Brain dynamics associated with recollective experiences of emotional events

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In this study, we used high-density event-related potentials to investigate the brain dynamics underlying the recollective experience for emotional and neutral pictures. Using the remember/know procedure, 12 male participants introspectively indicated whether their recognition was based on conscious recollection (remembered) or familiarity (known). The results show a higher rate of remember responses for emotional relative to neutral pictures, despite an equivalent memory accuracy. In the event-related potentials, the subjective recollective experience for emotional pictures relative to neutral pictures was accompanied by an enhanced old/new effect (500–800 ms) over parietal scalp locations.
The results provide electrocortical evidence for a contribution of the parietal old/new effect to the enhanced vividness of individuals' emotional memories and indicate that emotions enhance the subjective belief of recognizing memories. ***NeuroReport*** **21:827–831 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

The memory of emotional events is extremely robust and long lasting [1–3]. Recent research also indicates that the retrieval of emotional events is associated with greater retrieval accuracy and an intensified subjective recollective experience. As known from 'flashbulb memory' studies, the retrieval of highly emotional and consequential real-life events is often accompanied by greater subjective belief of remembrance (e.g. subjective vividness and confidence in memory) compared with remembering everyday events [4,5], even when the accuracy for contextual details is equivalent and declines over time.

In laboratory settings, such awareness of remembering is frequently examined using the remember/know paradigm [6,7]. This procedure differentiates between 'remember' and 'know' judgments during retrieval, which according to the dual process model of recognition tap different memory processes, namely 'recollection' or 'familiarity' [8]. The process of recollection involves consciously remembering specific contextual details about a previously encoded event, whereas the process of familiarity involves simply knowing that a stimulus was presented, without any additional contextual information about the learning episode [9]. Emotions particularly influence the recollection process [4,10,11]. Emotionally arousing events enhance subjective remember responses, whereas 'know' responses are largely unaffected by emotional factors. Brain imaging studies identified the amygdala and the hippocampus as loci of recollection-based responses for emotional categories [1,11]. In this study, we investigated the temporal characteristics underlying the enhanced recollection of emotional material.

To measure the brain dynamics associated with the subjective feeling of remembering emotional and neutral pictures, we used event-related potentials (ERPs). ERP studies on memory retrieval have shown a differential contribution of familiarity and recollection to the recognition memory process. In general, ERPs for old items are greater than those for new items. A frontal old/new difference (300–500 ms) is related to familiarity and a later parietal located old/new component (500–800 ms) to the process of recollection [12]. Accordingly, larger late-positive ERPs are greater for remember, and high confidence responses, relative to know and low-confidence responses [2,13].

Recent ERP studies showed that the parietal old/new effect is enhanced during long-term retrieval of emotionally arousing pictures [2,3,14]. The timing and spatial distribution of this emotional modulation suggested that the remembering of past emotions is mediated by the process of conscious recollection. However, remember/know judgments were not collected in these studies, thus it remains unclear whether the effect of emotion on the recollection-sensitive late parietal ERP effect is directly modulated by the subjective recollective experience. Here, we assessed the subjective experience of recognizing emotional and neutral pictures by measuring remember/know judgments while measuring event-related brain potentials.

The study was conducted at the Department of Biological and Clinical Psychology, University of Greifswald, Greifswald, Germany.

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Methods

Participants

Twelve healthy male students from the University of Greifswald (mean age: 25.5 years, range: 20–31 years, two were left handed) participated in the study. Only male students were included to avoid any confounding sex effects on learning and memory processes [15]. All had normal or corrected-to-normal vision. All participants provided written informed consent for the protocol approved by the Review Board of the University of Greifswald and received financial compensation for participation.

