does not have any pre-existing memory representation (Musen, 1991). Many of the theoretical issues surrounding the role of memory for visual details in picture identification are the same as those surrounding the use of word shape in word identification (Jacoby and Hayman, 1987). However, these two kinds of repetition priming have their own characteristics which need to be compared and explored. Schacter and Tulving have suggested that repetition priming effects or implicit memory largely reflect experience-induced changes in a cortically based, presemantic perceptual presentation system (PRS), which in turn, is composed of several domain-specific subsystems (Schacter, 1990, 1992; Tulving and Schacter, 1990). The visual word form system (Schacter, 1990; Schacter et al., 1990b), which represents orthographic information about words, is implicated in visual word repetition priming, while the structural description system (Plaut and Farah, 1990; Schacter et al., 1991b), which ciphers relations among parts of objects, is responsible for visual object repetition priming. Extrastriate cortex participates in mediating the visual word form system, and inferior temporal regions are involved in mediating the structural description system. Thus far, few studies have made a direct comparison between these two kinds of repetition priming.

The repetition priming effect was initially investigated using one or more overt measures of task performance as the dependent variable(s). A complementary approach is to study repetition effects with scalp-recorded event-related potentials (ERPs). The ERP technique provides a real-time measure of processing, which permits the comparison not only of the amplitudes, but also the time-course of repetition effects. ERPs can be recorded simultaneously from multiple scalp sites, making it possible to compare the patterns of neural activity to visual word and object repetitions, and hence determine whether the two types of repetition are associated with different neural mechanisms. Numerous studies have shown that ERPs are sensitive to word repetition (Bentin and Peled, 1990; Besson and Kutas, 1993; Otten et al., 1993; Rugg et al., 1988, 1995; Rugg, 1987, 1990; Van Petten et al., 1991; Young and Rugg, 1992). ERPs to repeated words were characterized by greater positive amplitude from approximately 300–600 ms post-stimulus relative to their first presentation counterparts. The magnitude of the ERP repetition effect is influenced by the 'level of processing' induced by task demand (Rugg et al., 1988). Recently, several researchers have suggested that visual–visual ERP repetition effects result from the modulation of at least two temporally and spatially overlapping components (Rugg, 1990; Van Petten et al., 1991; Young and Rugg, 1992). It has also been suggested that the earlier of these components corresponds to the 'N400' component, and the later one to the 'P3' or 'late positive component' (Rugg and Doyle, 1994; Van Petten et al., 1991).

Although identification of the repetition effect on ERPs has relied heavily on verbal stimuli, many similar experiments have been conducted by using pictorial stimuli to observe ERP repetition effect. In studies by Friedman et al., several positive late components, ranging from 300–600 ms after pictorial stimulus presentation, were elicited (Friedman et al., 1988, 1990). In a picture matching task, Friedman et al. observed that P400 was different from P500 in the following aspects: P400 was significantly larger in the 'same' than in the 'different' data set, whereas P500 did not differ between these conditions; P400 did not differ in latency between 'different' and 'same' ERP, whereas P500 did. The differences for P400 could be due solely to the underlying N400 component. However, whether these neuronal electrical patterns could be considered to be a reflection of similar functions, or due to different mechanisms remains obscure. A direct electrophysiological comparison between word and object picture priming might help to explain whether there are differences in neuronal mechanisms underlying these two processing phenomena.

Recently, with a modified delayed matching to sample paradigm and a modified electrical recording method, we observed a novel ERP component correlate of visual memory (Begleiter et al., 1993). We observed that for matching stimuli, the component of the ERP occurring between 170 and 240 ms was significantly smaller than the same component for non-matching stimuli. This component was most apparent over the occipito-temporal region in terms of its maximal amplitude and consistent morphology. Both the spatial and temporal characteristics of this component are similar to those found in single cell studies in monkeys (Mikami and Kubota, 1980; Miller et al., 1991). We named this component the visual memory potential (VMP) because it indexes properties related to visual memory. Several experiments on working memory have been performed with the modified delayed matching to sample paradigm, using shapes (Begleiter et al., 1993), faces and face scrambles (Hertz et al., 1994), familiar faces and unfamiliar faces (Begleiter et al., 1995), and concrete object pictures (Zhang et al., 1995) as stimuli. All of these studies generated the VMP with almost the same peak latencies and consistently over the occipito-temporal region, where the neural mechanisms of the medial and inferior temporal (TE) cortices play an important role in the linkage between vision and memory (Baylis and Rolls, 1987; Eskandar et al., 1992; Miller et al., 1991; Riches et al., 1991; Vogels and Orban, 1994). However, the demand characteristics of the modified delayed matching to sample paradigm involve both repetition priming and recognition, and both effects could influence the ERP patterns.

Several experimental results demonstrated that impossible objects show little or no repetition priming (Schacter et al., 1990a, 1991a). The repetition priming effects are likely to be supported by newly acquired memory representation (Micco and Masson, 1991; Musen, 1991). The current study was undertaken to determine whether the VMP can be elicited and reflect the repetition effects in an implicit memory task, using real words, object pictures, word scrambles and picture scrambles as stimuli. It should be difficult to establish representations in memory for these unidentified scrambles. We electrophysiologically examined implicit memory in normal subjects using a list of words and object pictures as stimuli. We focus here on visual repetition priming of words and object pictures, because the effects of repetition of words, objects and scrambles has not been studied simultaneously, and also to understand the functional architecture of the words and object repetition priming systems. We hypothesize that the scrambles will not produce the repetition priming effects at all. Thus, we chose scrambles to serve as a contrast for the priming effects of words and object pictures. Moreover, we used 61 electrodes and scalp current density to assess topographically the word and object picture repetition effects on ERPs.

2. Methods and materials

2.1. Subjects

The study included 74 subjects ranging from 19 to 35 on age. These subjects were recruited from the students and staff of the SUNY Health Science Center via ads posted on the campus. Of the 74 subjects recruited, 12 subjects whose ERP data contained excessive artifacts and 6 additional subjects who were left handed were removed from further analysis. Thus, the statistical analyses were performed on 56 subjects: 34 male (mean age: 24.72 ± 3.88) and 22 females (mean age: 23.64 ± 2.31). There was no significant age difference between male and female subjects ($T(52.5) = -1.289$, $P = 0.203$). No subject involved in the current experiment had a personal or family history of treatment for neurological disease, psychiatric illness, or alcohol/drug abuse. All subjects had normal vision or corrected normal vision.

2.2. Experimental design

2.2.1. Stimuli and stimulus presentation

The stimuli consisted of 120 images (pictures) of objects, 120 words, 120 picture scrambles, and 120 word scrambles. The total 480 stimuli were composed of 40 image same trials, by repeating each image once (40 images), 40 image different trials (80 images), 40 word same trials (40 words), 40 word different trials (80 words), 40 image scramble same trials, 40 image scramble different, 40 word scramble same, and 40 word scramble different trials. These trials were intermingled and presented consecutively in a pseudorandom order. The stimulus was white at the center of a computer monitor (cathode-ray tube, CRT), and was approximately 5–10 cm in height and 5–10 cm in width, thus subtending a visual angle of 5°–6°. The inter-stimulus and inter-trial intervals were all fixed at 1.2 s and the duration of presentation for each stimulus was 312 ms. The images were selected from the Snodgrass and Vanderwart (1980) set of 260 pictures, and the words were nouns corresponding to the objects presented in pictures. The presentation of a word on CRT matched its corresponding object picture in size. The presentations of scrambled words and images were made in the same manner. The graphic was centered in a square 260 × 260 pixels, and each square was divided into 169 smaller squares, 20 × 20 pixels. The positions of the smaller squares were then randomly shuffled to create a fractured image.

2.2.2. Subjects' task

The subjects' task was to decide whether each visual stimulus could be recognized or not. They were instructed to press a mouse key in one hand when they could recognize a stimulus, no matter whether it was a picture or a word, or to press a mouse key in the other hand when they could not recognize the stimulus (scramble). The designation of the hand indicating recognizable or unrecognizable was alternated across subjects. Response accuracy and speed were equally stressed.

2.2.3. Electrophysiological recording

The subject was seated in a reclining chair located in a sound-attenuated RF shielded room and fixated a point in the center of a computer display located 1 m away from his or her eyes. Each subject was fitted with a 61 lead electrode cap (ECI, Electrocap International). We used the entire 10-20 International montage along with an additional 41 sites as follows: Fpz, Afz, Af1, Af2, Af7, Af8, F1, F2, F5, F6, Fcz, Fc1, Fc2, Fc3, Fc4, Fc5, Fc6, Fc7, Fc8, C1, C2, C5, C6, Cpz, Cp1, Cp2, Cp3, Cp4, Cp5, Cp6, Tp7, Tp8, P1, P2, P5, P6, Poz, Po1, Po2, Po7 and Po8 (Standard Electrode Position Nomenclature, American Electroencephalographic Association, 1990). All scalp electrodes were referred to Cz. Subjects were grounded with a nose electrode and the electrode impedance was always below 5 kΩ. Two additional bipolar derivations were used to record the vertical and horizontal EOG. The signals were amplified with a gain of 10 000 by an Ep-A2 amplifier (Sensorium Inc.) with a bandpass between 0.02 and 50 Hz, and recorded on a Concurrent 55/50 computer. The amplified signals were sampled at a rate of 256 Hz during an epoch of 190 ms of pre-stimulus baseline and 800 ms following each stimulus presentation. Trials with excessive eye and body movements (>73.3 μV) were rejected on-line.

2.3. Data analysis

ERPs were derived by averaging the artifact-free EEG segments sampled during the second stimulus presentation in trials with correct responses, i.e., recognized or unrecognized. These procedures yielded 8 categories of ERPs according to the different stimulus conditions. Fig. 1a,b shows the ERPs to unrecognizable stimuli (image scramble same, image scramble different, word scramble same, and word scramble different) and recognizable stimuli (image same, image different, word same, and word different), respectively. As illustrated in Fig. 1a,b, these ERP waveforms consisted of 3 components which were most clearly discernible at the more posterior electrodes: component 1 (c110) ranging between 100 and 125 ms, component 2 (c180) ranging between 170 and 190 ms, and component 3 (c240) ranging between 220 and 260 ms. There was no absolute polarity in this experiment; the upgoing wave represented relative positivity at the recording electrode compared to the reference at Cz. Amplitude and latency for the three components were initially measured at P8, the electrode site with maximal amplitudes and the most consistent morphology. Amplitudes were measured from baseline to each peak, and latencies were recorded from the onset of stimuli to the peak of each component. Measurements at other electrodes were based on the latency of each component obtained at P8. Because the ERPs had no definite peaks beyond 400 ms, and there were apparently different slow shifts in ERP after c240, we computed the mean amplitudes of ERP epoch in the following time ranges: 300–400 ms (MAMP3_4) and 400–500 ms (MAMP4_5) post-stimulus for further comparisons between ERPs in different stimulus conditions.

