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Item and source memory for emotional associates is mediated by different retrieval processes

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A R T I C L E I N F O

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A B S T R A C T

Recent event-related potential (ERP) data showed that neutral objects encoded in emotional background pictures were better remembered than objects encoded in neutral contexts, when recognition memory was tested one week later. In the present study, we investigated whether this long-term memory advantage for items is also associated with correct memory for contextual source details. Furthermore, we were interested in the possibly dissociable contribution of familiarity and recollection processes (using a Remember/Know procedure). The results revealed that item memory performance was mainly driven by the subjective experience of familiarity, irrespective of whether the objects were previously encoded in emotional or neutral contexts. Correct source memory for the associated background picture, however, was driven by recollection and enhanced when the content was emotional. In ERPs, correctly recognized old objects evoked frontal ERP Old/New effects (300–500 ms), irrespective of context category. As in our previous study (Ventura-Bort et al., 2016b), retrieval for objects from emotional contexts was associated with larger parietal Old/New differences (600–800 ms), indicating stronger involvement of recollection. Thus, the results suggest a stronger contribution of recollection-based retrieval to item and contextual background source memory for neutral information associated with an emotional event.

1. Introduction

It has long been known that emotional arousal modulates episodic memories (reviewed in Dolcos et al., 2012, 2017; in press; Weymar and Hamm, 2013b). For instance, when emotional and neutral items (e.g. words, faces or scenes) are presented in isolation and item memory is tested at a later time, emotionally arousing items are better recalled (Bradley et al., 1992; Dolcos et al., 2004) and recognized (Dolcos et al., 2005; Weymar et al., 2009) than emotionally neutral items. Further evidence for enhanced memory for emotional items comes from research using the Remember/Know procedure (Tulving, 1985). In this procedure, participants are typically asked to indicate whether their memory for emotional stimuli comprises rich contextual details of the contiguous attributes conforming the encoding episode (i.e. Remember judgments), or rather lacks contextual specifics (i.e. Know judgments). This distinction thus allows to disentangle between recollection- (measured by Remember judgments) and familiarity-based retrieval (measured by Know judgments). Results showed that the memory advantage of emotional stimuli is often driven by Remember judgments (Ochsner, 2000; Sharot et al., 2004; Dolcos et al., 2005; Weymar et al., 2010), indicating a larger involvement of the recollection processes. If memories are related to emotional episodes (e.g. a traffic accident), the associated adjacent, contextual neutral details (e.g. the color of surrounding cars, or the weather that day) can be integrated into the memory representation, which, by means of associative processes (Davachi, 2006; Ventura-Bort et al., 2016a) can also be better recollected (Ventura-Bort et al., 2016b). Conversely, later exposure to such associated contextual cues alone can also trigger reactivation of past emotional experiences. Hence, binding individual features associated with an episodic event, such as items and context (e.g. time, place, and other associative cues) is an important aspect of human memory, and clarifying the neural mechanisms underlying these associative processes is relevant for understanding alterations associated with clinical conditions, such as stress-related disorders and addiction.

Despite abundant data showing enhancement of emotional information in item memory (see for review, Dolcos et al., 2017a, 2017b;

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Weymar and Hamm, 2013b), the evidence regarding emotional influences on the accuracy of remembering contextual details (source memory) is mixed (for reviews, see Chiu et al., 2013; Kensinger, 2009; Mather and Sutherland, 2011). Emotion can facilitate memory for intrinsically associated features of emotional stimuli, but can also impair memory for associated extrinsic cues of the emotional information (Chiu et al., 2013; Mather, 2007). For instance, memory for within-item associated details, such as color (Doerksen and Shimamura, 2001; D'Argembeau and Van der Linden, 2004), spatial location (D'Argembeau and Van der Linden, 2004; MacKay and Ahmetzanov, 2005; Mather and Nesmith, 2008; Schmidt et al., 2011), or temporal order (D'Argembeau and Van der Linden, 2005; Schmidt et al., 2011; but see Koenig and Mecklinger, 2008) is enhanced for emotional stimuli (e.g. scenes or words), in comparison to their neutral counterparts. Conversely, emotion can have a negative impact on memory for between-item contextual features, when emotional objects are accompanied by neutral scenes (Kensinger et al., 2007), when neutral stimuli (e.g. objects or words) are embedded in emotional contexts (Murray and Kensinger, 2012; Nashiro and Mather, 2011; Touryan et al., 2007; Rimmele et al., 2011; Zhang et al., 2015), or when emotional scenes are presented with color frames (Rimmele et al., 2011).

Mather and Sutherland have recently proposed a solution to reconcile these controversies in the so-called *Arousal-Biased Competition Theory* (ABC; Mather and Sutherland, 2011). The authors argue that modulatory effects of emotion on memory binding depend upon the attentional priority that the critical cue receives during learning (via bottom-up perceptual salience or top-down attentional focus). This suggests that emotional arousal enhances memory for neutral features of high priority information, as it occurs in within-item binding processes, while weakens memory for neutral information (low priority) presented at the same time with emotional cues, as it is the case for between-item binding processes. Substantiating this view, some studies showed that memory for neutral objects or words simultaneously presented with emotional cues (e.g. high arousing words or emotional scenes) can benefit from the emotional arousal, if participants are instructed to learn word-word associations (Guillet and Arndt, 2009; Pierce and Kensinger, 2011) or to mentally connect objects and images at encoding (Luck et al., 2014; Maratos and Rugg, 2001; Smith et al., 2004a, 2005; Ventura-Bort et al., 2016b, but see Nashiro and Mather, 2011; Bisby et al., 2014). Hence, when surrounding neutral stimuli are highly prioritized by becoming an intrinsic feature of the emotional event, emotion is also able to enhance memory for such neutral information (Mather and Sutherland, 2011; see also Murray and Kensinger, 2013). The question arises, however, whether enhanced memory for neutral information intrinsically related to emotional events also includes correct source information (i.e. details about the associated emotional event). Furthermore, it is unclear whether memory for emotional item and source information is related to such distinct processes as recollection or familiarity.

Event-related potential (ERP) recording is considered a suitable brain imaging technique to explore such distinct memory processes (Tsivilis et al., 2001; Wilding and Ranganath, 2012). Due to its high temporal resolution, this tool is fundamental for disentangling the contribution of different mechanisms involved in the accomplishment of a specific behavior. Thus, applied to memory research, ERPs together with fine-grained behavioral measures (e.g. Remember/Know paradigm; Diana et al., 2006; Tulving, 1985) can shed light on the distinct mnemonic processes involved in retrieval (Duarte et al., 2004; Tsivilis et al., 2001; Wilding and Ranganath, 2012). ERP memory research has shown that previously encoded items that are correctly recognized, generate larger positive-going ERPs than correctly identified new information (for reviews, see Rugg and Curran, 2007; Weymar and Hamm, 2013b; Wilding and Ranganath, 2012), an effect known as the ERP Old/New effect. Two dissociable ERP Old/New effects have been identified: (i) An early ERP Old/New effect, typically maximal at fronto-central (Rugg and Curran, 2007) or left-frontal sites (Woodruff et al., 2006; Yu and Rugg, 2010) around 300–500 ms after stimulus onset, which has been associated with the subjective experience of *familiarity*, a process that seems to be mediated by the perirhinal cortex (PrC; e.g. Eichenbaum et al., 2007); (ii) A late ERP Old/New effect, typically evident over centro-parietal (Weymar and Hamm, 2013b) or left-parietal regions (Rugg and Curran, 2007) starting around 400 ms after stimulus presentation, which has been linked to *recollection*, (e.g. Bridson et al., 2006; Curran, 2000; Duarte et al., 2004; Düzel et al., 2001; Rugg et al., 1998; Woodruff et al., 2006; Yu and Rugg, 2010; see for review Rugg and Curran, 2007), a process associated with hippocampus (HC) and parahippocampal cortex (PhC) activation (Düzel et al., 2001; Eichenbaum et al., 2007; Ranganath and Ritchey, 2012).

