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Event Related Potentials During Object Recognition Tasks

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ABSTRACT: In our previous studies, we have demonstrated an ERP correlate of visual memory with a modified delayed matching-to-sample paradigm using a series of nonsense line drawings or faces as stimuli. In this experiment, we employed pictures of objects to determine whether the ERP can reflect the object recognition process and whether visual stimuli with a verbal label would result in a different topographic distribution from past topography obtained with visual stimuli without a verbal label. The results of this study suggest that the amplitude of the ERP component (c247) to repeated (primed) pictures of common objects was significantly decreased as compared to the unrepeated (unprimed) pictures; the latency for the peak of c247 was decreased for the repeated compared to the unrepeated, and the response time was also significantly shorter to the repeated picture stimuli than to the unrepeated; the topographical distribution of c247 was mainly located in the occipitotemporal areas of the brain. However, the source energy density map showed that the topographic involvement of the brain regions to the c247 was different in the matching and nonmatching trials.

KEY WORDS: ERP, Memory, Recognition, Object picture, Pictorial stimuli.

INTRODUCTION

The neuronal mechanisms that link vision and memory remain largely unknown. However, anatomic, physiological, and ablation studies in monkeys suggest that this linkage may occur in the inferior temporal (IT) cortex [3,9,10,12,27,28]. A number of investigators have explored the role of IT neurons by studying monkeys trained to perform delayed matching-to-sample tasks. In these tasks, a sample stimulus is followed, after a brief delay, by a test stimulus. Generally, recordings of IT neurons during performance of working memory tasks have found that the responses are modulated when the current stimulus matched an item in memory. The memory of the sample stimulus affected not only the responses to matching stimuli but also those to nonmatching stimuli. Hence, the more similar a nonmatching stimulus to the sample, the more the response was suppressed [3,27,33]. Eskandar et al. [10] recorded the neuronal activity

from area TE of IT in monkeys during the performance of a delayed matching to sample task that used a set of 32 black and white Walsh patterns. They found that the waveforms of most neurons were significantly modulated by both the pattern and context of the stimulus presentation [41]. These results suggest that the role of IT neurons in visual memory tasks is to compare the internal representations of current visual images with the internal representations of recalled images.

Recently, we have identified an ERP component correlate of visual memory [4] elicited by a modified delayed matching-to-sample paradigm that used a series of nonsense line drawings. We observed that the ERP component to matching stimuli, which occurred between 170 and 240 ms, was much smaller than the ERP component to nonmatching stimuli. Both the spatial and temporal characteristics of this component, which is generally located in the occipito-temporal region, are in keeping with single cell studies in monkeys [26,27]. We named this component the visual memory potential (VMP) because it indexes properties related to visual memory.

The modified delayed matching to sample paradigm we used to elicit the VMP utilized nonsense line drawings and involved both repetition priming as well as recognition. However, this task did not allow us to assess the specific antecedents to the VMP. To assess the relationship between the VMP and priming and/or recognition separately [20], we next conducted a set of studies in which the stimuli were both unfamiliar faces and unrecognizable face scrambles. In the first experiment, which tested the effects of repetition priming, the subjects were presented with both unfamiliar faces and unrecognizable face scrambles; the latter were matched to the faces in intensity and number of computer pixels. An equal number of face and scramble stimuli were presented randomly, and the subjects were asked to press one button for faces and another button for scrambles. The results demonstrated that the amplitude of an ERP component occurring at approximately 240 ms was significantly reduced to primed faces; additional latency effects were present as early as 180 ms. These ERP findings are particularly striking in the absence of significant reaction time differences between primed and unprimed stimuli. The second experiment used the same group of

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subjects and the same stimulus sequence. However, in this experiment, the subjects were told specifically that the faces and scrambles would be repeated, and they were asked to press one button to repeated stimuli and another button to unrepeated stimuli. Here, our results indicated that there were significant differences between the ERPs to repeated and unrepeated faces but not to scrambles. The reaction time was also reduced to the recognized stimuli. One interpretation of these results is that stimuli that are initially well encoded will subsequently be better recognized.

The visual stimuli used in our former investigations were meaningless; that is, they were devoid of verbal labels, and the sole encoding properties were their physical characteristics. Because human memorization can frequently employ verbal cues, many measures of human recognition memory have used highly verbal stimuli. The significance of this feature is suggested by the reports that some amnesics may perform differently on recognition tasks using abstract rather than representational or verbal stimuli [40].