Stimulus materials

Stimuli consisted of 200 negatively arousing and 200 neutral photographs selected from the International Affective Picture Series (IAPS) [16], based on their standard scores for emotional arousal and emotional valence. Two sets of stimuli (encoding set vs. recognition set) were carefully matched according to their normative valence and arousal ratings of the standard sample (see IAPS norms for male participants, encoding set: valence mean = 3.0 and 5.3, arousal mean = 5.9 and 3.2; for unpleasant and neutral images, recognition set: valence mean = 3.0 and 5.1, arousal mean = 6.0 and 3.3) and also according to their semantic categories (e.g. human/animal attack, mutilation, neutral people, objects). Each of the two picture sets consisted of 100 unique pictures (50 unpleasant and 50 neutral pictures, respectively). In addition, individual valence and arousal ratings of the 100 pictures during encoding were obtained from the current sample to ensure that the ratings of the current sample corresponded to the reported IAPS norms. As expected, neutral pictures were rated as neutral (valence mean: 6.2) and emotional pictures as negative [valence mean: 3.2; $F(1,11) = 164.58$, $P < 0.001$]. Neutral pictures were rated as less arousing (arousal mean: 2.7) than emotional (arousal mean: 5.9) pictures [$F(1,11) = 66.50$, $P < 0.001$].

Procedure

During the encoding session, 100 pictures were presented for 3000 ms with a random intertrial interval of 3500, 4000, or 4500 ms. A 500 ms fixation cross preceded each picture onset to ensure that participants fixated the center of the screen. Participants were instructed to watch attentively the pictures displayed on the monitor. Following picture offset, participants were instructed to rate each picture on a keyboard according to arousal and valence using the SAM rating procedure [17]. Participants were not told that there would be a subsequent memory test. The pictures were presented in random order for each participant with the restriction that no picture from the same valence category was presented on more than three consecutive trials.

The day after the encoding session, participants went through a standard remember/know procedure [1,7], in which 100 pictures (50 unpleasant) were used as study items randomly intermixed with 100 new items. Each picture was displayed for 3000 ms with a preceding fixation cross of 500 ms. For each picture, participants made ‘remember’, ‘know’, or ‘new’ judgments. Instructions on how to use the response categories were both read by the participants and verbally explained. Participants were instructed to use the ‘remember’ option respond if they were certain they had seen the picture and could recollect specific associations that occurred at study and to respond ‘know’ if they were certain about previously studying the picture but could not recollect any specific associations. Participants were instructed to respond ‘new’ when they judged that a test picture was new or when they were uncertain whether the test picture was old. A keyboard was used to make the three responses. Before starting the retrieval task, participants were instructed to avoid eye blinks and body movements during ERP measurement.

Apparatus and data analysis

Electroencephalography signals were recorded continuously from 256 electrodes using an electrical geodesic system and digitized at a rate of 250 Hz, using the vertex sensor (Cz) as recording reference. Scalp impedance for each sensor was kept below 30 kΩ, as recommended by the manufacturer guidelines. All channels were band-pass filtered online from 0.1 to 100 Hz. Off-line analyses were performed using ElectroMagnetic EncephaloGraphy Software [18] including low-pass filtering at 40 Hz, artefact detection, sensor interpolation, baseline correction, and conversion to average reference. Stimulus-synchronized epochs were extracted from 100 ms before to 1200 ms after picture onset and baseline corrected (100 ms before stimulus onset). Owing to the low number of know trials in the recognition memory data (Table 1) the ERP analysis was restricted to the analysis of differences between correctly recognized ‘remember’ and ‘new’ responses for both the picture categories. To reveal effects of emotional picture content on processing of remember/new judgments, and to determine corresponding sensor clusters and time windows, visual inspection and single sensor waveform analyses were used in concert. For the waveform analyses, analysis of variances (ANOVAs) containing the factors

Table 1 Recognition judgments made to studied (presented during encoding) and new pictures at retrieval for each picture content

	Emotional	Neutral
Studied pictures		
Remember	0.82 (0.17)	0.65 (0.25)
Know	0.16 (0.17)	0.26 (0.24)
New pictures		
Remember	0.04 (0.07)	0.01 (0.01)
Know	0.09 (0.06)	0.06 (0.05)
Overall accuracy	0.85 (0.11)	0.84 (0.08)
Recollection	0.78 (0.16)	0.65 (0.24)
Familiarity (Fd′)	0.07 (0.18)	0.20 (0.26)

Data are presented in mean (standard deviation).

