# Electrophysiological Correlates of Encoding and Retrieving Emotional Events

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This study examined the impact of emotional content on encoding and retrieval processes. Event-related potentials were recorded in a source recognition memory task. During encoding, a posterior positivity for positive and negative pictures (250–450 ms) that presumably reflects attentional capturing of emotionally valenced stimuli was found. Additionally, positive events, which were also rated as less arousing than negative events, gave rise to anterior and posterior slow wave activity as compared with neutral and negative events and also showed enhanced recognition memory. It is assumed that positive low-arousing events enter controlled and elaborated encoding processes that are beneficial for recognition memory performance. The high arousal of negative events may interfere with controlled encoding mechanisms and attenuate item recognition and the quality of remembering. Moreover, topographically distinct late posterior negativities were obtained for the retrieval of the context features location and time that support the view that this component reflects processes in service of reconstructing the study episode by binding together contextual details with an item and that varies with the kind of episodic detail to be retrieved.

*Keywords:* emotion, attentional capturing, ERP old/new effects, source memory, posterior positivity, late posterior negativity, item–context bindings

Although the ability to remember our life experiences is limited, a multitude of factors influence whether an event is remembered or forgotten. The emotional salience of an event seems to be an important modulator of memory performance, as a person is more likely to remember events containing emotional relevance than those that do not. This memory enhancement effect has been shown for a large class of stimuli in diverse tests of memory. A robust pattern in free recall tests is that emotional stimuli are recalled to a greater extent than neutral stimuli (e.g., Cahill et al., 1996). Conversely, recognition memory shows a more inconsistent picture. In most cases, hits and false alarms are enhanced for emotional material, the so-called "emotion-induced recognition bias" that often results in comparable Pr values (i.e., old/new discrimination performance) for neutral and emotional stimuli (Johansson, Mecklinger, & Treese, 2004; Maratos, Dolan, Morris, Henson, & Rugg, 2000; Windmann & Kutas, 2001). This phenomenon, although not consistently found in recognition memory studies with emotional events, could reflect the higher biological relevance of emotional events that in an evolutionary sense may guarantee that biologically relevant events are not ignored or taken as irrelevant. With regard to the quality of remembering, recollection is found to be more likely and more pronounced for negative events, whereas positive and neutral stimuli are more frequently recognized on the basis of familiarity (Dolcos, LaBar, & Cabeza, 2004; Johansson et al., 2004; Kensinger & Corkin, 2004; Ochsner, 2000). In the domain of source memory, there are reports of impairment and enhancement effects for emotional stimuli. Source memory enhancement for emotional stimuli has been shown in studies in which the contexts used to test source memory were themselves emotional (e.g., Smith, Stephan, Rugg, & Dolan, 2006). Source memory impairments refer to the fact that peripheral elements of a scene (e.g., items presented outside the central part) or other nonemotional elements of a study episode are remembered less well when they are presented together with emotionally valenced information (Adolphs, Tranel, & Buchanan, 2005; Kensinger, Piguet, Krendl, & Corkin, 2005). Consistent with these latter studies, the focus of the present study is on recognition memory for emotional items and the mechanism by which these items are bound with neutral context features.

On a neural basis, memory enhancement and impairment effects for emotional events are attributable to interactions between the hippocampus and the amygdala. Amygdala signals can enhance the synaptic plasticity in the hippocampus and by this influence consolidation and binding processes within the hippocampus. As an example, after administration of epinephrine antagonists, recognition memory for emotional but not neutral events is attenuated (Cahill & McGaugh, 1998). Moreover, selective lesions of the amygdala can lead to specific impairments in emotional memory (Adolphs, Tranel, & Denburg, 2000). These patient data alone, however, do not shed light on the issue if the amygdala's modulatory role is restricted to encoding, consolidation, or retrieval processes. Another and more indirect way in which this modulation happens is suggested by the recent findings of Morris et al. (1998), who found a correlation between activity in the amygdala

and the visual cortex as participants viewed anxious faces. Additionally, activity in the amygdala predicted activity in several visual areas, which can be seen as a modulatory influence of the amygdala on sensory processing that in turn results in more detailed processing of these stimuli. Consequently, emotional events can become part of memory traces with high binding strength via the hippocampus. In accordance with this are studies that show enhanced perceptual processing of emotional events (they do not fall through the attentional blink; Anderson & Phelps, 2001) or enhanced attention for emotional events (Pratto & John, 1991).

Event-related potential (ERP) studies have consistently found that emotional pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) evoke a positive potential in stimulus classification paradigms, sometimes labeled *late positive potential* (Schupp, Flaisch, Stockburger, & Junghöfer, 2006). Even though this positive potential (referred to as *posterior positivity*) seems to be exclusively evoked by emotional stimuli, its functional significance is still unresolved. It is usually found over centro-parietal regions and is most apparent around 400–600 ms poststimulus onset. The posterior positivity is additionally modulated by the level of arousal, with more arousing pictures eliciting greater positive potentials than low-arousing ones (Schupp et al., 2000). In a recent study using combined ERP and functional MRI recordings (Sabatinelli, Lang, Keil, & Bradley, 2007), the posterior positivity was shown to be a reflection of activity in visual cortical structures, demonstrating a higher perceptual sensitivity to the relevance of emotional visual scenes. A modulation of the posterior positivity by emotional aspects of a scene was also observed during the encoding phase of a free recall test (Dolcos & Cabeza, 2002). In the latter study, the posterior positivity was modulated by arousal at parietal sites and by both arousal and valence at fronto-central sites. This finding was related to distinct neural systems involved in processing of emotional information by Dolcos and Cabeza (2002): An amygdala network mediates arousal (reflected in the posterior positivity), whereas a prefrontal cortex–hippocampus network is related to valence (reflected in a positivity for emotional as compared with neutral stimuli at frontal electrodes). Yet, the specific functional significance of the posterior positivity in the domain of memory remains an open issue. On the basis of findings that show that the posterior positivity is associated with the amount of attention paid to the emotional stimulus being processed (Diedrich, Naumann, Maier, & Becker, 1997) and that the amplitude of the posterior positivity is positively correlated with the number of subsequently remembered emotional events (Palomba, Angrilli, & Mini, 1997), one could assume that it reflects some kind of "attentional capturing" that leads to better memory for stimuli that contain these attention-grabbing properties. Moreover, this attentional capturing mechanism could also modulate the build up of memory-relevant associations (bindings) between stimuli and context features and thus lead to impairment effects in the domain of source memory.

