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Encoding and retrieval are two important phases of memory. Encoding produces memory en-gram and retrieval reactivates previously encoded information. Many researchers have found distinct neural mechanisms for encoding and retrieval. Tulving et al.[1] proposed a memory model of hemispheric encoding/retrieval asymmetry (HERA) on the basis of a lot of studies. That is, the prefrontal cortex plays different roles during encoding and retrieval. The left prefrontal cortex is more activated during encoding. On the other hand, the right prefrontal cortex is more activated during retrieval. Thus, retrieval is the reactivation of encoded information, but it is not the simple recovery of encoding.

One of the effective research paradigms of encoding is "subsequent memory", in which the items learned during study phase can be divided into two categories (the remembered and the forgotten) based on whether they could be retrieved successfully or not during test phase. The event-related potentials (ERPs) differences between these two categories during study phase are called subsequent memory effects. The first experiment of this paradigm was conducted by Sanquist et al.[2], who found that the remembered items elicited more positive brain waves than the forgotten items. Such differences are later named as Dm (Differential memory) effect[3]. The Dm effect has been demonstrated in language studies using western words and Chinese characters[4−6]. However, limited studies have been conducted using non-linguistic materials. The Dm effect using human faces has been reported[7]. However, the results of Dm effect using pictures are inconsistent. In order to investigate the role that medial temporal lobe (MTL) played in encoding, Elgar et al.[8] performed a continuous recognition test on pictures and words. They put electrodes in epilepsy patients' MTL and recorded the corresponding ERPs. Their results indicated that Dm effect existed in both pictures and words, and the duration of picture encoding was longer than that of word encoding. These results suggest MTL plays an important role in the encoding of pictures and words. Petten et al.[9] used meaningless pictures formed by 5 lines with 9 points in a 3×3 grid as stimuli and found no Dm effect. Yet, they found significant Dm effect on nouns by the same subjects. Petten et al. indicated that the insignificant Dm effect on meaningless pictures was due to the characteristics of the visual stimuli. Since there was not any prior knowledge presentation of the meaningless pictures in the participants' brain, it was impossible to have a detailed encoding for these pictures. Therefore, whether the Dm effect of picture is significant or not is still an unresolved problem.

As for retrieval research, the "old/new" paradigm is an effective one, which uses mixed studied (old) and unstudied (new) items to test participants. The participants are asked to discriminate whether the items are old or new. Many researchers have reported that the remembered old items had larger amplitudes than the correctly judged new items during retrieval—this difference was called old/new effect. Up to now, most of the studies on old/new effect were conducted using linguistic materials as stimuli and the results were consistent[10−14]. However, there were fewer reports using pictures as stimuli. In a recent study[15], three categories of pictures were included during test phase: old pictures, new pictures that were similar to the old ones, and new pictures that were distinct from the old ones. Then two tests with two difficulty levels were conducted. The difficult test required the participants to discriminate the pictures as old or new ones. In the easier test, the participants were allowed to regard the old pictures and the new pictures that were similar to the old pictures as the old ones, and only judge the new pictures completely different from the old pictures as the new ones. The results showed the significant left-parietal old/new effect in both tests, and left prefrontal cortex was only

present results suggest that the Dm effect of pictures is different from that of words and faces in spatial and temporal distributions. The neural mechanism of picture encoding activated in the difficult test but not in the easy one. The results indicate that extra cerebral areas are involved in the more difficult retrieval task. In another study[16], pictures used were shown either in red or green during study phase but were transformed into black against white background during test phase. The old/new effect could only be found at left-parietal cortex. As we can see, these results are inconsistent so far, which calls for further study on old/new effect using pictures as stimuli.

The present study examined whether the neural mechanisms of Dm effect and old/new effect on pictures are consistent with the model of HERA or not. The current event-related potentials experiment used meaningful line drawing pictures as visual stimuli. The ERPs were recorded during encoding and retrieval, and the data analysis examined the ERPs characteristics of Dm effect and old/new effect. First, the spatial and temporal differences between the remembered old pictures and the forgotten old ones were compared during encoding, and the Dm effect of previous studies was also compared to examine the specific characteristics of picture encoding. Second, to examine the characteristics of picture retrieval, the ERPs of the remembered old pictures were compared with that of the correctly judged new ones during retrieval. Lastly, the Dm effect and the old/new effect were compared to investigate whether the neural mechanisms of picture encoding and picture retrieval were the same.

1 Methods

(ⅰ) Participants. Fourteen healthy and right-handed undergraduates (7 men and 7 women) from The Capital Normal University participated the experiment and received monetary compensation. Their eyesight or corrected eyesight was above 20/40, and their age ranged from 19 to 24 (averaged: 21.7).

