

## ERP components in category matching tasks

Jun Ji<sup>a,b</sup>, Bernice Porjesz<sup>a,\*</sup>, Henri Begleiter<sup>a</sup>

<sup>a</sup>State University of New York, Health Science Center at Brooklyn, New York, NY 11203, USA

<sup>b</sup>Institute of Mental Health, Beijing Medical University, Beijing 100083, China

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### Abstract

The current experiment attempts to investigate (1) the effect of semantic information on the ERP correlate of visual short-term memory (VMP) and (2) the utilizing of the ERP as an objective investigative tool for the clinical observation of the existence of category-specific brain systems. Event-related potentials (ERPs) were recorded from 61 locations on the scalp of 39 healthy adults in a category (either animals or fruits/vegetables) match/non-match S1-S2 paradigm. The ERPs revealed a substantially smaller amplitude for the category matching than for non-matching pictures at the posterior brain regions, with greater activation of temporo-occipital brain regions changing from the right hemisphere at first to the left hemisphere later, as demonstrated by the current source density (CSD) maps. The ERPs elicited by the category of animal were larger than the vegetable category, similarly, the animal-animal matching condition elicited larger ERPs than did the vegetable-vegetable matching condition. In addition, the topographic distribution of the vegetable-elicited ERPs revealed additional involvement of the right frontal cortex which was absent in the topographic distribution of the animal-elicited ERPs. The spatial pattern of the VMP possesses features specific to semantic processing, and the ERPs differentiate the animal category from the vegetable category, suggesting an objective on-line method to investigate the category-specific information processing among brain-damaged patients. © 1998 Elsevier Science Ireland Ltd. All rights reserved

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### 1. Introduction

There is no general consensus as to whether the mental representations of pictures and words involve a common conceptual system or separate verbal and imagistic systems (Glaser, 1992). According to the hypothesis of a common abstract code (Kroll and Potter, 1984), picture, as well as word, stimuli are translated into an abstract format that allows their superordinate category membership to be determined. The dual code hypothesis, on the other hand, claims that the concrete, perceptual properties of concepts should be coded as internal pictures, while the abstract/functional features are coded in an internal word system (Paivio, 1978). The conceptual/abstract representation system has been described as two separate sets of features, i.e. perceptual or visual versus functional or verbal features (Warring-

ton and Shallice, 1984; Sartori and Job, 1988). For instance, in the visual identification of category, such as for living things, the role played by perceptual attributes is thought to be greater than the role played by functional attributes; in contrast in the identification of category such as for non-living things, the recognition of the functional attributes is thought to play a more important role than the perceptual attributes (Warrington and Shallice, 1984). Furthermore, the brain organization of the conceptual code system remains unknown. However, studies of case reports suggested a remarkably specific regional organization of categorical and semantic knowledge in the human brain. Patients with various brain lesions have been found to manifest a so-called category-specific impairment, such as selective impairment in naming members of the semantic categories of 'fruits' and 'vegetables' (Hart et al., 1985), or 'living things' (McCarthy and Warrington, 1988), or 'animals' (Silveri and Gainotti, 1988). For tackling hypothetical internal stages and debatable processes, the double-stimulation experiment, where two pictures are presented simulta-

\* Corresponding author. Department of Psychiatry, Box 1203, SUNY, HSCB, 450 Clarkson Avenue, Brooklyn, NY 11203, USA; Tel.: +1 718 2702024; fax: +1 718 2704081; e-mail: bp@bp.neurodyn.hscbklyn.edu

neously or in close temporal succession, turns out to be a very productive tool (Kantowitz, 1974). In addition, because event-related potential (ERP) recording provides a temporal readout of the brain's activity during information processing that is not necessarily contingent upon overt responding or conscious awareness (Hamberger and Friedman, 1992), the concurrent recording of ERPs is arguably useful in addressing these issues (Holcomb and McPherson, 1994).

Some ERP work with pictorial stimuli has employed picture-matching paradigms where subjects had to decide whether two sequentially-presented pictures were physically identical, or came from the same semantic category (Friedman et al., 1988; Barrett and Rugg, 1990; Hertz et al., 1994; Holcomb and McPherson, 1994; Begleiter et al., 1995; Zhang et al., 1995). When subjects were asked to match the first stimulus (S1) and the second stimulus (S2) in the categorical domain, a negative wave peaking at 450 ms was observed; this N450 was larger to the non-matching targets than to the matching targets. The N450 was interpreted as the picture N400 which has long been linked with processing in the semantic domain (Kutas and Hillyard, 1980; Nigam et al., 1992). Thus the picture negativity appears to be consistent with arguments for a common conceptual memory system (Holcomb and McPherson, 1994). In order to categorize the pictures in these picture-matching paradigms, subjects are forced to use information other than that available in the surface features of the pictures; that is, they need to respond with the superordinate labels. For example, when pictures of cow and cat are presented sequentially, instead of responding at the basic level (recognizing the pictures as 'cow' and 'cat'), responding at the superordinate label (categorizing the two pictures as 'animals') is required. Whereas in paradigms in which the subject is instructed to match S1 and S2 on physical identity, though neither the overt superordinate label nor the nominal code was anticipated, evidence showed that semantic information might have been extracted in parallel (Smith et al., 1978; Friedman et al., 1988). When pictures were matched along physical identity, an early positive wave peaking around 240 ms was elicited during the delayed match-to-sample task; this positive component was smaller to the matching stimuli than to the non-matching stimuli, and was interpreted as the ERP correlate of visual short-term memory (VMP) because it resembles the mnemonic role of the inferior temporal neurons of primates (Begleiter et al., 1993). The spatial topography of the VMP suggested that there are differences between the processing of object pictures with and without verbal labels (Zhang et al., 1995), suggesting that the semantic information about a pictorial concept might be extracted in parallel. The VMP component

has been observed not only in picture-matching paradigms (Hertz et al., 1994; Begleiter et al., 1995) but also in digit-matching paradigms in which the VMP was also smaller to the identical numbers than to the non-matching numbers, and the current density map suggested the same occipito-temporal functional loci for processing digit and picture stimuli (Ji et al., unpublished data). This may be taken as supporting evidence for the argument for a common conceptual system, since the ERP data did not differentiate the neural processing of words (digits) and pictures.

