Brain responses of explicit and implicit memory: an event-related potential study

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Implicit memory is acquired by an unintentional or unconscious learning. Recognition memory involves either automatic knowing or consciously controlled remembering. We provided an event-related potential paradigm capable of differentiating memory for the explicitly learned, implicitly learned and unstudied materials. In the explicit memory, we obtained both frontal (controlled retrieval) and parietal (recollection) old/new effects. In the implicit memory, we found persistent occipitotemporal activation (visual priming) and late attenuation in the temporoparietooccipital (repetition suppression). Event-related potential provides an insight into the dissociable mechanism of memory function that supports the dual process model with an enhanced temporal resolution on the dynamic process of both explicit perceptual learning and implicit perceptual priming. *NeuroReport* 17:1483–1486 © 2006 Lippincott Williams & Wilkins.

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Introduction

Implicit memory is acquired by unintentional or unconscious learning [1]. Participants of implicit learning experiments could make decisions with better-than-chance accuracy but had little ability to describe the rule, context or source of the learned information. Recognition memory is a fundamental facet of our ability to remember. Current research supports theories claiming that recognition memory involves two components interpreted within a dual-process independence model [2,3]. Knowing reflects an automatic form of memory and remembering reflects a consciously controlled form of memory [4].

The recognition memory has been studied by event-related potential (ERP) and a common finding of the ERP studies was the parietal old/new effect [5,6]. The majority of these studies have interpreted results from the perspective of dual-process models [7–9], although debates remained [5,10]. Some authors found it covaried with the number of accurate source judgments [11] while others did not agree [4,7]. In addition, some would attribute it to memory strength and decisional factors [12]. On the other hand, the frontal old/new effect was less well recognized or less comprehensively investigated than its parietal counterpart. The frontal old/new effect was considered to be related to familiarity and the effect was similar for words and non-words [13]; and it did not differ between deeply and shallowly encoded words [8].

In this study, we provided an ERP paradigm capable of differentiating memory for the explicitly learned, implicitly learned and unstudied materials. We provided either explicit perceptual learning or implicit perceptual priming without conceptual encoding [9]. We aimed to test the dual-process hypothesis of recognition memory and to explore the neural correlates of these posited dissociable mechanisms with a temporal resolution superior to functional imaging currently available.

Methods

Participants

Twenty-five right-handed study participants (mean age of 29.9 ± 4.6 years and mean education years 16.6 ± 2.0), colleagues or students working or studying at the university hospital, took part in the behavioral tasks. Fifteen of the 25 participants were female. Another 25 participants (mean age of 26.7 ± 6.9 years, mean education years 16.5 ± 1.9 and 15 of them were female) with similar backgrounds were recruited for the ERP study. The study was approved by the Institute Review Board of the university hospital. All participants gave informed consent.

Stimuli

Stimuli were figures consisting of a combination of simple geometry forms. We designed the pictorial stimuli in such a way as to make it difficult to generate verbal cues within the short display time given. After the 32 figures were constructed, they were randomly categorized into three sets of figures (eight, eight and 16, respectively) to equalize the stimuli in terms of complexity. The first eight figures were used for memorizing to test for the explicit memory. The other eight figures were used as the new (contrast) material during the first phase test for the explicit memory function and were also used as the targets of the implicit memory during the second phase test. The final 16 figures were used as the new material during the second phase test. All the stimuli were presented in a pseudorandom sequence such that the order of display is effectively a random sequence with the constraint of three identical consecutive figures at maximum.

Procedure

Behavioral task

During the learning phase, participants were presented with the first eight figures. Each figure was displayed for 2000 ms with repeated presentation six times each. Participants were instructed to memorize as many of these figures as possible. After an interval of 5 min, we performed the first phase test in which participants were instructed to judge whether they remembered the figures presented and to press a button representing either a yes or a no within an interval of 1500 ms. This phase included a total of 96 presentations from 16 different figures, each being shown six times. After another 5-min break, we performed the second phase test in which participants were instructed to judge whether there was any familiarity with the figures presented and to once again press the button for their decision within an interval of 1500 ms. In this phase, there were a total of 48 presentations (first set, eight figures two times + second set, eight figures two times + third set, 16 figures one time). All responses were recorded on a computer for further analysis. The correct rates were obtained by adding up the correctly accepted and the correctly rejected items. The stimuli were presented to the participants through a 15-inch LCD screen at a distance of about 60 cm; the figures were displayed in the size range of 4.5–5.5 cm in diameter, and hence a visual angle of 4.3–5.2°.