(ⅱ) Stimuli. The stimuli consisted of 312 line drawing pictures from Snodgrass et al. and were standardized to Chinese norms. The pictures were randomly divided into 3 blocks and were balanced on familiarity, naming difficulty, visual complexity and imaging consistency. There were 104 pictures in each block, 73 pictures in study phase with 10 targets and 2 fillers (the fillers were in the front of each block), 92 pictures during test phase, among which were 59 old pictures (with targets and fillers being excluded) and 33 new ones.

(ⅲ) ERP recording. Event-related potentials were recorded from 62 Ag/AgCl electrodes embedded in a cap of ESI-64-channel-electrophysiology-recording-analysis system produced by Neuroscan Company (Fig. 1). The electrodes were located according to an extension of the international 10—20 system. Vertical EOG was recorded by electrodes placed above and below the supra-orbital of left eye, and horizontal eye movements and blinks were monitored via a bipolar montage at the external canthi of both eyes. Reference electrodes were located on left and right mastoids. The ground was between Fpz and Fz. All signals were amplified with a gain of 500 and were sampled at a rate of 250 Hz per channel, and were filtered with a band-pass of 0.05—40 Hz. The impedances between scalp and electrodes were kept below 5 kΩ.

Fig. 1. The 64-channel montage is illustrated from the 10—20 system. The circled electrodes were those used in the data analysis.

(ⅳ) Procedure. The participants sat on a sofa in a sound insulated electronic-magnetic room. White line drawing pictures with black background were presented on a computer monitor. The horizontal visual angle was 0.84º—4.72º and the vertical visual angle was 0.52º—3.40º. The participants were required to control eye blinks when the pictures were presented. The presentation order for each block was a fixation cross (“+”) at the central location of the screen for 1500 ms, followed by an instruction of the experiment for 4000 ms, before the stimulus presentation. The actual experiment was divided into three phases for each block: (1) Study phase. Line drawing pictures were presented at the center of the monitor for 200 ms, ISI was 1300±100 ms, and subjects were told to press a key if the picture was an animal, which was regarded as a target; (2) Disturbance phase. A 3-digit number was presented, and subjects were asked to subtract 3 backwards and give vocal reports for 1 min; (3) Test phase. A series of pictures (with additional new pictures) were presented with a rate of 500 ms each and the ISI was 2000±100 ms (Fig. 2). Subjects were required to judge whether the pictures had been presented or not during study phase and to press “1” key if a picture was old and to press “4” key if a picture was new as quickly as possible. The keys to press, i.e. “1” and “4” keys, were counterbalanced among participants. In addition, the order of the blocks was also pseudo-randomized among participants.

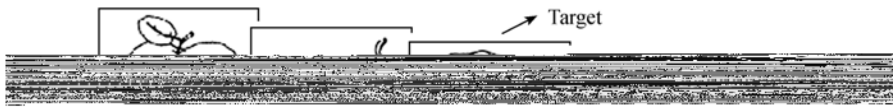

Fig. 2. Subjects were presented with a series of pictures and were required to judge whether a picture was an animal (target) or not during encoding (study) phase (top row), and each picture was presented for 200 ms. Following the study phase, subjects were tested and required to judge whether the pictures were old or new ones (bottom row), with each picture being presented for 500 ms.

(ⅴ) Data analysis. Event-related potentials were continuously recorded on-line and averaged off-line. The analysis epoch was –200—1000 ms. Eye movement artifact was rejected automatically and the excluding criterion of other artifacts was 75 μV. Several representative electrodes were selected for statistical analysis on the basis of the relationship between scalp and electrode sites. The electrodes included F3, Fz, F4 at frontal cortex, C3, Cz, C4 at central cortex, P3, Pz, P4 at parietal cortex and O1, Oz, O2 at occipital cortex (circled in Fig. 1). Three time windows were decided based on observation and previous studies: 400—500, 500—600 and 600—700 ms.

The results were analyzed using three-way repeated-measures ANOVA. The three factors during encoding were: memory judgment (2 levels: remembered and forgotten pictures), left-right electrode sites (3 levels: medial-midline in left hemisphere, midline, medial-midline in right hemisphere) and anterior-posterior sites (4 levels: frontal, central, parietal, occipital cortices). The three factors during retrieval were: memory judgment (2 levels: correctly judged old and new pictures), left-right sites (3 levels: medial-midline in left hemisphere, midline, medial-midline in right hemisphere) and anterior-posterior sites (4 levels: frontal, central, parietal, occipital cortices).