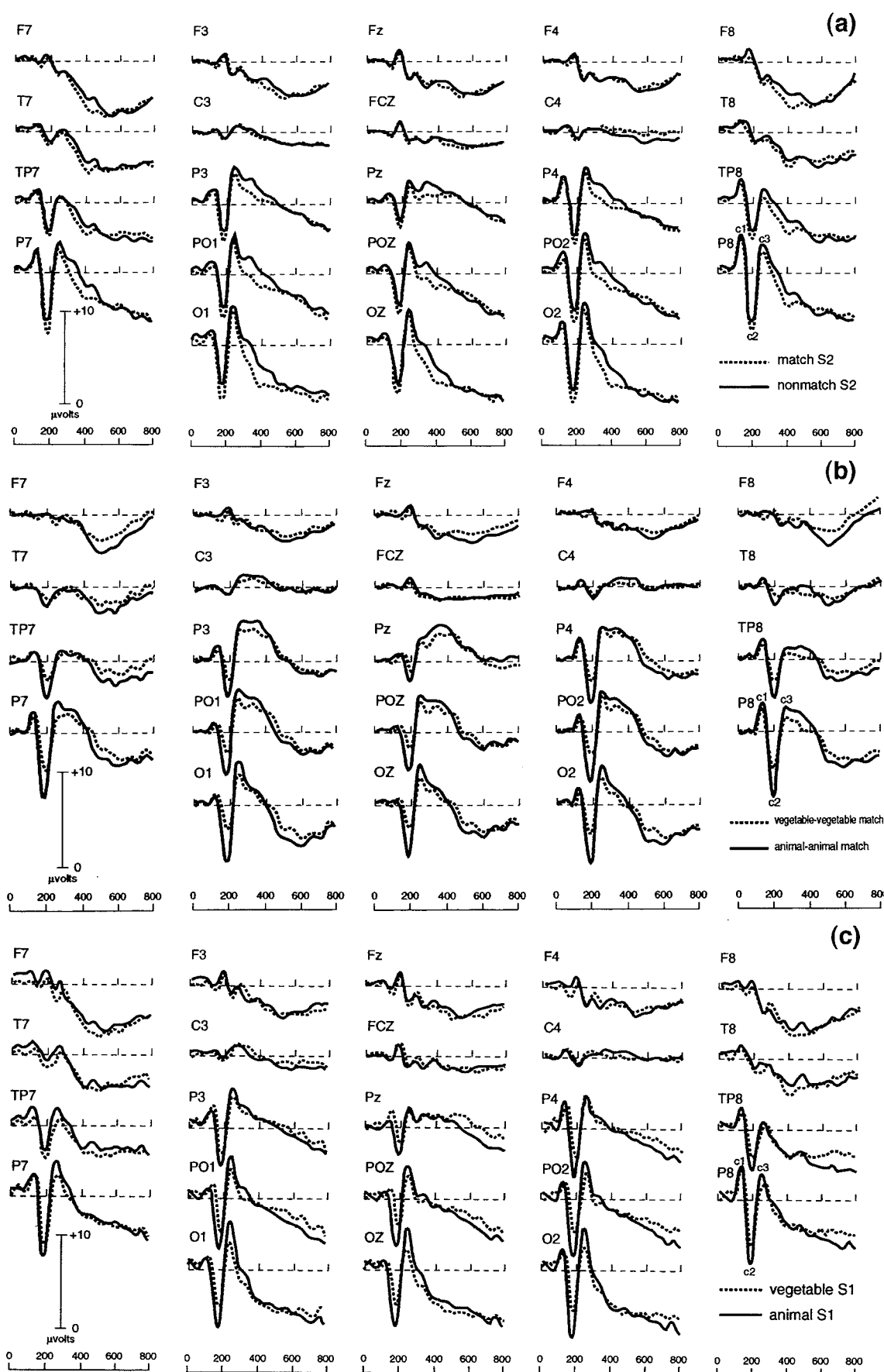
Although Friedman et al. (1988) failed to elicit the difference of S2 potentials (N400, P500 and P700) between different instruction conditions (physical identity matching, nominal matching and categorical matching), the depth of processing is thought to influence some ERP effects (Hamberger and Friedman, 1992). For example, the amplitude of P600 was sensitive to repetition only when a semantic discrimination (not orthographic discrimination) was required (Hamberger and Friedman, 1992). The current experiment attempts to investigate the effects of different levels of processing on the latency and/or amplitude and/or spatial pattern of the VMP. The task demands in the former VMP experiments were relatively superficial, given that subjects were instructed to make judgements based on the physical identity of visual stimuli. In this experiment, the task demands the subjects to make judgements as to whether two sequentially-presented pictures came from the same semantic category. Through this modulation, we hypothesized that the semantic information was extracted in order to make the correct judgements. We investigated whether the VMP spatial patterns which possesses features specific to the object with a verbal label (Zhang et al., 1995) would be elaborated by this semantic extraction.