Here we set out to investigate the impact of emotional content on encoding and retrieval processes in more detail. Three issues were addressed. First, we wanted to find out whether the posterior positivity for emotional pictures during encoding is directly associated with enhanced item memory on the one side and attenuated source memory performance on the other. More specifically, we predicted that to the extent to which the posterior positivity reflects attentional capturing mechanisms for emotional events, it should result in facilitated encoding for positive and negative pictures relative to neutral pictures. Simultaneously, attentional capturing by emotional pictures could attenuate the binding between these pictures and the features of the context in which they are presented and lead to impaired source memory performance. Second, we were interested to what extent the ERP old/new effects in the test phase are modulated by valence and arousal of the studied material. Consistent with the findings of Johansson et al. (2004) and Ochsner (2000), we predicted a larger amount of recollection-based memories for negative events. This should be evident in a larger (left) parietal old/new effect, that is, the putative ERP correlate of recollection (Friedman & Johnson, 2000; Mecklinger, 2006). Third, with regard to source memory we wanted to examine how the late posterior negativity (LPN) is modulated by source retrieval demands for emotional events (Herron, 2007; Johansson & Mecklinger, 2003). This component is repeatedly found in source memory tasks and has been associated with search for and retrieval of attribute conjunctions in the retrieval phase of these tasks. Two source retrieval conditions frequently used in experimental and clinical studies on memory (Mayes et al., 2004) were examined: time and location. These features constitute core elements of every experienced episode and are both derived from the external world (Simons, Gilbert, Owen, Fletcher, & Burgess, 2005), but should recruit differential posterior brain circuitries in reconstructing context-specific features from a study episode (Johansson & Mecklinger, 2003).

## Method

### Participants

Twenty volunteers (10 women and 10 men) between 18 and 23 years of age ($M = 21$ years) participated in this study. They were students at Saarland University (Saarbruecken, Germany), native German speakers, and right handed (as assessed by the Edinburgh Handedness Inventory; Oldfield, 1971) and had normal or corrected-to-normal vision. Data of 4 other participants were excluded because of excessive eye movement artifacts. All participants gave written informed consent.

### Experimental Material

Stimuli consisted of 480 pictures taken from the IAPS (Lang et al., 2005) divided into three categories: negative, neutral, and positive. They all differed with regard to valence (negative = 2.97; neutral = 5.09; positive = 7.13). Positive and negative pictures were equally arousing (positive = 5.04; negative = 5.2) and more arousing than neutral pictures (3.43). An analysis of variance (ANOVA) on the valence scores yielded a significant main effect of valence, $F(2, 318) = 2,394.15$, $p < .0001$, and post hoc tests showed significant differences between the valence scores of all three categories ($p < .0001$). A second ANOVA on the arousal scores of negative, neutral, and positive pictures revealed a significant main effect of arousal, $F(2, 318) = 255.14$, $p < .0001$, and post hoc tests showed significant differences between the arousal scores of positive and negative pictures with those of neutral pictures ($p < .0001$), but no significant differences between positive and negative pictures ($p > .05$).

## Procedure

Participants took part in two sessions separated by at least 3 but not more than 7 days. In each session, they completed one of two source memory tests, each consisting of a study phase and a test phase. Before starting the experimental session, each participant passed a practice run. Pictures used in the practice run were not used during the experimental session. Participants were comfortably seated in a dimly lit chamber at a distance of 100 cm from a monitor on which they saw the pictures. In the time session, they saw two lists of 60 pictures each with a break of 7.5 min between lists during which they performed a visuomotor tracking task. During the session, pictures appeared in the center of the screen for 2 s, and the participant's task was to memorize the picture and the list in which it was presented (before or after the break; i.e., list 1 or list 2). Additionally, the participants had to indicate via button press whether the depicted scene happened indoors or outdoors. This procedure was used to constrain the variability of possible mnemonic strategies during study and to ensure an appropriate encoding for each picture. In the test phase (administered 2.5 min later), the 120 old and 120 new pictures were presented for 500 ms each. The participants made an old/new decision. In case of an "old" response, a source decision (List 1 or List 2) was triggered by the appearance of three question marks in the center of the screen. After a "new" response, a fixation cross appeared to initiate the next trial. The test phase of the location session was identical to the time session and took place at the same computer; however, during study we placed participants in one of two booths. These chambers were two small rooms about 3 m$^2$ equipped with a desk and a comfortable chair. To rule out the possibility that time would be entirely predictive of location, participants had to change between the two booths three times so that they sat in each of them twice. Booth order, source task order, and response buttons were counterbalanced across participants. For a schematic illustration, see Figure 1.

## Electroencephalogram Recordings

Electroencephalograms (EEGs) were recorded using Ag/AgCl electrodes mounted in an elastic cap from 60 scalp sites at loca-

tions of the extended 10–20 system (Sharbrough et al., 1990). The ground electrode was placed at AFz. The EEG from all sites was recorded with reference to the left mastoid electrode and rereferenced off line to the average of the left and right mastoids. The vertical and horizontal electrooculographs (EOGs) were recorded from electrodes located below and above the right eye and at the outer canthus of each eye. Electrode impedance was kept below 5 kOhms. EEGs and EOGs were recorded continuously with a band pass from DC to 70 Hz and were sampled at a rate of 500 Hz.

## Data Analysis

Data were analyzed with repeated measures ANOVAs using a significance level of .05. For all effects with two or more degrees of freedom in the numerator, we adjusted when appropriate for violations of sphericity, which are inherent in ANOVAs, according to the Greenhouse and Geisser (1959) formula.

## Behavioral Data

The data analysis was based on reaction time measures for all correct responses, that is, item hits and correct rejections. Item hits were defined as correct old responses at test to pictures already presented during study, irrespective of the correctness of the subsequent source judgment. Correct rejections were defined as correct responses to new items presented at test for the first time. Recognition accuracy was estimated by means of Pr values (Snodgrass & Corwin, 1988). Pr is a measure that estimates the degree of true memory judgments by subtracting the false alarm rate, as an estimate of guessing, from the hit rate. Therefore, a Pr value of 1 indicates perfect recognition performance, whereas a Pr value of 0 indicates chance performance.

For the second (source memory) response, accuracy was calculated by dividing the probability of a correct source judgment by the probability of a correct "old" response [$p$(correct source)/ $p$(correct source + incorrect source)].

## ERP Data

ERPs were computed separately for each participant at all recording sites with epochs extending from 200 ms before stimulus
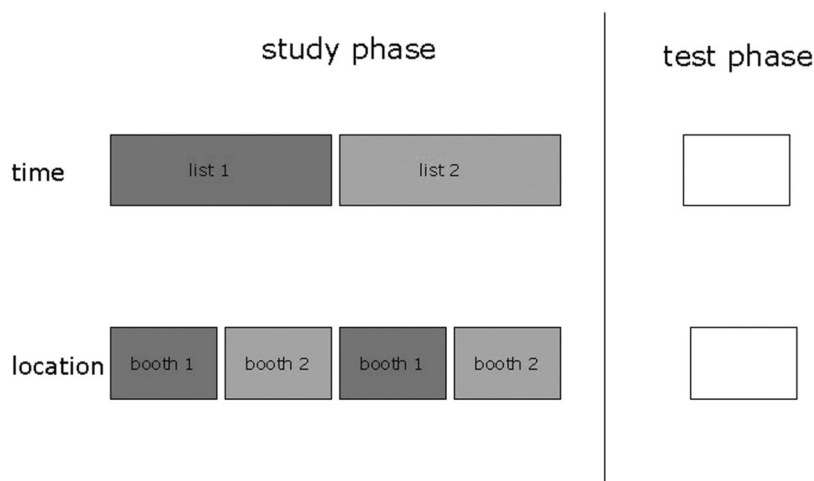


*Figure 1.* Schematic illustration of the structure of the study and test phases.

onset until 1,000 (study phase) or 2,000 ms (test phase) thereafter. The 200 ms before stimulus onset served as a baseline. EEG trials with artifacts (criterion: ±40 mV) were rejected. Eyeblink artifacts were corrected using a linear regression approach (Gratton, Coles, & Donchin, 1983) implemented in the EEProbe software package (A.N.T. Software BV, Enschede, the Netherlands).