The data analysis was performed by SPSS software and the ANOVA used Greenhouse-Geisser corrections.

2 Results

(ⅰ) Behavioral data. According to the signal-detection theory, if a subject's P(A) [P(A) = (hit numbers + miss numbers)/ total numbers of stimuli] is above 0.5, then his/her response is believable. As for accuracy, the targets' hit rate was 97.8% during encoding. During test phase, the hit and miss rates for judging studied old pictures were 58.8% and 36.7% respectively [P(A) = 95.5%], and the hit and miss rates for judging studied new pictures were 73.5% and 20.9% respectively [P(A) = 94.4%]. The P(A) values suggested that this experiment results were believable.

As for the reaction time (RT), the mean RT of targets was 586.1 ms during encoding. During retrieval, the mean RTs of the correctly and the incorrectly judged old pictures were 787.6 and 821.5 ms respectively, and the RT of the correctly judged new pictures was 828.2 ms. Statistical test results showed the mean RTs of the correctly and the incorrectly judged old pictures were significantly different (t = 4.484, P < 0.01), i.e. the response of the correctly recognized old pictures was faster than that of the incorrectly recognized old pictures; and the RTs of the correctly judged old and new pictures were also significantly different (t = 6.827, P < 0.001), which indicated that the correct judgment of the old pictures was faster than that of the new ones.

(ⅱ) ERPs characteristics. The ERPs of the remembered and the forgotten old pictures during encoding were averaged, with the targets and the disturbance of key-pressed movement being excluded, and the average numbers were 90 and 42 respectively. The ERPs of correctly judged old and new pictures during retrieval were also averaged and the average numbers were 75 and 52 respectively.

As shown in Fig. 3, during encoding phase, the ERPs of the remembered pictures and those of the forgotten ones were similar, but the waveforms of the former were more positive than those of the latter. At parietal-occipital sites (PO7/PO8), P1 (the averaged latency was 112 ms), N1 (144 ms), P2 (216 ms) were observed; at central site (Cz), there was a long lasting late positive component (LPC) with large amplitude from approximately 364 ms to the end. During retrieval phase, the ERPs of the correctly judged old and new pictures were also similar, but the waveforms of the former were more positive than those of the latter (Fig. 4). At parietal-occipital sites, P1 (96 ms), N1 (164 ms), P2 (224 ms) were observed; at the central site, LPC showed a large amplitude from 312 to 740 ms, with amplitudes for the old and new pictures reversed at approximately 580 ms, and thereafter the two curves overlapped till the end.

(iii) Statistical analysis of Dm effect. The three-way repeated-measures ANOVA of memory judgment (remembered/forgotten pictures)×left-right sites×anterior-posterior sites was performed for each latency window. For the 400—500 ms latency window, the global ANOVA found no main effect of memory judgment, but significant interaction of memory judgment×left-right sites [$F_{(2, 26)}$ = 4.653, P < 0.05], and also significant interaction of memory judgment×anterior-posterior sites [$F_{(3, 39)}$ = 11.705, P < 0.001]. Further simple effect test revealed significant Dm effect at frontal sites and central sites [frontal: $F_{(1, 13)}$ = 6.81, P < 0.05; central: $F_{(1, 13)}$=6.84, P < 0.05]. These results indicate that the positive waveforms of the remembered old pictures are much larger than those of the forgotten old pictures at these two areas. For the 500—600 ms latency window, significant interaction of memory judgment×anterior-posterior sites was found [$F_{(3, 39)}$ = 5.413, P < 0.01]. Further simple effect test found the Dm effect was significant at central sites [$F_{(1, 13)}$ = 6.02, P < 0.05], which suggests that the positive waveforms of the remembered old pictures are larger than those of the forgotten old pictures at central sites. For the 600—700 ms latency window, the interaction of memory judgment×anterior-posterior sites was significant [$F_{(3, 39)}$ = 3.402, P < 0.05]. Further simple effect test found significant Dm effect at central sites [$F_{(1, 13)}$ = 4.73, P < 0.05], positive waveforms for the remembered old pictures are larger than those for the forgotten old pictures at central sites (Fig. 3).

To sum up, the ANOVA results revealed the significant Dm effect at frontal and central areas from 400 to 500 ms; and the Dm effect was significant at central sites from 500 to 700 ms. These results are consistent with the surface potential maps (Fig. 5(a)) and the grand average ERPs (Fig. 3).