'emotion' (unpleasant vs. neutral) and 'memory' (remember vs. new) were calculated for each time point and after each picture onset separately for each individual sensor [2,19].

In the main analyses, repeated measures ANOVAs based on mean activity in selected sensor cluster and time window was performed. On the basis of the results of these analyses and in line with earlier findings [2,3,14], we selected a time window from 500 to 800 ms and an electrode cluster over the centro-parietal cortex (Fig. 1) for further statistical analyses. Mean ERP amplitudes (500–800 ms) of the centro-parietal sensor cluster were analyzed using an ANOVA including the factors emotion (unpleasant vs. neutral) and memory (remember vs. new). For effects involving repeated measures, the Greenhouse–Geisser procedure was used to correct for violations of sphericity.

Results

Behavioral data

As a measure of overall accuracy, hit rates (percentage of previously seen pictures that were correctly identified as old) were subtracted from the false alarm rate (percentage of new pictures that were incorrectly identified as old). Overall accuracy did not differ for emotional and neutral pictures [$F(1,11) < 1$]. In general, participants made more remember than know judgments [means (standard deviation (SD): 0.74, (0.20) vs. 0.21 (0.20); $F(1,11) = 21.45$, $P < 0.001$]. Importantly, remember and know judgments differed as a function of emotion. Emotional pictures received higher rates of remember judgments than neutral pictures [$F(1,11) = 14.88$, $P < 0.001$] (Table 1). In contrast, know responses for old pictures were lower for emotional than neutral stimuli [$F(1,11) = 5.62$, $P < 0.05$]. Estimated recollection and familiarity scores based on hits and false alarms [6,10] indicated that recollection was boosted for emotional (mean = 0.78, SD = 0.16) relative to neutral pictures (mean = 0.65, SD = 0.24) [$F(1,11) = 11.88$, $P < 0.001$], whereas familiarity was greater for neutral (mean = 0.20, SD = 0.26) relative to emotional stimuli (mean = 0.07, SD = 0.18) [$F(1,11) = 6.51$, $P < 0.05$]. False alarms for remember and know judgments did not differ between the two picture categories [remember: $F(1,11) = 2.31$, $P = 0.16$, know: $F(1,11) = 2.68$, $P = 0.13$].

Fig. 1

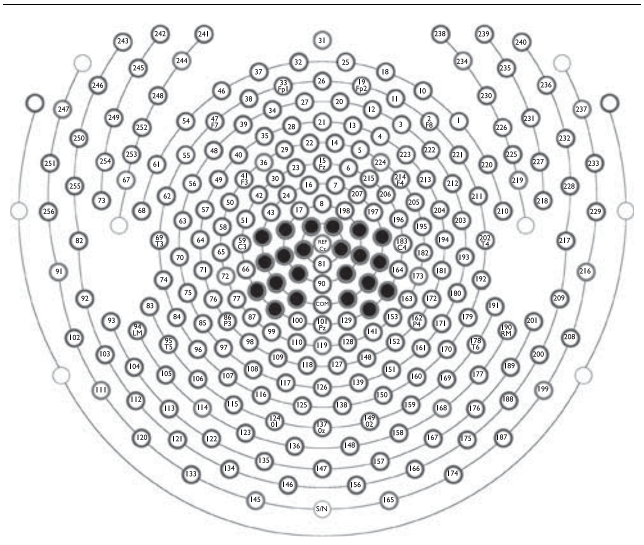


Illustration of the sensor montage of the high-density electroencephalography system: marked electrodes represent the cluster used for event-related potential analysis.

