Event-related potential repetition effects at encoding predict memory performance at test

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Received 3 September 2007; accepted 25 September 2007

The present study used multiple repetitions of meaningless pictorial stimuli to examine the electrophysiological correlates of the creation of a new stimulus representation. Study participants judged whether preexperimentally unfamiliar figures (meaningless line drawings) that were repeated up to four times contained a crossover in their contour. Stimulus repetition thereby led to a reduction of the visual N1 component in event-related potentials as well as to a late (430–600 ms), successively increasing positivity over posterior electrodes. In particular, the size of this latter event-related potential effect highly correlated with and thus predicted participants' performance in a subsequent recognition memory test. It can therefore be interpreted as neural correlate of the creation of a new memory-effective stimulus representation. *NeuroReport* 18:1905–1909 © 2007 Wolters Kluwer Health | Lippincott Williams & Wilkins.

Keywords: event-related potentials, recognition memory, repetition priming, stimulus novelty

Introduction

Repetition priming refers to processing advantages for repeatedly presented stimuli. Previous event-related potential (ERP) studies (e.g., [1,2]) yielded divergent findings concerning the electrophysiological correlates of such behavioral repetition effects. A possible factor accounting for these inconsistencies seems to be the type of stimulus material used [3]. In particular, it might be especially important for the appearance of ERP repetition effects whether or not it is possible to rely on an existing stimulus representation. For instance, Rugg *et al.* [4] observed more negative-going ERPs for possible and impossible objects, but no repetition effect for unstructured patterns. Rugg *et al.* attributed this failure to elicit repetition effects to the fact that illegal nonwords and nonsense figures cannot be represented in a 'unitized code', that is, they are not encoded at a level of abstraction beyond that of their surface features (e.g. in a lexical, semantic, or episodic code). In line with this suggestion, no repetition effects for unrecognizable scrambled words or pictures [5], illegal nonwords [6], and novel visual patterns [7] were observed. In contrast, reliable repetition effects were found for items with a preexisting stimulus representation (i.e. that can be represented in a 'unitized code', e.g. [1,2,7–9]).

The present study seeks to examine the electrophysiological correlates of the creation of a new stimulus representation by the use of multiple repetitions of novel line figures. Study participants were asked to judge the perceptual features of preexperimentally unfamiliar line figures, which were repeated up to four times in the course of the study phase. In a subsequent test phase, participants were asked to perform a recognition memory test on the items previously seen during study as well as on new ones. In this vein, we were able not only to investigate the changes of brain electrical activity associated with multiple repetitions of novel stimuli, but also to link potential ERP repetition effects to later episodic memory performance and thus to comment on the memory efficiency of newly formed stimulus representations. On the basis of the positive ERP repetition effects at parieto-occipital recording sites in the previous studies using preexperimentally familiar pictorial materials [1,9,10], we hypothesized that ERP effects in the present study may evolve in a similar appearance but depending on an increasing number of repetitions.

Methods

Participants

The present experiment was conducted with the understanding and written consent of each participant. It was done in accordance with the Declaration of Helsinki and the local ethical committee. Nineteen individuals participated in the study (mean age 25; range 21–33 years; 11 women; all right-handed) and all were paid for their participation. All of them had normal or corrected to normal vision and had no recorded history of neurological or psychiatric disorders.

Stimuli and procedure

Stimuli were 320 meaningless line drawings (see Fig. 1a; cf. [11]), of which one half had a crossover in the contour. Stimuli were presented in the center of the screen with an average diameter of 11° visual angle. The experiment was composed of eight study-test blocks. In each study phase, 20 items were presented, 10 of which were repeated twice and 10 were repeated four times, resulting in a total of 60 trials per study phase. The lag between subsequent repetitions of a given item varied between 10 and 18 items. Items were presented for 800 ms followed by a random interstimulus interval ranging from 1700 to 2700 ms. Participants were instructed to maintain central fixation at all times and to indicate with a button press as quickly and as accurately as possible whether or not an item had a crossover, and to simultaneously memorize the items while disregarding how often an item had been presented. In each test phase, all items from the preceding study phase together with an equal number of new items were presented. Participants were instructed to indicate as accurately as possible whether or not they remembered having seen the item in the study phase. Timing was identical to the study phase. Additionally, participants received a feedback on the correctness of their response. The order in which old items were presented in the test phase corresponded to the order of presentation in the study phase to keep the time lag between study and test of a given item as consistent as possible. A postexperimental interview revealed that none of the participants took note of this regularity. Presentation order, assignment of stimuli to experimental conditions, and response hand in the test phase was counterbalanced across participants.