(iv) Statistical analysis of old/new effect. The three-way repeated-measures ANOVA of memory judgment (old/new pictures)×left-right sites×anterior-posterior sites was performed for each latency window. For the 400—500 ms latency window, the global ANOVA found no main effect of memory judgment but significant interaction of memory judgment×anterior-posterior sites [$F_{(3, 39)}$ = 8.250, P < 0.001]. Further simple effect test found marginally significant old/new effect at frontal sites [$F_{(1, 13)}$ = 4.20, P = 0.061]. For the 500—600 ms latency window, significant interaction of memory judgment×left-right sites×anterior-posterior sites was found [$F_{(6, 78)}$ = 10.452, P < 0.001]. Further simple effect test found that the old/new effect was significant at medial-midline in both hemispheres [left: $F_{(1, 13)}$ = 6.54, P < 0.05; right: $F_{(1, 13)}$ = 4.74, P < 0.05], which suggest the positive waveforms of the correctly judged old pictures are much larger than those of the correctly judged new pictures at me-

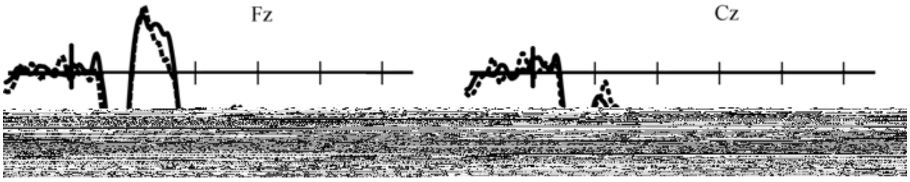

Fig. 3. Grand average event-related potentials (ERPs) elicited by the remembered old (solid lines) and the forgotten old (dotted lines) pictures during encoding phase (Dm effect). Data

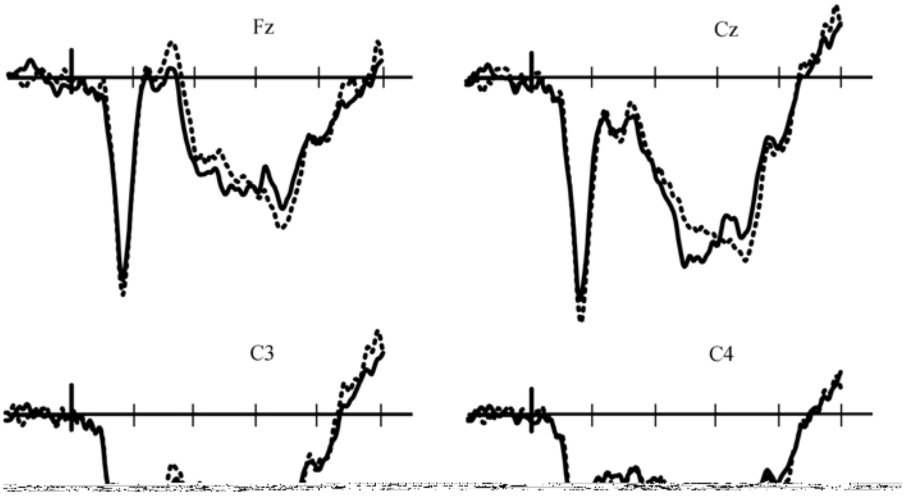

Fig. 4. Grand average event-related potentials (ERPs) elicited by the remembered old (solid lines) and the correctly judged new (dotted lines) pictures during retrieval phase (old/new effect). Data were depicted at 4 representative scalp electrodes: Fz, Cz, C3, C4. Note that the waveforms elicited by the remembered old pictures were more positive than those by the correctly judged new ones. Amplitudes were displayed in μV.