In this experiment, we selected a set of pictures of objects with definite verbal labels as stimuli, with the following considerations. Picture naming, reading, and categorizing have been widely used in cognitive psychology to explore human cognitive functions because their chronometric analysis elucidates cognitive structures and processes [17]. The double stimulation technique, such as that used in priming with pictures, is frequently used to tap working memory in cognitive psychology, and has also been extensively employed to elicit cognitive ERPs [2,6,21,30,32,34–36]. For example, N400 appears to be sensitive to the degree to which the target stimulus is in agreement with a previously established context. Although N400 was discovered using sentences to establish context [24], many recent studies have focused on the specific nature of the context established during various paired-stimuli priming situations [1,2]. Still others have begun to investigate priming effects with non-linguistic and paralinguistic stimuli [21,30,32]. The relationship observed indicates that the greater the degree of incongruity between the prime and the target stimuli, the greater the N400 effects. In one study in which subjects determined whether pairs of sequentially presented pictures were semantically associated, Barrett and Rugg [2] reported a component (labelled N300) that was larger to nonmatching than to matching targets and speculated that it might be specific to picture processing. In several investigations [11,15], first presentation items were averaged according to behavioral performance on second presentation. The ERP wave forms of first presentation items that were subsequently correctly recognized or recalled, were more positive across much of the waveform (and not just in the P300 portion of the ERP) compared to those items that were not. Consequently, the results of these recent studies suggest that the late, cognitive components of ERPs reflect the processes that occur during the storage of items in, and the retrieval of items from, memory.

In this experiment, we employed visual stimuli with a verbal label to determine whether the VMP could also be obtained from familiar objects with known labels. There is evidence from both the reading and naming task literature [17] that pictures are more effective as primes and are more primeable as targets. Further, we used the modified delayed matching-to-sample paradigm described by Begleiter et al. [4]. Last, we made recordings from 64 scalp electrodes and obtained measures of scalp current density to determine if visual stimuli with a verbal label would, in fact, elicit a different topographic distribution than that obtained with visual stimuli without a verbal label.

METHODS

Fourteen male (24.3 + 3.1 yr old) and 14 female (23.2 + 1.7 yr old) subjects participated in this experiment. There was no age difference between male and female subjects in group mean age ($T(21.8) = -1.11, p = 0.277$). All the subjects were right-handed and had no personal and no family history of alcohol and drug abuse, or any history of neurological or psychiatric disease. All subjects had normal vision or corrected normal vision.

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, AFz, AF8, F1, F2, F5, F6, FCz, 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 kOms. Two additional bipolar deviations were used to record the vertical and horizontal EOG. The signals were amplified with a gain of 10,000 by Ep-A2 amplifiers (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 prestimulus baseline and 1440 ms following each stimulus presentation. Trials with excessive eye and body movements ($>73.3 \mu\text{V}$) were rejected on-line.

The stimuli were composed of 90 pictures of objects that were chosen from the 1980 Snodgrass and Vanderwart picture set [31]. All the pictures selected represented different concrete objects and were easily named. These stimuli were presented on a white background at the center of a computer monitor and were approximately 5–10 cm in height and 5–10 cm in width, thus subtending a visual angle of 0.05° – 0.1° . To elicit the ERP, a modified delayed matching-to-sample task was used in which two picture stimuli appeared in succession with a 1.6 s fixed interstimulus interval. The duration for the first (S1) and second (S2) picture stimulus in each test trial was 300 ms. The interval between each trial was fixed to 3.2 s. All pictures were paired into two conditions, that is, matching and nonmatching. In the matching condition, the S1 was repeated as S2. In the nonmatching condition, the S1 was followed by a picture that was completely different from S1 in terms of its semantic category. No S1 was repeated as S1. The presentation of matching and nonmatching trials was randomized. On half of the trials, the test stimuli (S2) were identical to S1; on the other half of the trials, the S2s were different from S1.

The subjects' task was to decide whether the second picture (S2) was the same as the first stimulus (S1). They were asked to press a mouse key in one hand if the S2 matched S1 and to press a mouse key in the other hand if the S2 differed from S1 after the presentation of S2 on each trial. The designation of the hand indicating match or nonmatch was alternated across subjects. Response accuracy and speed were equally stressed.