Electroencephalogram recording and analysis

The experiment was run in an electrically shielded and sound-attenuated cabin. A TFT monitor was placed outside this cabin behind an electrically shielded window. All devices inside the cabin were battery-operated to avoid interference of the line frequency. Electroencephalogram was recorded with a BrainAmp amplifier (Brain Products, Munich, Germany) using 32 sintered Ag/AgCl electrodes mounted in an elastic cap (EasyCap, FalkMinow Services, Munich, Germany) and placed according to the 10–10 system. Electrode impedances were kept below 10 kΩ. Data were sampled at 500 Hz (analog band-pass filter 0.01–250 Hz) and referenced to the nose-tip. Vertical and horizontal eye movements were monitored from two electrodes placed above and lateral to one eye. ERPs were extracted from −200 to 800 ms around stimulus onset during study. Data were baseline-corrected with respect to the 200 ms prestimulus interval and digitally band-pass filtered at 0.2–20 Hz (slope 24 dB). Trials containing electrooculography activity or other artifacts (maximum amplitude in the recording epoch, ±150 μV; maximum difference between the two successive sampling points, 50 μV; maximum difference of two values in the interval, 150 μV; lowest allowed activity change, 0.5 μV in successive intervals of 100 ms) were excluded from averaging.

ERPs were averaged for four conditions (with the mean number of valid trials per condition given in parentheses): first presentation (142), second (145), third (72), and fourth (71). On the basis of our hypotheses (see Introduction), mean voltages were computed at a posterior electrode cluster (averaged over Pz, P3, P4, P7, P8, O1, and O2). For statistical analysis, the Greenhouse–Geisser [12] correction for nonsphericity was used; original degrees of freedom, the correction coefficient ε, and corrected *P* values are reported in the following.

Results

Behavioral data

Reaction time (RT) and accuracy during study were subjected to repeated measures analysis of variance (ANOVA) comprising the within-subject factor Condition (first presentation, second, third, fourth). RT significantly decreased with repetition [means: 667, 669, 643, 634 ms; standard errors (SE): 31, 38, 30, 32 ms; for first, second, third, and fourth, respectively; $F(3,54)=7.91$, $P<0.001$]. Post-hoc tests (Tukey HSD) revealed that the third and fourth presentation items were judged significantly faster than the first and second presentations (all $P<0.05$). In contrast, accuracy was not affected by stimulus repetition (means: 89, 90, 91, 89% correct responses; SE: 2, 2, 2, 1; $F<1$). In the recognition memory test, items previously seen four times [Pr score (defined as proportion of hits−proportion of false alarms)=0.49, SE=0.04] were recognized significantly better than those seen twice [Pr=0.40, SE=0.04; $F(1,18)=44.93$, $P<0.001$]. When linking study and test performances, repetition priming (operationalized as RT difference between fourth and first presentations) and participants' overall Pr score (averaged over items seen twice and four times), however, did not correlate ($r=0.05$, $t<1$).

Event-related potential data

In the ERP waveforms during study (see Fig. 1b) a reduction of the N1 component for repeated presentations was discernable in addition to the expected later component, the latter one passing from a more negative into a more positive deflection for repeated compared with first presentations. For reasons of completeness, both effects were analyzed by means of repeated measures ANOVAs on mean voltages in the time windows ranging from 130 to 180 ms and 430 to 600 ms [The exact position and expansion of the time windows was based on visual inspection.] comprising the within-subject factor Condition.

ANOVA in the N1 time window resulted in a significant main effect of Condition [$F(3,54)=3.46$, $P<0.05$, $\varepsilon=0.96$], which was further explored by post-hoc comparisons. These analyses showed that the reduction of the N1 was significant for third presentations ($P<0.05$) and marginally so for fourth ones ($P=0.055$). In the 430–600 ms time window, the overall main effect of Condition [$F(3,54)=9.28$, $P<0.001$, $\varepsilon=0.91$] was mainly due to fourth presentations as they were significantly more positive than the first ($P<0.01$) and the second ($P<0.001$) presentations and marginally so compared with the third ones ($P=0.07$). Additionally, third presentation items showed a tendency toward more positive waveforms than second presentations ($P=0.05$).