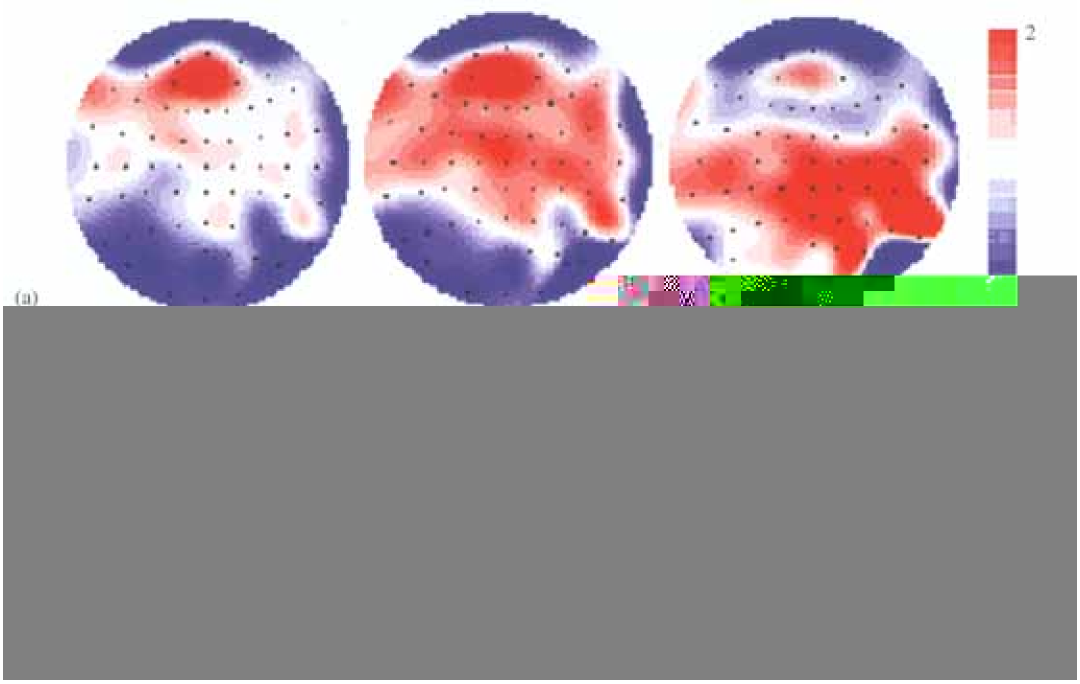

Fig. 5. Surface potential maps based on the difference waveforms of the Dm effect during encoding phase (a) and of the old/new effect during retrieval phase (b) for the three latency windows: 400—500, 500—600, 600—700 ms. Red areas reflect positive activity, blue areas reflect negative activity. Dots represent the 62 scalp electrode positions. And the activities were displayed in μV.

dial-midline in both hemispheres. For the 600—700 ms latency window, significant interaction of memory judgment×left-right sites was found [$F_{(2, 26)} = 5.778$, $P < 0.05$]. Further simple effect test found the old/new effect was marginally significant at midline [$F_{(1, 13)} = 4.02$, $P = 0.066$] (Fig. 4).

To sum up, our ANOVA results revealed the marginally significant old/new effect at frontal sites from 400 to 500 ms, and significant old/new effect at medial-midline in both hemispheres from 500 to 600 ms. These results are also consistent with the surface potential maps shown in Fig. 5(b) and the grand average ERPs shown in Fig. 4.

3 Discussion

The present experiment found not only significant Dm effect and old/new effect for pictures but also the differential spatial and temporal distribution characteristics of the two effects.

The current study revealed that the positive waveforms of the remembered old pictures were much larger than those of the forgotten old pictures from 400 to 700 ms during encoding. This Dm effect was observed at frontal and central areas from 400 to 500 ms, and at central sites from 500 to 700 ms. These results showed some consistency and inconsistency with pervious studies. Previous studies using linguistic materials indicated that the Dm effect mainly concentrated on two areas[17,18,5,6]: central-parietal and frontal sites. Meanwhile, the previous results also found the appearance of Dm effect for linguistic materials at approximately 230 ms, which was earlier than that of our present finding. In addition, a study on faces also found the Dm effect concentrated on these two areas. The spatial distribution of Dm effect for pictures in the current experiment was also significant at frontal sites, which was consistent with the results using linguistic materials and faces from other studies. However, the current results were somewhat unique as well. The Dm effect of pictures was not significant at parietal sites but moved a bit forward, i.e. the Dm effect of pictures was significant at central sites. The Dm effect for pictures appeared much later in time than the Dm effect using linguistic materials. The possible reason for this late appearance may be the difference of encoding mode. In general, the encoding of word is more top-down and the encoding of picture is more bottom-up; thus the word encoding is faster than picture encoding. In addition, the spatial and temporal differences between materials may be due to the fact that the resources transferred and assigned to pictures were different from those to other materials. Thus, material-specific was one important factor that influenced the spatial and temporal distributions of Dm effect.

In the past 20 years, a lot of studies have confirmed that the positive waveforms of the correctly judged old items are much larger than those of the correctly judged new ones[10,12,13], with a left-parietal old/new effect at approximately 300—800 ms post-stimulus onset. This effect is regarded as a neural correlate of conscious recollection for episodic events and it is also the electrophysiological index of successful retrieval. Comparatively speaking, the temporal distribution of old/new effect for pictures was similar to previous results, but the spatial distribution was much wider and mostly at medial-midline in both hemispheres. As for the reason of such difference, maybe the material-specific is a key explanation, but not an exclusive answer. There may be two other possibilities: (1) The dif-

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