The measurements of amplitudes of each component at each electrode were organized into groups by region. The frontal region consisted of Fp1, Fp2, Fpz, Af7, Af8, Af1, Af2, Afz, F7, F8, F5, F6, F3, F4, F1, F2, Fz; the central region consisted of Fc1, Fc2, Fc3, Fc4, Fc5, Fc6, Fcz, C1, C2, C3, C4, C5, C6; the parietal region consisted of Cp1, Cp2, Cpz, Cp3, Cp4, Pz, P1, P2, P3, P4; the occipital region consisted of Po1, Po2, Poz, O1, O2, Oz. The left temporal region consisted of T7, Tp7, Cp5, P5, P7, Po7; and the right temporal region consisted of T8, Tp8, Cp6, P6, P8, Po8. A number of MANOVAs were carried out separately for each component amplitude at each regional electrode array as a dependent vector for comparisons among different stimulus conditions.

Because the scalp potentials may reflect the average activity of multiple neural sources recorded at a distance, they are neither reference-free, nor independent of the volume conductor effects. These limitations mean that ERP components will be altered if the placement of the reference is changed or if it is not a 'quiet' reference (Nunez et al., 1991) and there may be spatial smearing of the potential record as a consequence of volume conductor effects. For further analysis of our electrophysiological data, we made topographic maps of SCD (Source Current Density). The SCD represents both scalp sources and sinks of current, reflecting mainly cortical activity; a scalp region having a positive current density corresponds to a source region where a local radial current is flowing through the skull into the scalp.

3. Results

We initially performed several MANOVAs to explore the gender effects on ERP amplitudes over corresponding brain regions; however, no positive results could be revealed. Moreover, there was no age difference between our male and female subjects. Thus, the comparisons between ERP amplitudes to different stimulus conditions over analogous brain regions were based on the combination of all subjects. On the issue of laterality, however, we separately analyzed the data by gender.

3.1. Behavioral performance

As the subjects made very few errors in the identification of recognizable and unrecognizable stimuli, we did not perform statistical analysis on these data. However, the reaction times (RTs) to recognizable stimuli were analyzed by two-way ANOVA, with two between-groups factors. The analysis revealed significant main effects for stimulus condition ($F(3,212) = 11.85$, $P = 0.0001$) and gender ($F(1,212) = 14.80$, $P = 0.0002$). The female subjects generally had longer RTs that the male subjects. No significant interactions could be revealed by the two-way ANOVA. Because the stimulus condition affected the RTs in exactly the same way between the male and female subjects as indicated by separate Bonferroni t tests (SAS V6.09), Table 1 only illustrates the grand means of RTs for total subjects and the comparison results by Bonferroni t test. Among the RTs listed in Table 1, the word same condition produced the shortest RT and the image different condition elicited the longest. The subjects had a significantly faster RT to the word same compared to the word different condition, and to the image same compared to the image different condition. Though no robust differences in RTs were found between the word same and image same condition, the RT to image different stimuli was significantly longer than that to word different stimuli. We also deducted RTs in 'same' stimuli from RTs in corresponding 'different' stimuli and then compared the image and word repetition priming effects with a t test. It turned out that there was a tendency to have a larger priming effect for image stimuli than for word stimuli ($T = 1.93$, $P = 0.0555$). RTs to scramble stimuli were also analyzed using a two-way ANOVA, with two between-groups factors: stimulus condition and gender. No positive results could be documented.

3.2. ERP data

Statistical analyses (MANOVAs) demonstrated our initial impressions from Fig. 1b that stimulus condition had no robust effects on c110 for recognizable stimulus

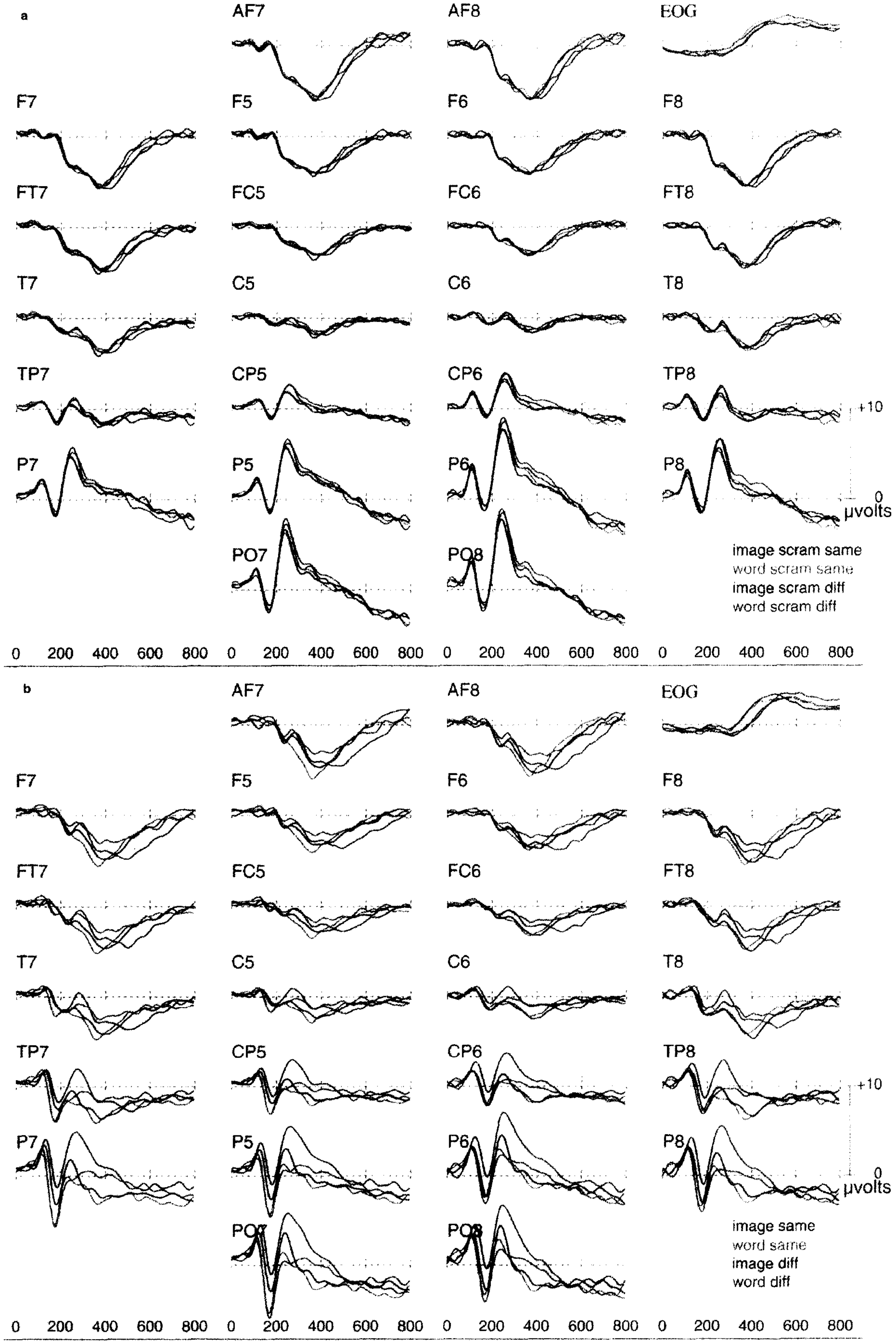

a
AF7
AF8
EOG
F7
F5
F6
F8
FT7
FC5
FC6
FT8
T7
C5
C6
T8
TP7
CP5
CP6
TP8
+10
P7
P5
P6
P8
0
µvolts
PO7
PO8
image scram same
word scram same
image scram diff
word scram diff
0 200 400 600 800
0 200 400 600 800
0 200 400 600 800
0 200 400 600 800
b
AF7
AF8
EOG
F7
F5
F6
F8
FT7
FC5
FC6
FT8
T7
C5
C6
T8
TP7
CP5
CP6
TP8
+10
P7
P5
P6
P8
0
µvolts
PO7
PO8
image same
word same
image diff
word diff
0 200 400 600 800
0 200 400 600 800
0 200 400 600 800
0 200 400 600 800

Table 1

Results of Bonferroni t tests on reaction times in different stimulus conditions (total subjects, $n = 56$)

	Mean ± S.D.	Image same	Word same	Image difference	Word difference
Image same	390.5 ± 67.2	0.0	–	–	–
Word same	368.3 ± 64.8	–22.20	0.0	–	–
Image difference	441.9 ± 70.3	51.40*	73.60*	0.0	–
Word difference	406.1 ± 71.1	15.60	37.80*	–35.80*	0.0

The data in the first column of the table are mean values and standard deviations of response times in each stimulus conditions listed in corresponding columns. The other values in the table are derived by substracting the mean RTs in rows from those in columns.
*P-value in the Bonferroni t test between RT in stimulus condition in row and in column is less than 0.05.

trials. For unrecognizable stimulus trials, stimulus condition had no significant effects on c110, c180, and c240, nor on the mean amplitudes of prefixed time windows over 300–400 and 400–500 ms post-stimulus.

3.2.1. Comparisons between ERPs to image same and image different conditions

Fig. 2a shows the ERPs to image same and image different stimuli. The figure suggests that the ERPs to image different stimuli have a positive shift beginning about 110 ms (c110) and lasting for approximately 600 ms after stimulus presentation. These phenomena are particularly obvious in the posterior electrodes. With the exception of the occipital region, the amplitude difference between the two conditions reached significance by MANOVAs on c240 in the left temporal region ($F(7,102) = 2.923$, $P = 0.0079$), right temporal region ($F(7,102) = 5.199$, $P = 0.0001$), parietal region ($F(10,99) = 4.961$, $P = 0.0001$), central region ($F(13,96) = 3.015$, $P = 0.0009$), and frontal region ($F(17,92) = 2.438$, $P = 0.0035$). The mean amplitudes of ERPs in the left temporal area to image different stimuli were significantly higher than those to image same stimuli after c240 were confirmed by MANOVAs only on MAMP3_4 ($F(7,102) = 2.259$, $P = 0.0353$).

