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Brain Potentials and Repetition Effects During Encoding and Retrieval of Words

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Abstract

Using Event-Related Potentials (ERPs), the present study utilized a study-test paradigm to investigate the existence of a common mechanism underlying repeated learning effects during encoding and retrieval. Results showed repeated learning effects occurred in both encoding and retrieval. However, the effect of encoding appeared earlier and lasted longer than that of retrieval. Furthermore, the effect of implicit retrieval appeared earlier than that of explicit retrieval. The main scalp distributions of the repetition effects related to both encoding and retrieval occurred at parietal and central sites. Both ERP repetition effects manifested significantly larger and positive-going ERP response of repeated words compared to the words' first appearance. The ERP repetition effects support the hypothesis that there is common learning-related automatic processing during encoding and retrieval.

Keywords

encoding; retrieval; implicit memory test; explicit memory test; repetition enhancement

Introduction

Since Ebbinghaus's famous study of memory and the learning curve [1], repeated learning has been used as an important measure of memory improvement. *Repetition effect* differs from *old/new* effect. The former refers to comparing the *same* items studied once versus multiple times; while the latter refers to comparing *different* studied items versus new, non-studied, items.

Previous studies have reported distinct neural mechanisms between encoding and retrieval [2], between implicit and explicit memory retrieval [3], and between target and non-target retrieval [4]. Paller reported repeated learning effects of ERPs during encoding in a directed forgetting study. They found that from 200–800 ms there was a large effect of stimulus repetition on ERPs for both intentionally remembered faces and forgotten faces during

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encoding. Although these effects were apparent at almost all scalp locations, they were largest at posterior locations. However, the authors did not find differences between stimulus type (remembered-faces and forgotten-faces) and repeated learning [5]. Finnigan et al. along with Van Strien and Hagenbeek observed ERPs repeated learning effects at parietal electrodes in direct tests at 500–800 ms [6,7]. Henson et al. found parietocentral repeated learning effects in implicit memory tests between 400 and 600ms, which were reliable for delayed repetition. However, no significant interaction with stimulus type (familiar faces and unfamiliar faces), in any of the behavioral, ERP, or functional magnetic resonance imaging (fMRI) data were found [8]. Although previous studies have examined repeated learning effects during different levels of processing of encoding and retrieval, few have compared repeated learning effects of encoding and retrieval tasks simultaneously. Although prior investigations have reported repeated learning effects on target encoding, the effects of repeated learning on non-target encoding and retrieval are not clear. The objective of the present study was to investigate the repeated learning effects of encoding and implicit/explicit retrieval in one experimental paradigm.

The present study attempted to systematically compare repeated learning effects during target and non-target encoding, and implicit and explicit retrieval. High temporal resolution and high-density scalp recordings of event-related potentials (ERPs) allow sensitive indices of repeated learning effects [5–8].

Methods

Six males and nine females participated in the experiment. All were right-handed college students between 17 and 23 years of age (mean=20) in Beijing, China. The experiment consisted of three parts: (1) encoding, (2) memory interference, and (3) memory retrieval.

(1) Encoding

During the initial encoding learning stage, a total of 28 Chinese phrase pairs were presented (each phrase consisted of two Chinese characters). For each display, two phrase pairs were presented simultaneously. A fixation cross was presented between word stimuli. The fixation cross was shown during the interstimulus interval for 1700 ± 100 ms. The position of the fixation cross, balanced at either the upper or lower position, indicated the position of the target pair presented next. For instance, if the fixation cross appeared in the upper part of the screen, the phrase appearing in the upper location on the next screen was the target phrase (Figure 1).

Participants were told to judge whether the target phrase was a noun or a verb. Subjects pressed the “1” key if the phrase was a noun and pressed the “4” key if the phrase was a verb. After the first presentation, half of the previously seen phrases were extracted in random order and presented again in random order. The participants were asked again to distinguish between nouns and verbs. Each visual page was presented for 500ms and the interval between the first and second presentation of the stimuli was 32.8s.

(2) Memory interference

A three-digit number was presented and participants were asked to continually subtract three from this number and provide verbal responses for one minute.

(3) Memory Retrieval

Each encoding stage was followed by one of two retrieval tests: a lexical decision test (word versus non-word) or a recognition test (new versus studied). The order of these tests was counterbalanced. During the lexical decision test, participants were required to make a series of word/non-word judgments; they were to press the “1” key if a word was presented and to press the “4” key if a non-word appeared. They were also informed that the task was meant only to test their reaction speed and accuracy. During the recognition test, participants were required to make a series of old/new judgments; they were to press the “1” key if a word was previously studied and to press the “4” key if a word was new. During retrieval, each word was presented for 500ms and the interstimulus interval was 2100 ± 100 ms. The keys to press, i.e. “1” and “4” keys, were counterbalanced among participants.

During the encoding part of the experiment, each of 28 phrase-pairs was presented one at a time. Data analysis included 24 pairs, i.e., eight pairs were presented only once while the other eight pairs were repeated twice. To avoid primacy and recency effects due to order of presentation, an additional four word pairs were used at the beginning and end of the encoding, which were not included in data analysis.