Prior ERP studies testing item memory found that the retrieval of emotional pictures is associated with an enhanced centro-parietal ERP Old/New effect in the recollection-sensitive time window (Schaefer et al., 2011; Weymar et al., 2009, 2010, 2011, 2013a; Wirkner et al., 2013, 2015; reviewed in Weymar and Hamm, 2013b), an effect that is also related to Remember rather than Know judgments (Weymar et al., 2010). In a recent study (Ventura-Bort et al., 2016b), enhanced ERP positivity during retrieval was also observed for objects previously associated with emotional background scenes. When participants were instructed to actively integrate neutral objects in emotional and neutral scenes (instruction supporting within item/context binding; c.f., Kensinger, 2009, Mather and Sutherland, 2011), emotion enhanced memory was found for the arousing contexts and the associated objects, in comparison to their neutral counterparts (for similar results, see also Maratos and Rugg, 2001; Martinez-Galindo and Cansino, 2017; Smith et al., 2004). In ERPs, neutral objects paired with emotional contexts produced larger early fronto-central and late centro-parietal Old/New differences than objects from neutral contexts, indicating better memory for this material (Ventura-Bort et al., 2016b).

In this latter study, however, based on the ERPs, no clear conclusion could be drawn on whether memory for emotional associates was based on rich contextual details or not (acontextual remembering). Therefore, the main goal of the present study was to follow up on this matter and clarify (1) the differential contribution of recollection and familiarity processes, by assessing Remember/Know judgments (Ochsner, 2000; Sharot et al., 2004; Tulving, 1985), and (2) the associated electrophysiological correlates, by assessing the ERP Old/New effects. Considering the possible hemispheric asymmetries in the early and late ERP Old/New effects (Rugg and Curran, 2007; Woodruff et al., 2006; Yu and Rugg, 2010), the Old/New differences were analyzed in two symmetrically lateralized sensor clusters in frontal and parietal regions.

It has been observed that the retrieval of contextual information is associated with recollection, as indexed by larger parietal Old/New differences, when contextual details of a previous event are correctly recognized (Wilding and Rugg, 1996; Wilding, 2000). However, recent evidence suggests that when context and item are processed as a single unit (i.e. unitized), source memory can also be supported by familiarity-related processes (Diana et al., 2008; Bader et al., 2010), eliciting larger frontal Old/New effects (Diana et al., 2011). Additionally, it has also been shown that enhanced memory for emotional compared to neutral backgrounds is specifically supported by recollection, as indexed by more accurate remember judgments (Rimmele et al., 2011), and larger parietal Old/New effects (Smith et al., 2004a; but see Maratos and Rugg, 2001), in comparison to neutral contextual information. Therefore, based on these prior studies (Diana et al., 2008; Smith et al., 2004a; Weymar et al., 2009, 2010; Wilding, 2000), we expected that both familiarity and recollection processes would facilitate memory performance for item and source memory, but that increased memory for objects encoded in emotional contexts and the associated source information would be primarily driven by recollection processes.

2. Method

2.1. Participants

Thirty-three healthy students (30 women, 3 men; mean age = 21.8) from the University of Greifswald participated for course credits or financial compensation. All participants had normal or corrected-to normal vision and were perfect German speakers. Each individual provided written informed consent for a protocol approved by the Review Board of the German Psychological Society. Data from five participants (5 females) could not be analyzed due to various reasons (i.e. technical problems, poor EEG quality).

2.2. Stimulus material

Stimuli consisted of 360 neutral objects and 180 background scenes. Neutral objects were selected from *The Bank of Standardized Stimuli* (BOSS; Brodeur et al., 2010, 2014) and *the Ecological Adaptation of Snodgrass and Vanderwart* set (Moreno-Martínez and Montoro, 2012). Objects belonged to a heterogeneous variety of semantic categories (e.g. office supplies, electronics, household objects) and were distributed in 6 different sets of sixty items each (see Ventura-Bort et al., 2016b, for more details about the sets construction). In order to counterbalance object/scene pairings across participants, the six object sets were arranged in six different lists (for list construction see Jaeger et al., 2009; Smith et al., 2004a; Ventura-Bort et al., 2016b). Background scenes were selected from the *International Affective Picture System* (IAPS; Lang et al., 2008) and consisted of 60 pleasant (e.g. erotic, adventure, babies, animals), 60 neutral (e.g. buildings, neutral views, neutral human faces) and 60 unpleasant (e.g. mutilation, attack, disgust, accident) pictures. The three categories were matched for complexity, brightness and contrast (*ps* > .14). Normative valence and arousal ratings were 7.02 (.52) and 5.88 (.077) for pleasant scenes; 5.08 (.45) and 3.37 (.45) for neutral scenes; and 2.58 (.73) and 6.00 (.54) for unpleasant scenes. The three picture categories did not overlap in the valence x arousal space (see for similar approach Iordan et al., 2017). Pleasant, neutral and unpleasant scenes differed in normative valence ratings (*ps* < .001). The arousal ratings did not differ for pleasant and unpleasant pictures (*ts* < 1), and were reliably higher for emotional (both pleasant and unpleasant) compared to neutral scenes (*ps* < .001).

2.3. Procedure

The experimental design is displayed in Fig. 1. During the encoding session, 180 neutral objects were superimposed on 180 emotional or neutral background scenes. Objects (mean vertical and horizontal visual angle of 4.96°) and background scenes (vertical visual angle of 7.73°, horizontal visual angle of 10.93°) were presented on a 20” computer monitor located 150 cm in front of the participant. Unlike previous studies (e.g. Jaeger et al., 2009; Jaeger and Rugg, 2012; Smith et al., 2004a), in which objects were visually separated from the scenes (white background and/or yellow frame), we facilitated object-scene integration by presenting the objects unframed and with transparent background (Ventura-Bort et al., 2016b). For each trial, objects were presented on a black background in one of the four quadrants of the screen. The four positions of the objects were randomly selected and balanced across context categories. After 3000 ms, an emotional or neutral scene was added as background. Each object and scene pairing was presented together for 5000 ms, with an inter-trial interval (ITI) of 3000, 3500, or 4000 ms. In an attempt to simulate automatic, everyday-life item-context binding, participants were not encouraged to actively bind object and scene (unlike our previous study: Ventura-Bort et al., 2016b), but to attentively watch the object and the image when displayed together on the monitor. Moreover, item-context pairings were presented only once (and not twice, as in Ventura-Bort et al., 2016b). No mention of a memory test was made (i.e. incidental encoding).

One week after the encoding session, participants returned to the lab for a memory task, in which old and new objects were presented. The task took place in the same sound-attenuated dimly lit room. Each participant viewed 360 objects (i.e. the three old-objects sets and three novel-objects sets). To reduce fatigue, the recognition task was split in two experimental blocks. Object presentation was pseudo-randomized, so that an equal number of objects per condition was presented in each block with the restriction that no more than six objects of the same condition (old or new) were presented consecutively.