ERPs were averaged only on artifact-free trials with correct responses for two cases, match S2 and nonmatch S2. This experiment yielded an ERP waveform consisting of three components which were most clearly discernible at the more posterior electrodes (Fig. 1): component 1 (c110) ranging between 100 and 125 ms, component 2 (c175) ranging between 160 and 190 ms, and component 3 (c247) 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 and vice versa. Amplitude and latency for the three components were initially measured at P8, because the ERP components at this electrode site had the most consistent morphologies, and thus, could be most easily identified. Amplitudes were measured from baseline to each peak, and latencies were recorded from the onset of stimuli to the peaks of each component. Measurements at other electrodes were based on the latency of each component obtained at P8.

For further analysis of our electrophysiologic data, we employed the newly developed methods of Surface Energy (SE), Surface Energy Density (SED), and Distance of Surface Energy Density [42]. These methods were based on the spherical spline and the entire scalp current density field (surface Laplacian of scalp potential field). The SE gives a global field measure, and a SE wave in a time interval shows continuous time elements and can be used in topographic component recognition. The SED indicates the amount and scalp distribution of SE at a fixed time. The DSED measures the pattern difference of two surface energy density fields. Because these measures are free of the reference electrode and any physical conductive model of the head, they provide a common base for comparisons among different subjects, time points, regions of the scalp or experimental conditions.

RESULTS

The subjects made few response errors during the experiment, namely, 0.92% for matching trials and 0.57% for nonmatching

TABLE 1
SUBJECT RESPONSE TIMES

	Match		Nonmatch	
	Mean	SD	Mean	SD
Male	604	92.5	678	93.8
Female	638.8	102.4	694.6	100.9
Total	620.8	97.2	686.1	95.9*

* $p < 0.05$.

trials. The subjects' response times for each stimulus condition are listed in Table 1. A two-way ANOVA was run according to the general linear model (GLM, SAS v6.09), indicating a significant stimulus effect ($F = 6.45, p < 0.014$), but no significant gender effect ($F = 1, p = 0.32$) and gender \times stimulus interaction ($F = 0.72$).

For the MANOVA on amplitudes, the measurements of amplitudes of each component at each electrode were organized into groups by region. The frontal region (Fp1, Fp2, Fpz, Af7, Af8, Af1, Af2, Afz, F7, F8, F5, F6, F3, F4, F1, F2, Fz) was excluded due to a marked inconsistency in wave form morphology both between subjects as well as within the same subject when compared with the wave form at other regions. The central region