When linking these ERP effects to the behavioral performance during study and test, respectively, neither the N1 reduction nor the later positivity (measured as ERP differences between initial and each repeated presentation, respectively) was related to behavioral priming during study (operationalized as the difference between fourth and first presentations again). The positive deflection of waveforms for fourth presentations in the later time window, however, highly correlated with the participants' overall Pr score in the subsequent recognition memory test [$r=0.72$, $t(19)=4.24$, $P<0.001$]. In a similar way, the correlation between the N1 reduction for the fourth presentations and the Pr score was marginally significant [$r=0.42$, $t(19)=1.92$, $P=0.07$]. Figure 2 illustrates these coherences by showing the scatter plots of the correlation between ERP repetition effects at study and memory performance at test.

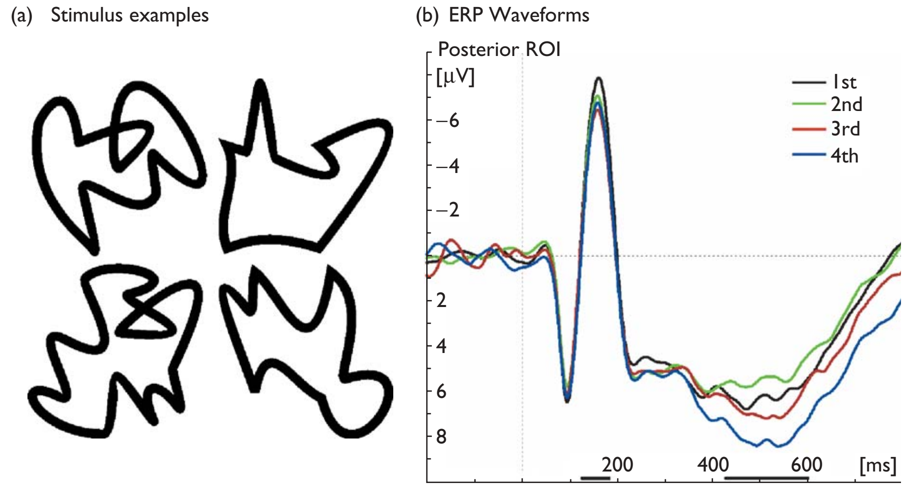

Fig. 1 (a) Examples of meaningless line figures used in the present study. (b) Grand average waveforms (nose-tip referenced) at the posterior region of interest (ROI) in the study phase as a function of Condition (1st, 2nd, 3rd, and 4th presentation); positive values are displayed downward; horizontal black bars on the *x*-axis highlight the two time windows used for statistical analysis.

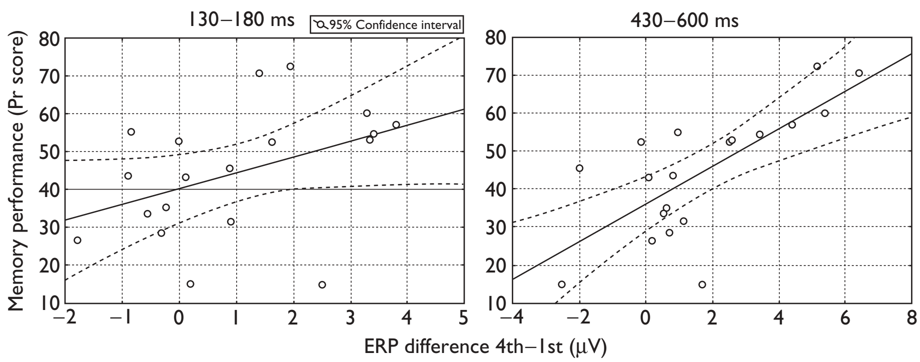

Fig. 2 Scatterplots of the correlation between study ERP repetition effects (operationalized as difference between 4th and 1st presentations) and memory performance at test (overall Pr score) in the early (130–180 ms) and late (430–600 ms) time windows.

Discussion

The present study investigated the ERP correlates of the creation of a new stimulus representation by the use of multiple repetitions of meaningless pictorial stimuli. To the best of our knowledge, this is the first study that correlated ERP effects associated with repetition of novel stimuli with behavioral measures of repetition priming on one hand and episodic memory performance on the other.