Event-related potential task

The presentation parameters and the instruction for the participants in the learning phase and in the first phase test were identical to those in the behavioral tasks. After a 5-min break, we performed the second phase test in which the figures were presented for 500 ms and then a blank screen was presented for 200 ms. In this phase, there were a total of 144 displays (first set, eight figures six times + second set, eight figures six times + third set, 16 figures three times). During the second phase test, the participants were asked to keep their full attention on the very short display and to judge whether there was any familiarity with the figures presented. They were informed that the total duration of this phase was less than 2 min.

ERPs were recorded with a 32-channel montage in a NeuroScan System (NuAmps, Compumedics, El Paso, Texas, USA), with a sampling rate of 1 kHz and a band-pass of 0.1–100 Hz. Evoked potentials were obtained from averages of 48 study blocks of each category. Two additional eye channels were used to detect ocular movements. Blocks contaminated by blinks or eye movement artifacts ($>\pm75\,\mu V$) were removed from further analysis. In addition, visual inspection of all segmented epochs was performed to assist the pre-analysis artifact rejections. The artifact-free electroencephalogram segments were subjected to baseline adjustments with the mean amplitude of the whole segment (−50 to 700 ms) and were then averaged over the same segment. Averaged reference was applied to obtain the scalp topography using double spline interpolation to minimize the reference-site effect [14]. ERP components were identified through the global field power curves (Fig. 1) [15]. Statistical analysis comparing areas under curve of the three different tasks were performed in every channel. Further computation of the between-task t-Maps was also performed. Positions and t values were reported with the nomenclature of the 10–10 International System.

Results

No statistical significance was observed between the two groups of participants in sex, age ($t=-1.6$, $P=0.29$, d.f.=48) and education years ($t=0.00$, $P=0.59$, d.f.=48).

Behavioral performance

The mean correct rates were 96.7 ± 4.3% for explicit memory and 96.8 ± 2.9% for implicit memory in the behavioral tasks, and 96.2 ± 9.7% for explicit memory in the ERP tasks. Objectively, there was no significant intergroup difference (explicit memory: $t=0.58$, $P=0.51$, d.f.=48) and no significant intertask difference (explicit versus implicit: $t=-2.54$, $P=0.80$, d.f.=24). Subjectively, the participants reported that they could mentally visualize the explicitly learned pictures but not the implicitly learned ones.

Event-related potential performance

The field potential changes through time represented by global field power bore similar basic structures in the three different tasks (Fig. 1). The first positive peak was around 150 ms followed by a prominent negativity at 400 ms and then a positive slow component. We computed the areas under the curve for the four segments, namely, 100–200,

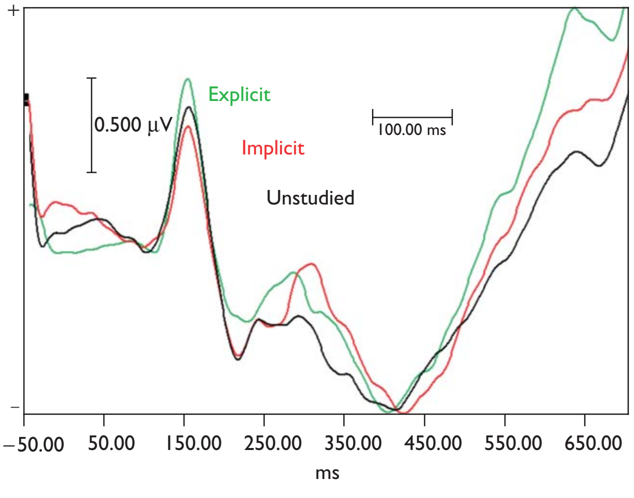

Fig. 1 Curves of global field power from event-related potential of three different tasks.

200–400, 300–500 and 500–700 ms, in every channel. Then we performed multivariate analysis of variance for different tasks testing the interactions of locations × tasks with a Bonferroni post-hoc test. No significant intertask difference of areas under the curve was found between 100 and 200 ms and between 200 and 400 ms in all channels. For the explicit memory, scalp locations with statistical significance were mainly over either the parietal region between 300 and 500 ms; for the implicit memory, significant locations were at the temporal–occipital areas between 300 and 500 ms and between 500 and 700 ms (Table 1).