3.2.2. Comparisons between ERPs to word same and word different conditions

Fig. 2b illustrates ERPs from the same electrode composition as Fig. 2a, but to word same and word different stimuli. Fig. 2b indicates that the ERPs to different word stimulus conditions have almost identical patterns in c110 and c180. However, the patterns of c240 to word stimuli apparently differ from those to image stimuli; rarely were the amplitudes of c240 in the word same condition larger than in the word different condition at posterior electrodes. MANOVAs confirmed that no significant stimulus condition effect could be found on c110, c180, and c240 at any of our pre-delineated brain regions. After c240, the ERPs to word different stimuli became more positive than to word same stimuli until 600 ms post-stimulus at most electrodes; then, the patterns of ERPs to the two kinds of word stimuli overlapped to the end of the recording epoch. MANOVAs on MAMP3_4 over the left temporal region ($F(7,102) = 2.256$, $P = 0.0355$) demonstrated a strong stimulus condition effect on the mean amplitude between 300 and 400 ms post-stimulus. The robust stimulus condition effect was obtained on MAMP3_4 in both the left frontal region ($F(7,102) = 2.508$, $P = 0.0203$) and the right ($F(7,102) = 2.154$, $P = 0.0445$) frontal regions. No statistical differences could be documented between mean amplitudes of ERPs to the two word stimulus conditions over 400–500 ms, despite its suggestion in Fig. 2b.

3.2.3. Comparisons between ERPs to image different and image scramble different stimuli

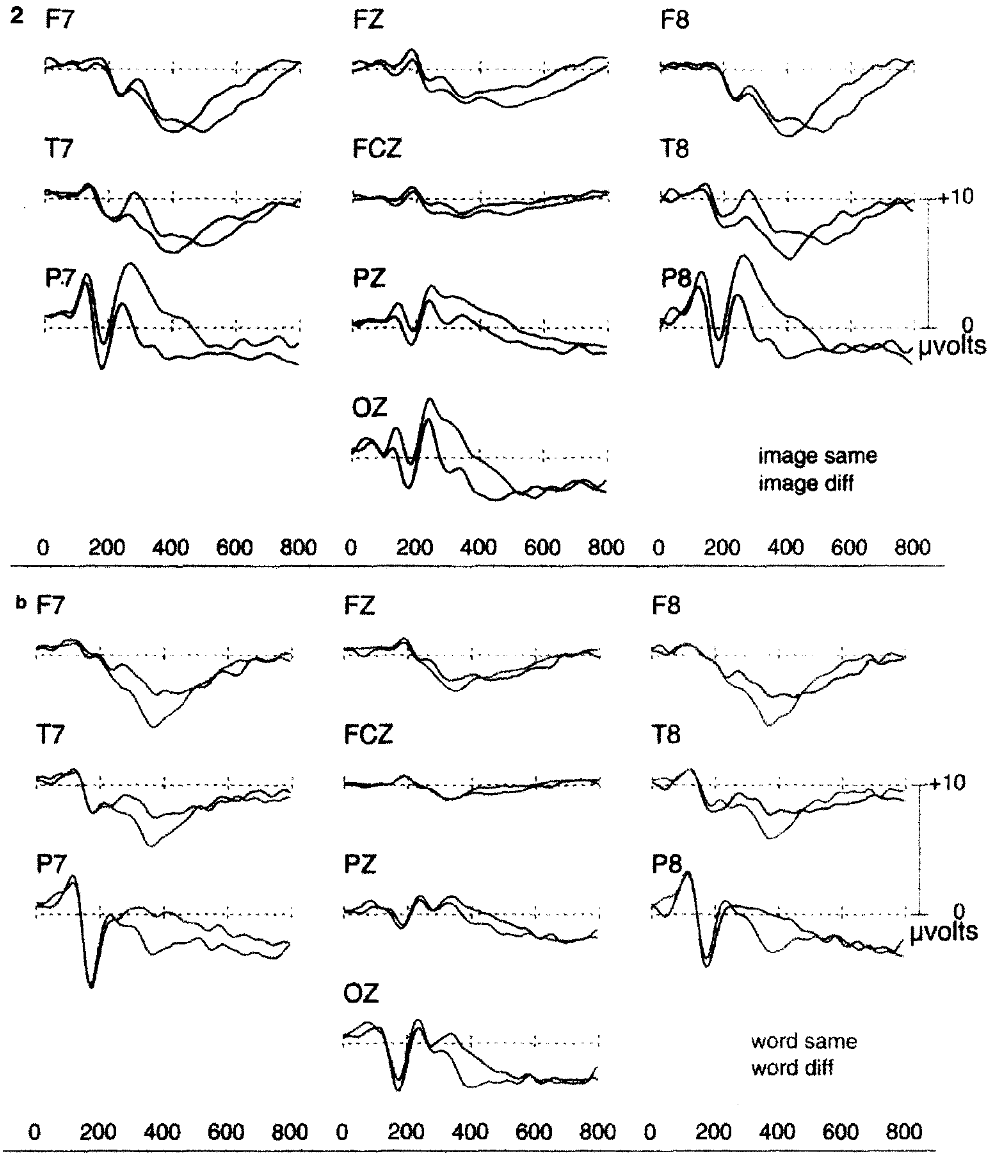
A different electrode composition, which consisted of temporal electrodes (P7, P8), parietal electrodes (P3, P4, Pz), and occipital electrodes (O1, O2, Oz), was used in Fig. 3 to show the ERP patterns to image different and image scramble different stimuli. As Fig. 3a illustrates, the differences between the ERPs to these two stimulus conditions obviously came from occipital electrodes, and mainly occurred at early components. This observation was confirmed by several MANOVAs. The stimulus condition effects on c180 reached significance only over the occipital region ($F(6,103) = 2.484$, $P = 0.03$ 14).

3.2.4. Comparisons between ERPs to word different and word scramble different stimuli

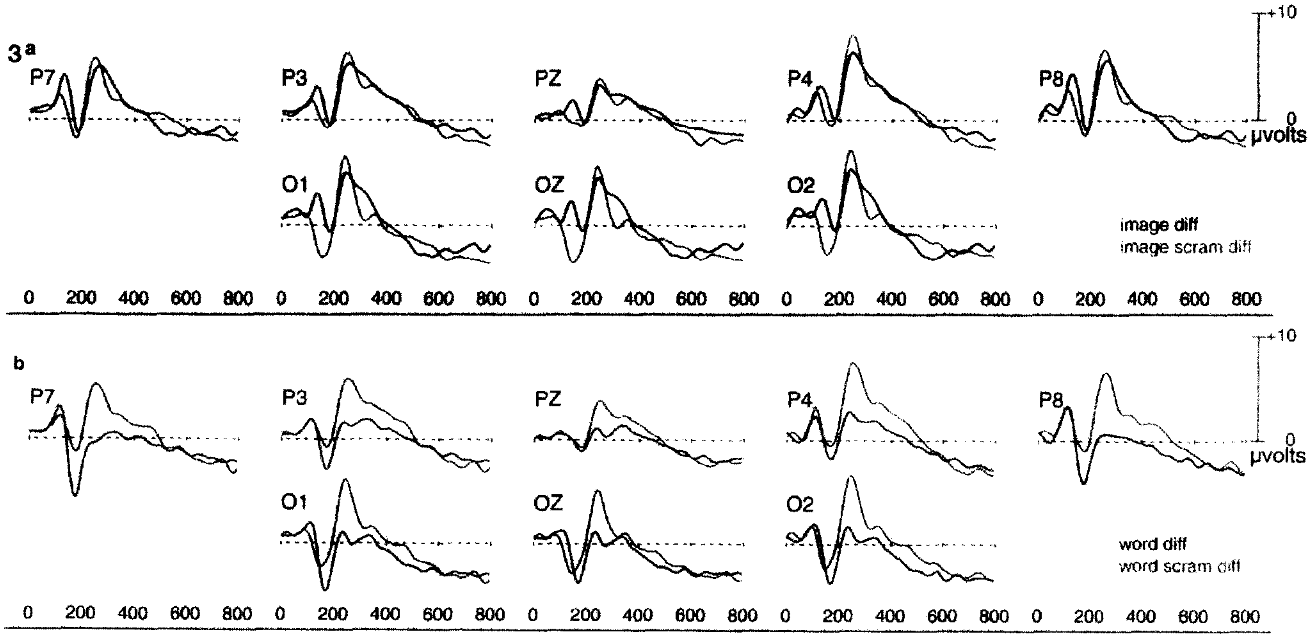
Beginning at 170 ms post-stimulus and ending approximately at 600 ms, the ERPs to word scramble stimuli at posterior electrodes showed a positive deflection, which was much higher than the ERPs to word stimuli as

Fig. 1. Grand mean ERPs to different kinds of unrecognizable stimuli. The ERPs to unrecognizable stimuli have almost identical patterns with almost the same amplitudes. ERP patterns to all kinds of unrecognizable stimuli consist of three components which are most discernible at more posterior electrodes. Due to limitation of space, only data from 24 electrodes referenced to Cz are presented. (b) Grand mean ERPs to different kinds of recognizable stimuli. Although they have identical patterns which are also composed of three clearly discernible components, the component three (c240) to different recognizable stimuli has a different amplitude. Due to limitation of space, only data from 24 electrodes referenced to Cz are presented.

2


F7
FZ
F8
T7
FCZ
T8
+10
P7
PZ
P8
0
μvolts
OZ
image same
image diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800
b
F7
FZ
F8
T7
FCZ
T8
+10
P7
PZ
P8
0
μvolts
OZ
word same
word diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800

3a


+10
P7
P3
PZ
P4
P8
0
μvolts
O1
OZ
O2
image diff
image scram diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800
b
+10
P7
P3
PZ
P4
P8
0
μvolts
O1
OZ
O2
word diff
word scram diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800

shown by Fig. 3b. The visual impression was confirmed by MANOVAs. The significant effects of stimulus condition on c180 were documented mainly at the posterior regions: left temporal region ($F(7,102) = 2.554$, $P = 0.0183$), right temporal region ($F(7,102) = 2.219$, $P = 0.0386$), occipital region ($F(6,103) = 3.111$, $P = 0.0077$), and parietal region ($F(10,99) = 2.435$, $P = 0.0122$). The significant stimulus condition effects on c240 could be found extensively throughout all brain regions: left temporal region ($F(7,102) = 6.958$, $P = 0.0001$), right temporal region ($F(7,102) = 6.107$, $P = 0.0001$), occipital region ($F(6,103) = 6.430$, $P = 0.0001$), parietal region ($F(10,99) = 2.872$, $P = 0.0035$), central region ($F(13,96) = 4.158$, $P = 0.0001$), frontal region ($F(17,92) = 1.782$, $P = 0.0423$). MANOVAs on MAMP3_4 indicated that stimulus condition effects on the mean amplitudes between 300 and 400 ms post-stimulus could be found over left temporal region ($F(7,102) = 3.762$, $P = 0.0011$), right temporal region ($F(7,102) = 3.804$, $P = 0.0010$), central area ($F(13,96) = 2.947$, $P = 0.0012$), left frontal region ($F(7,102) = 2.402$, $P = 0.0257$), and right frontal region ($F(7,102) = 2.7644$, $P = 0.0113$).