With regard to the brain organization of a category code system, Dehaene (1995) demonstrated that ERPs can represent the timing and coarse localization of category-specific knowledge about words. We were also interested in testing whether the ERP, as an objective investigative tool, would add evidence to establish the existence of a category-specific brain systems (Caramazza and Hillis, 1991). We selected the pictures of animal and vegetable/fruit as the visual stimuli, since both of the two categories have been reported to be selectively impaired in patients with specific neurological disorders (Hart et al., 1985; Silveri and Gainotti, 1988).

## 2. Methods

Twenty-three males and 16 females participated in this experiment. None of the 39 volunteers has reported any

Fig. 1. (a) Grand-mean ERPs elicited by S2, category match (dashed line) versus category non-match (solid line) stimuli at 23 electrodes over the scalp. Note that ERP components c1, c2 and c3 are marked at the P8 electrode. (b) Grand mean ERPs elicited by S2, vegetable-vegetable match (dashed line) versus animal-animal match (solid line) stimuli at 23 electrodes over the scalp. Note that ERP components c1, c2 and c3 are marked at the P8 electrode. (c) Grand mean ERPs elicited by S1, vegetable (dashed line) versus animal (solid line) sample stimulus at 23 electrodes over the scalp. Note that ERP components c1, c2 and c3 are marked at the P8 electrode.



history of neurological or psychiatric disease. All subjects were right-handed and had normal or corrected normal vision.

The stimuli consisted of 184 trials of pictures, or 92 picture pairs. Every picture in this experiment was in one of two categories: either an animal, or a fruit/vegetable. A match/non-match S1-S2 paradigm was employed, in which framed pairs of animal drawings or fruit/vegetable drawings were presented, with a 1.6 s interstimulus interval and the stimulus duration was 15 ms. The interval between each trial was fixed to 3.2 s. Each picture was presented on a computer screen subtending a visual angle of 6–8°. In half of the trials both the first stimulus (S1) and the second stimulus (S2) were of the same category, but S2 was never the same animal or fruit/vegetable as the first. It was always another kind of animal or another kind of fruit/vegetable; in the other half of the trials the S1 and S2 were not of the same category.

The 61 lead electrode cap (Electro-Cap International, Inc.) where all sites are included in the standard electrode position nomenclature (American Electroencephalographic Society, 1990) was fitted to each individual. The reference electrode was Cz, and the impedances were kept below 5 k $\Omega$ . The Cz electrode was used as the reference electrode since some components, such as the VMP, could best be visualized with this electrode montage, and also due to our interest in studying topographic distributions using the Laplacian operator (see Begleiter et al., 1993). Subjects were grounded with a forehead electrode. The vertical and

horizontal EOG were recorded. Trials with artifacts ( $>73.3$   $\mu$ V) were rejected on-line. The signals were amplified with a gain of 10 000 by a set of amplifiers (Sensorium 2000) with a bandpass of 0.02–50 Hz, and recorded on a Concurrent 5550 computer. The sampling rate was 256 Hz. The total length of the ERP epoch was 1600 ms, including a prestimulus period of 187 ms. The data were averaged and digitally filtered with a 32 Hz low-pass filter.

The subject was seated in a reclining chair located in a sound-attenuated RF shielded room (IAC) and fixated on a point in the center of a computer display located 1 m away from his/her eyes. Subjects were told: 'you will see a frame on the screen which contains a drawing of something which is either an animal or a fruit/vegetable; the second drawing will never be exactly the same animal or fruit/vegetable as the first; it will be just another kind of animal or another kind of fruit/vegetable.' On each trial, after the presentation of S2, the subject was asked to press a mouse key in one hand if both the first and second drawing were at the same category, and to press a mouse key in the other hand if not. The designation of the hand indicating match or non-match was alternated across subjects. Response accuracy and speed were equally emphasized.

The ERPs were averaged for 4 cases: case 1 – animal S1 (46 pictures), case 2 – fruit/vegetable S1 (46 pictures), case 3 – category same S1 and S2 (46 pictures: 23 animal-animal and 23 vegetable-vegetable), case 4 – category S1 different from S2 (46 pictures: 23 animal-vegetable and 23 vegetable-animal). Grand-average waveforms are shown in Fig. 1a