For statistical analysis, a hypothesis-driven approach was chosen. On the basis of prior studies, for the evaluation of the posterior positivity and other emotion-specific effects in the encoding phase, we used the mean amplitudes in three different time windows that were derived by visual inspection of the grand-average waveforms: 250 to 450 ms, 450 to 650 ms, and 650 to 850 ms. The mean amplitudes in the 250–450-ms time interval are hereinafter referred to as posterior positivity. For the quantification of the ERP old/new effects in the test phases, the mean amplitudes in two different time windows were used. On the basis of visual inspection of the grand average waveforms and consistent with prior studies (reviewed in Friedman & Johnson, 2000, and Mecklinger, 2006), the early frontal old/new effect was examined in a time window between 350 and 500 ms, and the parietal old/new effect was defined as between 500 and 650 ms. This analysis aimed primarily at tapping the old/new effects related to familiarity and recollection, respectively. Consistent with prior studies (Cycowicz & Friedman, 2003; Friedman, Cycowicz, & Bersick, 2005; Leynes & Bink, 2002), the LPN was examined in a late time window between 1,000 and 2,000 ms. For the statistical evaluation of the study and test phase ERPs, we used 12 electrode sites in the overall ANOVA: left anterior-frontal (AF3), middle anterior-frontal (FZ), right anterior-frontal (AF4), left fronto-central (FC3), middle fronto-central (FCZ), right fronto-central (FC4), left centro-parietal (CP3), middle centro-parietal (CPZ), right centro-parietal (CP4), left parieto-occipital (PO3), middle parieto-occipital (POZ), right parieto-occipital (PO4), left parietal (P3), middle parietal (PZ), right parietal (P4), left occipital (O1), middle occipital (OZ), and right occipital (O2). The LPN was examined at more electrode sites to allow a more sensitive analysis of possible topographical differences: AF3, AF4, FZ, FC3, FCZ, FC4, C3, CZ, C4, CP3, CPZ, CP4, P3, PZ, P4, PO3, POZ, PO4, O1, OZ, O2. To test whether the topography of the LPNs for the two source retrieval conditions differed, the ANOVAs were conducted on the rescaled difference waveforms (source hits minus correct rejections) such that amplitude differences between the two contrasted conditions were removed (McCarthy & Wood, 1997).

For the study phase, the overall repeated measures ANOVA included the following factors: emotion (negative, neutral, or pos-

itive), task (source task time or source task location), laterality (left, middle, or right), ANTPOS (anterior-frontal, fronto-central, centro-parietal, or parieto-occipital), and window (250–450 ms, 450–650 ms, or 650–850 ms). In the case of significant main effects and interactions involving the factors emotion or task, subsidiary one-way ANOVAs and planned pairwise comparisons were performed to examine the effects in more detail.

For the quantification of the old/new effects for the test phase, two repeated measures ANOVAs (factors: emotion, task, laterality, and ANTPOS) were performed for each of the two time windows with the additional factor response type (hit or correct rejection). Again, in the case of significant main effects and interactions involving any of these factors, subsidiary one-way ANOVAs and planned pairwise comparisons were performed to examine the effects in more detail. For the calculation of the LPN, the ANOVA involved the factors emotion (negative, neutral, or positive), source type (source hit or correct rejection), task (source task time or source task location), laterality (left, middle, or right) and ANTPOS (frontal, fronto-central, central, centro-parietal, parietal, parieto-occipital, or occipital).

## Results

### Behavioral Data

An overview of item, source memory performance, and reaction time data is given in Table 1.

The ANOVA performed on the Pr values for the two source tasks (time and location) and the three emotional conditions (positive, negative, and neutral) revealed a significant main effect of emotion, $F(2, 38) = 5.33, p = .009$, suggesting that the emotional status of the pictures influenced participants' ability to accurately discriminate between old and new stimuli. The subsidiary one-way ANOVAs and planned pairwise comparisons showed that this effect was attributable to the fact that positive pictures were better remembered than both neutral pictures, $F(1, 19) = 9.70, p = .006$, and negative pictures, $F(1, 19) = 7.24, p = .0145$.

The analysis of response bias measures revealed no significant effect involving the factors emotion and task.

The ANOVA on the reaction time measures for hits and correct rejections gave rise to a main effect of response type, $F(1, 19) = 32.95, p < .001$, confirming that correct rejections were faster than hits. There also was a main effect of emotion, $F(2, 38) = 13.52, p < .001$. Decomposition of this effect revealed that irrespective of response type, responses to neutral items, $F(1, 19) = 40.43, p <$

Table 1

*Measures of Old/New Discrimination (Pr) and Source Memory Performance and Reaction Times for Hits and Correct Rejections for the Two Source Test Tasks Separately for Negative, Neutral, and Positive Pictures*

| Source task | Negative | Neutral | Positive | Negative | Neutral | Positive |
|---|---|---|---|---|---|---|
| | | Pr | | | Source performance | |
| Time | 0.67 (.04) | 0.65 (.04) | 0.71 (.03) | 0.60 (.03) | 0.60 (.03) | 0.63 (.03) |
| Location | 0.60 (.04) | 0.65 (.04) | 0.69 (.04) | 0.57 (.03) | 0.55 (.02) | 0.57 (.02) |
| | | Hit | | | Correct rejection | |
| Time | 978.32 (34) | 947.84 (34) | 962.25 (41) | 884.02 (26) | 846.16 (25) | 861.37 (25) |
| Location | 1,044.18 (44) | 977.77 (34) | 984.71 (40) | 907.98 (30) | 863.53 (28) | 894.57 (28) |

*Note.* Standard errors of the mean are given in parentheses. Reaction times are displayed in msec.

.0001, and positive items, $F(1, 19) = 7.96$, $p = .011$, were given faster than to negative items.

