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Dissociating electrophysiological correlates of subjective, objective, and correct memory in investigating the emotion-induced recognition bias

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ABSTRACT

Performance on tasks requiring discrimination of at least two stimuli can be viewed either from an objective perspective (referring to actual stimulus differences), or from a subjective perspective (corresponding to participant's responses). Using event-related potentials recorded during an old/new recognition memory test involving emotionally laden and neutral words studied either blockwise or randomly intermixed, we show here how the objective perspective (old versus new items) yields late effects of blockwise emotional item presentation at parietal sites that the subjective perspective fails to find, whereas the subjective perspective ("old" versus "new" responses) is more sensitive to early effects of emotion at anterior sites than the objective perspective. Our results demonstrate the potential advantage of dissociating the subjective and the objective perspective onto task performance (in addition to analyzing trials with correct responses), especially for investigations of illusions and information processing biases, in behavioral and cognitive neuroscience studies.

1. Introduction

Behavioral and Cognitive Neuroscience experiments typically involve two or more stimulus conditions in which responses are being observed, to be linked later on with brain measures or reaction times. Before data analysis, researchers typically sort the trials in which the dependent measures were taken into "bins" that are then to be compared. The sorting is usually performed in accordance with the pre-defined task design, and demarcates objective stimulus differences between conditions. Trials with incorrect responses are often eliminated so that only correct responses are compared between conditions. Most rarely, researchers adopt the subjective perspective onto task conditions by sorting trials into bins depending on the experience of the participants as indicated by their responses, whether or not these are objectively correct.

When task performance is perfect, the objective perspective onto differences between experimental conditions corresponds one on one with both, the subjective perspective and the analysis of correct response trials. However, inasmuch as the task is difficult or otherwise induces uncertainty or ambiguity, the subjective, objective, and correct perspectives

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should yield quite different pictures. Particularly interesting are cases where participants *believe* that their responses are correct when this belief is independent of, or even contrasts with, objective reality. Such systematic deviations of the subjective from the objective perspective usually occur due to biases or illusions.

The interesting question for scientists interested in cognition and consciousness is how and at what level of processing objective stimulus features are being transformed by the brain into subjectively experienced attributes that determine responses. What might be expected is that input-driven, bottom-up processes covary more with variations in objective stimulus attributes whereas the decision output is more reflective of the selective, distorted, or otherwise biased processes controlled by subjects. Such dissociations between the objective and the subjective realm are conceivable for all kinds of cognitive tasks including perceptual, memory, reasoning, and decision-making tasks. The present article attempts to apply this rationale in investigating accurate versus biased recognition memory processes as indexed by event-related potentials (ERPs).

Two prior experiments that have taken ERPs while participants performed a recognition memory task illustrate some of the potential benefits associated with adopting different perspectives onto the data. First, Rugg et al. (1998) found a fascinating dissociation between ERP correlates of implicit/unconscious and explicit/conscious recognition memory. They made use of the fact that ERPs recorded during memory tests are typically more positive going for studied (old) items relative to unstudied (new) items, a difference called the ERP old/new effect (Allan, Wilding, & Rugg, 1998; Mecklinger, 2000; Rugg & Curran, 2007). Rugg et al. (1998) found that at parietal sites between 300 and 500 ms poststimulus, ERPs associated with correctly identified studied items (hits) and ERPs associated with incorrectly identified studied items (misses) were both more positive going than were ERPs associated with correctly identified unstudied items (correct rejections). Apparently, ERPs generated from implicit/unconscious memory systems detected the *objective* difference between studied and unstudied items while participants *subjectively* did not (in the case of the missed items). By contrast, later during the recording epoch, between 500 and 800 ms poststimulus, ERPs associated with missed studied items did indeed go alongside ERPs associated with correctly identified unstudied items (correct rejections), whereas ERPs to correctly identified old items (hits) were more positive going. Thus, ERPs in that later time-window (the late positive complex, LPC) reflected the *subjective* perspective onto the study status of the items. Finally, at around 400 ms poststimulus, ERPs indexed a subjective feeling of "familiarity" that is thought to arise automatically but lacks conscious recollection and thus appears to mark the transition between unconscious and conscious memory processes. It is presumably at this processing stage when automatically processed, input-driven memory processes are accessed by subjective experience. Later investigations with magnetoencephalography confirmed the time-point and the frontal distribution of this transition process (Staresina, Bauer, Deecke, & Walla, 2005).