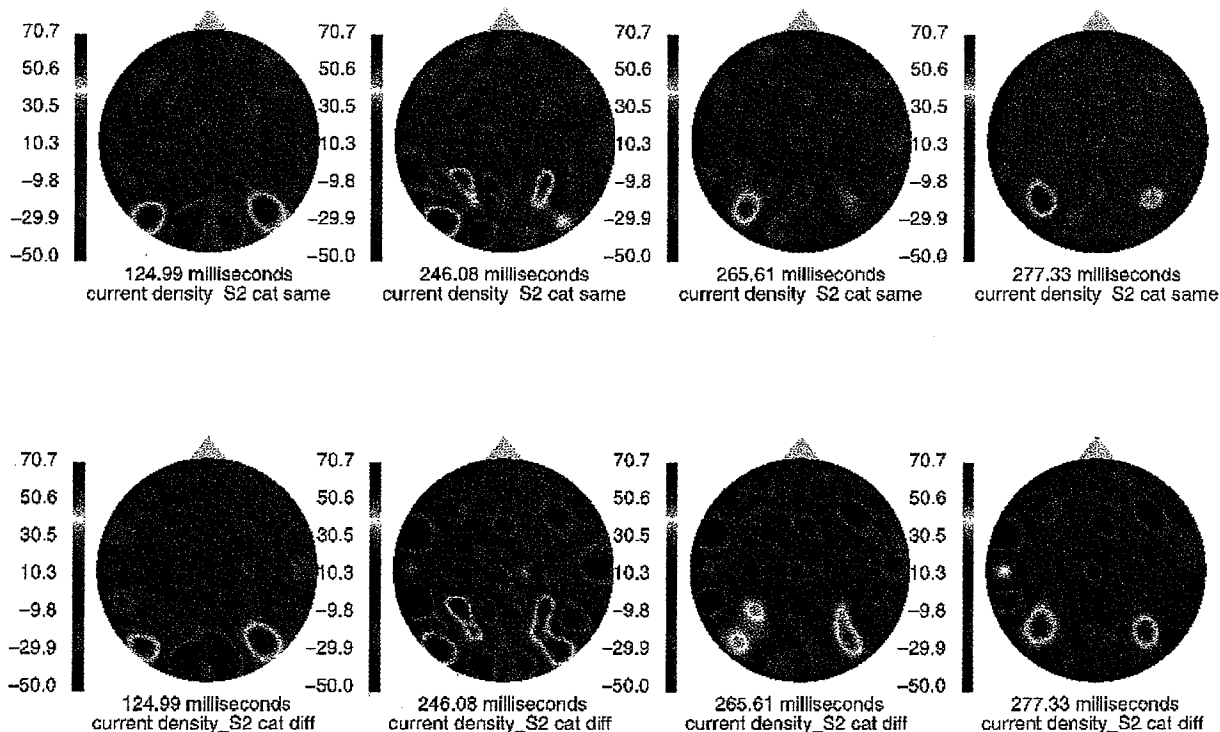


Fig. 2. Current source density maps for the match/non-match conditions over time: S2 cat same refers to matching trials, S2 cat differ refers to category non-matching trials. The unit of the scale is ( $\mu$ V/ $r^2$ )/cm $^2$ .

(S2s: category match vs. category non-match), Fig. 1b (for S2 in category matching condition, the data were reaveraged along the animal-animal category or vegetable/fruit-

vegetable/fruit category) and Fig. 1c (S1s: animal vs. vegetable). At the most posterior electrodes the ERPs take the form of 3 discernible deflections, which will be labeled as