For source memory performance, an ANOVA with the factors task and emotion revealed a marginally significant effect for task, $F(1, 19) = 3.03$, $p = .098$, suggesting that performance tended to be better in the time task than in the location task. The emotional status of an item did not seem to modulate source memory performance, which was also well above chance level (i.e., $<.50$, $ps < .05$) in both tasks.[1]

### ERP Data

*Encoding phase.* The grand average ERP data of the encoding phase, separately for the two source tasks and the three emotion conditions, are depicted in Figure 2. The overall morphology of the waveforms was similar for positive, negative, and neutral pictures in both the time and the location tasks and was characterized by a N300-P300-SW complex. More specific examination of the grand average ERPs reveals three distinct effects.
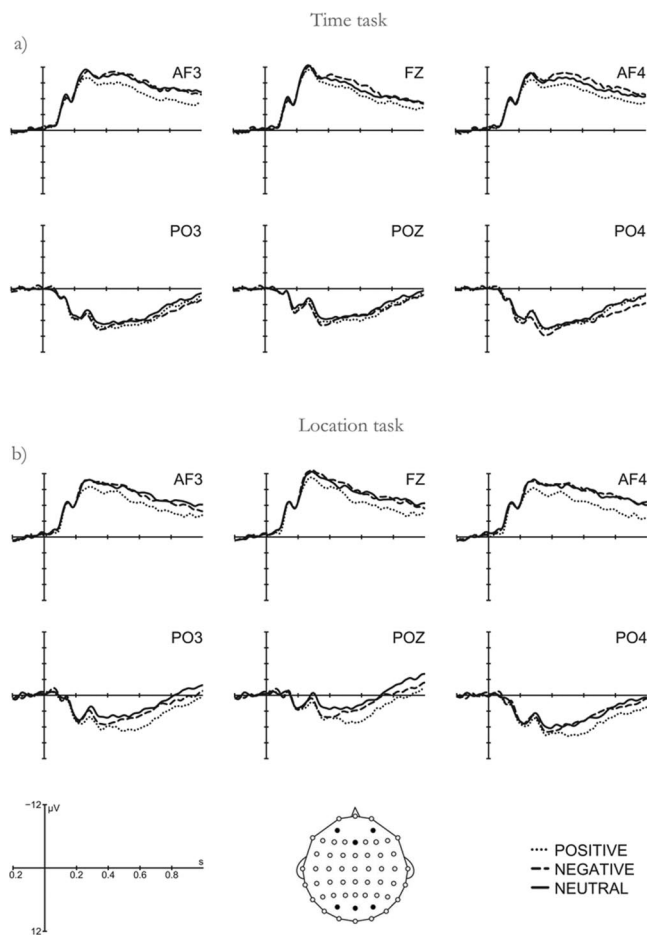


*Figure 2.* A: Grand average event-related potentials (ERPs) elicited by positive, negative, and neutral pictures during encoding in the time task at anterior-frontal (AF) and parieto-occipital (PO) electrodes. B: Grand average event-related potentials elicited by positive, negative, and neutral pictures during encoding in the location task at AF and PO electrodes.

The first effect starts at around 250 ms poststimulus onset at frontal sites and lasts until the end of the recording epoch (1,000 ms). In this interval, the ERPs were more positive-going for positive pictures as compared with negative and neutral pictures at anterior-frontal and fronto-central recording sites in both source tasks, albeit smaller in the time task than in the location task.

The second effect is manifested in more positive-going waveforms for positive and negative pictures as compared with neutral ones in the location condition at parieto-occipital sites in an early time window (lasting from 250 to 450 ms), which is consistent with our previous definition of the posterior positivity.

The third effect is characterized by a posteriorly distributed positive slow wave that was obtained only for positive pictures in the location task, starting at around 450 ms and lasting until the end of the epoch.

Table 2 shows the results of the initial ANOVAs performed for the encoding phase. We obtained significant main effects for the factors emotion, laterality, and window. Additionally, two interactions emerged: Emotion × ANTPOS and Emotion × Window. For the first interaction, subsidiary ANOVAs and planned pairwise comparisons revealed that a main effect of emotion was present at anterior-frontal sites, $F(2, 38) = 14.61$, $p < .0001$, and fronto-central sites, $F(2, 38) = 13.28$, $p < .0001$. It reflects significant differences between the waveforms elicited by positive and neutral ($p < .05$) and positive and negative pictures ($p < .05$), with no differences between negative and neutral pictures ($p > .05$). Investigation of posterior sites revealed an Emotion × Window interaction, $F(2, 38) = 9.49$, $p = .0005$, and an Emotion × Task interaction, $F(2, 38) = 3.61$, $p = .039$. Decomposition of these effects showed that in the time window of the posterior positivity as well as in the two other time windows, there was a main effect of emotion in the location task ($p < .05$), but not in the time task ($p > .05$). Further analyses of the emotion effect in the location task revealed that in the time window of the posterior positivity, the waveforms elicited by positive and negative pictures were more positive-going than those elicited by neutral pictures ($p < .05$). In the middle and late time window, we found that in the location task positive pictures gave rise to more positive-going waveforms than did both negative and neutral pictures (with no difference between the two; $p < .05$). Contrasting the two task versions revealed that in all three time windows, waveforms for positive pictures were comparable in the location and time tasks ($p > .05$), whereas those for neutral and negative pictures were more positive-going in the time task than in the location task ($p < .05$).

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[1] In light of the tentatively higher source memory performance in the time task, it could be argued that source discrimination in the time task may have been facilitated especially for those items presented at the extremes of time, that is, at the beginning of the first list and the end of the second list. To examine this, we compared source memory performance for high separated items (the first 20 trials of List 1 and the last 20 trials of List 2) and low separated items (last 20 items of List 1 plus the first 20 items of List 2). Source memory performance was .62 and .59 for the high and low separated items, respectively, with this difference not being significant ($p > .05$). On the basis of this post hoc analysis, we feel safe in concluding that source discrimination was not selectively facilitated for highly distant items.

Table 2
*Analysis of Variance Results in the Encoding Phase*

| Effect | F | df | p |
|---|---|---|---|
| Emotion | 10.85 | 2,38 | .0004 |
| Laterality | 6.22 | 2,38 | .0046 |
| ANTPOS | 78.69 | 3,57 | <.0001 |
| Window | 22.04 | 2,38 | <.0001 |
| Emotion × ANTPOS | 3.05 | 6,114 | .036 |
| Emotion × Win | 3.56 | 4,76 | .019 |

*Note.* Only effects reaching significance are shown. Emotion = positive vs. negative vs. neutral; laterality = left vs. middle vs. right; ANTPOS = anterior-frontal vs. fronto-central vs. centro-parietal vs. parieto-occipital; window = 250–450 ms vs. 450–650 ms vs. 650–850 ms.

*Retrieval phase.* Grand averages for correct responses to old and new pictures in all three emotion conditions for the time and location tasks are displayed in Figure 3. As expected, correctly recognized old pictures elicited more positive-going ERPs than correctly rejected new pictures. This old/new effect started at around 250 ms poststimulus and lasted until 700 ms at posterior electrodes. Remarkably, these effects appear to vary as a function of emotional condition, time, and task, with neutral and positive pictures showing an early frontal and a late parietal old/new effect irrespective of task and negative pictures eliciting only a frontal old/new effect in the location task while showing the same effects as neutral and positive pictures in the time task.