For each retrieval trial, an object was presented in the center of the screen (mean vertical and horizontal visual angle of 5.92°) without context for 3000 ms. After the object's offset, the question “Remember/Know/New?” appeared on the screen for 3000 ms, and participants made Remember, Know, or New judgments (Fig. 1). Participants were instructed to press the Remember button on the keyboard when they were certain that they had seen the object during encoding and they could bring back specific associated information that occurred at study (e.g. thoughts evoked by the object when seen for the first time). The Know button was to be pressed if the object was recognized as presented during encoding but no specific information could be recollected. Participants were instructed to press the ‘New’ button when the object was not seen during encoding. When objects were judged as remembered or known, participants had to retrieve specific source information associated with the object (location and picture content). Therefore, two consecutive images appeared on the screen, each presented for 3000 ms. Firstly, four possible positions (i.e. upper right, upper left, lower right, and lower left) were shown and participants had to indicate in which quadrant of the screen the object was displayed during encoding. Secondly, the words “Unpleasant, Pleasant, and Neutral” were displayed, and participants had to indicate the correct content of the picture the object was associated with. During all parts of the study, participants were instructed to avoid eye blinks and body movements, to reduce recording artifacts.

2.4. Apparatus and data analysis

EEG signals were recorded continuously from 257 electrodes using an Electrical Geodesics (EGI) high-density EEG system with NetStation software on a Macintosh computer. The EEG recording was digitized at a rate of 250 Hz, using vertex sensor (Cz) as recording reference. Scalp impedance for each sensor was kept below 30 kΩ, as recommended by manufacturer guidelines. All channels were band-pass filtered online from .1 to 100 Hz. Stimulus-synchronized epochs were extracted from 100 ms before to 1200 ms after stimulus onset and then submitted to the procedure proposed by Junghöfer et al. (2000) as implemented in the EMEGS software provided by Peyk et al. (2011) that included lowpass filtering at 40 Hz, artifact detection, sensor interpolation, baseline correction, and conversion to the average reference (Junghöfer et al., 2000).[1] The MATLAB-based toolbox BioSig (Vidaurre et al., 2011) was used for eye movement and blink artifacts corrections of the extracted epochs. This method is based on linear regression to reliably remove electrooculogram activity from the EEG (Schlögl et al., 2007). For each participant, separated ERP averages were computed for each sensor and each condition. Due to the low number of hits for the Remember and Know conditions, both response types were merged into one ‘Old’ condition. For item memory, only the trials correctly identifying old and new objects were included for ERP averaging (number of trials per condition: M = 21.1 [min = 8, max = 75], SD = 6.9). Furthermore, the low number of valid trials for correct contextual information did not allow reliable ERP analyses of contextual source memory (number of trials per condition: M = 7.6 [min = 3, max =

[1] In order to check for the reference dissimilarities between the current and other ERP memory studies, ERPs were reanalyzed using a linked-mastoids reference. The results yielded essentially the same effects.

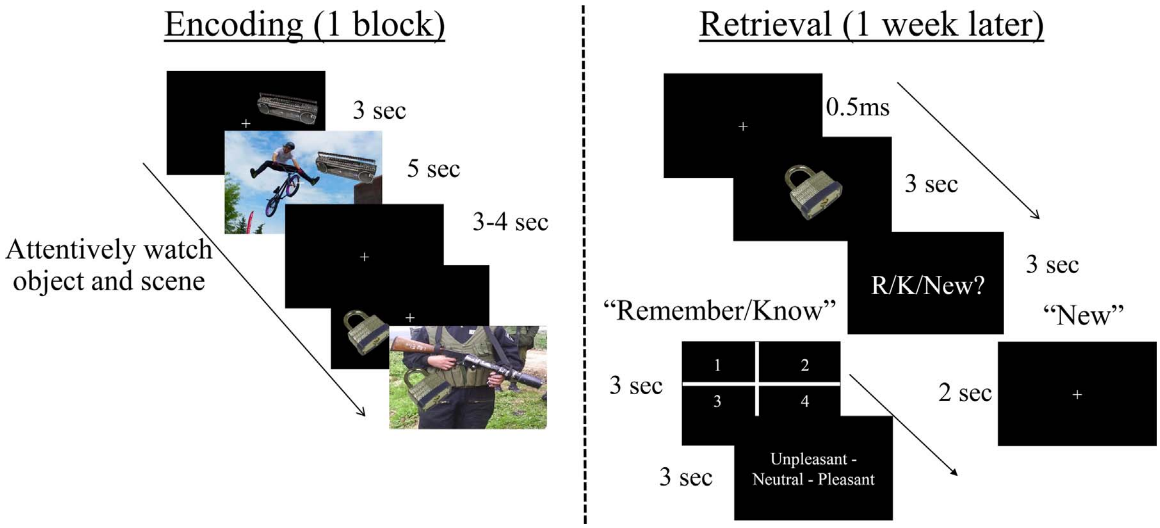

Fig. 1. Schematic view of the stimulus presentation during encoding and retrieval. During encoding, participants viewed 180 neutral objects paired with 180 emotionally arousing or neutral background scenes. During retrieval, 360 neutral objects (180 old) were presented while item (using a Remember/Know procedure) and source memory were assessed.

39], *SD* = 2.7). However, given the evidence regarding larger late ERP Old/New effects when contextual information is retrieved (Wilding and Rugg, 1996), especially when these are emotionally charged (Maratos and Rugg, 2001), exploratory analyses were performed to investigate the ERP correlates of correctly retrieved contextual information.

Based on previous studies (Duarte et al., 2004; Woodruff et al., 2006; Yu and Rugg, 2010; Ventura-Bort et al., 2016b; Tsivilis et al., 2015; Weymar et al., 2009), and based on visual inspection of the waveforms, sensor clusters and time windows were identified where the difference between old and new conditions was maximal. The early ERP Old/New effect was analyzed in a 300–500 ms time window over frontal regions (EGI HydroCel sensors left: 16, 17, 22, 23, 24, 27, 28, 29, 30, 34, 35, 36, 42, 43, and 44; right: 4, 5, 6, 7, 12, 13, 14, 20, 185, 197, 198, 206, 207, 215, and 225), and the late ERP Old/New effect was analyzed in a window 600 and 800 ms over a centro-parietal cluster (EGI HydroCel sensors left: 9, 17, 44, 45, and 53; right: 132, 144, 185, 186, and 198). Emotion effects (late positive potential, LPP) were also recorded, irrespective of context judgments. For this analysis, mean ERP amplitudes were calculated for the time windows 600–800 ms and 800–1200 ms over centro-parietal clusters, as in previous ERP studies (see for review Hajcak et al., 2012).

To investigate item memory performance, hit rates were analyzed using a repeated-measures ANOVA involving the within factors *Memory Type* (Remember vs. Know) and *Emotion* (neutral objects encoded in pleasant contexts vs. neutral contexts vs. unpleasant contexts). If the interaction reached significance, follow-up analyses were performed to elucidate the cause of the interaction effect. Because Know responses are mathematically constrained by Remember responses, hit rates for Remember and Know judgments (irrespective of context category) were further scored with respect to the independence-of-redundancy assumption (Yonelinas and Jacoby, 1995). That is, remember responses (indexed by Remember hit rate - Remember false alarm) were compared to independent Know responses (as indexed by [Know hit rate/1- (Remember hit rate)] - [Know false alarm /1- (Remember false alarm)]), which represent the probability that an old object is recognized as known given that it was not categorized as remembered. For source memory performance, hit rates were calculated for correct location of each object (hit location/ hit object). For correct background picture, the unbiased hit rate (*Hu*) was calculated (Wagner, 1993). The *Hu* index takes into account not only the stimulus performance, but also the judge performance, and is defined as the conjoint probability of the correct identification of a stimulus and the correct use of a response (Wagner, 1993). For instance, for pleasant contexts of objects restricted to Know judgments, the Hu is calculated as follows:

$$\frac{Hit\,Pleasant\,Context}{(Hit\,Pleasant\,Context + Error\,Pleasant\,Context)} * \frac{Hit\,Pleasant\,Context}{N\,of\,Pleasant\,Contexts\,Chosen}$$

Memory performance for both location and background recognition was analyzed using a repeated-measures ANOVA involving the factors *Memory Type* and *Emotion*. If the interaction reached significance, follow-up analyses were performed to elucidate the cause of the interaction effect.