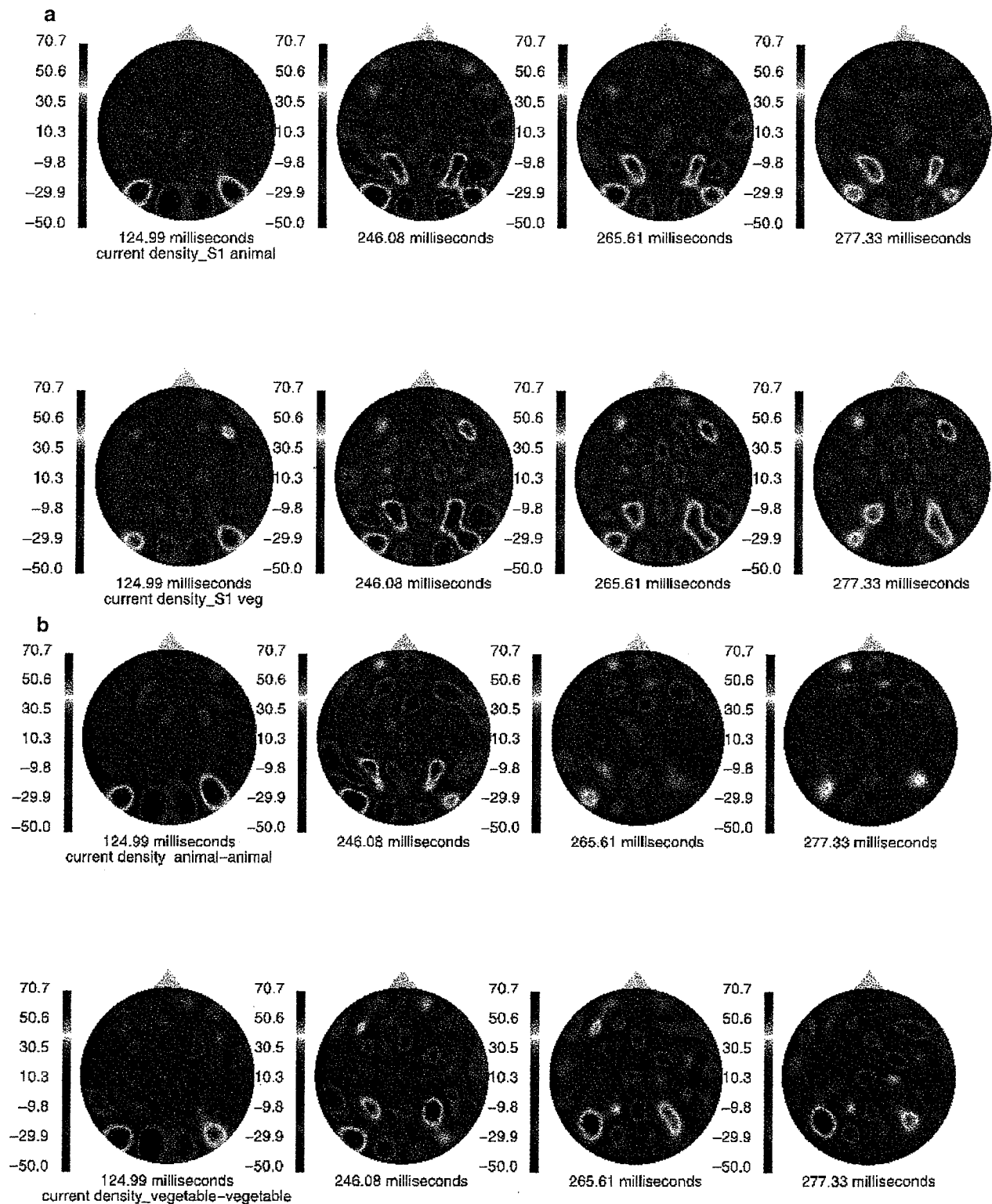


Fig. 3. (a) Current source density maps for different categories over time: S1 animal refers to animal sample, S1 veg refers to vegetable/fruit sample. The unit of the scale is  $(\mu V/r^2)/cm^2$ . (b) Current source density maps for the matching conditions: animal-animal refers to animal-matching trials, vegetable-vegetable refers to vegetable/fruit-matching trials. The unit of the scale is  $(\mu V/r^2)/cm^2$ .

c1, c2 and c3, respectively (Fig. 1), while at the anterior electrodes the 3 ERP components are much less discernible. The peaks are measured with respect to a 125 ms baseline. Latencies were measured from the time of the stimulus-onset to the peak of each component; peak latency at electrode P8 was used to help to identify the components at the other electrode sites, due to morphological consistency. We identified the c3 as the VMP due to their temporal and morphological similarity. The c3 and the VMP will be used in this paper interchangeably. In addition, the morphological features of the c3 indicate that there is an obvious difference between stimulus conditions at the downward side of the c3 (242–488 ms); thus we further quantified the mean amplitude of the c3 for each subject.

Statistical analyses of ERP data were only conducted on artifact-free trials with correct behavioral responses. The measurements of amplitudes of each component at each electrode were organized into groups by region. The frontal region consisted of FP1/2, FPz, AF7/8, AF1/2, AFz, F7/8, F5/6, F3/4, F1/2, Fz; the central region consisted of FC5/6, FC3/4, FC1/2, FCz, C5/6, C3/4, C1/2; the parietal region consisted of CP3/4, CP1/2, CPz, P3/4, P1/2, Pz; the occipital region consisted of PO7/8, PO1/2, POz, O1/2, Oz; the temporal region consisted of FT7/8, T7/8, TP7/8, CP5/6, P7/8, P5/6. The electrode sites organized into each brain region were generally corresponding to the underlying brain cortex. A number of MANOVAs (SAS v6.09, PROC GLM) were carried out separately for each component using the amplitude or latency at each of the 5 regional electrode arrays as a dependent vector, gender as between-subject effect, condition (S2 category match vs. S2 category non-match) and electrode site as within-subject effect. As the electrodes employed in each analysis are within each brain region, the main effect of electrode site and its interaction with other main effects were not reported since these effects have no practical significance.

The topographic distribution of the c3 component (Fig. 2) was obtained by using the grand mean of Spline-Laplacian transformations. The surface Laplacian is an estimate of the local current density through the skull into the scalp (Nunez and Pilgreen, 1991). Positive values of the current source density indicate local current flow out of the skull, whereas negative values indicate current flow into the skull. Fig. 3 shows the topographic distribution of animal/vegetable effects.

### 3. Results

Twenty-three males ( $25.4 \pm 4.4$  years old) and 16 females ( $23.9 \pm 3.7$  years old) participated in this experiment. There was no significant difference ( $F = 1.16$ ,  $P = 0.29$ ) between the group mean age of male and female subjects.

Table 1 shows the response time and accuracy data. No significant effect emerged in the two-way (stimulus condi-

tion and gender) ANOVA of the response time data. However, the paired  $t$  test showed that subjects were less accurate in judging category match trials (91%) than in judging category-non-match trials (95%) ( $T(39) = -3.20$ ,  $P < 0.01$ ). To be conservative, ceiling effects in performance (over 90% accuracy) might make this accuracy difference less conclusive.

As can be seen in the grand-mean ERP waveforms (Fig. 1), the ERPs were characterized by 3 major components at the posterior electrodes. The comparison between category match and category non-match conditions were first conducted on each component; the differences between the ERP waveforms of animal (S1) and vegetable (S1) were then compared. Further, the averaged amplitudes of c2 (145–200 ms) and c3 (210–270 ms) were calculated for the two category match conditions, i.e. animal-animal matching (S2) and vegetable-vegetable matching (S2) conditions, separately.