During the memory retrieval part of the experiment, the lexical decision task included 96 phrases (48 words, and 48 non-words). The recognition task included 48 phrases (32 old, 16 new). The order of the visual presentation was pseudo-randomized and phrases in all lists were balanced in word frequency. Low-frequency Chinese words were selected (mean=2.87 occurrences/million [9]). Each word subtended a visual angle of $2.4^\circ \times 3.7^\circ$ and $2.4^\circ \times 1.2^\circ$, respectively.

The EEG recordings were made from 62 scalp sites using Ag/AgCl electrodes arranged in an elastic cap according to an extension of the International 10–20 system. Two channels were used for monitoring horizontal and vertical eye movements. Trials with a voltage, relative to the 100ms baseline, exceeding $\pm 75 \mu\text{V}$ at any electrode were excluded from analysis, as were trials with artifacts in the EOG channels. The EEG recorded from all electrodes was referenced to linked mastoids offline. Impedance was less than 5 k Ω . EEG signals were filtered with a bandpass of 0.05–40 Hz and sampled at a rate of 250 Hz. Each averaging epoch lasted 1000ms, including 100ms prior to stimulus onset. ERP measurements were evaluated using analysis of variance (ANOVA) with Greenhouse-Geisser corrections where applicable.

Results

The results showed that during encoding the repeated learning targets were responded to faster and more accurately than the first learning targets. Mean reaction times were 679ms versus 736ms, respectively, $t(14) = 4.99$, $p < 0.001$, and the accuracy was 95% versus 88%,

respectively, $t(14) = 6.64$, $p < 0.001$. These results indicated that repeated learning made the target task of judging noun/verb easier.

The results of mean reaction times (RTs) and accuracy of identification during retrieval are listed in Table 1. A repeated-measure ANOVA was applied to the behavioral RTs data, in which the 2×2 factors tested were retrieval tasks (lexical decision, recognition), encoding type (target, non-target), and repetition (first, repeated). The results showed a repeated learning effect, i.e. repeated words were responded to faster than non-repeated words in both tests [lexical decision: $F(1,14)=15.70$, $p<0.01$; recognition: $F(1,14)=25.13$, $p<0.001$]. However, interaction between stimulus type and repetition was not significant.

A three-way repeated-measures ANOVA was conducted on ERPs during encoding: repetition (first, repeated) $\times$ time intervals (300–400, 400–600, 600–900ms) $\times$ electrode location (Fpz/Fz/Cz/Pz/Oz).

Memory Encoding

Three-way interaction was significant [$F(8,112) = 31.50$, $p < 0.001$]. At 300–400ms, repetition $\times$ location interaction was significant [$F(4,56) = 9.53$, $p < 0.01$]. Repeated learning effect was significant at five electrode sites ($ps < 0.01$) and the largest difference was at Pz (2.50 μ V). At 400–600ms, repetition $\times$ location interaction was significant [$F(4,56) = 46.13$, $p < 0.001$]. The repeated learning effect was significant at Fz, Cz, Pz, and Oz ($ps < 0.01$) and the largest difference was observed at Pz (3.70 μ V). At 600–900ms, repetition $\times$ location interaction was also significant [$F(4,56) = 4.31$, $p < 0.05$]. The repeated learning effect was significant at all five electrode sites ($p < 0.01$) and the largest difference was at Cz (2.31 μ V).

During retrieval, a four-way repeated-measures ANOVA was conducted with factors including repetition, stimulus type (target, non-target), time intervals, and electrode location. Analysis of new words is not included in the present article.

Retrieval during lexical task

Four factor interaction was significant [$F(8,112) = 5.23$, $p < 0.01$]. At 300–400ms, repetition $\times$ location interaction was significant [$F(4,56) = 4.19$, $p < 0.05$]. Repetition was significant at the Pz electrode site [Pz: $F(1,14) = 6.70$, $p < 0.05$]. At 400–600ms, repetition $\times$ location interaction was significant [$F(4,56) = 14.64$, $p < 0.001$]. Repeated learning effect was significant at Fz, Cz, Pz, and Oz electrode sites ($ps < 0.05$) and the biggest difference was at Pz (1.69 μ V). At 600–900ms, there was no repeated learning effect. Repetition did not interact with stimulus type.

Retrieval during recognition task

Four factor interaction was marginally significant [$F(8,112) = 2.85$, $p = 0.06$]. At 300–400ms, there was no repeated learning effect. At 400–600ms, repetition $\times$ location interaction was significant [$F(4,56) = 10.66$, $p < 0.001$]. Repeated learning effect was significant at Fz, Cz, Pz, and Oz electrode sites ($ps < 0.01$) and the largest difference was at

Pz (2.82 μ V). At 600–900ms, there was no repeated learning effect. Again, there was no interaction between stimulus type and repetition.

Discussion

Because the repeated learning effect was not related to encoding type, both targets and non-targets data were combined in figures showing ERP responses (Fig. 1, b and c).