Table 3 shows the results of the initial ANOVAs performed for each time window. Analyses performed on the early time window (350 to 500 ms) revealed main effects of emotion, response type, laterality, and ANTPOS. Additionally, two interactions emerged:
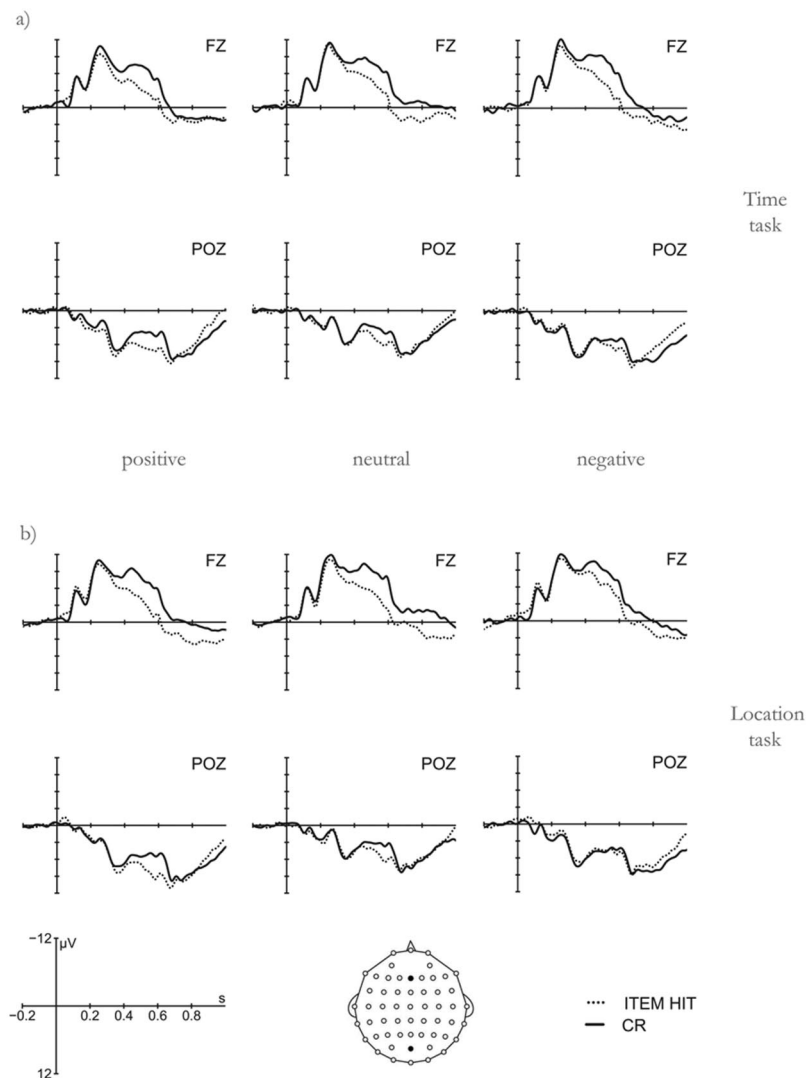


*Figure 3.* A: Grand average event-related potentials (ERPs) elicited by correct responses to old and new positive (left), neutral (middle), and negative (right) pictures in the time task at fronto-central (FZ) and parieto-occipital (POZ) sites. B: Grand average ERPs elicited by correct responses to old and new positive (left), neutral (middle), and negative (right) pictures in the location task at FZ and POZ sites.

Table 3
*Analysis of Variance Results for the Old/New Effects and Late Posterior Negativities*

| Time window and effect | F | df | p |
|---|---|---|---|
| **350–500 ms** | | | |
| Emotion | 14.81 | 2,38 | <.0001 |
| Response type | 31.09 | 1,19 | <.0001 |
| Laterality | 4.56 | 2,38 | .018 |
| ANTPOS | 66.12 | 3,57 | <.0001 |
| Emotion × ANTPOS | 14.54 | 6,114 | <.0001 |
| Response Type × ANTPOS | 33.42 | 3,57 | <.0001 |
| **500–650 ms** | | | |
| Emotion | 14.36 | 2,38 | <.0001 |
| Response type | 81.36 | 1,19 | <.0001 |
| ANTPOS | 40.33 | 3,57 | <.0001 |
| Emotion × Task | 3.31 | 2,38 | .059 |
| Emotion × ANTPOS | 3.64 | 6,114 | .019 |
| Response Type × ANTPOS | 14.24 | 3,57 | <.0001 |
| **1,000–2,000 ms** | | | |
| Source type | 46.21 | 1,19 | <.0001 |

*Note.* Only effects reaching significance are shown. Emotion = positive, vs. negative, vs. neutral; response type = hits vs. correct rejections; task = location vs. time; laterality = left vs. middle vs. right; ANTPOS = frontal vs. fronto-central vs. central vs. centro-parietal vs. parietal vs. parieto-occipital vs. occipital; source type = source hits vs. correct rejections.

Emotion × ANTPOS and Response Type × ANTPOS. For the first interaction, subsidiary ANOVAs revealed main effects of emotion at all levels of the ANTPOS factor ($p < .05$) and of response type ($p < .05$) at all sites besides parieto-occipital. In this early time window, old/new effects seem to be prominent at anterior-frontal, fronto-central, and centro-parietal electrodes for all of the emotion conditions in both source tasks.

For the late time window (500 to 650 ms), the following main effects were obtained: emotion, responses type, and ANTPOS. Here, additional interactions involved Emotion × Task, Emotion × ANTPOS, and Response Type × ANTPOS. On the basis of these interactions, three-way ANOVAs (emotion, task, and response type) were performed for each level of the ANTPOS factor. At parieto-occipital electrodes, we found an Emotion × Task interaction, $F(2, 38) = 4,56$, $p = .025$, and an Emotion × Response Type interaction, $F(2, 38) = 3.32$, $p = .053$. Decomposition of these interactions confirmed the visual impression that the late old/new effect was present for all emotion conditions in the time task ($p < .05$), whereas in the location task it was present for neutral and positive events ($p < .05$) but not for negative events ($p > .05$).

Visual inspection of Figure 4 showing the ERPs in the test phase for a duration of 2,000 ms reveals a large and posteriorly distributed LPN for source hits as compared with correct rejections in a time window from 1,000 ms until 2,000 ms in both tasks. This topographical distribution is well in agreement with earlier source memory studies (e.g., Cycowicz & Friedman, 2003; Friedman et al., 2005; Johansson & Mecklinger, 2003; Leynes & Bink, 2002), and ANOVAs performed on this effect reveal a highly significant main effect of source type (source hits vs. correct rejections; Table 3). The LPN was not modulated by emotional context as none of the analyzed factors revealed an interaction with the factor emotion.

Figure 5 depicts the topographic maps showing the distribution of the LPN for the time and location task in a time window from 1,000 to 2,000 ms. As can be seen in the figure, the distribution of the LPN is more fronto-centrally accentuated in the time task than in the location task, although the maxima of both effects seem to be at parieto-occipital sites. This observation is confirmed by a post hoc ANOVA on the difference waveforms (source hits minus correct rejections) collapsed across the emotion factor with the factors task (time vs. location), ANTPOS (seven levels), and laterality (left, middle, and right) with amplitude normalized data (McCarthy & Wood, 1997). This analysis revealed an Task × ANTPOS interaction, $F(6, 114) = 3.17$, $p = .03$, supporting the view that the LPN was topographically different in the two source memory tasks.