#### 3.1. c1

No significant effects of amplitude between stimulus conditions were revealed for c1, nor was there a significant interaction between stimulus condition and gender. There were significant main gender effects at the parietal region ( $F = 6.45$ ,  $P < 0.05$ ), occipital region ( $F = 10.12$ ,  $P < 0.01$ ) and temporal region ( $F = 8.96$ ,  $P < 0.01$ ); the amplitude of c1 for female subjects was larger than for male subjects at these regions (parietal: 3.16 vs. 2.16  $\mu V$ ; occipital: 5.99 vs. 3.26  $\mu V$ ; temporal: 4.24 vs. 2.66  $\mu V$ ). A significant latency effect was obtained at the central region ( $F = 4.83$ ,  $P < 0.05$ ); the latency of non-match c1 (123.93 ms) was longer than that of match c1 (118.77 ms). In addition, the interaction between stimulus condition and gender for c1 latency was significant only at the temporal region ( $F = 11.77$ ,  $P < 0.01$ ); this is due to the latency of c1 for female subjects, which is longer in match trials than in non-match trials (123.57 vs. 120.70 ms) while male subjects showed the opposite effect (113.76 vs. 122.57 ms).

#### 3.2. c2

Amplitude analysis gave rise to significant main effects of stimulus condition at the parietal region ( $F = 8.04$ ,  $P < 0.01$ ), occipital region ( $F = 11.03$ ,  $P < 0.01$ ) and temporal region ( $F = 5.53$ ,  $P < 0.05$ ); this is due to the non-matching c2 which is less downward-going than the match-

Table 1

Response time and accuracy

	Response time (ms)	Correct rate
Category match	754.03 $\pm$ 126.60	0.9108 $\pm$ 0.0900
Category non-match	803.14 $\pm$ 144.38	0.9517 $\pm$ 0.0520

ing c2 at these regions (parietal:  $-2.84$  vs.  $-3.32$   $\mu\text{V}$ ; occipital:  $-6.86$  vs.  $-7.75$   $\mu\text{V}$ ; temporal:  $-4.17$  vs.  $-4.65$   $\mu\text{V}$ ). No significant interaction between stimulus condition and gender was obtained, nor was there a main gender effect. For the latency of c2, no significant main effects were obtained. However, there was a significant interaction between stimulus condition and gender ( $F = 4.81$ ,  $P < 0.05$ ) at the occipital region, because the latency of c2 for female subjects was longer in match trials than in non-match trials (184.53 vs. 179.31 ms), while male subjects showed the opposite effect (174.28 vs. 179.31 ms).

### 3.3. c3

Category match/non-match differences take the form of a more upward-going waveforms under the non-matching condition. The peak amplitudes of non-matching S2s were larger than those of matching S2s, and this effect was significant at the parietal ( $F = 5.38$ ,  $P < 0.05$ ) and occipital ( $F = 9.66$ ,  $P < 0.01$ ) regions. The mean amplitudes were also larger for non-matching S2s than for matching S2s at parietal ( $F = 12.16$ ,  $P < 0.01$ ), occipital ( $F = 35.92$ ,  $P < 0.001$ ) and temporal ( $F = 14.09$ ,  $P < 0.001$ ) regions. Male and female subjects did not differ in their responses to match/non-match stimuli; no gender effect nor interaction effect between gender and stimulus condition appeared to be significant. With regard to latency, there were no significant main effects for either stimulus condition or gender; however, the interaction effect between the two is significant at parietal ( $F = 6.22$ ,  $P < 0.05$ ), and occipital regions ( $F = 4.49$ ,  $P < 0.05$ ). This is caused by the latency of c3 for female subjects which was longer in match trials than in non-match trials (parietal: 253.52 vs. 248.23 ms; occipital: 246.69 vs. 243.45 ms), while male subjects showed the opposite effect (parietal: 249.56 vs. 252.26 ms; occipital: 242.55 vs. 246.14 ms).

The topography of c3 is shown by deriving its current source density, as illustrated in Fig. 2. There were small

sources at the temporal region as early as 124 ms, with greater involvement of the right temporal area. At a latency of 246 ms, strong sources were revealed at both left and right temporal regions; the right source was somewhat stronger than the left source for both category matching and non-matching conditions. Later, at the latency of 265 ms, the right source became amorphous for the category matching condition but not for the category non-matching condition. Still later, at a latency of 277 ms, the right source almost disappeared for the category matching condition, and became very ambiguous for the category non-matching condition. This left-greater-activation effect on non-match trials was further supported by MANOVAs with hemisphere (match:  $F = 3.87$ ,  $P = 0.057$ ; non-match:  $F = 7.10$ ,  $P = 0.011$ ) as a within-subject factor performed on mean amplitudes at P5/6 and PO7/8.

### 3.4. Analysis of animal/vegetable effects

The MANOVA of S1 (summarized in Table 2) revealed the following significant results (illustrated in Fig. 1c): the peak amplitudes of c2 were larger (downward-going) for the animal S1 than for the vegetable S1 at parietal ( $-3.32 \pm 3.59$  vs.  $-2.17 \pm 2.90$   $\mu\text{V}$ ), occipital ( $-7.94 \pm 6.50$  vs.  $-4.72 \pm 5.45$   $\mu\text{V}$ ), and temporal ( $-5.08 \pm 4.97$  vs.  $-3.49 \pm 4.08$   $\mu\text{V}$ ) regions. Similarly, the c3 amplitudes were larger (upward-going) for animal S1 than for vegetable S1 at these regions (parietal:  $3.68 \pm 3.47$  vs.  $3.16 \pm 2.92$   $\mu\text{V}$ ; occipital:  $6.58 \pm 5.97$  vs.  $5.14 \pm 5.28$   $\mu\text{V}$  and temporal:  $3.14 \pm 4.71$  vs.  $4.43 \pm 4.12$   $\mu\text{V}$ ). The only significant effect revealed for c1 was that the latency was longer for the animal S1 than for the vegetable S1 at the central region ( $120.15 \pm 29.87$  vs.  $114.80 \pm 30.41$  ms ( $F = 4.80$ ,  $P < 0.05$ )). No significant effects were revealed for the c2 and c3 latencies.