Stimulus repetition in the study phase led to significant behavioral repetition priming effects, but starting not until the third presentation. No priming effect for the second presentation of a novel item was observed. This result is in accordance with previous behavioral findings and corroborates an abstractionist view of repetition priming, namely that it is only observable for items with a preexisting stimulus representation (cf. [13,14]). For the present study, it can be assumed that such a representation is established in the course of the study phase owing to multiple repetitions, as reliable priming effects were observed for the third and fourth presentations. The ERP correlate(s) associated with stimulus repetition in the present experiment, however, seem(s) not to indicate a direct neural correlate of repetition priming, as neither the N1 reduction nor the later positive component was correlated with behavioral priming.

Concerning the N1 effect, a recent study linking ERP repetition effects for possible visual objects and behavioral priming [15] observed enhanced N1 and N2 amplitudes, whereas in the present study a reduction of the N1 was found. The N1 has been associated with the orienting response [16] and is usually enhanced for attended-location stimuli [17]. As the reduction in the present study tended to be correlated with later recognition memory performance, we assume that it reflects attentional processes related to episodic memory encoding, for instance an increased 'ease' of encoding owing to repeated presentation (e.g. in terms of lesser top-down control processes; cf. [18]).

Concerning the later component, one possible explanation for the lack of correlation between behavioral priming and ERP effect may be that the ERP repetition effect observed here simply does not directly tap the cognitive processes that are responsible for the behavioral RT speedup. That is, while the ERP effects might be a correlate of the creation of a cognitive representation (see below), the behavioral priming effect might be based on the acceleration of the perceptual crossover task (in terms of a transfer appropriate processing account, see [19]).

A second explanation stems from the influence of the repetition lag. It has been shown [20] that higher numbers of intervening items between initial and second presentation lead to a decrease of ERP repetition effects. In a similar vein, a so-called short-term priming effect has been observed up to lags of six intervening items [14] that can be dissociated from more enduring long-term priming (see also [21]). In accordance with this idea, reliable ERP repetition effects have been observed for novel items using short lags up to four items [8,22]. Interestingly, reduced repetition positivities over parieto-occipital recording sites were found in these studies, and it is worth mentioning that there is at least a numerical tendency toward a less positive deflection for second presentations in the present data set (cp. Fig. 1b).

Finally, a third related but even more methodological explanation is that after several intervening items, ERPs might not be able to capture the subtle neural processes associated with repetition priming in early visual areas. Accordingly, in addition to the ERPs reported in the present manuscript, we also analyzed time–frequency data in the γ band. These analyses showed a very early (i.e. around 90 ms) reduction of the evoked γ band response for repeated compared with initial presentations, and this reduction was related to the behavioral priming effect during study (see [23]).

In the present case, multiple repetitions of novel items were mainly associated with a larger positive deflection of waveforms. In our view, the functional significance of this component is still ambiguous. First, one could hypothesize that it reflects the more long-term priming effects mentioned above, but no correlation of behavioral priming and the ERP repetition effect was observed. Second, we argue that it probably does not represent a novelty P3, as the repetition of (familiar) stimuli led to a reduction of the P3 [24], whereas in the present experiment a larger positivity was observed for repeated items. Moreover, the distinct parieto-occipital distribution of the effect in the present experiment speaks against a novelty P3 interpretation (cf. [24]). Third, on the basis of the high correlation of the late positive component with later recognition memory performance, it could be argued that it reflects episodic retrieval processes (i.e. a conscious recollection of the previous occurrence of a particular item). Note that the effect, however, cannot be a direct correlate of episodic retrieval during study, as second presentations (much like fourth ones) led to a reliable memory performance at test [which was significantly different from chance performance, t (19)=10.78, $P<0.001$] but did not elicit a reliable ERP positivity during study. A recent study using a continuous recognition paradigm [25] observed a similar increasing positivity for up to nine repetitions that was interpreted as being related to episodic memory strength. On this note, we assume that the late positive component observed in the present study might reflect a combination of encoding and retrieval operations in episodic memory and thus indicates the creation of a new memory-effective stimulus representation.

Conclusion

In the present paper, it is shown for the first time that an evolving ERP component associated with the repetition of novel pictorial stimuli can predict performance in a subsequent memory test. It is thence concluded that this component represents the electrophysiological correlate of the creation of a new (memory-effective) stimulus representation.

Acknowledgements

The authors thank Thorsten Brinkmann, Anke Dudek, Stefanie Thaerig, and Daniel Lenz for research assistance. This study was supported by the German Research Foundation (Deutsche Forschungsgemeinschaft, Grants HE 3353/2-2 and Zi 308/4-2).

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