In the topographic studies, we obtained t-Maps for the explicit memory from comparison of ERP between tasks with the well learned and unstudied figures; and t-Maps for the implicit memory between the unintentionally learned and unstudied figures. Finally, t-Maps for explicit versus implicit memory were from comparison between the well learned and unintentionally learned figures. In the t-Maps of the explicit memory (Fig. 2a), the first significant activity appeared in the right occipitotemporal regions (around 275 ms), soon extending to the left side (325 ms) ($t > 2.8$, $P < 0.01$). At about 400 ms, a very prominent activation was noticed at the temporoparietooccipital regions of either hemisphere especially on the right side ($t > 2.8$, $P < 0.01$). A small but significant ($t > 2.1$, $P < 0.05$) left frontal activation occurred at 450 ms and later a right frontal activation occurred at around 500 ms ($t > 2.1$, $P < 0.05$). The t-Maps of the implicit memory (Fig. 2b) carried a similar spatial–temporal profile with the explicit memory except that there was no such significant left frontal activation (450 ms) or strong parietal spread (400 ms). All activities centered at 400 ms were much less than their explicit counterparts. The implicit memory has a very strong negativity at the temporoparietooccipital regions after 600 ms ($t < -2.8$, $P < 0.01$). The t-Maps of explicit versus implicit memory (Fig. 2c) showed significant difference at the right temporal region around 475 ms ($t > 2.5$, $P < 0.02$).

Table 1 Scalp locations with statistical significance in the memory event-related potential

	300–500 ms	500–700 ms
Explicit	T3 (0.013), T5 (0.014), TP7 (0.009), CP3 (0.031), P3 (0.022), O1 (0.039), Pz (0.041), T4 (0.047), T6 (0.002), TP8 (0.004), CP4 (0.022), P4 (0.005), O2 (0.004)	
Implicit	P4 (0.036), O2 (0.004), O1 (0.017)	T6 (0.005), P4 (0.028), O2 (0.01), O1 (0.006)

P values from multivariate analysis of variance with Bonferroni post-hoc test for scalp locations × tasks on area under curve in every channel are given in parentheses. Explicit: well learned versus new material; implicit: unintentionally learned versus new material; electrode positions named after the 10–10 international nomenclature; as no significant difference was found between 100 and 200 ms and between 200 and 400 ms in all channels, it is not listed in the table.

Discussion

Whether the participants learned the figures intentionally or unintentionally, they can recognize the figures with almost no difficulty in either group. The visual memory tasks were purposely designed to obtain a ceiling effect of learning to ensure that the participants had learned all the necessary material before the ERP study. The two sets of figures, however, were quite differently learned in terms of awareness. The participants reported that they could mentally visualize the explicit learned material while the unintentionally learned material could be recognized only