Considering the significant effects (Table 2: animal-ERPs were significantly different from vegetable-ERPs) obtained above, and the morphological consistency at the parietal occipital and temporal regions, further comparisons between animal-animal and vegetable-vegetable matching conditions (illustrated in Fig. 1b) were conducted at these posterior regions. The MANOVA of c2 (145–200 ms) amplitude revealed significant main effects in the matching condition at parietal ( $F = 8.25$ ,  $P < 0.01$ ), and occipital ( $F = 22.72$ ,  $P < 0.0001$ ) regions. The amplitudes of c2 were larger (downward-going) for the animal-animal than for the vegetable-vegetable matching conditions at these brain regions (parietal:  $-7.95 \pm 11.41$  vs.  $-3.19 \pm 12.24$   $\mu\text{V}$ ; occipital:  $-21.17 \pm 21.60$  vs.  $-11.85 \pm 20.77$   $\mu\text{V}$ , respectively). The males and females did not differ in the c2 amplitudes to the two matching conditions (neither the interaction effect of matching condition by gender nor the gender effect was significant). The amplitudes of c3 (210–270 ms) were larger (upward-going) for the animal-animal than for the vegetable-vegetable matching conditions at occipital ( $-12.99 \pm 18.95$  vs.  $7.34 \pm 18.69$   $\mu\text{V}$ ,  $F = 13.43$ ,

Table 2

MANOVA results of amplitude comparisons (animal vs. vegetable,  $P$  values)

	Stimulus condition (S.)	Gender (G)	Interaction of S $\times$ G
<b>C2</b>			
Frontal	n.s.	n.s.	n.s.
Central	n.s.	n.s.	n.s.
Parietal	0.0015	n.s.	n.s.
Occipital	0.0001	n.s.	n.s.
Temporal	0.0001	n.s.	n.s.
<b>C3</b>			
Frontal	n.s.	n.s.	n.s.
Central	n.s.	n.s.	n.s.
Parietal	0.0379	n.s.	n.s.
Occipital	0.0031	n.s.	n.s.
xTemporal	0.0187	n.s.	n.s.

$P < 0.01$ ) and temporal ( $4.16 \pm 16.34$  vs.  $0.10 \pm 16.62 \mu\text{V}$ ,  $F = 11.40$ ,  $P < 0.01$ ) regions.

Compared with the CSD map of animal S1, sources at the frontal region appeared stronger on the CSD map of vegetable S1, and the frontal source became stronger over time (Fig. 3a). The sources in Fig. 3b showed different dynamic changes over time at the temporo-occipital region between animal-animal and vegetable-vegetable matching conditions.

## 4. Discussion

### 4.1. Match/non-match effects

The ERPs revealed a substantially smaller amplitude (c3) for the category matching (peak latency around 250 ms) than non-matching (peak latency around 248 ms) pictures between 242 and 488 ms, and this effect was significant only at the posterior brain regions. The current source density maps of the c3 component illustrate the dynamic involvement of temporo-occipital brain regions, with greater activation changing from the right hemisphere at first to the left hemisphere later. The lateral shift of the activation area appeared early, and ended earlier in matching than non-matching processes.

In processes of matching pictures, the activation of the category representation of a picture (S1) in memory might temporarily increase the availability of that kind of picture. This availability may force subjects to use less data for a 'match' than for a 'non-match' decision. Therefore, the c3 amplitude differences between category matching and non-matching conditions may stem from this category availability. The c3-effect manifested this cognitive efficiency in the form of the smaller amplitude under the category matching condition. The cognitive efficiency indexed by the c3 resembled the role of the picture-elicited N450 reported by Barrett and Rugg (Barrett and Rugg, 1989; Barrett and Rugg, 1990), and word-elicited N400 reported by Bentin et al. (1985), because these two ERP components manifested a suppressed amplitude to the matching pictures/words. The ERP-finding of an amplitude reduction is also in agreement with those reported by Begleiter et al. (1993), Hertz et al. (1994) and Zhang et al. (1995); all are studies in which subjects were instructed to match sequentially-presented pictures (faces or objects) on the basis of visual identity. A component (VMP) peaking around 240 ms was observed in these studies, and the amplitude was smaller to identical than to different pictures. The amplitude of the VMP therefore might index a more general mnemonic comparison rather than the different judgement criteria employed in these studies and the current study. The suppressed amplitude was the common observation for the different matching processes, i.e. categorical/identical matching in the case of the VMP, phonological/orthographical matching in the case of the N450 and semantic matching in the case of the N400.

Considering the general matching effect indexed by these ERP components (Barrett and Rugg, 1990; Revonsuo and Laine, 1996), we may assume that the amplitude of ERP components does not index specific aspects of matching cognitive processes.