3.2.5. Comparisons between ERPs to image different and word different stimuli

The ERPs to image different stimuli drifted positively as compared to the ERP to word different stimuli (Fig. 4a). These trends, which were most discernible within the time range between 150 to 500 ms post-stimulus, occurred mainly in posterior electrodes. The MANOVAs demonstrated that the differences between ERPs to these two stimulus conditions at c180 could be found mainly over the posterior brain regions, namely left temporal ($F(7,102) = 3.532$, $P = 0.0019$), right temporal ($F(7,102) = 2.259$, $P = 0.0353$), occipital ($F(6,103)=2.916$, $P = 0.0114$), and parietal ($F(10,99) = 2.459$, $P = 0.0114$) regions. The stimulus condition had a robust effect on c240 over every brain region as indicated by MANOVAs: left temporal ($F(7,102) = 4.068$, $P = 0.0006$), right temporal ($F(7,102) = 5.245$, $P = 0.0001$), occipital ($F(6,103) = 3.412$, $P = 0.0041$), parietal ($F(10,99) = 4.961$, $P = 0.0001$), central ($F(13,96) = 4.307$, $P = 0.0001$), and frontal ($F(17,92) = 2.704$, $P = 0.0012$). Fig. 4a indicates that the amplitudes of c240 to image different stimuli were higher in posterior electrodes and lower in the frontal area. The significant stimulus condition effect on MAMP4_5 was revealed only on the left temporal region ($F(7,102) = 2.493$, $P = 0.0210$).

3.2.6. Comparisons between ERPs to image same and word same stimuli

Fig. 4b illustrates that ERPs to word same stimuli manifest a stronger negative c180, especially at the left posterior electrodes, and a lower c240 than to image same stimuli, which mainly occurred at posterior electrodes. MANOVAs demonstrated a significant stimulus condition effect on c180 in several scalp regions such as occipital ($F(6,103) = 3\ 434$, $P = 0.0039$), and parietal ($F(10,99) = 4.092$, $P = 0.0001$) regions. The other visual impressions could not be verified with MANOVAs, and statistical analyses did not reveal differences between the ERPs to the two stimulus conditions.

3.2.7. ERP Laterality influenced by gender and stimulus conditions

In order to determine the effects of gender and stimulus condition on laterality differences between homologous electrode pairs, we devised the following transformation of the amplitude data:

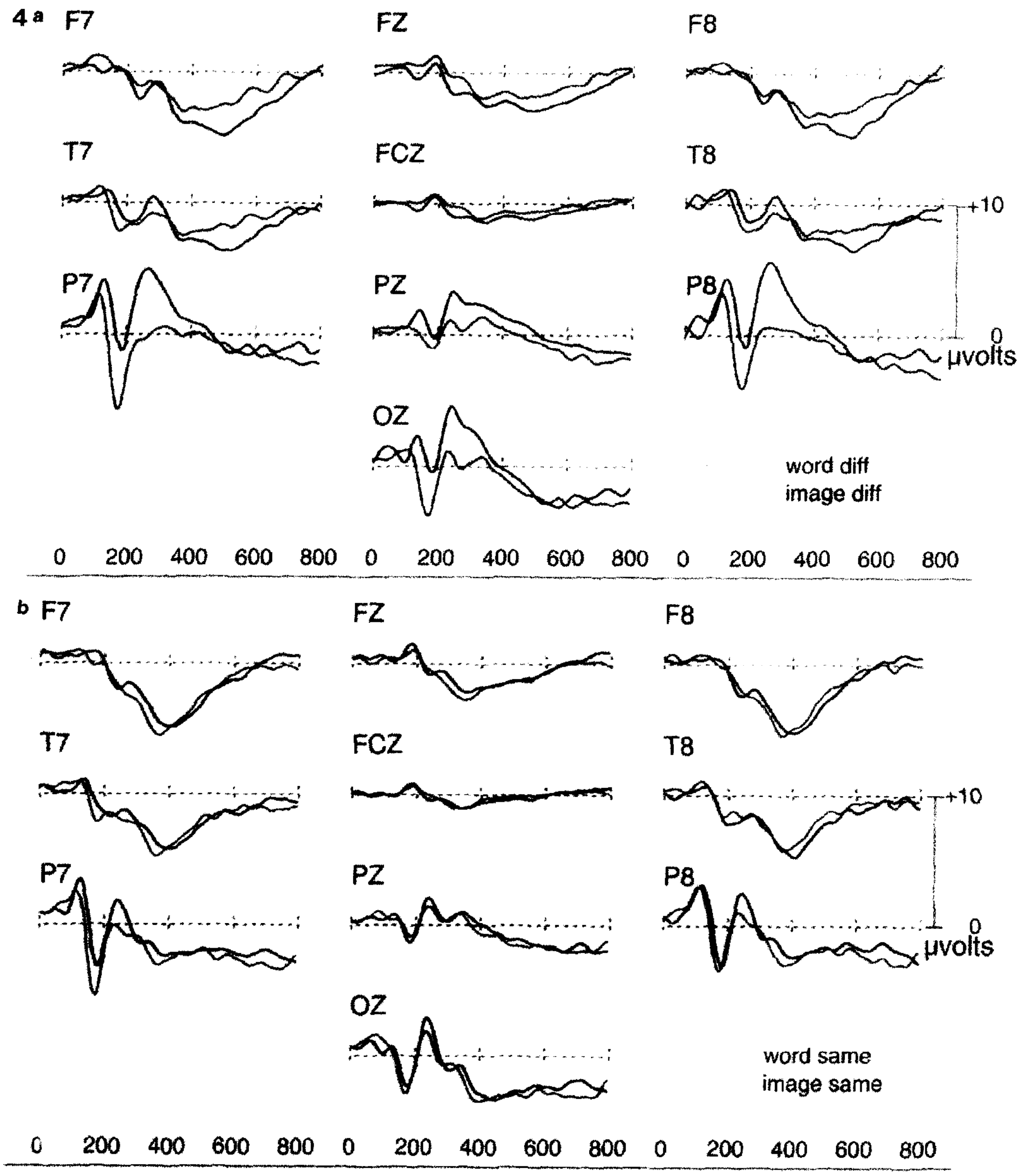
$$P_{7 \text{ or } 8} = \frac{P_{7 \text{ or } 8} - P_{8 \text{ or } 7}}{P_7 + P_8}$$

If the transformation yields a value of 0, the ERP amplitudes between the homologous electrode pair are symmetrical; a (+) or (−) value indicates a laterality difference. If the denominator equals zero, the original data are kept for further analyses. Then, we compared the homologous brain regions of the two hemisphere with MANOVAs using the transformed c240 and MAMP3_4 as dependent variables because most of our aforementioned positive results came from these two ERP components.

MANOVAs demonstrated that the male and female subjects displayed a similar laterality pattern of c240 to image stimuli in the temporal region, i.e., both the image same ($F(7,58) = 2.596$, $P = 0.0224$) and the image different ($F(7,58) = 5.548$, $P = 0.0001$) stimuli elicited stronger activity on the right side for the males, and both the image same ($F(7,36) = 7.234$, $P = 0.0001$) and the

Fig. 2. (a) Grand means ERPs to word same and word different stimuli. The ERP to image different stimuli have a positive shift beginning about 110 ms (c110) and lasting approximately 600 ms poststimulus. This phenomenon is most clearly seen at the P8 electrode. (a) Grand means ERPs to word same and word different stimuli. Due to space limitation, only 10 electrodes referenced to Cz are selected. (b) Grand means ERPs to word same and word different stimuli. Unlike the ERPs to image stimuli, the ERPs to word different stimuli have a positive shift between approximately 300 and 600 ms poststimulus. Due to space limitation, only 10 electrodes referenced to Cz are selected.

Fig. 3. ERPs to image different and image scramble different stimuli. In the occipital region, c180 for the image scramble stimulus condition is much more negative than for the image different stimulus condition. Cz is the reference electrode for this illustration. (b) ERPs to word and word scramble different stimuli. The ERPs to word scramble stimuli at posterior electrodes sustained more positive deflection than those to word stimuli over the period between 170 nd 600 ms post-stimulus. Cz is the reference electrode for this illustration.


4a
F7
FZ
F8
T7
FCZ
T8
P7
PZ
P8
OZ
+10
0
µvolts
word diff
image diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800
b
F7
FZ
F8
T7
FCZ
T8
P7
PZ
P8
OZ
+10
0
µvolts
word same
image same
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800