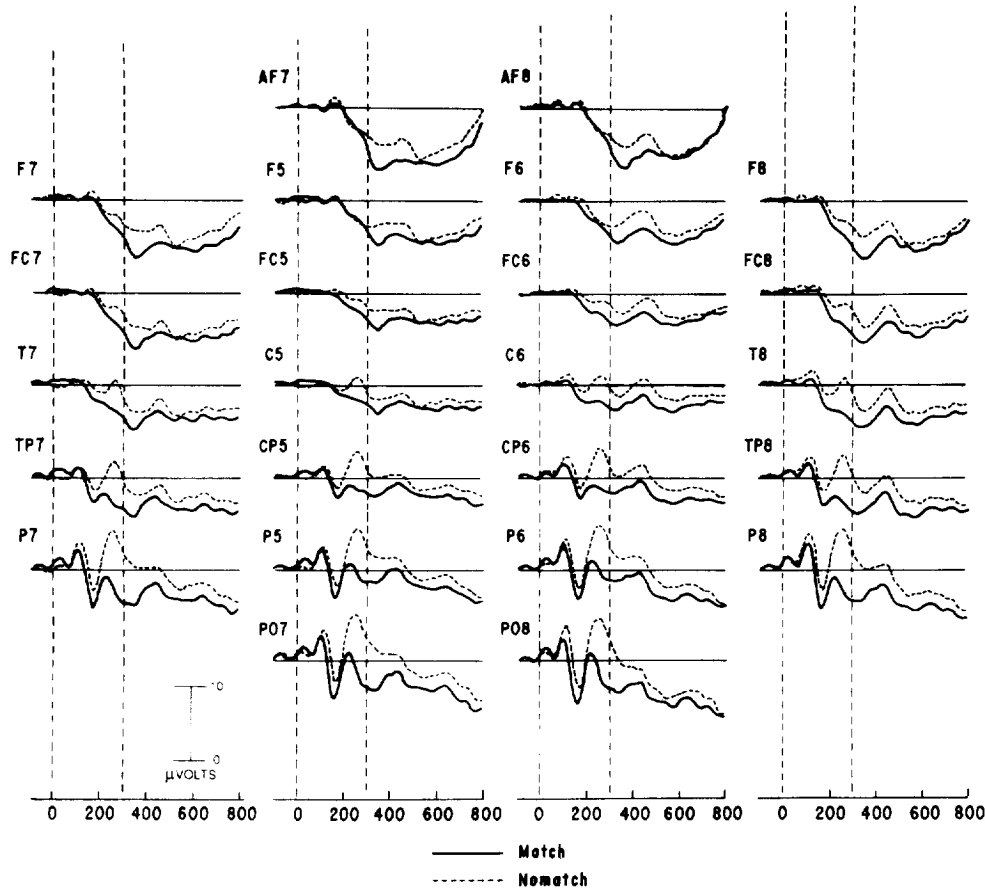


FIG. 1. Grand mean ERPs obtained in all subjects. Peak-to-peak voltage is approximately 10 μ V. A downward deflection indicates greater negativity for the posterior electrodes with respect to the vertex electrode. Only 24 channels are selected due to the limitation of space.

consisted of Fe1, Fe2, Fe3, Fe4, Fe5, Fe6, Fez, 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, Po7, Po8, O1, O2, Oz. And the temporal region consisted of T7, T8, Tp7, Tp8, Cp5, Cp6, P7, P8, P5, P7. A number of MANOVAs were carried out separately for each component using amplitudes at each regional electrode array as a dependent vector for comparisons among different stimulus conditions. No significant stimulus effects on c110 and c175 could be demonstrated, but the amplitudes of c247 in central ($F = 4.38, p < 0.0001$), parietal ($F = 2.74, p < 0.0097$), and temporal ($F = 3.66, p < 0.0005$) regions were significantly smaller in match trials than those in nonmatching trials (Fig. 2). There were no significant lateral effects on these three components both in matching and nonmatching trials. For the comparisons between male and female subjects, a number of MANOVAs were applied separately for each component to assess gender differences in amplitudes during each kind of trial condition. No significant gender effects on any component could be obtained.

Table 2 shows the means and standard deviations of latencies for the three components. A two-way ANOVA from the general linear model (GLM) procedure (SAS v6.09) was run for the analysis on latencies of the three components. The only significant stimulus effect found was on the c247 component ($F = 14.94, p < 0.0003$). No significant gender effects and no effects of gender \times stimulus interactions could be obtained on the three components.

We applied the new measures SE, SED, and DSED to further analyze the spatial and temporal properties of our ERP data. Figure 3 was drawn from the grand mean data of all subjects. Several SE components in each stimulus condition could be identified, because they were related to the peaks in the SE wave and the peaks and flat intervals in the DSED wave. We focused on the Surface Energy Contour (SEC) ranging from 200 ms to 260 ms because this component seemed to reflect, in the time range, the c247, which had a significant amplitude difference between stim-

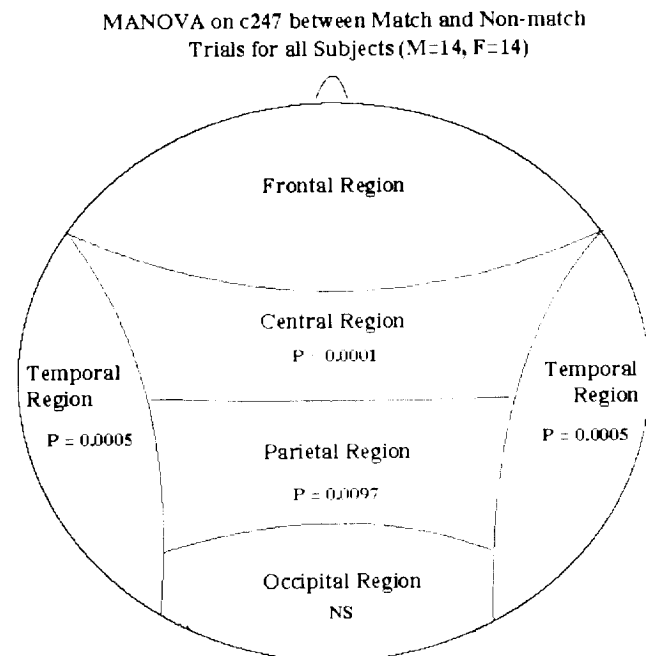


FIG. 2. MANOVA p values for c247 amplitude from comparison of the repeated object pictures and different object pictures.