The present study compared the ERP responses repeated learning effect during encoding and retrieval in one paradigm. The present results are consistent with previous investigations, in which separate encoding and retrieval experiments were carried out [5–8]. From 300–400ms, the ERP repeated learning effect was robust at most scalp locations but peaked at the parietal location during encoding. However, the repeated learning effect was only significant at the parietal location for the implicit memory test (lexical decision). In the explicit memory test there was no ERP repeated learning effect for the early time interval. At 400–600 ms, the ERP repeated learning effect was apparent in both encoding and retrieval of implicit and explicit memories and was largest at the parietal location. At 600–900 ms, the ERP repeated learning effect was apparent at almost all scalp locations but was largest at the central location during the encoding. However, there was no ERP repeated learning effect in the implicit and explicit memory tests for this late time interval.

These results show that the ERP repeated learning effect during encoding appeared earlier and lasted longer than the ERP repeated learning effect during retrieval. Main scalp distributions of repeated learning effects peaked at parietal and central sites for both encoding and retrieval. The current results reveal that repetition enhancement associates with ERP responses. The scalp distributions of repeated learning effects were similar during encoding and retrieval, which suggest possibly similar cognitive processing. In a recent study, the late posterior ERP repetition reduction effect was centered over parietal sites and began after 550 ms with less positive and smaller ERP responses to repeated items than their initial presentations [10]. Importantly, this late repetition effect was independent of whether the memory item was a target match or non-target in the delayed match-to-sample task, or if it was previously studied or new, which indicates a “universal” automatic process [10]. The current study reported the ERP repetition enhancement effect in both encoding and retrieval [5–8]. So far, most studies that reported repetition reduction effect [10,11,12] used objects as study materials. While, like the current study, studies that reported “repetition enhancement” often used words [5–8]. Rugg et al. suggested that ERP repetition effect depends on stimulus characteristics, e.g., words vs. objects. That is, the stimuli types may modulate the ERP amplitude of the repetition effect [12]. Furthermore, Paller et al. [5] reported that repeated learning effects were not related to depth of processing. Thus ERP repeated effects may be independent of in-depth cognitive processing. Curiously, results from single-cell and fMRI studies have reported repetition reduction. Evidence from single-cell studies in monkeys has revealed reduced activation when presented with repeated stimuli, which may reflect neurons’ tuning to a specific stimulus [13]. Evidence from fMRI studies shows that neural attenuation is found between first and repeated exposures of each scene at the peak of the hemodynamic response [14]. Repetition attenuation or suppression has been linked to

priming, which may reflect an automatic facilitated processing [15]. Repetition priming does not require the active maintenance of any internal representation [16].

In line with similar studies [17], repeated learning effects during the implicit memory test occurred earlier than those during the explicit memory test, which may reflect different neural mechanisms. Paller pointed out that recollection is due to consolidation of either cortico-thalamic or cortico-hippocampal networks, whereas perceptual priming reflects preserved plasticity within single neocortical zones. ERP response to perceptual priming appears earlier than ERPs of recollection [17]. However, another reason that may not be excluded is that the earlier repeated learning effect between 300–400ms for lexical decision relative to recognition is due to faster RT for a lexical decision task, regardless of implicit/explicit memory. As for this problem, further research is necessary to explore its full implication. Both implicit and explicit memory tests varied between degrees of unconscious and conscious retrieval [18]. Therefore repetition effects during implicit memory tests may reflect more automatic processing during retrieval, and explicit memory tests may reflect more controllable processing during retrieval. Our behavioral data showed consistently that whether presented once or presented twice, the reaction times for targets were faster and more accurate than the RTs for non-targets. The ERP results at 400–600ms showed that the waveforms of the targets were larger and more positive than ERPs of non-targets. However, there was no significant interaction between encoding type and repetition in either test. These results are consistent with previous reports by Henson et al [13]. In an indirect memory test, they failed to find reliable evidence for either a qualitative difference between repetition effects or for interaction with familiarity in any of the behavioral, ERP or fMRI data. Evidence from the retrieval period further supports the interpretation that repeated learning might be an automatic facilitation, unaffected by level of processing.

Conclusion

The present study investigated the existence of a common mechanism underlying repeated learning effects during encoding and retrieval. Results showed that repeated learning effects, as measured by ERP, occurred during both encoding and retrieval. These findings suggest that a common learning-related automatic process is present during encoding and retrieval.

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Fig. 1.

a) Sample stimuli and procedure for repeated target and non-target encoding. Target phrase appeared in the same location as previous location of the fixation cross. b) ERPs of the first and repeated learning during memory encoding, lexical decision, and recognition tasks. c) Topographic maps based on the difference waveforms of the first and repeated encoding, lexical decision, and recognition tasks.

Table 1

Mean Reaction times in ms and Mean % Accuracy in Retrieval Tasks.

		Lexical decision		Recognition	
		RT (SE)	Percent (SE)	RT (SE)	Percent (SE)
Target	first	520 (10)	98 (0.5)	605 (19)	86 (2.9)
	second	517 (9)	97 (0.4)	566 (14)	97 (0.9)
Non-target	first	552 (9)	93 (1.4)	656 (27)	48 (2.9)
	second	538 (11)	94 (1.0)	621 (21)	70 (3.4)