Given that preliminary ERP analyses demonstrated that ERP amplitudes for objects from pleasant and unpleasant categories contexts did not differ in the chosen time windows and clusters (*ps* > .29), and that the focus of the present study was to explore the effects of emotion on item and source memory, we decided to collapse them together in one "emotion category" to facilitate the interpretation of the results (see for similar approach, e.g. Smith et al., 2004, 2005). To examine the electrophysiological correlates of item and context source memory, analyses were performed using repeated-measures ANOVAs with the within-subject factors *Memory* (old objects vs. new objects) and *Laterality* (left vs. right) over the fronto- and centro-parietal clusters. If a main effect of *Memory* or interaction was significant, follow-up analyses were performed testing the Old/New effects for each emotional category, separately. To investigate emotional differences in object processing, a 2 (*Emotion:* neutral objects encoded in emotional contexts vs. neutral contexts) × 2 (*Laterality*: Left vs. Right) repeated-measures ANOVA was performed over the centro-parietal cluster.

3. Results

3.1. Behavioral data

Table 1 summarizes the mean (standard deviation) hit rates for item and source memory by context category.

3.1.1. Item memory

3.1.1.1. Item memory was driven by Know judgments irrespective of emotional context. The analysis of item memory performance showed a main effect of *Memory Type* ($F[1,28] = 29.79$, $p < .001$ $\eta_p^2 = .52$), indicating that objects were more often categorized as known (*M* = .34, *SD* = .14) than as remembered (*M* = .14, *SD* = .1; see Fig. 2A). No effect of *Emotion* ($F[1,28] = 1.02$, $p = .37$ $\eta_p^2 = .04$) or *Memory Type* x

Table 1
Correct rejection and hit rate means (standard deviation) for correctly identified new objects, and hit rates for correctly recognized old objects encoded in pleasant, neutral, and unpleasant contexts.

	Item recognition				*Source location*		*Source background (Hu)*	
	Correct Rejection	*Total hits*	*Remember*	*Know*	*Remember*	*Know*	*Remember*	*Know*
New objects	.72 (.12)	.28 (.12)	.05(.06)	.23 (.1)				
Old objects								
Pleasant context		.49 (.15)	.14 (.10)	.35 (.15)	.20 (.20)	.23 (.08)	.17 (.2)	.08 (.05)
Neutral context		.48 (.15)	.14 (.11)	.34 (.12)	.28 (.23)	.24 (.09)	.07 (.08)	.08 (.05)
Unpleasant context		.47 (.15)	.14 (.11)	.33 (.15)	.24 (.16)	.24 (.13)	.1 (.1)	.07 (.08)
Overall		.48 (.14)	.14 (.1)	.33 (.14)				
Correcting for Dependency			.08 (.06)	.15 (.07)				

Emotion interaction ($F < 1$) were observed. After correcting for the dependency of Know and Remember responses, the analysis still revealed that memory for objects was predominantly based on knowing (M = .15, SD = .08), than remembering (M = .09, SD = .06), $t(28) = 3.87$, $p < .001$, d = .7. Know and Remember judgments also significantly differed from 0 ($ps < .001$), after correcting for the response dependency, indicating that participants deliberately distinguished between old and new items (no judgment based on chance).

3.1.2. Source memory

For location source memory, no main effect of *Memory Type* ($F < 1$) and *Emotion* ($F < 1$) was found, replicating the results of our previous study (Ventura-Bort et al., 2016b). No *Memory Type* x *Emotion* interaction was observed ($F < 1$). The hit rates did not significantly differ from chance level (.25; $ts < 1.43$, $ps > .16$), indicating that participants were guessing the location of the object during encoding.

3.1.2.1. Contextual source memory was driven by Remember judgments and enhanced for emotional background contents. For correct background pictures, the analysis revealed a significant effect of *Memory Type* ($F[1,28] = 4.49$, p = .043, η_p^2 = .14), indicating that, overall, memory for contextual backgrounds was driven by Remember judgments. A trend effect for *Emotion* $F(2,56) = 2.79$, p = .07, η_p^2 = .09 was also observed. Interestingly, we found an interaction between *Emotion* and *Memory Type* ($F[2,56] = 4$, p = .024, η_p^2 = .13). Subsequent one-way ANOVAs with the factor *Emotion* were computed for each *Memory Type,* separately: For Know judgments, the *Emotion* effect did not reach significance ($F < 1$). For Remember judgments, however, the main effect of *Emotion* was significant ($F[2,56] = 3.78$, p = .028, η_p^2 = .12). Post-hoc t-comparisons showed that memory was better for the emotional contextual information compared to neutral contextual information (pleasant contexts vs. neutral contexts: $t[28] = 2.36$, p = .025, d = .44; unpleasant contexts vs. neutral contexts: $t[28]$ = 1.61, p [one-tailed] = .059, d = .31; see Fig. 2B). No differences were observed between pleasant and unpleasant contexts ($t[28] = 1.55$, p = .13, d = .29; see Fig. 2B). Furthermore, unbiased hit rates were significantly higher than the estimated expectancy of chance level for each judgment ($ts > 2.85$, $ps < .009$), suggesting that the observed memory effects were not related to chance.

In summary, item memory performance was mainly driven by the subjective experience of familiarity, irrespective of whether the objects were previously encoded in emotional or neutral contexts. Although location source memory was at chance level, contextual source memory for backgrounds was enhanced when item memory was driven by recollection. Interestingly, recognition for contextual cues (correct background picture assignment) varied as a function of the emotional properties of the contexts. Although no emotional facilitation was observed when item memory was driven by familiarity, emotional contextual cues, especially pleasant ones, were retrieved more often when item memory was based on recollection. Thus, behavioral findings, confirm our hypotheses about the involvement of both familiarity and recollection in item and context memory. However, our predictions about the emotional modulatory effects on memory performance for both item and context were only partially confirmed.

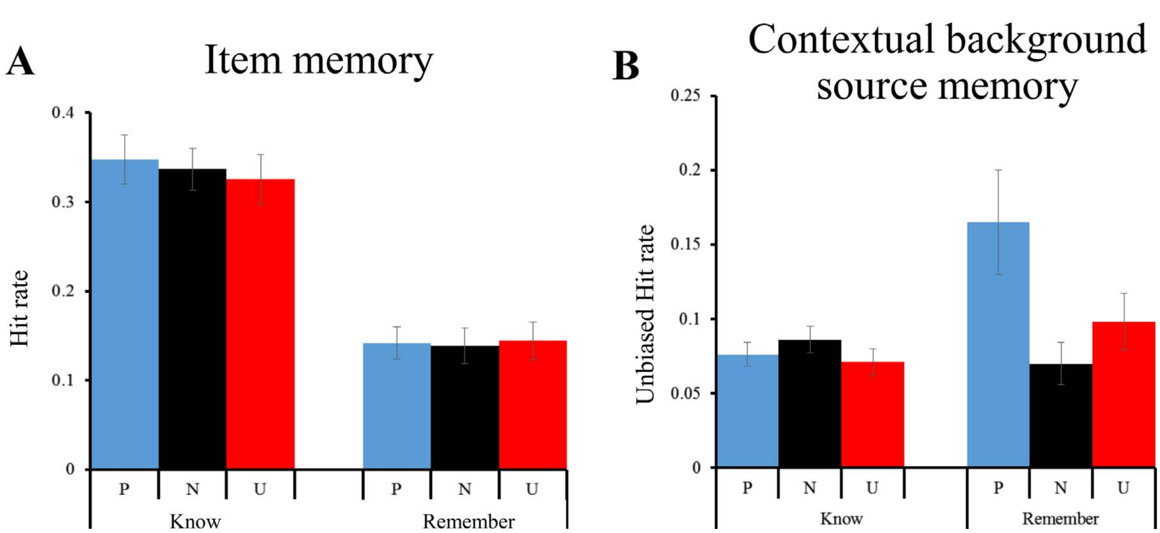

Fig. 2. Memory performance in the *Remember/Know* paradigm. A: Know (left) and Remember (right) hit rates for objects encoded in pleasant (blue), neutral (black), and unpleasant (red) contexts. **B:** Unbiased hit rates for contextual background source memory based on Remember and Know judgments for objects encoded in pleasant (blue), neutral (black), and unpleasant (red) contexts. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