TABLE 2
ERP LATENCIES ON THREE COMPONENTS

		Males	Females	Total
C110	M	113 \pm 11	110 \pm 17	111.5 \pm 14
	N	118 \pm 14	110 \pm 14	114.3 \pm 15
C175	M	172 \pm 13	178 \pm 18	175.1 \pm 16
	N	170 \pm 13	176 \pm 17	173.6 \pm 15
C247	M	232.5 \pm 16.9	241.9 \pm 28.8	237.0 \pm 19.8
	N	256.5 \pm 21.8	261.4 \pm 17.8	258.9 \pm 19.7*

* $p < 0.05$.

ulus conditions. The peak of SE in the time window between 200 and 260 ms to nonmatching stimuli was much larger than that to matching stimuli as illustrated by Fig. 3. The duration of the SE component in the above time window to nonmatching stimuli was almost twice as long as those to matching stimuli.

Figure 4 shows the total grand mean SED fields and their contours at the point where the SE component reached its maximum for each stimulus condition. It was easy to see that the SE in both matching and nonmatching trials came mostly from occipitotemporal regions. However, prefrontal areas contributed a good deal to the sources of the SE in matching tasks. Furthermore, the right posterior region demonstrated nearly equal energy to the left counterpart in the matching trials; but in nonmatching trials, the left posterior region seemed to be more activated.

DISCUSSION

In this experiment, we found that (1) the amplitude of the ERP component (c247) to repeated (primed) pictures of common objects was significantly decreased as compared to that elicited by unrepeated (unprimed) pictures; (2) the latency for the peak of c247 was shortened for repeated trials compared to unrepeated; (3) the response time was also significantly shorter for repeated picture stimuli than for unrepeated; and (4) the topographic distribution of c247 was mainly localized to the occipitotemporal areas of the brain. However, the Surface Energy Contour (SEC) map showed that the topographic involvement of the brain regions contributing to c247 differed in matching and nonmatching trials.

The results of this experiment, as they pertain to c247, basically agreed with our previous studies of visual short-term memory in which we identified an ERP potential we named the visual memory potential (VMP) [4,20]. Because C247 resembled the VMP morphologically and had a similar latency, we identified it as the VMP and suggest that it reflects the information processed in visual short-term memory.

The recognition and comparison of object pictures may be affected by several factors which generally include "name agreement," "image agreement," "familiarity," and "complexity." Posner [28] reported that physical matches were processed faster than name matches, which in turn were faster than abstract matches. He concluded that the relevant underlying processes were hierarchically organized within the nervous system. Further, Sperber et al. [38] demonstrated that if both pictures belonged to the same superordinate category, the response latency to the target was much shorter than when the target belonged to a different category. In this study, the test (second) stimulus in the matching trials was the repetition of the sample (first) stimulus. Repeating the same stimulus should enhance the subsequent priming effects. In contrast, sample stimuli in nonmatching trials,

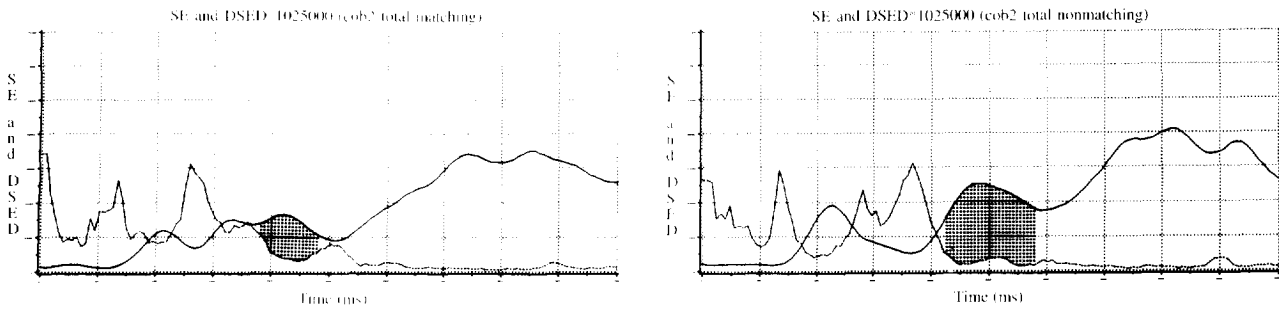


FIG. 3. SE waves and DSED waves (the value of the DSED between successive surface energy fields is multiplied by 10 in order to compare it with the SE) in two conditions. Left figure is for the matching case, and the right is the nonmatching case. Solid lines are the SE waves, and dashed lines are the corresponding DSED waves. The interval between two adjacent reference lines at the time-axis (horizontal axis) is 50 ms.