## Discussion

We examined the electrophysiological correlates of encoding and retrieving emotional pictures and context features of the study
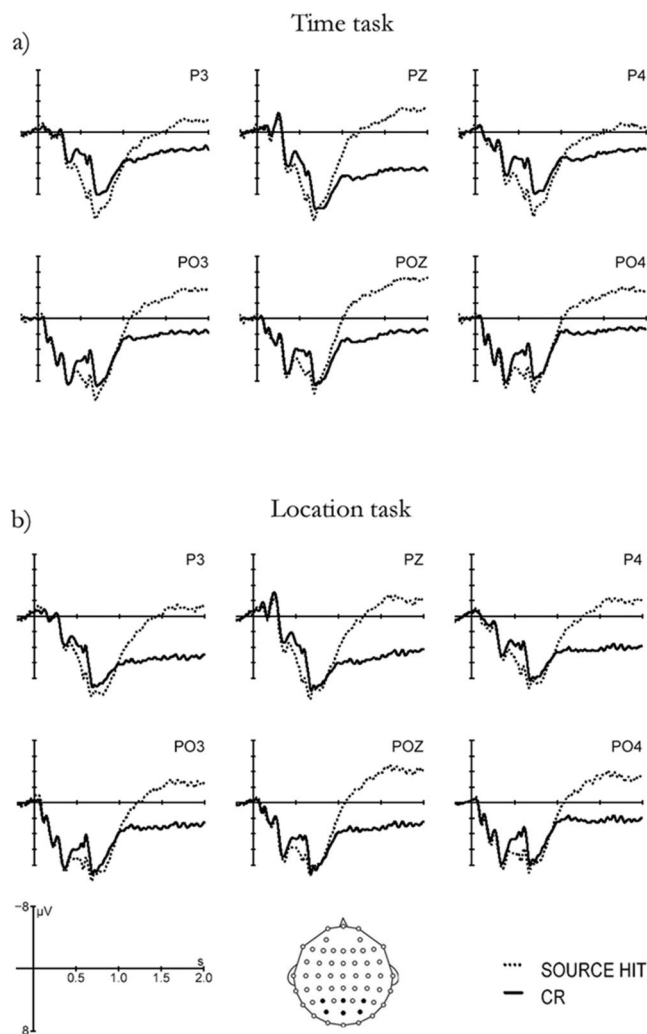


*Figure 4.* A: Grand average event-related potentials (ERPs) for the late posterior negativity (LPN) for the time source test. B: Grand average ERPs for the LPN for the location source test. P = parietal; PO = parieto-occipital.
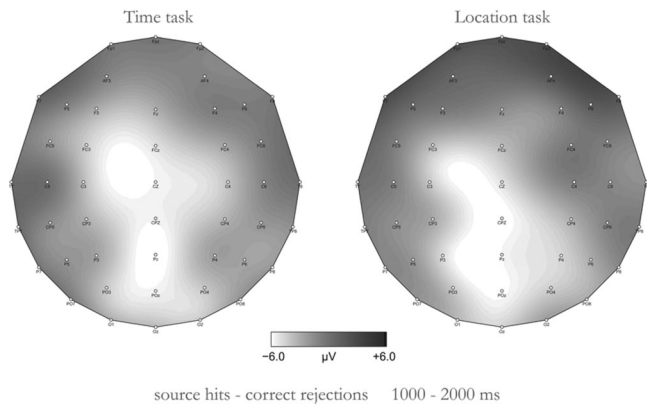
Time task          Location task



−6.0    µV    +6.0

source hits - correct rejections    1000 - 2000 ms

*Figure 5.* A: Topographical distribution of the late posterior negativity (LPN) for the time source test as expressed via the difference of source hits and correct rejections. B: Topographical distribution of the LPN for the location source test as expressed via the difference of source hits and correct rejections.

episode. Specifically, three issues were addressed: First, we explored the extent to which the posterior positivity for emotional pictures during encoding is associated with item memory and source memory performance. On the assumption that it reflects attentional capturing by emotional events, we explored whether the posterior positivity at encoding is associated with enhanced item memory for emotional events on the one side and attenuated source memory for neutral context features on the other side. Second, we were interested to what extent the old/new effects in the test phase of the recognition task are modulated by valence and arousal of the studied materials. Are the putative ERP correlates of familiarity and recollection differentially influenced by the emotional status of an item? Third, we examined whether the LPN is modulated by different source retrieval demands for emotional events.

The emotional status of the pictures affected recognition memory performance with better memory performance for positive pictures than for neutral or negative ones. Unexpectedly, we did not obtain the predicted pattern of results of the posterior positivity being associated with enhanced item memory and attenuated source memory. Rather, the posterior positivity was found in the 250–450-ms time interval for positive and negative pictures in the location task, whereas no such modulations were obtained in the time task. The finding that memory performance was enhanced for positive events as compared with negative events irrespective of task, whereas the posterior positivity was obtained for positive and negative events in the location task only, is inconsistent with the attentional capturing view of the posterior positivity. A more direct correspondence between emotion-induced ERP effects at study and item recognition memory performance was obtained for the ERP effects in the middle and late time intervals (i.e., from 450 to 850 ms). At anterior recording sites, positive slow wave activity was obtained for positive stimuli in both tasks for which enhanced memory performance was obtained. A similar pattern was found at posterior recording sites, at which the better remembered positive events were associated with enhanced encoding-related ERP positivities.

An additional, albeit less direct link between emotion-induced ERP modulations at study and recognition memory performance can be derived from the analysis of the ERP old/new effects. Although a parietal old/new effect was present for all positive and neutral pictures irrespective of source task, no such ERP old/new effect was found for negative events in the location task, for which positive slow wave activity between 450 and 850 ms at anterior and posterior recording sites was significantly reduced (i.e., not present) in the encoding phase. It is generally assumed that the magnitude of the parietal old/new effect is associated with the amount of information of a study episode being retrieved on the basis of recollection (e.g., Wilding & Herron, 2006). However, in the present study participants showed lower hit rates to negative pictures than to positive pictures in the location task (.67 and .75, respectively, $p < .05$). Also, the proportion of guess responses (estimated from the false alarm rates [Snodgrass & Corwin, 1988], which were .08 for negative pictures and .05 for neutral pictures, $p < .05$) was presumably larger for negative events than for neutral events. This suggests that the attenuated parietal old/new effect for negative pictures more likely reflects the smaller amount of negatively valenced items retrieved on the basis of recollection.

With respect to the third issue addressed in the current study, the ERP correlates of source retrieval requirements for emotional events, we obtained pronounced late posterior negative slow wave activity (i.e., the LPN) for correctly retrieved item–source associations in both tasks. Although the amplitude of the LPN was not affected by source type or emotional status of the pictures, the LPN in the time task was more fronto-centrally distributed than in the location task. This suggests that even though performance differences in source memory were only marginally significant, a difference in underlying brain activity for the retrieval of item-context associations in the late phase of the retrieval phase could be observed.