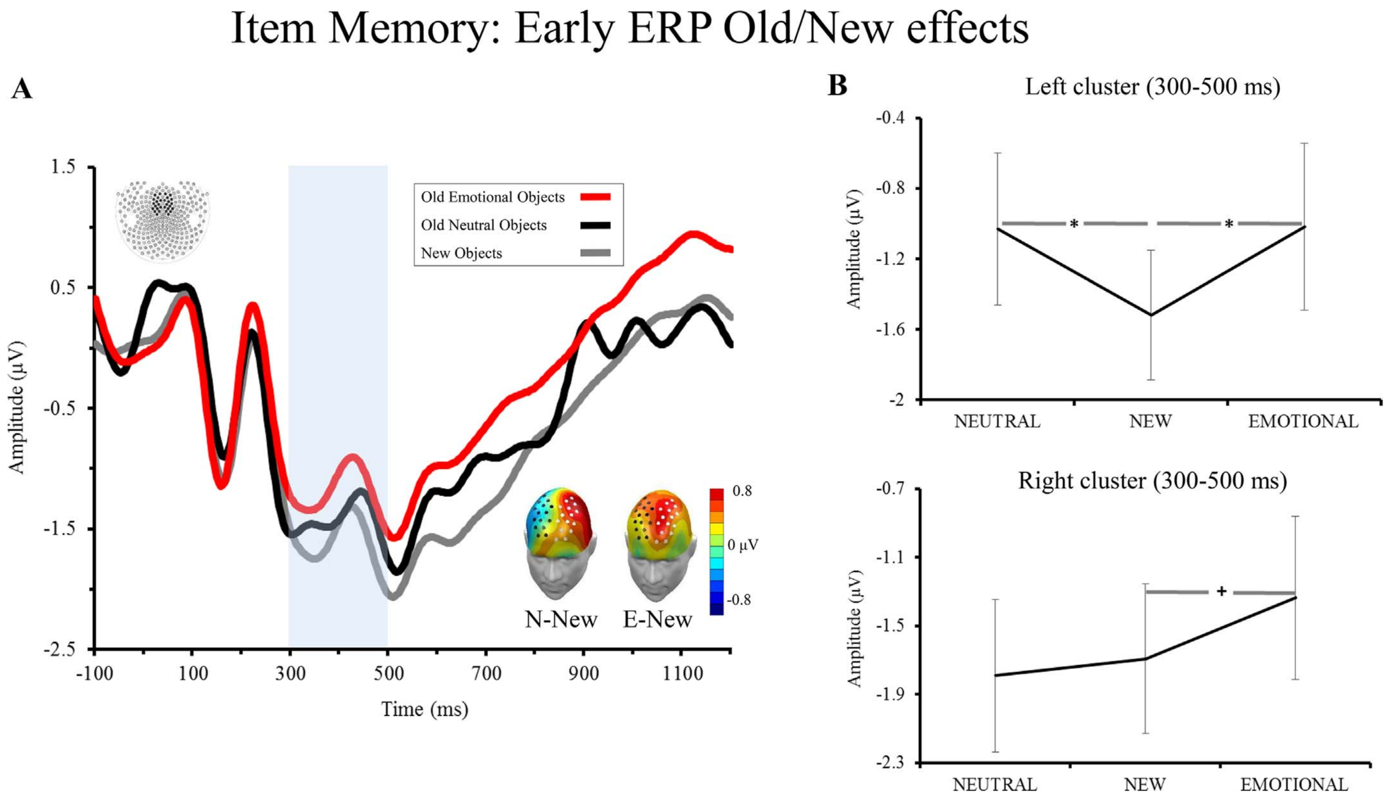

Fig. 3. Early ERP Old/New effect for item memory. A: Grand average ERPs in response to correctly recognized new objects (gray), old objects previously encoded with neutral backgrounds (black), and old objects previously encoded with emotional backgrounds (red). ERPs were averaged across electrodes within left and right frontal clusters (see upper right inset). Lower right inset: Scalp topographies for the ERP Old/New differences for each context category during the 300–500 ms time window between correctly identified old objects encoded in neutral contexts (N) and new objects (left), and correctly identified old objects encoded in emotional contexts (E) and new objects (right). **B:** Upper: Mean (standard error) ERPs of the left frontal cluster during 300–500 ms. Lower: Mean (standard error) ERPs on the right frontal cluster during 300–500 ms. * $p < .05$; + $p < .05$ one-sided. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

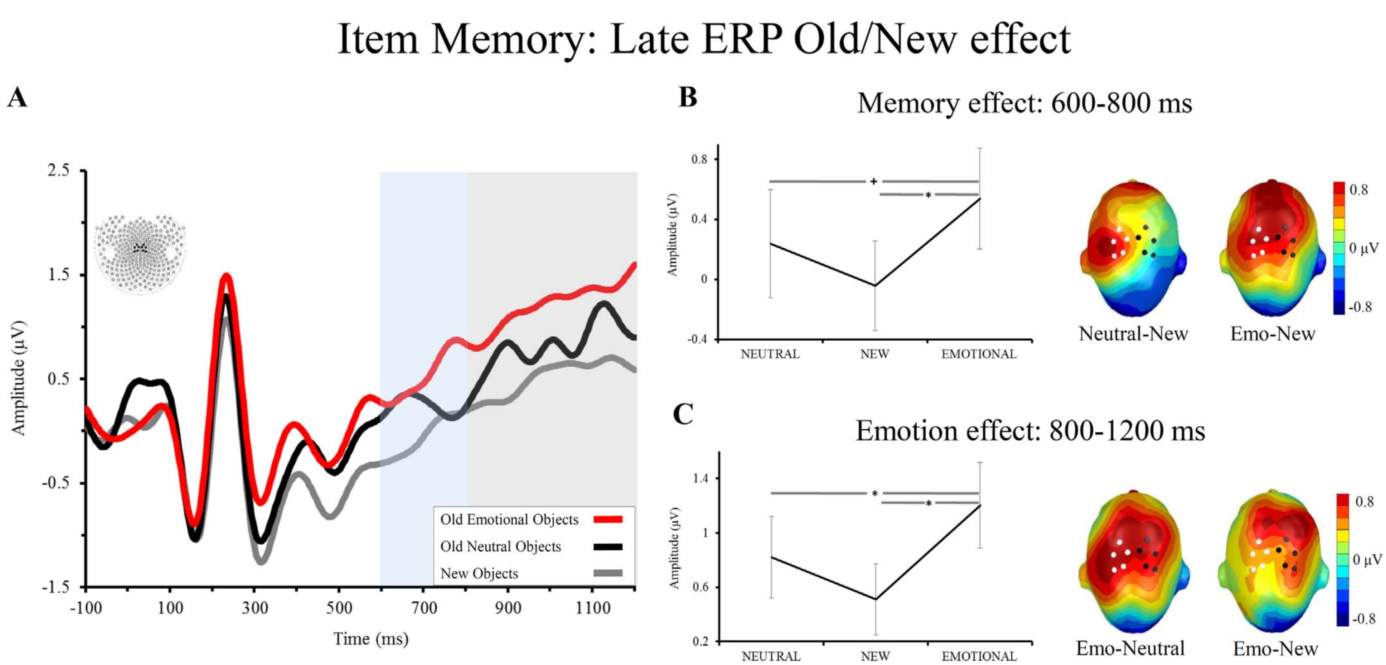

Fig. 4. Late ERP Old/New effect for item memory. A: Grand average ERPs prompted by correctly recognized new objects (gray), old objects previously encoded with neutral backgrounds (black), and old objects previously encoded with emotional backgrounds (red) of representative lateralized centro-parietal clusters (see inset). **B:** Memory effect. Left: Mean (standard error) ERPs across electrodes within left and right centro-parietal clusters during 600–800 ms. Right: Scalp topographies for ERP Old/New differences during 600–800 ms for each context category. **C:** Emotion effect. Left: Mean (standard error) ERPs of the whole centro-parietal cluster (800–1200 ms.) Right: Scalp topographies for ERP Old/New differences (800–1200) ms for each context category. * $p < .05$; + $p < .05$ one-sided. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. ERP data