5

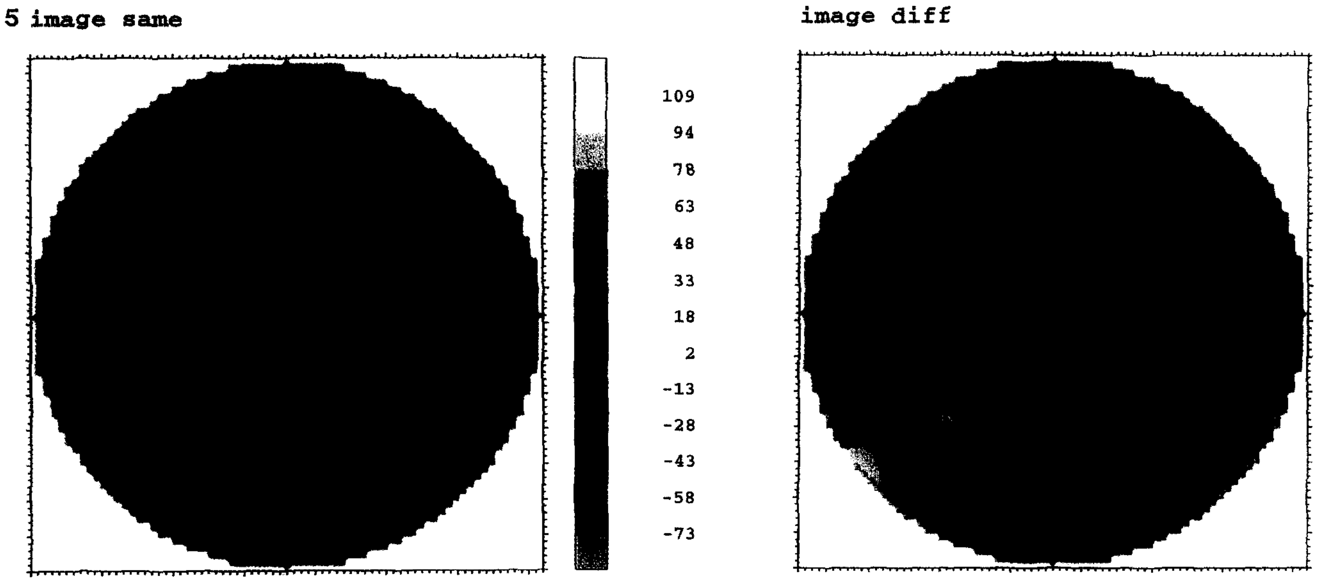


image same
image diff
109
94
78
63
48
33
18
2
-13
-28
-43
-58
-73

image different ($F(7,36) = 2.581$, $P = 0.0290$) stimuli evoked stronger activity on the right side for the females. However, a gender difference on laterality of c240 to image stimuli could be revealed by MANOVAs at the parietal region. The male subjects had stronger c240 activity during the image same ($F(4,61) = 3.103$, $P = 0.0217$) and image different ($F(4,61) = 6.994$, $P = 0.0001$) trials at the right parietal region compared to the left parietal region. This asymmetrical pattern could not be demonstrated in our female subjects. We could not further document significant laterality patterns for c240 to image stimuli at any other brain regions either in the male or female subjects. Though c240 to the word stimuli was not significantly asymmetrical, the results from MANOVAs indicated a strong laterality of MAMP3_4 to word stimuli in the male subjects. The MAMP3_4s both to the word same stimuli ($F(7,58) = 3.170$, $P = 0.0066$) and to the word different stimuli ($F(7,58) = 2.619$, $P = 0.0202$) were significantly higher in the left temporal region than in the right temporal region in the male group. Similar results could be found at the parietal region; namely, the word same stimuli ($F(4,61) = 5.148$, $P = 0.0012$) and word different stimuli ($F(4,61) = 2.787$, $P = 0.0342$) evoked stronger activity at the left parietal than the right parietal region in the male subjects. However, the word same stimuli could also produce a stronger MAMP3_4 at the left parietal region compared to the right parietal region ($F(4,39) = 3.117$, $P = 0.0256$) in the female subjects. Although the female subjects did not display the asymmetrical pattern to word stimuli in temporal and parietal regions as the male subjects did, the two groups manifested a very similar laterality pattern of MAMP3_4 to word stimuli at the frontal region. In addition to the word same stimuli eliciting stronger activity at the left frontal region in both the male ($F(7,58) = 3.051$, $P = 0.0084$) and the female ($F(7,36) = 2.926$, $P = 0.0157$) groups, the word different stimuli could also evoke stronger activity at the left frontal region in both the male ($F(7,58) = 2.419$, $P = 0.0304$) and the female ($F(7,36) = 3.958$, $P = 0.0027$) groups.

3.2.8. Comparisons between SCD mapping of ERPs to image and word stimuli

As shown in Fig. 5, the topographic analyses revealed that the SCD distribution pattern of c240 to image different stimuli, where the most significant differences in potential amplitudes between different image stimuli were found, could be distinguished most clearly from that to image same stimuli. Though the current sources were most active in the occipito-temporal regions in both of the stimulus conditions, the current source densities for the image different stimulus condition were much stronger than those for the image same stimulus condition at the occipito-temporal regions. Furthermore, the frontal regions were more involved during image different trials compared to image same trials. The different SCD topographic patterns between the two image stimulus conditions provide another comparison which had been confirmed to be significant by MANOVAs.

The SCD topographic maps for word stimuli were developed at 375 ms post-stimulus, where the ERPs to the word same stimuli differed most clearly from those to the word different stimuli. The SCD maps for words (Fig. 6) showed that the word same stimuli evoked stronger current source densities than the word different stimuli. In contrast to the SCD for image stimuli, the current sources were mainly located in the frontal regions for both the word same and different conditions. However, the occipito-temporal regions were more activated during the word same trials than the word different trials. A number of repeated ANOVAs on normalized SCD data at different brain regions were performed for comparison between word and image stimuli. As listed in Table 2, the repeated ANOVAs indicated that the SCD for the image and the word same stimuli differed from each other significantly at all of the brain regions, while the difference between the SCDs for the image and word different stimuli reached significance only at the central and the parietal regions. These results not only confirmed the previous statistical analyses on the comparisons of different word stimulus conditions, but also suggest different neuro-processings underlying visual object and word repetition priming.

4. Discussion

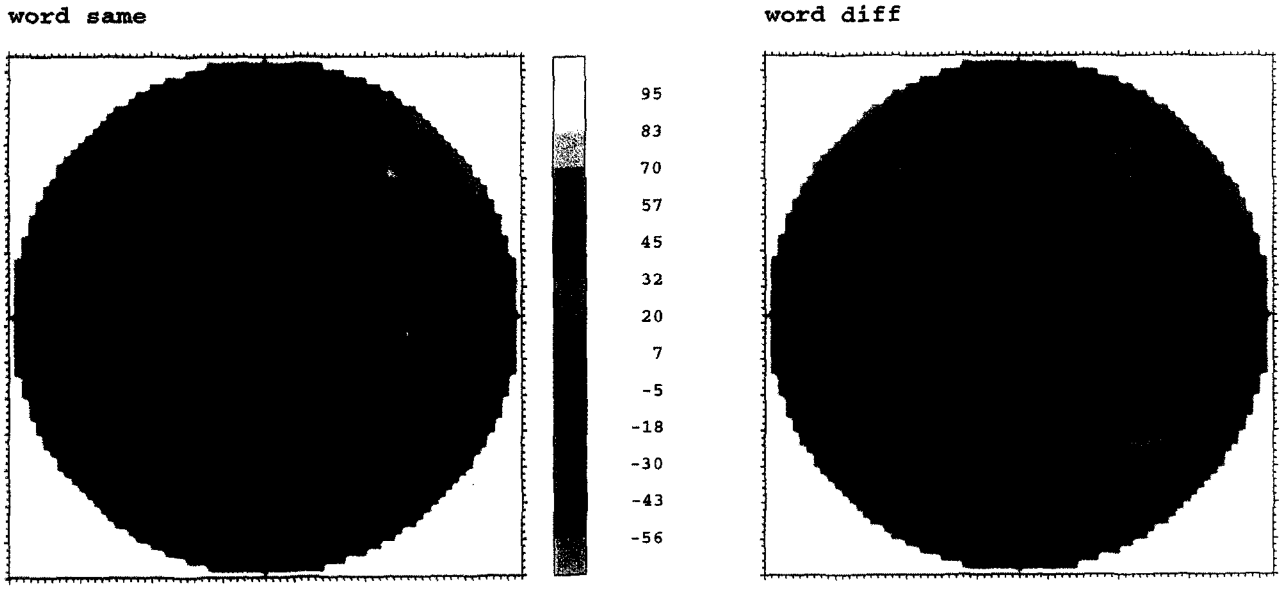
Overall, the main results of the study are as follows. First, pre-exposure of recognizable stimuli shortened the response time in identifying their repetitions. Second, repetition of unrecognized scrambles of words or object pictures did not show any effects on ERP patterns. Third, ERPs distinguished recognizable from unrecognizable stimuli. Fourth, repetitions of both words and pictures strongly influenced the patterns of ERPs, though the ERPs to word stimuli differed from the ERPs to picture stimuli.

The task in this experiment demanded the subjects to direct their attention toward the category decision, not

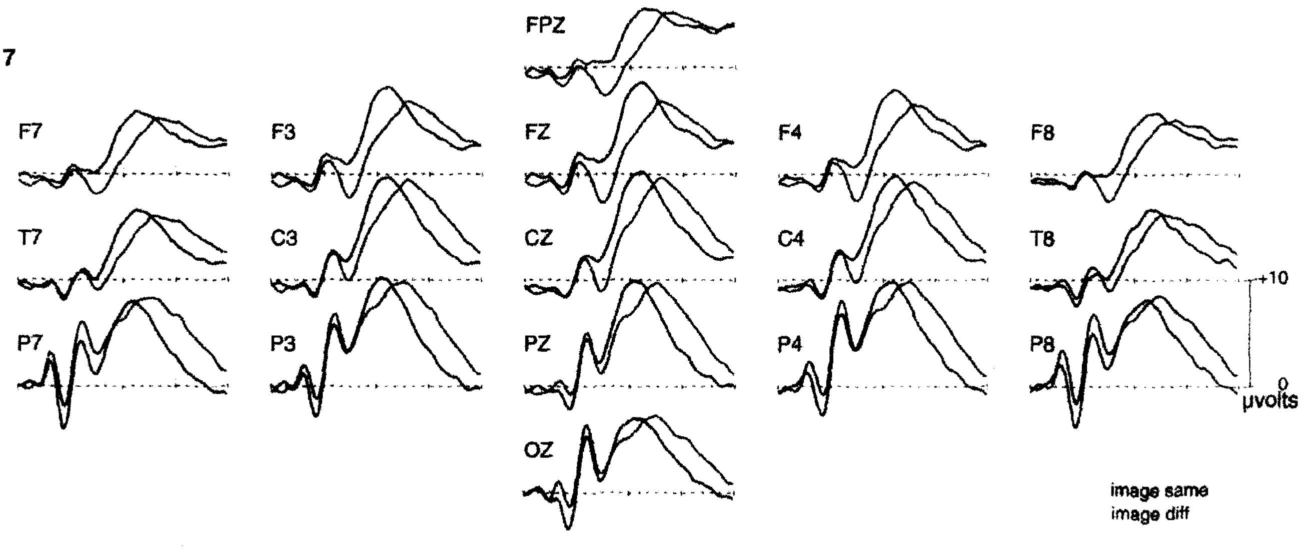
Fig. 4. (a) Grand mean ERP to image and word different stimuli. The ERPs to image different stimuli drift much more positively than to word different stimuli for c240 at P8 and Oz electrodes. All data are referenced to Cz. (b) Grand mean ERPs to image and word same stimuli. The ERPs to these two stimuli have almost identical patterns. All data are referenced to Cz.

Fig. 5. SCD maps of c240 to image same and image different stimuli.