which differed from the target stimuli both physically and semantically, did not facilitate recognition of the target stimulus. Though the subject had to encode the information from the sample stimulus, hold its representation in memory during the delay interval, and subsequently retrieve and compare the representations for sample and target stimuli, the neuropsychological processes underlying matching and nonmatching trials should differ in some stage.

The decreased amplitude and shortened latency of c247 in matching trials compared to nonmatching trials suggested that the recognition of the object pictures could be facilitated by the previous registration of the same picture in memory. These phenomena are in fact the electrophysiological representations of the repetition effect during picture recognition. Further, these results agree with the results of animal studies, wherein the responses

to matching stimuli were suppressed [12,26,27,33]. Moreover, in monkeys tested with delayed matching-to-sample paradigms, Miller et al. [27,28] reported that for most affected neuronal cells, the responses to matching stimuli were significantly attenuated compared to the nonmatching stimuli. However, in a few cells the opposite effect was seen. The memory of the sample stimulus affected not only the responses to matching stimuli, but also those to nonmatching stimuli; that is, the more similar a nonmatching stimulus was to the sample, the more the response was suppressed.

The suppressed ERP amplitude to stimuli that match short term memory traces is also consistent with some neural network architectures for memory storage [7,22,25] as well as with the results of a recent PET study of cortical activation in humans [39]. In the latter study, subjects performing a visual word-stem