4.1. Item memory

4.1.1. Early ERP Old/New effect (300–500 ms) irrespective of emotional context

Fig. 3 illustrates grand average ERPs for representative frontal sensor clusters for correctly recognized old objects encoded in emotional and neutral contexts, and correctly identified new objects. At frontal regions, correctly recognized old objects elicited a larger positivity than correctly identified new objects, as shown by a main effect of *Memory*: $F(1,27) = 5.45$, $p = .027$, $\eta_p^2 = .17$. A main effect of *Laterality* was also found ($F[1,27] = 10.1$, $p = .004$, $\eta_p^2 = .27$), indicating larger overall activity over left electrode locations. However, a *Memory* x *Laterality* interaction was not observed ($F[1,27] = 2.71$, $p = .11$, $\eta_p^2 = .09$; see Fig. 3A).

To follow up on the main effect of *Memory*, the Old/New effect was assessed separately for objects encoded in emotional contexts and for those encoded in neutral contexts. Objects paired with emotional contexts elicited a larger ERP activity than new objects (neutral objects encoded in emotional contexts vs. new objects: $F[1,27] = 5.19$, $p = .031$, $\eta_p^2 = .16$). No interaction with *Laterality* was observed ($F < 1$). For objects associated with neutral contexts, overall, ERPs did not show a larger positivity activity than new objects (neutral objects encoded in neutral contexts vs. new objects: $F < 1$), however a significant interaction with *Laterality* was found ($F[1,27] = 4.29$, $p = .048$, $\eta_p^2 = .14$). Follow-up comparisons revealed that objects associated with neutral contexts elicited an Old/New effect over left ($t[27] = 2.14$, $p = .041$, $d = .40$), but not over right brain regions ($t < 1$; see Fig. 3B).

4.1.2. Late ERP Old/New effect (600–800 ms) for objects encoded in emotional contexts

Fig. 4 illustrates grand average ERPs for correctly recognized old objects encoded in emotional and neutral backgrounds, and correctly identified new objects for representative centro-parietal sensor clusters. At parietal sites, ERP differences were found between correctly recognized old objects and correctly identified new objects, as indicated by a main effect of *Memory* ($F[1,27] = 5.14$, $p = .031$, $\eta_p^2 = .16$). Neither a main effect of *Laterality* ($F < 1$) nor a *Memory* x *Laterality* interaction ($F[1,27] = 1.71$, $p = .20$, $\eta_p^2 = .06$) were observed. Because no *Laterality* effects were found, follow-up analyses were performed collapsing sensors across sites. T-test comparisons revealed that objects associated with emotional contexts showed Old/New differences ($t[27] = 3.06$, $p = .005$, $d = .57$), whereas ERPs did not differ between objects associated with neutral contexts and new objects ($t[27] = 1.27$, $p = .21$, $d = .24$; see Fig. 4B), replicating our previous work (Ventura-Bort et al., 2016b).

4.1.3. Enhanced emotion effect (LPP) for objects encoded in emotional contexts

During the 600–800 ms time window over parietal regions, objects associated with emotional backgrounds scenes showed a more positive-going waveform than objects paired with neutral contexts, but this difference was only significant at trend level (*Emotion:* $F[1,27] = 3.61$, $p = .07$, $\eta_p^2 = .12$). *Laterality* effects were not significant (main effect: $F < 1$; interaction: $F[1,27] = 2.5$, $p = .12$, $\eta_p^2 = .09$). During 800–1200 ms, however, analyses revealed that objects associated with emotional compared to neutral contexts evoked significantly larger LPP amplitudes (*Emotion:* $F[1,27] = 5.61$, $p = .025$, $\eta_p^2 = .17$ see Fig. 4C). Again, no *Laterality* effects were observed (*Laterality*: $F < 1$; interaction: $F < 1$).