6


word same
word diff
95
83
70
57
45
32
20
7
-5
-18
-30
-43
-56

7


FPZ
F7
F3
FZ
F4
F8
T7
C3
CZ
C4
T8
P7
P3
PZ
P4
P8
OZ
+10
0
µvolts
image same
image diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800

8

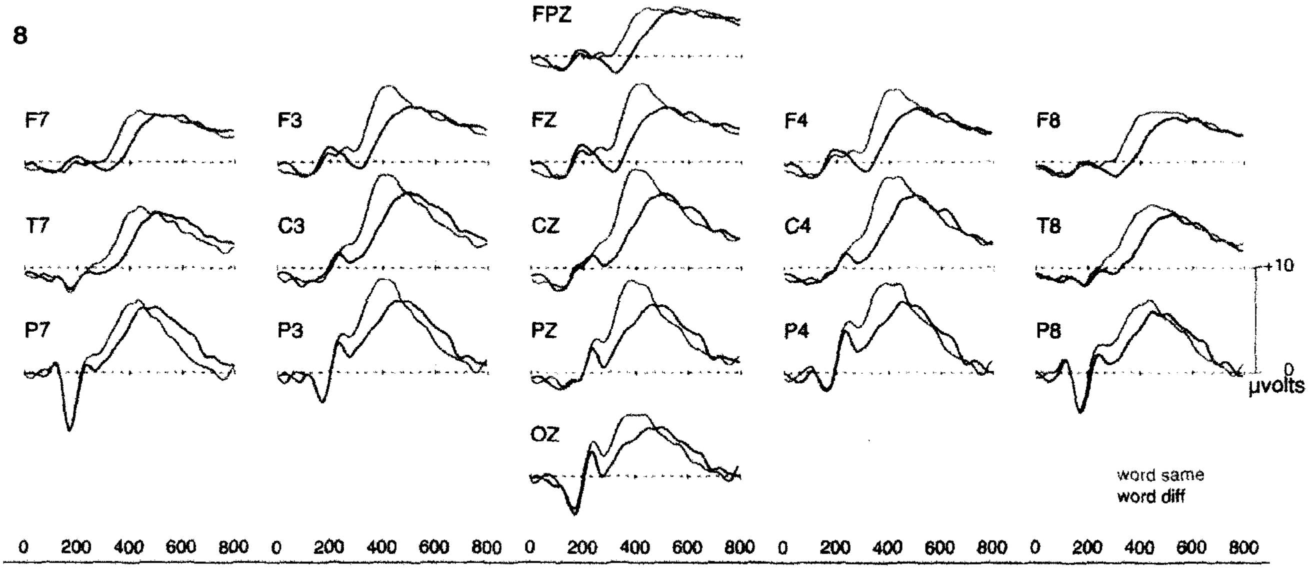

FPZ
F7
F3
FZ
F4
F8
T7
C3
CZ
C4
T8
P7
P3
PZ
P4
P8
OZ
+10
0
µvolts
word same
word diff
0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800 0 200 400 600 800

Table 2

Repeated analysis of variance on normalized data

Brain region	Object vs. word same	Object vs. word different
Frontal	$F(16,105) = 2.93$, $P = 0.0005$	$F(16,105) = 0.79$, $P = 0.6964$
Central	$F(13,108) = 3.13$, $P = 0.0005$	$F(13,108) = 1.76$, $P = 0.0588$
Parietal	$F(10,111) = 4.92$, $P = 0.0001$	$F(10,111) = 4.33$, $P = 0.0001$
Occipital	$F(6,115) = 4.04$, $P = 0.0020$	$F(6,115) = 1.31$, $P = 0.2625$
Temporal	$F(14,107) = 3.63$, $P = 0.0001$	$F(14,107) = 2.79$, $P = 0.0018$

The statistical analyses in this table are based on normalized SCD data in four different stimulus conditions. The first column indicates brain regions on which the comparisons are performed. The second column shows the results of comparisons between object same and word same stimulus conditions. The third column indicates the results of comparisons between object different and word different stimulus conditions.

toward the unique features of stimuli. Although the subjects made very few mistakes in classifying the recognizable and unrecognizable (scrambles) stimuli, they were assumed to perform the task implicitly. The RTs in this experiment were faster both for repeated images and repeated words compared to both the corresponding unrepeated images and unrepeated words. There were no RT differences across the unrecognizable stimulus conditions. The significant facilitation in identifications of the repeated object pictures in the current study was in accordance with the results of object decision studies, in which subjects were shown drawings of real and nonsense objects (Kroll and Potter, 1984) or structurally possible and impossible objects (Schacter et al., 1990a). Our priming effect in repeated word recognition is in keeping with the previously similar studies in which faster RTs for repeated than for unrepeated items were reported (Bentin et al., 1992; Berman and Friedman, 1993; Rugg and Doyle, 1994; Schacter et al., 1990a). Another phenomena about the RTs is that the RTs for object picture stimuli tend to be longer than those for word stimuli. We believe that the gap between the RTs for word and for picture stimuli may not only be due to the differences in physical appearance between the two kinds of stimuli, but also a reflection of differences in cognitive processing of visual word and picture stimuli. The word identification in this experiment was primarily guided by the physical properties of test cues, i.e., English letter or letters. Thus, the subjects could judge the stimulus as recognizable by any letter within the presenting word. However, object picture consisted of much more irregular strokes than word. The subjects had to determine the meaning of the pictorial stimulus before identifying it as recognizable (Theios and Amrhein, 1989).

The ERPs were sensitive to recognizable stimuli in our implicit test of memory. In the object image recognition process, the initial significant amplitude reductions of ERPs to object image same stimuli occurred at the c180 at the right temporal area. These decreases became more obvious at 240 ms post-stimulus. Though the c240 could be recorded at all brain regions, it was more prominent at the temporal regions. These findings regarding object image processing are in agreement with earlier studies on visual short-term memory in which we observed an ERP component named visual memory potential (VMP) (Begleiter et al., 1993; Begleiter et al., 1995; Hertz et al., 1994; Zhang et al., 1995). Our current data could also find support from animal studies in which the firing rate in single cells in inferior temporal (IT) areas to matching stimuli was suppressed (Fahy et al., 1993; Miller et al., 1991; Riches et al., 1991). Moreover, Miller et al. further indicated that though the neuronal electrical responses to matching stimuli were significantly attenuated compared to the non-matching stimuli, the retention of the sample stimulus simultaneously would also influence the response to non-matching stimuli, i.e., the more similar a non-matching stimulus is to the sample, the more the response is suppressed (Miller et al., 1991; Miller et al., 1993). The most widely accepted hypothesis for the role of IT in object recognition is that IT provides perceptual constancy, that is, the ability to see that two inputs with different retinal positions, orientations, and sizes arise from the same physical object (Desimone et al., 1985; Iwai, 1985). Plaut and Farah (1990) proposed that regions of IT play a major role in computing the global form and structure of visual objects. Therefore, the most ostensible difference between ERPs to matching and non-matching object image stimuli in this experiment occurred in occipital-temporal regions, not only reflecting the electrophysiological processing differences in repetition priming and non-priming effects, but also suggesting that the IT or the analogous system in humans plays a significant role in object decision priming (Plaut and Farah, 1990; Schacter et al., 1991b; Schacter, 1993).

The differences in ERPs to word recognition processes reached significance during the period of 300–400 ms post-stimulus, and the robust differences were localized to the left temporal, the left and the right frontal regions. These results suggested that: (1) the priming effects of word repetition take place at longer latencies than the

Fig. 6. SCD maps to both word same and word different stimuli. These maps are developed at 375 ms post-stimulus, where the ERPs to word same stimuli differ most clearly from those to word different stimuli.

Fig. 7. The same ERP data as shown in Fig. 2a, but referred to the nose electrode.

Fig. 8. The same ERP data shown in Fig. 2b, but referred to the nose electrode.

visual object repetition priming effects; (2) the ERP patterns reflecting word repetition priming effects are different than those representing picture repetition priming effects; (3) there are neurons, which are sensitive to word stimuli, in occipito-temporal regions (Nobre et al., 1994). The longer latency for visual word than for visual object repetition priming effects suggests an asymmetry of access to the encoded representation for pictures and words. From the viewpoint of cognitive psychology (for review, see Glaser, 1992), the internal code of concepts could be represented pictorially, and they essentially comprise physical features. The codes are generally unconscious and not accessible to introspection, whereas a word as a perceptual object has its graphemic and phonemic features which are internally connected with representations of morphemes and lexemes. Thus, the internal representation contains concrete and abstract properties. The pictures have priorities to form or access their internal representations. At the present time, it is difficult to relate our word repetition priming results with other studies in the ERP literature, since we employed Cz as the reference electrode, which is not commonly used, as is the nose or mastoid. However, the selection of this reference electrode is based on the best results being obtained during a pilot study. Moreover, Rudell and Fox (1991) suggested that the vector of electrode position as well as the absolute position may be critical in observing certain physiological data. By using the Cz reference as compared to the nose reference, we could more clearly document the ERP changes that occurred at the temporo-occipital regions where the neurons play an important role in visual object repetition priming.

The different patterns between ERPs to word and to object image in the current study indicate that the visual word and visual object repetition priming take place in different neural processes. Studies of brain lesions (Damasio and Damasio, 1983; DeRenzi et al., 1987) and cortical stimulation (Luders et al., 1991) in patients suggest that there is a specialized region for the processing of written words in the inferior temporal lobe. A PET study in normal subjects (Howard et al., 1992) also reported increased blood flow in the inferior temporal lobe during reading. In an ERP study on occipito-temporal gyrus (fusiform gyrus) using intracranial electrodes, Nobre et al. (1994) reported that an ERP component named N200 could be elicited by all types of letter-strings, but not semantic variation; however, another component (P400) in anterior fusiform gyrus could be affected by semantic priming. In similar intracranial studies, both McCarthy et al. (1995) and Nobre and McCarthy (1995) documented that the anterior medial temporal lobe was involved in semantic processing and that the language-sensitive field potential was generated in the neocortex near the collateral sulcus and anterior fusiform gyrus. Our present data on the word repetition priming are complementary to the aforementioned studies.