Event-related potential data

Late parietal old/new effect: 500–800 ms

The ERP analyses were restricted to trials associated with correct remember and new responses. Analyses of the ERP waveforms depicting correctly classified remember and new responses indicated greater ERP positivity for remembered pictures relative to correctly classified new pictures [memory: $F(1,11) = 107.38$, $P < 0.001$] (Fig. 2a). This remember/new difference was greatest over parietal recording sites (for distribution of F values see Fig. 3) for both emotional [$F(1,11) = 110.71$, $P < 0.001$] and neutral picture contents [$F(1,11) = 20.46$, $P < 0.001$]. Most importantly, the parietal ERP old/new effect (500–800 ms) varied as a function of emotional content of the pictures [emotion × memory: $F(1,11) = 8.92$, $P < 0.001$]. The magnitude of the remember/new difference was significantly larger for retrieval of emotional pictures relative to neutral pictures (Fig. 2b).

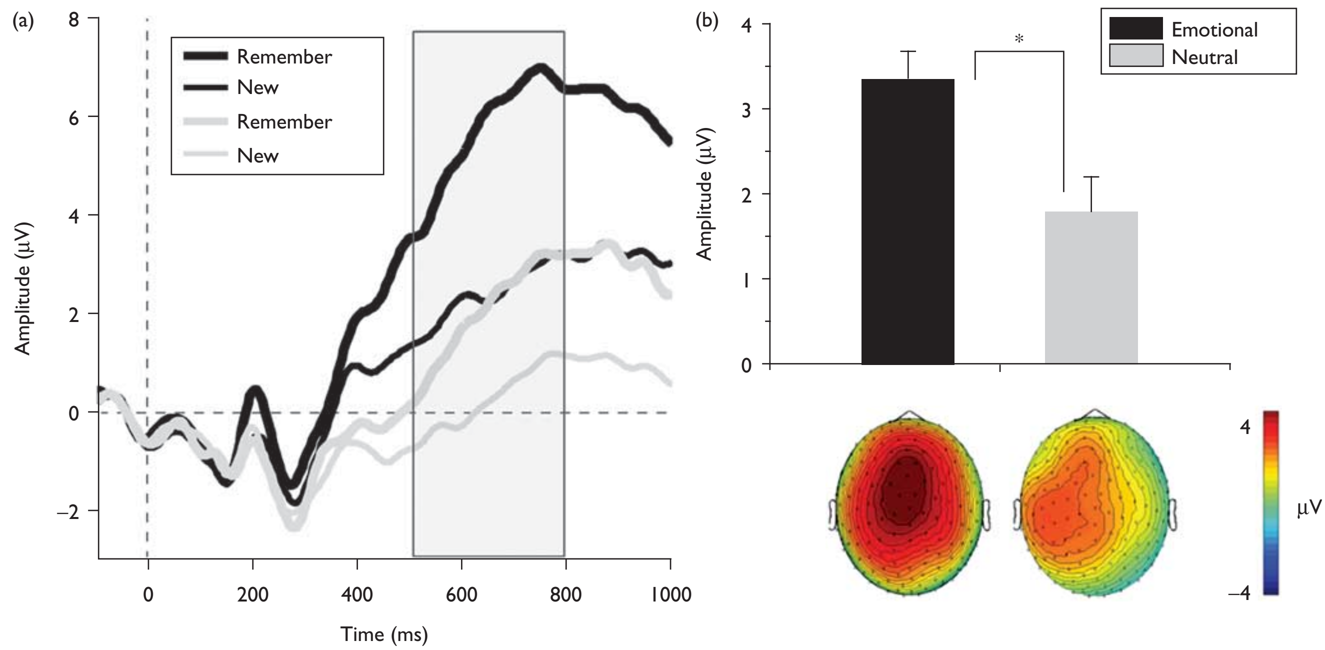
In addition, emotion-specific effects were found for the parietal sensor cluster [emotion: $F(1,11) = 70.28$, $P < 0.001$] with more ERP positivity for emotional pictures in comparison with neutral pictures [19].