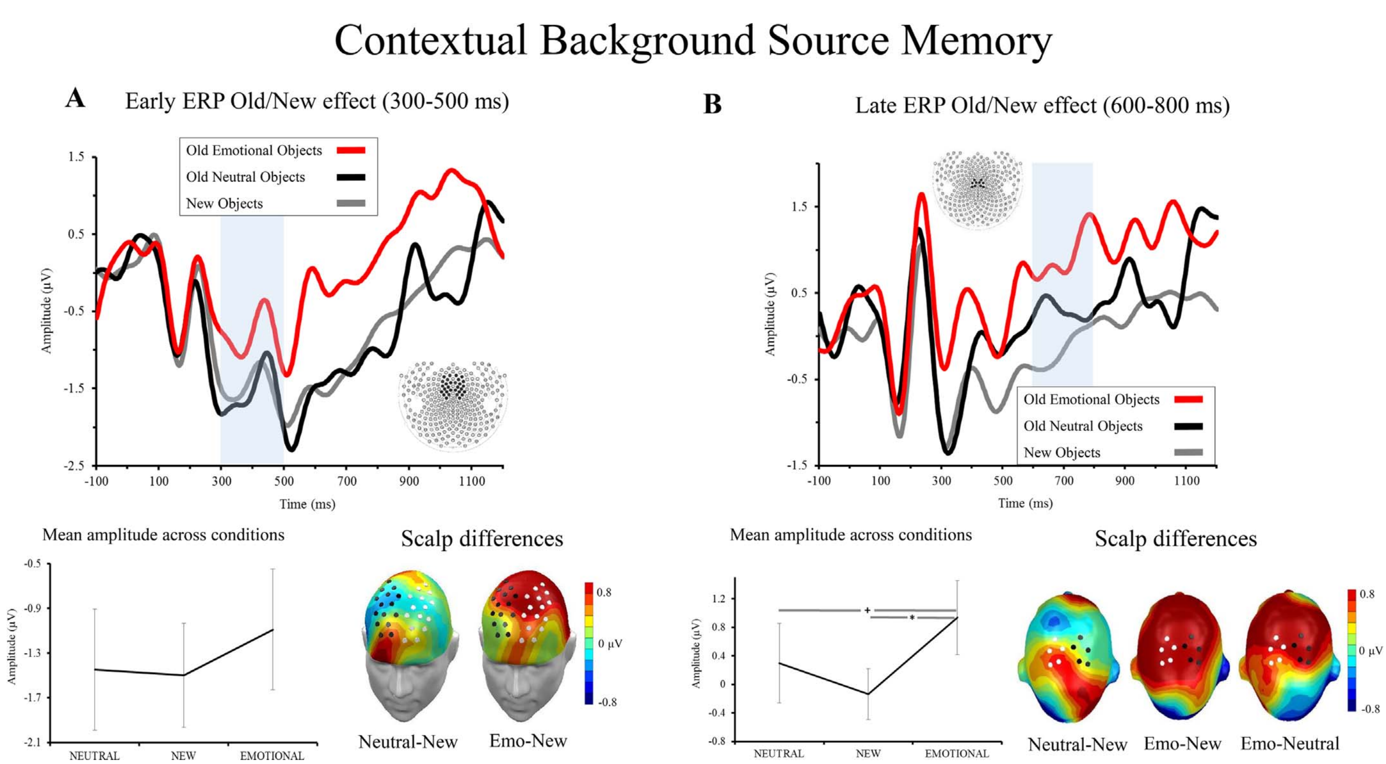

Fig. 5. Early and late ERP Old/New effects related to contextual background source memory. A: Early ERP Old/New effect. Upper: Grand average ERPs in response to correctly recognized new objects (gray), old objects with correctly recognized neutral backgrounds (black), and old objects with correctly recognized emotional backgrounds (red). ERPs were averaged across electrodes within two frontal clusters (see inset). Lower left: Mean (standard error) ERPs across frontal clusters during 300–500 ms. Lower right: Display of the scalp topographies of the ERP Old/New differences. **B:** Late ERP Old/New effect. Upper: Mean ERPs evoked by correctly recognized new objects (gray), old objects with correctly recognized neutral backgrounds (black), and old objects with correctly recognized emotional backgrounds (red). Waveforms represent ERPs averaged across electrodes over centro-parietal sensors (see inset). Lower left: Mean (standard error) ERPs across centro-parietal clusters during 600–800 ms. Lower right: Scalp topographies of the ERP Old/New differences and ERP emotional differences. * $p < .05$; + $p < .05$ one-sided. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4.2. Contextual source memory for backgrounds

Fig. 5 illustrates grand average ERPs for old neutral objects presented in correctly recognized contextual emotional and neutral backgrounds and correctly identified new objects for representative frontal (Fig. 5A) and centro-parietal electrode clusters (Fig. 5B).

4.2.1. Early ERP Old/New effect (300–500 ms) was not modulated by correct contextual background source memory

When contextual cues (background pictures) were correctly recognized, ERP amplitudes for the associated objects did not differ from new objects, *Memory*, $F < 1$. Neither *Laterality* ($F < 1$) nor interaction ($F < 1$) effects were observed (see Fig. 5A).

4.2.2. In contrast, late ERP Old/New effect (600–800 ms) was modulated by correctly recognized contextual background source

Over centro-parietal regions, ERPs to old objects with correctly recognized background pictures showed larger positivity when compared to new objects, as indicated by a significant main effect of *Memory* ($F[1,22] = 4.37$, $p = .048$, $\eta_p^2 = .17$). *Laterality* effects did not reach significance level (main effect: $F[1,22]$ 3.35, $p = .08$, $\eta_p^2 = .14$; interaction: $F < 1$). Again, because no *Laterality* effects were found, follow-up analyses were performed collapsing both sensor sites. T-comparisons revealed that, when emotional contextual cues were correctly recognized, the associated neutral objects elicited a parietal ERP Old/New difference ($t[22] = 2.83$, $p = .01$, $d = .59$), whereas the recognition of neutral contextual cues did not evoke such an effect ($t[22] = 1$, $p = .32$, $d = .21$; see Fig. 5B).

In summary, correctly recognized old objects evoked frontal ERP Old/New effects (300–500 ms) irrespective of context category. In a later time-window (600–800 ms), parietal Old/New differences were exclusively observed for objects encoded in emotional, but not in neutral contexts. In addition, larger LPPs were observed over parietal electrodes (800–1200 ms) for objects associated with emotional contexts, compared to neutral ones. In contrast to item memory, contextual background source memory did not show ERP Old/New effects at frontal regions. However, parietal ERP Old/New effects (600–800 ms) were observed particularly for correctly recognized emotional contexts, indicating recollection-based remembering. These ERP findings support our second hypothesis concerning the modulatory effect of emotion on the Old/New effect: for both item and background source memory, emotional enhancing effects were observed in the late ERP Old/New effect, reflecting a greater involvement of recollection-based memory.

5. Discussion

In the present study, we investigated item and source recognition for episodic events that involved neutral objects encoded in emotional or neutral contexts. Using a Remember/ Know paradigm, a dissociation of the mnemonic mechanism underlying item and contextual background source memory was observed. Whereas memory performance for neutral objects was mainly driven by familiarity-related judgments, independently of the emotional contexts, memory for contextual background sources was more related to recollection processes, especially for emotionally arousing backgrounds. In line with the behavioral performance, we found early frontal Old/New differences (300–500 ms) in the ERPs during object retrieval irrespective of encoding context. Parietal Old/New differences (600–800 ms), however, were found particularly for objects associated with emotional contexts. Emotional differences between objects emerged in parietal areas during 800–1200 ms, as indexed by larger LPP amplitudes for emotional compared to neutral associates. These findings will be discussed in detail below.

We observed that memory for neutral objects encoded in both emotional and neutral contexts was strongly guided by familiarity (rather than recollection) judgments, when given one week after encoding. This behavioral finding was also visible in the ERPs, in which Old/New differences were observed over frontal regions irrespective of contextual information, supporting previous studies that associate this component to familiarity (e.g. Curran, 2000; Duarte et al., 2004; Woodruff et al., 2006; Yu and Rugg, 2010; see for review Rugg and Curran, 2007). A recent ERP study (Tsivilis et al., 2015) also observed that long-term memory (4-weeks delay) for neutral objects relies more on familiarity than recollection, supporting our item memory finding. Contrary to our predictions, we did not observe memory-enhancing effects on performance for neutral objects paired with emotional contexts. The current finding contrasts with our previous results in which memory recognition was enhanced for objects associated with emotional compared to neutral contexts (Ventura-Bort et al., 2016b). In ERPs, similar to our prior research (Ventura-Bort et al., 2016b), enhanced parietal Old/New differences were found for neutral objects encoded in emotionally arousing context, suggesting a stronger recollective experience for these items.

The dissimilarities in memory performance between the present and our former study could have methodological reasons. In our previous study, we facilitated item/context binding by instructing participants to actively imagine the objects in the background contexts. We also presented the object-context pairings twice to ensure deeper encoding (Kensinger, 2009; Mather and Sutherland, 2011). In the current study, however, we attempted to generate a more realistic scenario with no “artificial” item-context binding instruction and only a single presentation of each object/background pairing. According to the ABC theory, it is possible that these variations weakened object/context binding and lessened the attentional priority for the objects during encoding (Mather and Sutherland, 2011), which might have impacted the behavioral but not the neural mnemonic enhancement. Given that ERPs are considered a fine-grained tool to detect changes in cognitive processing, even in the absence of behavioral indicators (e.g. Jaeger et al., 2009), these methodological changes may have led to the lack of emotional effects on memory performance in the presence of enhanced parietal ERP Old/New effects.

Interestingly, we observed ERP differences over parietal regions in a later time window (800–1200 ms) between objects from emotional and neutral backgrounds. This slow positive-going waveform resembles the LPP in time and location (e.g. Cuthbert et al., 2000; Foti et al., 2009; Hajcak and Olvet, 2008; see for review, Hajcak et al., 2012; Lang and Bradley, 2010). The LPP is a sustained positive-going waveform maximal at central posterior sites from 500 ms to several seconds after stimulus presentation (e.g. Hajcak and Olvet, 2008), and is larger following the presentation of both pleasant and unpleasant compared to neutral stimuli (Cuthbert et al., 2000; Dolcos and Cabeza, 2002; Foti et al., 2009; Schupp et al., 2000 see for review, Hajcak et al., 2012). The LPP is considered a neural index that reflects facilitated allocation of attention to motivational stimuli by means of which relevant information received increased processing resources (Ferrari et al., 2008). Associative learning studies have also observed that neutral stimuli (e.g. faces or objects) associated with emotionally relevant information (e.g. shocks or emotional pictures) evoke larger LPP amplitudes than prior to association and compared to neutral stimuli associated with non-relevant information (Pastor et al., 2015; Pizzagalli et al., 2003; Ventura-Bort et al., 2016a), indicating an increase of motivational relevance toward the emotional associates. In line with these results, the present finding seems to indicate that objects from emotional contexts, acquired motivational value, leading to more sustained processing.