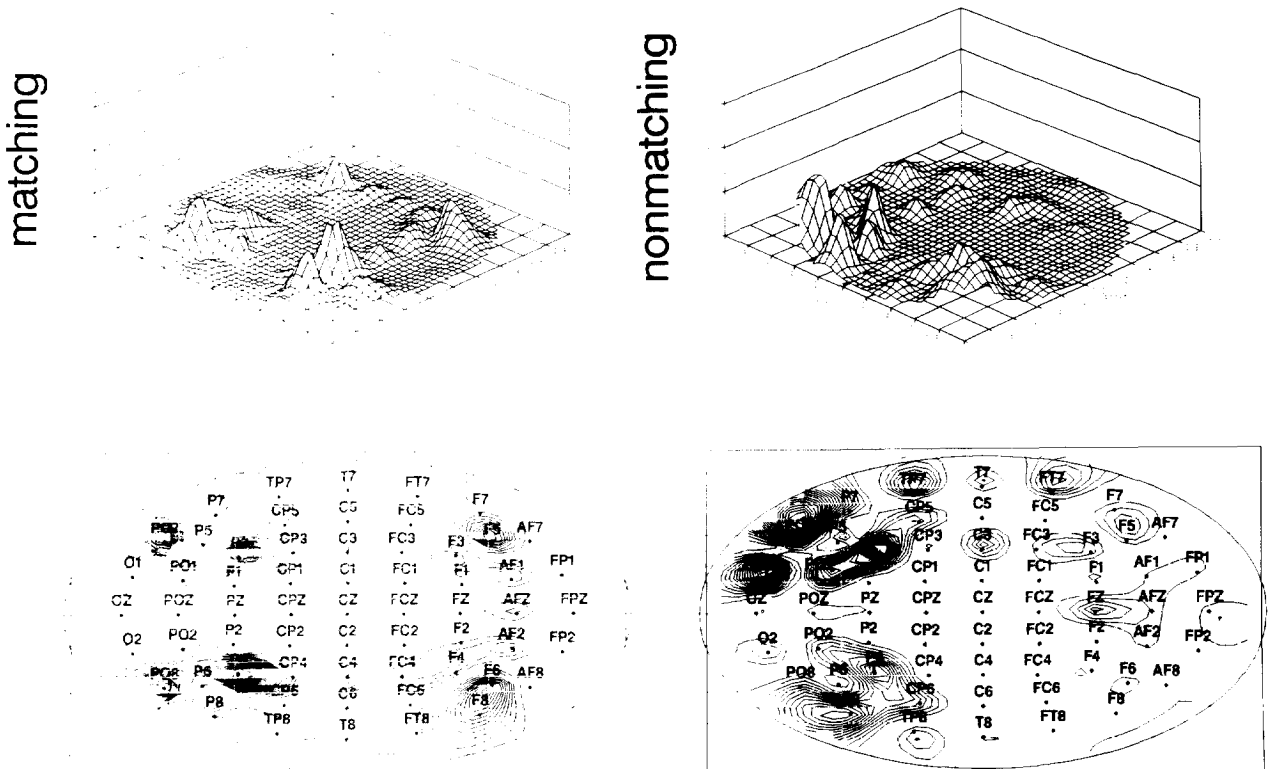


FIG. 4. SED fields on the x-y plane at SEC226 for matching condition and at SEC249 for nonmatching condition. On lower row are SED contours of the corresponding SED fields in the upper row.

completion task showed less activation of temporal cortex when they had recently seen the same word than when the words had not been seen.

We note that our current ERP results differ from those of the recent investigations which employed similar techniques to explore memory. For example, Friedman [13] suggested that a negativity (Cz maximum) at 300 ms was the most likely candidate for the brain event reflecting the retrieval of the item from memory; N300 might be specific to picture processing [2]. However, our recognition paradigm differs from Friedman's in two ways. First, we employed a delayed matching-to-sample paradigm in which the subjects had to decide whether the second stimulus was the same as the first. Second, we used a Cz reference; the difference in the selection of the reference might be responsible for the different results. As shown in Fig. 5, the ERP pattern is similar to previous similar studies [14,16] if the reference electrode at Cz is replaced by the electrode on the nose.

Our behavioral data also showed the effects of priming on picture recognition. The shorter reaction times on repeated trials suggested the initial registration of the picture produced physical or lexical traces that could facilitate the recognition and judgement of the forthcoming picture. These results concurred with the findings of earlier behavioral studies. For example, Kroll and Potter [23] showed that judgements involving related line drawings had faster RTs. In picture naming studies, Sperber et al. [38] and Carr et al. [8] each reported that the response time for naming primed pictures was shortened by 175 ms compared to that for unprimed picture naming. Last, Young et al. [44] revealed

that there was a priming effect to semantic decisions (occupation) of familiar but not unfamiliar faces, regardless of prior familiar or semantic decisions about the same face.

The results of our surface energy (SE) analysis for c247 indicate that the primed and unprimed recognition of object pictures involve different cortical regions. Thus, whereas the occipito-temporal areas are involved in both primed and unprimed trials, frontal areas participate only in the processing of primed pictures. Furthermore, the left occipito-temporal area compared to the right is more activated during nonmatching trials.

Our observation here that the occipito-temporal area is involved in processing pictures of objects is similar to the findings of both Begleiter et al. [4] and Hertz et al. [20]. Each documented a significant involvement of the occipito-temporal region in eliciting the VMP, the former using line stimuli, the latter using faces. Further, our data closely parallel the well-established findings in monkeys that bilateral excision of the anterior inferior cortex produces a severe and lasting deficit in visual object recognition [29]. However, whereas anterior temporal lesions impaired visual pattern discrimination, more posterior, temporo-occipital lesions produced the more severe perceptual deficits [9,29].

In this study, differences in the SED analyses of the matching and nonmatching stimuli suggest that the recognition of primed and unprimed pictures may be mediated by different neuronal processes. The involvement of frontal areas, and the greater activation of the right occipito-temporal area in matching trials, supports the recent findings of Begleiter et al. [5] that the rec-