Given the unexpected findings of no memory enhancement for negative pictures relative to neutral ones, in a first step we examined whether the valence and arousal induction via the IAPS stimulus materials influenced our group of participants in the intended way. Even though the arousal levels of positive and negative pictures were equated preexperimentally by means of the IAPS ratings, on the basis of the present results it cannot be excluded that the individual arousal levels of our group of participants were higher for positive than for negative pictures. We reinvited the 20 participants to rate the 480 pictures used in the experiment using the self-assessment manikin (SAM) procedure (Lang et al., 2005). In contrast to the IAPS ratings, the arousal ratings for negative and positive pictures differed in the way in which positive pictures were far less arousing than negative pictures (3.23 vs. 5.73). In fact, positive pictures were only marginally significantly different from neutral pictures in their arousal ratings (3.23 vs. 2.56). This was confirmed by an ANOVA that indicated arousal differences between positive and negative pictures ($p < .05$) and negative and neutral pictures ($p < .05$) and only a marginally significant difference between positive and neutral pictures ($p < .10$). In contrast to the arousal ratings, the valence ratings of our group of participants were analogous to that from the IAPS. This means that the effects of the present study may be attributable to differences in the amount of arousal experienced for positive and negative stimulus materials.

A hint toward an interpretation of the present results in light of these valence and arousal ratings is given by a recent study by

Kensinger and Corkin (2004). Using functional MRI and behavioral measures, they found that distinct neurocognitive processes contribute to memory for highly arousing versus only mildly arousing emotion words. An amygdala–hippocampus network was active during the encoding of highly arousing words, whereas a prefrontal–hippocampal circuitry was engaged in the encoding of nonarousing words. This is in agreement with the interpretation of Dolcos and Cabeza's (2002) ERP results of an amygdala (related to arousal) and a prefrontal-hippocampus network (related to valence) and lends further support to a dissociation of valence- and arousal-related brain systems. An additional behavioral study by Kensinger and Corkin revealed that memory for highly arousing words was still enhanced even when a divided attention manipulation was used at study, whereas memory for low-arousing words declined when encoding resources were devoted to a secondary task. It is argued that memory enhancement for valenced but nonarousing materials relies on controlled and self-generated encoding processes such as elaboration and rehearsal, whereas memory enhancement for arousing words occurs automatically. On an electrophysiological level, this is confirmed by the anterior positivity that was obtained for positive pictures irrespective of task and by only a late posterior positivity obtained for positive pictures in the location task. Even though inferences from the scalp topography of ERP effects on underlying neural generators are in most cases problematic and comparisons can only be speculative, the anterior scalp distribution and the sustained nature of the anterior positive slow wave to positive pictures resembles the inferior prefrontal cortex activity to low-arousing emotion words in the Kensinger and Corkin (2004) study and may reflect enhanced prefrontal cortex activation devoted to the encoding of positive and low-arousing emotional stimulus materials. The high relevance of the prefrontal cortex in situations in which the retrieval of emotional information is task relevant was also recently demonstrated in a study examining the effective connectivity between brain regions relevant for processing mnemonic and emotional information (Smith et al., 2006). In a condition in which emotional contexts of a study phase had to be discriminated, Smith et al. (2006) found enhanced effective bidirectional connectivity between hippocampus and amygdala and enhanced activity in the orbitofrontal cortex, which in turn increased the hippocampus–amygdala connectivity. This suggests that the requirement to retrieve emotional information constitutes a cognitive set that modulates retrieval in a top–down manner. An interesting issue to be pursued in further studies would be to examine whether the retrieval of high- and low-arousing emotional events is mediated by different cognitive sets and brain circuitries.

Negative and highly arousing pictures evoked a posterior positivity similar to positive pictures in the location task in an early, 250–450-ms time interval, suggesting that the initial attentional capturing mechanisms were highly similar for both classes of stimuli. However, although positive stimuli were subjected to elaborated encoding processes as revealed by sustained positive slow wave activity and enhanced recognition memory performance for these stimuli, negative pictures apparently did not enter this processing stage.

To further test the idea of controlled and top–down-driven encoding processes for positive and low-arousing pictures, we conducted a subsequent memory analysis (for a review, see Paller & Wagner, 2002). In such an analysis, the ERPs at encoding are sorted according to memory performance at test (remembered vs. forgotten). There is some consensus that parts of ERP subsequent memory effects reflect top–down-driven processing like attentional orienting toward events or elaborated mnemonic strategies in support of episodic encoding (Mecklinger & Müller, 1996; Paller & Wagner, 2002). If controlled and top–down modulated encoding strategies were engaged and are reflected in the anterior slow wave, then this component should be sensitive to the later memory status. To test this assumption, we sorted the trials according to their later memory status being either "remembered" (hits at retrieval) or "forgotten" (misses at retrieval). As Pr values were not significantly different between source tasks, the ERPs of both source tasks were collapsed for this analysis. We found that the anterior positive slow wave (450 ms to 850 ms) was larger for later remembered positive pictures as compared with later forgotten ones, whereas the posterior positivity (250–450 ms) was not modulated by subsequent memory performance[2] (see Figure 6). This selective modulation of the anterior positive slow wave by subsequent memory performance confirms the view that it reflects top–down-driven encoding processes for positive and low-arousing events. In contrast, the posterior positivity may reflect the automatic bottom–up-driven attentional capturing of valent stimuli.

The finding that no memory enhancement was obtained for negative stimuli, even though they were rated as highly arousing in the IAPS and the postexperimental rating studies, could also be accounted for by the characteristics of the memory task used in the present study. There is increasing evidence for the view that memory enhancement for highly arousing stimuli is especially pronounced in memory tests with a longer retention interval (LaBar & Phelps, 1998; Sharot & Phelps, 2004). As consolidation of memory occurs over a period of time, and in the case of emotional materials involves noradrenergic mechanisms (McGaugh, 2006), the effect of arousal on memory consolidation will be apparent only following a delay. The exact duration of this consolidation process is uncertain, but behavioral effects may be evident as soon as 1 hour after encoding (LaBar & Phelps, 1998) and are expected to be visible at least 24 hr later (Sharot & Phelps, 2004). The combined item and source memory requirements in our study did not allow longer retention intervals than 2 to 3 min and by this may have wiped out arousal related memory enhancements.