In contrast, the topographic distribution of the VMP has demonstrated features that seem to be specific to semantic information. The face-identity tasks (Hertz et al., 1994; Begleiter et al., 1995) demonstrated a greater activation of the right hemisphere than the left. The greater activation of the left side was observed under the object and digit non-matching condition where the parallel or implicit extraction of the semantic information might take place (Zhang et al., 1995; Ji et al., unpublished data). Semantic information is traditionally assumed to engage processing systems predominating in the left hemisphere, and the labile view of hemispheric asymmetries states that hemispheric asymmetries are not fixed in either size or direction, but labile, depending on stimulus context and processing demands (cf. Hass and Whipple, 1985). With the explicit extraction of semantic information in the present study, the involvement of the left hemisphere demonstrated a more active role than the right under both matching and non-matching conditions, even though the stimulus itself is not in the semantic domain. This is concordant with the labile view of hemispheric asymmetries. Accordingly, the topographical shift over time, which progresses from the right to the left hemisphere, may index an underlying ongoing process; that is, the initial encoding of pictures, which was assumed to engage processing systems predominating in the right cerebral hemisphere (Hass and Whipple, 1985; Underwood and Whitfield, 1985) progressed to the semantic extraction which was processed mainly in the left hemisphere. Therefore, the nature of the hemispheric distribution of the match/non-match c3 effect seems to be more a reflection of the localization of the semantic extracting process than of the employment of orthographic material. This is concordant with a functional MRI study (McCarthy et al., 1996) which indicated that the relative weighting of hemispheric activation was affected by the mnemonic content of the task. Furthermore, the different time pattern of the involvement of the left temporo-occipital area in the matching versus non-matching process again confirms the empirical assumption that the underlying neural process is quite different between matching and non-matching stimuli.

### 4.2. Animal/vegetable effects

The ERP waveforms from animal and vegetable/fruit are significantly different from each other at the posterior electrodes (Fig. 1c); the category of animal elicited larger ERP potentials (c2 and c3) than the vegetable category, and the difference was more significant for the c2 component than for the c3 component (Table 2). Similarly, the animal-animal matching condition elicited larger potentials of c2 and



c3 than did the vegetable-vegetable matching condition (Fig. 1b).

The larger potential relative to the animal stimuli was quite consistent across different cognitive processes, that is, under both the encoding process of S1 and the matching process of S1-S2. In other words, because the difference between the animal-animal and vegetable-vegetable matching conditions is solely the different category of the to-be-matched stimuli, the larger potentials relative to the animal-animal matching condition provided confirming evidence for the category-specific features possessed by the elicited potentials (mainly the c2 or c180). Hertz et al. (1994) reported a larger potential (c2 or c180) from the meaningful face stimulus than from the meaningless stimulus. These findings indicate that the processing system for faces is functionally separated from general visual processing systems. Thus it seems that the c180 component possesses some features which are category-specific. However, in an ERP study to investigate the time-course of visual word processing, Dehaene (1995) reported that the earliest category-specific difference appearing in ERPs was at 250–280 ms after the stimulus. Many experiments (see Glaser, 1992) replicated the observation that there is a reliable picture-word difference in categorizing latency, and pictures have privileged access to the semantic system in comparison with words. It is possible that the time course of visual picture processing could manifest relatively earlier category-specific ERP differences than at 250 ms. In fact, category-related ERP components were also recorded by Seeck and Grusser (1992) who employed photographs of faces, persons, flowers and tools as visual stimuli. In particular, their findings agreed with the ERP finding of face-related components described by several laboratories such as Jeffreys (Jeffreys, 1989; Jeffreys, 1993), and Allison et al. (1994a,b), where electrodes were implanted on the surface of the extrastriate visual cortex of epileptic patients. The face-related components are prominent in the waves peaking from as early as 130 ms to 250 ms (Seeck and Grusser, 1992; Jeffreys, 1993; Allison et al., 1994a,b). Considering the fact that the visual stimuli employed in these studies (faces, animals and vegetables) are subcategories of living things, another interpretation is also possible: all living things may yield a greater ERP amplitude at 180–200 ms, as demonstrated in Hertz et al.'s study (Hertz et al., 1994) and the present study. It is unknown whether differences in ERPs between the stimulus category of living things and non-living things may appear when other members of non-living things are tested. So far, our results indicate a correlation between living things and the c2 component.

In addition, the topographic distribution of the vegetable-elicited ERPs revealed additional involvement of the right frontal cortex which was absent in the topographic distribution of the animal-elicited ERPs. Furthermore, the ERPs from the vegetable-vegetable matching condition contributed in major part to the later involvement of the left temporo-occipital area in the category matching condition,

while the ERPs from the animal-animal matching condition contributed mainly to the earlier involvement of the temporo-occipital brain area. Evidence from clinical observation strongly suggested a remarkably specific organization of categorical knowledge in the brain (Hart et al., 1985; McCarthy and Warrington, 1988; Caramazza and Hillis, 1991). For example, patients with herpes simplex encephalitis, which usually impairs the temporo-limbic structures of both hemispheres, showed a selective inability to identify living things and foods, but retained the ability to identify others (Warrington and Shallice, 1984; Warrington and McCarthy, 1987). Silveri and Gainotti (1988) speculated that similar anatomical lesions corresponded to the similar category-specific impairment observed in these patients. Along with these clinical observations, the present data demonstrated that the information corresponding to a specific category was not processed identically in both spatial and temporal aspects in the brain. The ERP topographic patterns for the animal and vegetable stimuli in healthy subjects are different. Unlike the additional involvement of the right frontal cortex in processing vegetable stimuli, the brain involvement of processing animal stimuli is limited to the temporo-occipital region. This observation may be helpful in understanding why the animal class was the more frequently and more severely affected among the living things category (Sartori and Job, 1988; Silveri and Gainotti, 1988). However, it would be too speculative for us to locate animal or vegetable specific brain regions on the basis of a single experiment. Rather, the present ERP data suggest an objective on-line method to investigate category-specific information processing among brain-damaged patients.

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