The logic of implicit memory tests is that information related to previous experience must have been retained in memory since it affects performance. The ERP patterns obtained from the different scramble conditions in the experiment were almost identical. These duplicated ERP patterns to the different scramble stimulus conditions may be due to their null and void or meaningless internal representations in memory. It had also been documented that impossible objects show little or no priming because it is difficult to form an internal representation of their global three-dimensional structure (Schacter et al., 1990a; Schacter et al., 1991a). Our ERP data further suggested that the differences in the occipital region between neuro-processing for word, object, and scramble might occur as early as 170 ms post-stimulus. This means that the subjects could detect the stimulus as a word or an object or a meaningless scramble within a very short time. Similarly in an intracranial ERP study, Nobre et al. (1994) reported that there was a separate stream specialized for word recognition within the ventral visual pathway, and that a sequence of processing occurred over a period of ~200 ms. The ERPs to image different stimuli differed more strongly from the ERPs to word different stimuli at c240, although the ERPs to image same and to word same heavily overlapped. These results suggest that the processing of word and object perceptual identification in memory may involve different mechanisms. Moreover, the current experiment demonstrated that object and word processing have different SCD distribution patterns. The occipito-temporal regions were predominantly responsible for the current source during visual object processing, whereas the current sources were more widespread during word processing. The frontal regions became the principal current sources during the recognition of words, although the occipito-temporal region also manifested major current sources. The evidence of the involvement of frontal regions during word processing was provided by Nenov et al. (1991), who found an increased cerebral glucose metabolism in the anterior cingulate gyrus during a word repetition task. In an intracranial study, Guillem et al. (1995) also indicated that there was local generation of an ERP component sensitive to repeated effects, within the anterior cingulate gyrus and the gyrus rectus. Tulving and Schacter (1990) suggested that repetition priming and perceptual identification were expressions of a single perceptual representation system (PRS), which exists separately from but interacts closely with other memory systems. The facilitation (repetition priming) processes for both words and objects may be the different in this experiment, as suggested by the normalized SCD data in word and object stimulus trials. Moreover, the perceptual identification processes for the two types of stimuli would be different because access to information that supported repetition priming was very inflexible, or hyperspecific (Tulving and Schacter, 1990). Therefore, the different patterns of ERPs to word and object different stimuli might be a reflection of neuro-processes in gaining access to different representations in memory.

The different asymmetric patterns obtained between the ERP amplitudes to picture and to word stimuli provide evidence to support our notion that different neuronal mechanisms underlie the visual object and word repetition primings; c240, an ERP component reflecting visual object repetition priming, is stronger in the right than in the left hemisphere; MAMP3_4, a mean amplitude between 300 and 400 ms post-stimulus where maximal repetition priming effects occur for word stimuli, is more robust in the left than in the right hemisphere. The current opinion regarding visual perception (for review, see Brown and Kossly, 1993) indicated that the right hemisphere appears to be relatively better than the left at encoding overall patterns, representing specific instances, and encoding coordinate metric spatial relations; in contrast, the left hemisphere appears to be relatively better at encoding component parts, representing visual category, and encoding categorical spatial relations. Our observations can also be explained by the results of a recent study measuring cerebral blood flow (CBF) (Gur et al., 1993) indicating that CBF increased asymmetrically on the left hemisphere for word recognition and on the right for face recognition. Furthermore, a consistent relationship was observed between laterality of lesion and type of selective memory impairment in brain damaged patients, i.e., word recognition was selectively impaired by left and picture recognition by right brain injury (Gainotti et al., 1994). In the current experiment, male subjects tended to manifest stronger laterality than the female subjects did. Neither asymmetry of c240 to object stimuli between the right and left temporal regions nor laterality of MAMP3_4 to word stimuli between the left and right temporal regions could be demonstrated by MANOVAs. Wendt and Risberg (1994) reported that the CBR increased asymmetrically in the right parieto-temporo-occipital border zone (PTO region) during the solving of certain spatial tasks. Our data indicated that the male subjects tend to show more hemispheric asymmetry at the parietotemporal regions than the females during cognitive tasks. One explanation for the gender difference in hemisphere asymmetry is possible sex differences in cognitive strategies rather than in hemispheric specialization. However, it has long been observed that there is sex differentiation of the human temporo-parietal region for functional asymmetry. The functional laterality differences between genders may even be formed at the early developmental stage of the human brain (McMaster and Hamilton, 1991). Thus, we tend to agree that the gender differentiation in hemisphere laterality during cognitive performance may be physiologically based.

Numerous studies have shown that ERPs are sensitive to item repetition (Begleiter et al., 1993; Bentin and Peled, 1990; Besson and Kutas, 1993; Friedman, 1990; Otten et al., 1993; Rugg et al., 1988, 1995; Rugg, 1990; Van Petten et al., 1991; Young and Rugg, 1992), in that ERPs to repeated items are generally more positive-going than those to the first presentation. This difference, reflecting the ERP repetition effect, begins around 250 ms post-stimulus, and persists for a further 300–400 ms; the scalp distribution patterns manifest larger potentials over posterior than anterior recording sites, and slightly larger potentials at the right than the left hemisphere (Kutas et al., 1988) when words are used as stimuli. As we felt that discrepancies between our current data and other similar studies could be primarily attributable to the selection of a different reference electrode, we referenced our data to use a nose reference. As Fig. 7 illustrates, our ERP data are almost identical with other studies in the literature. Fig. 7 illustrates that the same ERP data as in Fig. 2a, but referenced to the nose electrode, indicating that both image same and different conditions elicit a positive component peaking around 450 ms. The latencies of the component to image same were generally shorter than to image different stimuli: the amplitudes of the component to image same seemed to be more positive than to image different stimuli only at the frontal region. Our ERP pattern to object images was almost the same as the ERP evoked during a continuous recognition memory for pictures (Friedman, 1990). It was more striking when we referenced our ERP data to the nose reference in the word stimulus conditions. As shown in Fig. 8, the ERP repetition effects to words were more marked than when we used the Cz reference, and were consistent with the results of other ERP studies on word repetition effects. The transformed data in Fig. 8 clearly indicate that the word repetition effect could be reflected by a positive component peaking around 400 ms post-stimulus. We believe that the task for the subjects in our present study was implicit; thus the word processing should have occurred in a pre-semantic stage. The repetition effects would also contribute to the generation of the extensively studied N400, as Besson et al. (1986) indicated that the N400 is sensitive to both semantic congruity and repetition. Furthermore, the temporally and topographically different ERP patterns reflecting the repetition effect between object images and words indicate that the visual word and visual object repetition priming involve different neural processes. The different ERP patterns obtained by changing the reference electrode suggest that Cz is a more suitable reference in observing the phenomena of visual object repetition priming, while the nose reference is better for studying the effects of visual word repetition priming.

Thus, the present findings demonstrated the electrophysiological differences between visual word and object repetition priming processes. The differences between these two processes are mainly due to the neural processes in the unprimed (non-repeated) word and object trials. The present results also underscore the power of ERPs to study and compare repetition-sensitive cognitive processes. Further research will be needed to understand word and object repetition effects, and their relation to various memory processes.

Acknowledgements

The authors wish to thank Arthur Stimus, Sergio Valentini, Marc Ostrega and Elisabeth Iskander for recruiting the subjects and electrophysiological data collection. We also appreciate the computer programming assistance of Douglas Harsch and David Chorlian. We acknowledge three anonymous reviewers' helpful comments and suggestions. Supported by NIH grants: AA05524 and AA02686 to HB.

References

Baylis, G.C. and Rolls, E. Responses of neurons in the inferior temporal cortex in short term and serial recognition memory tasks. Exp. Brain Res., 1987, 65: 614–622.

Begleiter, H., Porjesz, B. and Wang, W. Event-related potentials differentiate priming and recognition to familiar and unfamiliar faces. Electroencephalogr. Clin. Neurophysiol., 1995, 94: 41–49.

Begleiter, H., Porjesz, B. and Wang, W. A neurophysiologic correlate of visual short-term memory in humans. Electroencephalogr. Clin. Neurophysiol., 1993, 87: 46–53.

Bentin, S., Moscovitch, M. and Heth, I. Memory with and without awareness: performance and electrophysiological evidence of savings. J. Exp. Psychol. Learn. Mem. Cogn., 1992, 18: 1270–1283.

Bentin, S. and Peled, B.S. The contribution of stimulus encoding strategies and decision-related factors to the repetition effect for words: electrophysiological evidence. Mem. Cogn., 1990, 18: 359–366.

Berman, S. and Friedman, D. A developmental study of ERPs during recognization memory: effects of picture familiarity, word frequency, and readability. J. Psychophysiol., 1993, 7(2): 97–114.

Besson, M. and Kutas, M. The many facets of repetition: a behavioral and electrophysiological analysis of repeating words in same versus different sentence context. J. Exp. Psychol. Learn. Mem. Cogn., 1993, 19: 1115–1133.

Besson, M., Kutas, M. and Van Petten, C. Effect of semantic expectancy upon information retrieval. Psychophysiology, 1986, 23: 425–426.

Brown, H.D. and Kossly, S.M. Cerebral lateralization. Curr. Opin. Neurobiol., 1993, 3(2): 183–186.

Damasio, A.R. and Damasio, H. The anatomic basis of pure alexia. Neurology, 1983, 33: 1573–1583.

DeRenzi, E., Zambolin, A. and Crisi, G. The pattern of neuropsychological impairment associated with left posterior cerebral artery infarcts. Brain, 1987, 110: 1099–1116.

Desimone, R., Schein, S.J., Moran, J. and Underleider, L.G. Contour, color and shape analysis beyond the striate cortex. Vis. Res., 1985, 25(3): 441–452.

Eich, E. Memory for unattended events: remembering with and without awareness. Mem. Cogn., 1984, 12: 105–111.

Eskandar, E.N., Richmond, B.J. and Optican, L.M., Role of inferior temporal neurons in visual memory. I. Temporal encoding of information about visual images, recalled images, and behavioral context. J. Neurophysiol., 1992, 68: 1277–1295.

Fahy, F.L., Riches, I.P. and Brown, M.W. Neuronal activity related to visual recognition memory: long term memory and the encoding of recency and familiarity information in the primate anterior and medial inferior temporal and rhinal cortex. Exp. Brain Res., 1993, 90: 397–412.

Friedman, D. Cognive event related potential components during continuous recognition memory for pictures. Psychophysiology, 1990, 27: 136–148.

Friedman, D., Sutton, S., Putnam, L. and Brown, C. Jr., Erlenmeyer-Kimling. ERP components in picture matching in children and adults. Psychophysiology, 1988, 25: 570–590.

Gainotti, G., Cappa, A., Perri, R. and Silveri, M.C. Disorders of verbal and pictorial memory in right and left brain-damaged patients. Int. J. Neuroscience, 1994, 78 (1–2): 9–20.

Glaser, W.R. Picture naming. Cognition, 1992, 42: 61–105.

Graf, P. and Mandler, G. Activation makes words more accessible, but not necessarily more retrievable. J. Verb. Learn. Verb. Behav., 1984, 23: 553–568.

Graf, P. and Schacter, D.L. Implicit and explicit memory for new associations in normal and amnesic patients. J. Exp. Psychol. Learn. Mem. Cogn., 1985, 11: 501–518.

Graf, P. and Schacter, D.L. Selective effects of interference on implicit and explicit memory for new associations. J. Exp. Psychol. Learn. Mem. Cogn., 1987, 13: 45–53.

Graf, P., Mandler,. G. and Haden,. P.E. Simulating amnesic symptoms in normals. Science, 1982, 218: 1243–1244.