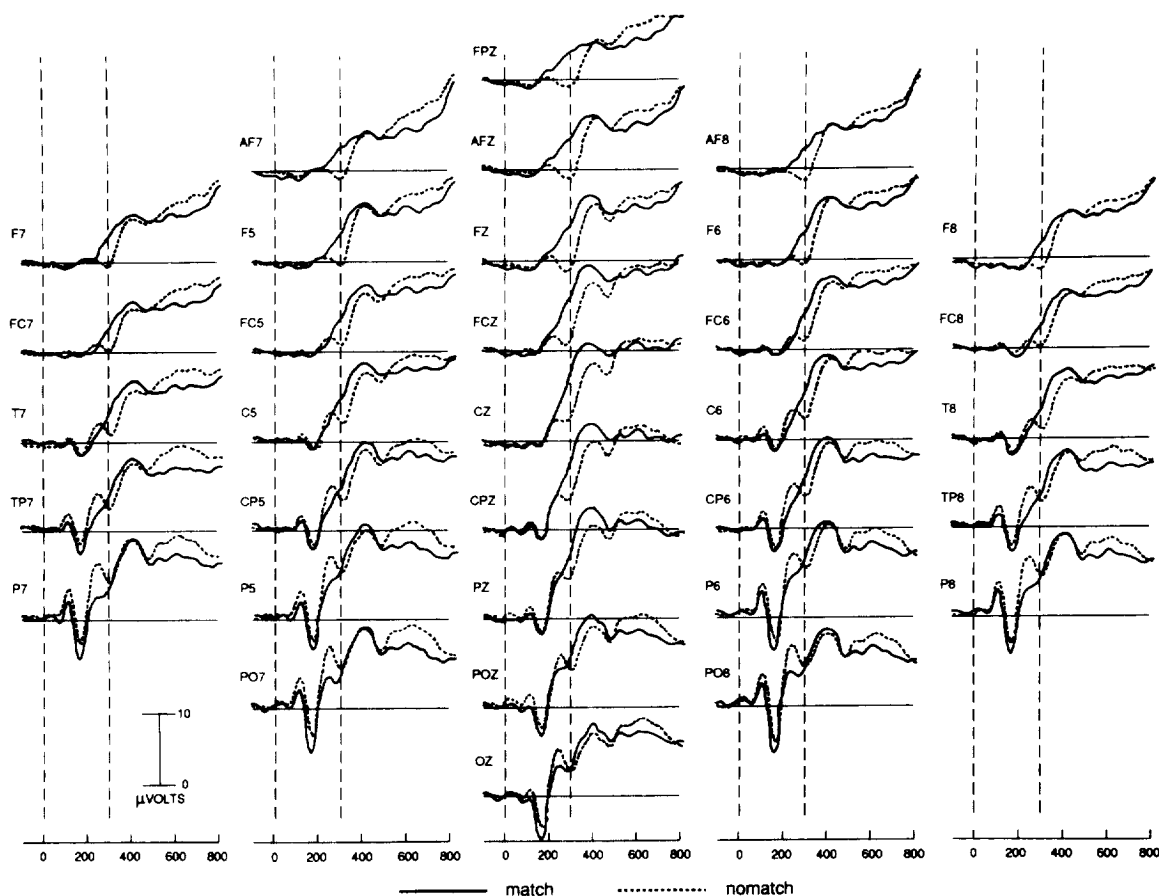


FIG. 5. The same ERP data shown in Fig. 1 but referred to the nose reference.

ognition of familiar faces involves both the temporal and frontal regions. The involvement of frontal cortex in the recognition of visual stimuli also has been demonstrated in nonhuman primates [19,43]. However, in our previous studies in which we presented nonsense line drawings [4] or unfamiliar faces [20], we never observed greater activation in the left occipito-temporal area than the right during nonmatching trials. This discrepancy in activation asymmetry might reflect differences in information processing in the brain, that is, regional differences in processing both meaningful pictorial stimuli and meaningless stimuli. In this experiment, the encoding information in memory by sample stimuli could be both physical and semantic. Glaser [18] described a lexical hypothesis for a model of picture naming that could account for the processing of physical objects, printed or written words, and spoken words. In this hypothesis, initial processing, for example, perception and imagery of the physical features, occurs in the executive system. The second processing step, the semantic analysis of the perceived pictures and objects, then occurs in the semantic system. In this context, we hypothesize that the initial comparison between our sample and the test stimuli involves comparing the physical images; this process ceases when there is a match between sample and test stimulus. If no match occurs, the process would proceed to the next stage for semantic comparison. This explanation might account for our observation of greater activation of the left occipito-temporal area during nonmatching trials in this experiment.

The data in this study revealed that the priming effect for object picture cognition may take place around 240 ms. The involvement of the occipito-temporal areas as revealed by topographic analysis suggested that these regions play a key role in high level visual information processing. This possibility is supported by studies in animals. Furthermore, the patterns generated by the topographic analysis suggest processing differences between visual information with and without verbal labels. These findings open the possibilities to explore human memory using electrophysiological techniques with high temporal resolution.

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