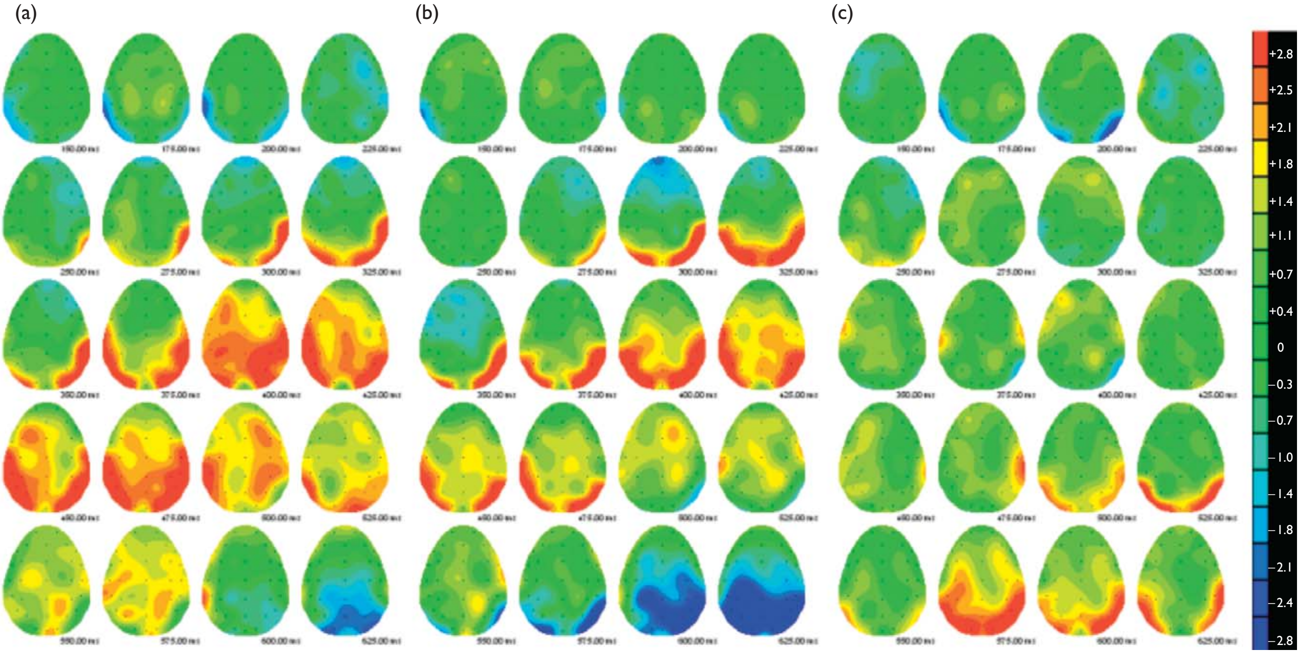

Fig. 2 (a) t-Maps for the explicit memory from comparison of event-related potential between tasks with the well learned and unstudied figures. (b) t-Maps for the implicit memory between the unintentionally learned and unstudied figures. (c) t-Maps for explicit versus implicit memory between the well learned and unintentionally learned figures. The color bar on the right side indicates the statistical significance levels: red for $P < 0.01$, $t > 2.8$, orange for $P < 0.05$, $t > 2.1$, deep blue for $P < 0.01$, $t < -2.8$ and blue for $P < 0.05$, $t < -2.1$.

through a sense of familiarity. Thus, brain responses of pictorial learning with different levels of awareness could be differentiated through ERP compatible with a previous study [16].

Although an early effect of perceptual learning has been reported in the closure-related priming activity [17], in this study, the ERP around 150 ms was not significantly different; thus, it reflected merely an initial visual perceptual processing maximal at the occipital regions [18] but not related to memory function. The initial brain responses for either explicit or implicit memory effect of this study appeared at the right occipitotemporal region around 275–375 ms. Activation of the visual associate cortex, that is, occipitotemporal regions, around 200–350 ms was interpreted as repetition-related processes for pictures or symbols, which might imply an encoding process essential for a further recognition memory process [19–21]. A prominent activation of the explicit memory at the parietal regions around 400–475 ms was observed in this study. This is the parietal old/new effect considered to be associated with recollection [7,16]. While processing the knowing but not memorized pictures, that is, the implicit memory, the parietal old/new effect around 400–475 ms was much less prominent than its explicit counterpart. The implicit memory relied on the perceptual priming-related mechanism occurring at the associate visual cortex, which was demonstrated in our study by persistent occipitotemporal activation (275–475 ms) compatible with the previous neuroimaging and electrophysiological studies [19,20,22]. As for the late positive component, the main effect appeared as a marked attenuation in the temporoparietooccipital areas after 600 ms (Fig. 2b). This is probably a consequence of the repetition suppression, that is, decreased strength of stimulus-related neuronal responses after repeated processing of identical stimuli in the extrastriate visual cortex [22].

The frontal old/new effect was also observed and it mainly occurred in the anterior frontal region while testing the explicit memory. Neuroimage evidence supported the crucial role of the anterior frontal regions in processing the studied words mainly with the remembering judgment and less with the knowing ones [23]. Frontal regions may contribute to the controlled processes that guided the retrieval and interacted with different posterior regions to complete the recollection process. To sum up with a previous ERP study for remembering and knowing, the maximal effects were over the parietotemporal and bilateral frontal electrode sites [24].

This study has successfully demonstrated dissociable forms of memory function with ERP, thus supporting the dual-process model of recognition memory. We presented the figures 12 times for the explicit learning tasks and six times for the implicit learning tasks before ERP study. Thus, the effect of memory strength could not be totally disregarded [12]. This is a limitation of our study.

Conclusion

Dissociable ERP patterns for recognition memory can be obtained through a carefully designed experiment. A controlled retrieval process of the frontal region interacting with the parietal recollection and the temporal encoding fulfill the explicit memory function. Occipitotemporal perceptual priming with repetition suppression in the extrastriate visual cortex characterizes the implicit memory function. ERP provides an insight into the dynamic process of the recognition memory function with an enhanced temporal resolution.

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