Graf, P., Shimamura, A.P. and Squire, L.R. Priming across modalities and priming across category levels: extending the domain of preserved function in amnesia. J. Exp. Psychol. Learn. Mem. Cogn., 1984a, 11: 385–395.

Graf, P., Squire, L.R. and Mandler, G. The information the amnesic patients do not forget. J. Exp. Psychol. Learn. Mem. Cogn., 1984b, 10: 164–178.

Guillem, F., N'kaoua, B., Rougier, A. and Claverie, B. Intracranial topography of event related potentials (N400/P600) elicited during a continuous recognition memory task. Psychophysiology, 1995, 32: 382–392.

Gur, R.C., Jaggi, J.L., Ragland, J.D., Resnick, S.M., Shltasel, D., Muenz, L. and Gur, R.E. Effects of memory processing on regional brain activation: cerebral blood flow in normal subjects. Int. J. Neurosci., 1993, 72(1–2): 31–44.

Hertz, S., Porjesz, B., Begleiter, H. and Chorlian, D. Event-related potentials to faces: the effects of priming and recognition. Electroencephalogr. Clin. Neurophysiol., 1994, 92: 342–351.

Howard, D., Patterson, K., Wise, R., Brown, W.D., Friston, K., Weiller, C. and Frackowiak, R. The cortical localization of the lexicons. Positron emission topography evidence. Brain, 1992, 115: 1769–1782.

Iwai, E. Neuropsychological basis of pattern vision in macaque monkeys. Vis. Res., 1985, 25(3): 425–439.

Jacoby, L.L. and Dallas, M. On the relationship between autobiographical memory and perceptual learning. J. Exp. Psycho. Gen., 1981, 110: 304–340.

Jacoby, L.L. and Hayman, C.A.G. Specific visual transfer in word identification. J. Exp. Psychol. Learn. Mem. Cogn., 1987, 13: 456–463.

Kroll, J.F. and Potter, M.C. Recognizing words, pictures, and concepts: a comparison of lexical, object and reality decisions. J. Verbal Learn. Verbal Behav., 1984, 23: 39–66.

Kutas, M., Van Petten, C. and Besson, M. Event related potential asymmetries during the reading of sentences. Electroencephalogr. Clin. Neurophysiol., 1988, 69: 218–233.

Luders, H., Lesser, R.P., Hahn, J., Dinner, D.S., Morris, H.H., Wyllie, E. and Godoy, J. Basal temporal language area. Brain, 1991, 114: 743–754.

McCarthy, G., Nobre, A.C., Bentin, S. and Spencer, D.D. Language-related field potentials in the anterior-medial temporal lobe. I. Intracranial distribution and neural generators. J Neurosci., 1995, 15(2): 1080–1089.

McMaster, U. and Hamilton, O.N. Neural sexual mosaicism: sexual differentiation of the human temporo-parietal region for functional asymmetry. Special Issue: Neuroendocrine Effect on Brain Development and Cognition. Psychoneuroendocrinology, 1991, 16(1–3): 131–153.

Micco, A. and Masson, M.E. Implicit memory for new associations: an interactive process approach. J. Exp. Psychol. Learn. Mem. Cogn., 1991, 17: 1105–1123.

Mikami, A. and Kubota, K. Inferotemporal neuron activities and colour discrimination with delay. Brain Res., 1980, 182: 65–78.

Miller, E.K., Li, L. and Desimone, R. A neural mechanism for working and recognition memory in inferior temporal cortex. Science, 1991, 254(5036): 1377–1379.

Miller, E.K., Li, L. and Desimone, R. Activity of neurons in anterior inferior temporal cortex during a short-term memory task. J. Neurosci., 1993, 13(4): 1460–1478.

Musen, G. Effects of verbal labeling and exposure duration on implicit memory for visual patterns. J. Exp. Psychol. Learn. Mem. Cogn., 1991, 17: 954–962.

Musen, G. and Treisman, A. Implicit and explicit memory for visual patterns. J. Exp. Psychol. Learn. Mem. Cogn., 1990, 16: 127–137.

Nenov, V.I., Halgren, E., Smith, M.E., Badier, J.M., Ropchan, J., Blahd, W.H. and Mandelkern, M. Localized brain metabolic response correlated with potentials evoked by words. Behav. Brain Res., 1991, 44: 101–104.

Nobre, A.C., Allison, T. and McCarthy, G. Word recognition in the human inferior temporal lobe. Nature, 1994, 372(17): 260–263.

Nobre, A.C. and McCarthy, G. Language-related field potentials in the anterior-medial temporal lobe. II. Effects of word type and semantic priming. J. Neurosci., 1995, 15(2): 1090–1098.

Nunez, P., Pilgreen, K.L., Westdorp, A.F., Law, S.K. and Nelson, A.V. A visual study of surface potentials and Lapacians due to distributed neocortical sources: computer similations and evoked potentials. Brain Topogr., 1991, 4: 151–168.

Otten, L.J., Rugg, M.D. and Doyle, M.C. Modulation of event-related potentials by word repetition: the role of selective attention. Psychophysiology, 1993, 30: 559–571.

Plaut, D.C. and Farah, M.J. Visual object presentation: interpreting neurophysiological data within a computational framework. J. Cogn. Neurosci., 1990, 2: 320–343.

Riches, I.P., Wilson, F.A.W. and Brown, M.W. The effects of visual stimulation and memory on neurons of the hippocampal formation and the neighboring parahippocampal gyrus and inferior temporal cortex of the primate. J. Neurosci., 1991, 11: 1763–1779.

Rudell, P.A. and Fox, S.E. The propagation potential: an axonal response with implications for scalprecorded EEG. Bio-phys. J., 1991, 60: 556–567.

Rugg, M.D. Event-related potentials dissociate repetition effects of high and low frequency words. Mem. Cogn., 1990, 18: 367–379.

Rugg, M.D. Dissociation of semantic priming, word and non-word repetition by event-related potentials. Q. J. Exp. Psychol., 1987, 39A: 123–148.

Rugg, M.D. and Doyle, M.C. Event related potentials and stimulus repetition in indirect and direct tests of memory. In: H. Heinze, T. Munte and G.R. Mangun (Eds.), Cognitive Electrophysiology, Cambridge, MA: Birkhauser, Boston, MA, 1994, pp. 124–148.

Rugg, M.D., Furda, J. and Lorist, M. The effects of task on the modulation of event related potentials by word repetition. Psychophysiology, 1988, 25: 55–63.

Rugg, M.D., Micheal, C.D. and Wells, T. Word and nonword repetition within- and across-modality: an event-related potential study. J. Cogn. Neurosci., 1995, 7: 219–227.

Schacter, D.L. Priming of old and new knowledge in amnesic patients and normal subjects. Ann. NY Acad. Sci., 1985, 444: 44–53.

Schacter, D.L. Implicit memory: history and current status. J. Exp. Psychol. Learn. Mem. Cogn., 1987, 11: 501–551.

Schacter, D.L. Perceptual representation systems and implicit memory: towards a resolution of the multiple memory system debate. Ann. NY Acad. Sci., 1990, 608: 543–571.

Schacter, D.L. Understanding implicit memory: a cognitive neuroscience approach. Am. Psychol., 1992, 47: 559–569.

Schacter, D.L. Implicit memory: a selective review. Annu. Rev. Neurosci., 1993, 16: 159–182.

Schacter, D.L., Harbluk, J.A. and Mclachlan, D.R. Retrieval without recollection: an experimental analysis of source amnesia. J. Verb. Learn. Verb. Behav., 1984, 23: 593–611.

Schacter, D.L., Cooper, L.A. and Delaney, S.M. Implicit memory for unfamiliar objects depends on access to structural descriptions. J. Exp. Psychol. Gen., 1990a, 119: 5–24.

Schacter, D.L., Rapcsak, S.Z., Rubens, A.B., Tharan, M. and Laguna, J.M. priming effects in a letter-by-letter reader depend on access to the word form system. Neuropsychologia, 1990b, 28: 1079–1094.

Schacter, D.L., Cooper, L.A. and Delaney, S.M. Implicit memory for possible and impossible objects: constraints on the construction of structural descriptions. J. Exp. Psychol. Learn. Mem. Cogn., 1991a, 17: 3–19.

Schacter, D.L., Cooper, L.A., Tharan, M. and Rubens, A.B. Preserved priming of novel objects in patients with memory disorders. J. Cogn. Neurosci., 1991b, 3: 118–131.

Schacter, D.L., Chiu, C.-Y.P. and Ochsner, K.N. Implicit memory: a selective revlew. Annu. Rev. Neurosci., 1993, 16: 159–182.

Squire, D.L. Memory and hippacampus: a synthesis from findings with rats, monkeys, and humans. Psychol. Res., 1992, 99: 195–231.

Squire, L.R., Shimamura, A.P. and Graf, P. Independence of recognition memory and priming effects: a neuropsychological analysis. J. Exp. Psychol. Learn. Mem. Cogn., 1985, 11: 37–45.

Snodgrass, J.G. and Vanderwart, M. A standardized set of 260 pictures: norms for the naming agreement, familiarity, and visual complexity. J. Exp. Psychol: Hum. Learn. Mem., 1980, 6: 174–215.

Theios, J. and Amrhein, P.C. Theoretical analysis of the cognitive processing of lexical and pictorial stimuli: reading, naming, and visual and conceptual comparisons. Psychol. Rev., 1989, 96(1): 5–25.

Tulving, E. and Schacter, D.L. Priming and human memory systems. Science, 1990, 247: 301–306.

Tulving, E., Schacter, D.L. and Stark, H. Priming effects in word-fragment completion are independent of recognition memory. J. Exp. Psychol. Learn. Mem. Cogn., 1982, 8: 336–342.

Van Petten, C., Kutas, M., Kluender, R., Mitchiner, M. and McIsaac, H. Fractionating the word repetition effect with event-related potentials. J. Cogn. Neurosci., 1991, 3: 129–150.

Vogels, R. and Orban, G.A. Activity of inferior temporal neurons during orientation discrimination with successively presented gratings. J. Neurophysiol., 1994, 71(4): 1428–1452.

Wendt, P.E. and Risberg, J. Cortical activation during visual spatial processing: relation between hemispheric asymmetry of blood flow and performance. Brain Cogn., 1994, 24(1): 87–103.

Young, M.P. and Rugg, M.D. Word frequency and multiple repetition as determinants of the modulation of event related potentials in a semantic classification task. Psychophysiology, 1992, 29: 664–676.

Zhang, X.L., Begleiter, H., Porjesz, B., Wang, W. and Litke, A. Event related potentials during object recognition tasks. Brain Res. Bull., 1995, 38(6): 531–538.