We further observed that emotion enhanced the recollection of contextual background sources. This result is consistent with prior studies assessing memory for neutral and emotional scenes (Dolcos et al., 2005; Ochsner, 2000; Sharot et al., 2004; Weymar et al., 2009, 2010), in which participants were more likely to experience vivid memories for emotionally arousing images compared to neutral ones, as indicated by higher Remember judgements and recognition confidence rates. The present finding also replicates previous results showing that memory for emotional contextual cues is related to recollection processes (Rimmele et al., 2011, 2012). Moreover, the exploratory ERP analyses showed larger late parietal ERP Old/New effects exclusively when emotional information was correctly retrieved, giving further support to the greater involvement of recollection processes in emotional contextual memory. Interestingly, participants were more prone to recollect information about contextual cues, when these were pleasant. This result is somewhat unexpected, particularly considering previous research emphasizing memory enhancement of unpleasant information following long delays for item (e.g., Weymar et al., 2011) and contextual cues (Pierce and Kensinger, 2011). One possible explanation could be related to the characteristics of the negative contexts per se in combination of the encoding instructions. It could be that with negative contexts, participants' attention was specially directed to the threatening cues and, in absence of an explicit binding instruction, the item-context association was diminished, leading to less accurate recognition of the contextual cues.

In terms of the underlying neural mechanisms of item and contextual background source memory, there is a large number of studies reporting that memory-related subregions of the medial temporal lobe (MTL), involving the PRc, PHc and the HC, may have different influence on the retrieval of item and source information (see for reviews, Davachi, 2006; Diana et al., 2007; Eichenbaum et al., 2007; Ranganath, 2010; Ranganath and Ritchey, 2012). The PRc receives projections from multiple perceptual regions that collect information about unidimensional characteristics of items (the 'what' stream), whereas the PHc receives projections from posterior cortical areas, gathering information about contextual details (the 'where' stream). The 'what' and 'where' routes converge in the HC where contextual- and item-related information are elaborated and integrated to form the representation of the episodic event (e.g. Diana et al., 2007). Consistent with this, neuroimaging and lesion studies have observed that the PRc activity is related to item, but not to source memory, while the PHc and the HC (and to some extent also the retrosplenial cortex) activation is associated with source memory (e.g. Davachi et al., 2003; reviewed in Davachi, 2006; Ranganath and Ritchey, 2012). In turn, the PRc activity can support item representations in long-term memory, when no specific contextual information is retrieved, as it is the case in familiarity-based recognition. Alternatively, PHc activity is involved in the representation of the contextual information associated with such items in long-term memory, as it occurs in recollection. Evidence for this distinction comes from studies showing that activity in the PRc is increased for items that are later recognized as familiar, whereas activity in the PHc (and HC) selectively predicts later recollection processes (e.g. Dolcos et al., 2005; Ranganath et al., 2003; see for reviews, Eichenbaum et al., 2007; Diana et al., 2007).

The fact that in the present study item recognition was mainly based on familiarity, independently of the contextual details, concurs with evidence for the involvement of the PRc in item memory (e.g. Diana et al., 2010; Staresina and Davachi, 2008; Staresina et al., 2011). Greater influence of recollection processes in the retrieval of contextual cues is also consistent with a greater contribution of the PHc to source memory (e.g. Davachi et al., 2003; Ranganath et al., 2003). Finally, the modulatory effects of emotion on recollection-based memory also seems coherent with the greater involvement of the PHc (Smith et al., 2004b), mediated by the amygdala (Ritchey et al., 2008), in emotional memory. The present findings therefore expand prior evidence in favor of the existence of two processes influencing recognition (Yonelinas, 2002), demonstrating that familiarity and recollection are distinct memory processes that differently contribute to item and contextual memory. Our data also support the view that memory for emotionally relevant information is based on recollection processes (Dolcos et al., 2005; Weymar et al., 2010). However, we can only draw tentative conclusions regarding the brain structures underlying the different mnemonic mechanisms, based on ERP data. Thus, future neuroimaging studies are needed to shed light on the specific brain regions involved in item and source (background) emotional memory.

Prior source memory studies have observed that the enhanced memory for source information may be the result of a greater unitization (Diana et al., 2011). Unitization is understood as a process by means of which source and item information are codified as a single event (e.g. Bader et al., 2010), which is associated with familiarity-based memory and larger frontal ERP Old/New effects (Diana et al., 2011). When this integration involves emotionally relevant information, memory for the integrated neutral events seems to be enhanced (e.g. Guillet and Arndt, 2009). This is in line with our previous study, in which we instructed participants to actively bind item and emotional source information, and found larger frontal ERP Old/New effects for items previously associated with unpleasant backgrounds, which may, in part, be due to stronger unitization processes (Ventura-Bort et al., 2016b). In the present study, in the absence of any integration-related instructions during encoding, the observed frontal ERP Old/New effect was emotion-unspecific and only present for item memory, suggesting that the involvement of unitization was rather scarce. In contrast, the emotional enhancing effects on item and contextual background source memory were only observed for the parietal Old/New effect, indicating a greater involvement of recollection-based (likely PHc and HC-mediated) processes.

5.1. Caveats

Although this study provides new insights on distinct processes involved in item and contextual background source memory, some limitations need to be mentioned. First, memory for location source information was at chance level. The inability to remember the position of the objects at encoding could be related to the relevance given to the specific information about the locus of the items (Mather and Sutherland, 2011). Indeed, attention towards irrelevant information diminishes in favor of more relevant emotional information (Schupp et al., 2007). In the present study, emotional context effects were observed during retrieval, suggesting that participants considered the background information, compared to object location as more potentially relevant, leading to better memory storage. Second, although the encoding instruction (attend to item and context) meant to simulate automatic, everyday-life binding, it came with memory detrimental costs, as observed in an overall low hit rates, which were not optimal to study the electrophysiological correlates of contextual memory. Indeed, compared to our previous study (Ventura-Bort et al., 2016b), in which participants were encouraged to actively bind object and background scene, memory performance was notably reduced (.48 vs .63, $t[57] = -4.43$, $p < .001$, $d = 1.15$). Consequently, for ERP analyses, the number of valid trials per condition was also diminished. To overcome this limitation, future studies should try and ensure a larger number of trials for ERP analyses, for instance, by instructing the participants to bind object and scene, duplicating the number of item-background presentation, and/or reducing the time interval between encoding and recognition.

6. Conclusion

Taken together, we found that familiarity guided object recognition, irrespective of context category, whereas contextual background information facilitated recollection-based memory retrieval. Importantly, emotion enhanced recollection memory for item and correct contextual background source, as indicated by larger late parietal ERP Old/New effects. Our findings highlight the importance of considering mnemonic processes, such as familiarity and recollection, to provide a better understanding of the mechanisms underlying item and contextual background source memory, in interaction with emotion. The ability to trigger past contextual information is crucial for the survival of the individual (McGaugh, 2000). However, in some circumstances, when the contextual cues are bound to traumatic events or to impulsive behaviors, the retrieval of these cues might bring back emotional and motivational states that, in extreme cases, could lead to the development and/or maintenance of clinical conditions, such as stress- and trauma-related disorders and addiction (Dolcos, 2013; Ehlers and Clark, 2000; Robinson and Berridge, 1993).

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