Discussion

We examined the brain dynamics associated with the subjective experience of recognizing emotional and neutral pictures. We showed that the retrieval of emotional stimuli was accompanied by enhanced remember judgments relative to neutral pictures, although memory accuracy did not differ. In accordance with the behavioral data, the enhanced recollective experience for emotional contents was related to greater ERP amplitudes in the parietal old/new effect in the time range of 500–800 ms.

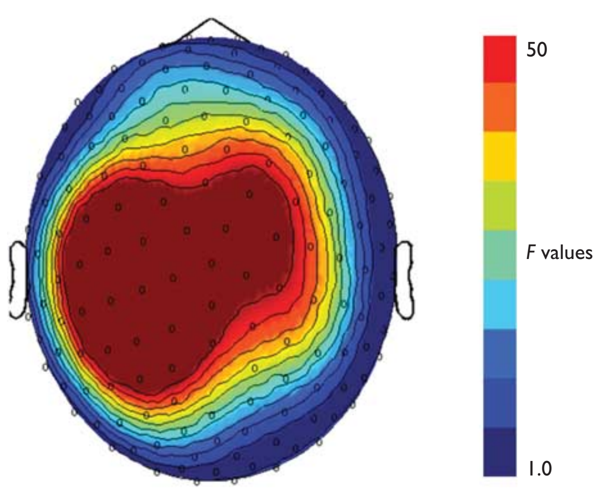
The results of this study show that the subjective experience of recollection is enhanced for emotional pictures relative to neutral ones [10,11]. This enhanced recollective experience for emotional stimuli was clearly supported by larger ERP amplitudes for remember responses relative to new responses over the parietal scalp region. This finding shows that the parietal old/new effect is modulated by recollection-based remember responses. Earlier studies reported that the parietal old/new effect

Fig. 2



Neural correlates of conscious recollection. (a) Recognition test event-related potentials (ERPs) averages across the parietal channel cluster are shown for correctly 'remembered' old and correctly classified new items depicted for emotional and neutral pictures. The shaded areas represent the time window between 500 and 800 ms used in the analyses. (b) The upper section shows the ERP voltage difference recorded over the centro-parietal electrode cluster in the 500–800 ms time window separately for the two picture categories. The lower section displays the corresponding scalp distribution of the remember/new difference. *$P < 0.001$.

Fig. 3



Topographical distribution of the statistical main effect of memory in repeated measures analysis of variances calculated for each sensor and mean time interval (500–800 ms).

is insensitive to familiarity strength and sensitive to other factors influencing recollection, such as depth of processing and correct source judgments [20]. This suggests that the process of recollection, as indexed by the parietal old/new component, is supported both by memory for context details, and subjective high confidence recognition [8]. In this study, we used the remember/new paradigm to directly assess the recollective experience, and show that the remember/new difference was greater for emotional than for neutral pictures. This clearly extends earlier research [2,3,14,21–23], by showing that the emotional modulations of the recollection-sensitive parietal old/new effect depends on the subjective recollective experience.

In recent ERP studies, the (emotional) parietal old/new effect has been related to activation of the parietal cortex [3,14,24], although the exact role of parietal cortex activation during retrieval is not fully understood. It is suggested that the parietal lobe activity serves in guiding attention to internal representations, as an episodic working memory-type buffer, as a mnemonic accumulator or as a gauge of individuals' subjective experience of recollection [25]. With regard to the subjective recollection hypotheses, the present findings could indicate that the parietal old/new effect is involved in the vivid recollection of emotional experiences.

The subjective quality of memory was more biased by emotional contents than the accuracy of memory. The enhanced belief of consciously recollecting an emotional event has been interpreted as an evolutionary adaptive mechanism that protects emotional memories from forgetting. Boosting the subjective confidence in memory for emotional experiences is critical for survival because it enables fast actions to avoid fearful events, a mechanism particularly more important for survival than accurate memory [4].

Conclusion

The recollective experience for emotional and neutral pictures was examined using high-density ERPs. The present results give behavioral and electrophysiological support for the idea that emotions selectively enhance the feeling of recollection.

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