Additionally, prior studies have shown that encoding instructions can be a critical variable for the occurrence of memory enhancements and impairments for emotional materials. In support of this view is a recent study by Kensinger et al. (2005), which revealed that under incidental encoding instructions, in which participants are unaware that their memory will be tested subsequently, young adults show good memory for arousing central elements of a scene and poor memory for nonarousing peripheral

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[2] The anterior positivity elicited by positive pictures was tested in a repeated-measures ANOVA with the factor memory status (remembered or forgotten) in the 450–850-ms time window at fronto-central and revealed a significant main effect of memory status, $F(1, 19) = 3.56$, $p < .05$. The posterior positivity was tested in a repeated-measures design with the factor memory status (remembered or forgotten) in the 250–450-ms time window at parieto-occipital and revealed no significant result, $F(1, 19) = 0.14$, $p > .71$.
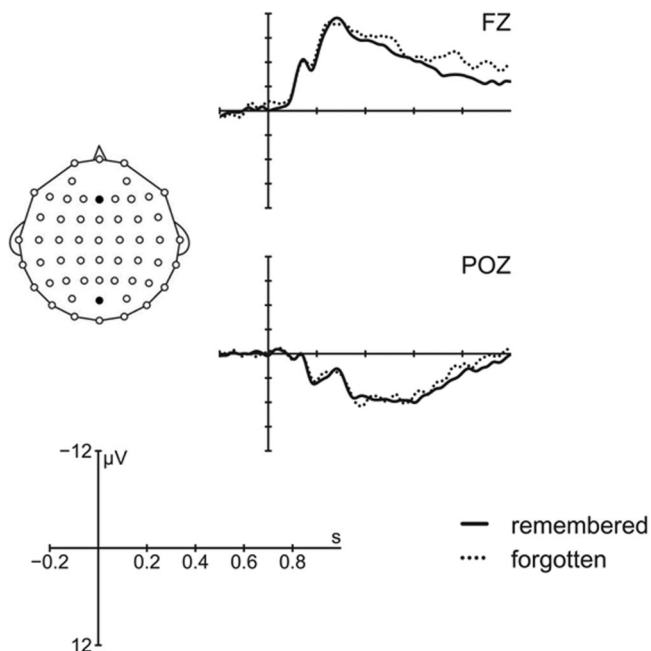
*Figure 6.* Grand average event-related potentials in the encoding phase elicited by subsequently remembered and forgotten positive pictures at fronto-central (FZ) and parieto-occipital (POZ) sites.

elements. This memory trade-off disappears under intentional encoding instructions, in which young adults show the same memory for peripheral features of emotional and neutral scenes. In light of these findings, the result that no impairments of source memory for emotional materials was found in the present study could be accounted for by controlled encoding strategies, set in train by the intentional encoding instructions. Participants may have associated the emotional stimuli with the features of the source task (where and when was a particular event encountered), and this may have overwritten the attentional capturing effects for emotional events and detrimental effects on source memory performance. The finding of slow wave activity at frontal sites for positive material only, being related to subsequent memory performance, is consistent with this view.

The observation that the presentation of negative pictures initiated a similar early posterior positivity as the presentation of positive pictures may suggest that similar attentional capturing mechanisms were initiated during the encoding of both classes of stimuli. As no memory enhancement was obtained for negative pictures, it is conceivable that negative events, because of their high-arousing characteristics, may have initiated the retrieval of autobiographical memories or personal experiences of task-irrelevant events (e.g., the last personal encounter with a given object) and by this were subjected to controlled encoding operations to a lower extent than positive and neutral events. This phenomenon could reflect the higher biological relevance of negative stimuli, which in an evolutionary sense may guarantee that biologically relevant events are not ignored or taken as irrelevant. The fact that an attenuated parietal old/new effect was observed for negative pictures is consistent with such a memory distraction function of highly arousing events. This distraction function of

highly arousing events observed in the present study may just be another instance of the automatic capture of attention by emotional events, as for example observed in the form of interference effects of emotionally valenced words in the emotional Stroop paradigm (Pratto & John, 1991). The absence of a parietal old/new effect for negative events could also be a result of an enhanced positivity to correct rejections that presumably elicited spurious or "illusory" episodic memories (Maratos, Allan, & Rugg, 2000) and by this were indistinguishable from the hits.

There are a number of studies on emotional source memory in which neutral items are presented in either neutral or emotional contexts (Maratos & Rugg, 2001; Smith, Dolan, & Rugg, 2004, Smith et al., 2006). On one hand, these studies have reliably demonstrated a positive effect of the emotional content of information on source memory, that is, when the contexts to be retrieved are themselves emotional (Smith et al., 2006). On the other hand, specific ERP effects have been observed for correctly retrieved emotional contexts (Maratos & Rugg, 2001; Smith et al., 2004). As these studies consistently used neutral items (presented in either emotional or nonemotional contexts) and the present study used emotional items in neutral context, the aforementioned studies and the present study differ in important aspects. By this, the latter findings do not speak against the present interpretation of an attentional capturing function of negative and highly arousing events. Rather, the findings of both experimental approaches suggest that depending on task characteristics and retrieval demands, the emotional content of information exerts differential mnemonic effects. It is conceivable that attentional capturing is more likely to occur for high levels of arousal and the high salience and high arousal level of the negatively valenced pictures in the present study may have enhanced the attentional narrowing and mnemonic distortion effects of these stimuli.

A final issue addressed in the present study was the extent to which the LPN, a posteriorly distributed negative slow wave frequently obtained in the test phases of source memory tasks, is modulated by source retrieval requirements in the case of emotional events. Former studies have shown that the LPN has a parieto-occipital maximum, onsets at around the time at which a response is given, and is of equal amplitude for correct and incorrect source judgments (Friedman et al., 2005; Herron, 2007; Johansson & Mecklinger, 2003). It was proposed that the LPN reflects the search for and retrieval of contextual features in tests of source memory and retrieval processes that may act to reconstruct a prior study episode when item-context features are not sufficiently recovered or need continuous evaluation. Consistent with prior studies, the present study revealed a pronounced LPN in both source tasks, underlining the high relevance of this component in the search and retrieval of attribute conjunctions. Interestingly, even though LPN amplitude was not affected by the emotional contents to be associated with either time or location characteristics of the study episode, it differed in scalp topography between the two source memory tests. Retrieving/searching conjunctions between pictures and study time elicited a more widespread LPN than those between pictures and their study location. The meaning of this finding is difficult to interpret. Notably, as recently pointed out by Urbach and Kutas (2006), inferences drawn from topographical differences of ERP effects on underlying brain generators have to be made with caution because a multitude of factors may contribute to such a pattern of results.

In conclusion, the present study sheds new light on the issue of how encoding mechanisms for emotional events affect subsequent item and source memory performance. Negative and positive events elicit a posterior positivity between 250 and 450 ms that presumably reflects attentional capturing of emotionally valenced stimuli. Positive events gave rise to additional anterior and posterior slow wave activity as compared with neutral and negative events and also showed enhanced recognition memory. In light of a postexperimental rating study that revealed that positive events in the present study were perceived as less arousing than negative events, we take the latter results to suggest that positive and low-arousing events enter controlled and elaborated encoding processes that are beneficial for recognition memory performance. The high arousal of negative events, however, may interfere with controlled encoding mechanisms and attenuate item recognition and the quality of remembering. Finally, we obtained topographically distinct LPNs in both source tasks, suggesting that this component reflects processes in service of reconstructing the study episode by binding together contextual details with an item, and these mechanisms vary with the kind of episodic detail to be retrieved.

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