The second recognition memory study demonstrating dissociations between subjective and objective perspectives onto ERP old/new differences investigated the response bias in recognition memory judgments (Windmann, Urbach, & Kutas, 2002). The response bias can be defined as the tendency to guess "old" when there is uncertainty as to which response, "old" or "new", is correct. Windmann et al. (2002) compared ERPs of one group of individuals who showed a spontaneous tendency to guess liberally in favor of old items (i.e., who showed a preference to respond "old" when they were unsure), with those participants who spontaneously adopted a conservative bias (i.e., a preference to respond "new" when unsure). While the two groups of individuals were comparable in terms of accurate recognition memory performance (i.e., correct old/new discrimination), their frontal ERPs recorded at 300–500 ms poststimulus showed differential amplitudes depending on their preferred response biases. Most importantly, the groups differed significantly in their ERP old/new effects only when ERPs associated with "old" responses were compared with ERPs associated with "new" responses. By contrast, there were no significant group differences in ERP old/new effects for the objective perspective (contrasting old items versus new items), and only marginally significant group differences for correct responses (contrasting hits versus correct rejections). Thus, subject-controlled, bias-related memory processes were maximally reflected in ERP old/new differences when participant's responses determined trial sorting into the to-be-compared bins, least successful when the objective perspective was applied, and half-way successful when correct responses were analyzed as typically done in ERP analyses of recognition memory processes.

In the present study, we applied that same logic to an ERP investigation of the mechanisms underlying a phenomenon in which individuals shift their response bias following semantic analysis of test stimuli. The phenomenon has been termed the *emotion-induced recognition bias* and refers to the finding that in a recognition memory task with words, participants use a more liberal response criterion for "old" responses when classifying test items with an emotional meaning compared to emotionally neutral items, whether or not the items are in fact old (Dougal & Rotello, 2007; Maratos, Allan, & Rugg, 2000; McNeely, Dywan, & Segalowitz, 2004; Windmann & Krüger, 1998; Windmann & Kutas, 2001). Research in natural settings has described similar effects by showing that memories of emotional events such as 9/11, the Estonia ferry disaster, or the O.J. Simpson trial are biased in a similar vein: The memories appear subjectively stronger than is objectively justified (cited, e.g., in Phelps & Sharot, 2008; Rimmele, Davachi, Petrov, Dougal, & Phelps, 2011). Functional magnetic imaging studies have suggested that this illusory feeling of remembering can result from misattribution of emotional arousal induced by the amygdala at the time of retrieval (Sergerie, Lepage, & Armony, 2007; Sharot, Delgado, & Phelps, 2004), although the mechanisms of the misattribution remain unclear.

Cognitive studies have linked the emotion-induced recognition bias to the kinds of memory intrusions that are induced by semantically cohesive stimulus lists, as in the Deese–Roediger–McDermott (DRM) paradigm, where studying semantically interrelated words such as "tooth, bite, ocean, and fish" can prompt participants to produce the semantically central word "shark" in a subsequent memory test (Roediger & McDermott, 1995). As in the case of the emotion-induced recognition bias, some researchers have described memory intrusions prompted by the DRM paradigm in terms of a shift of the bias to respond "old" (Miller & Wolford, 1999; Miller, Guerin, & Wolford, 2011; Zhu, Chen, Loftus, Lin, & Dong, 2013). A shift of bias can occur inadvertently due to stimulus-driven processes when interconnected representations tend to automatically coactivate each other during memory encoding and retrieval, thereby strengthening their connections, and rendering semantically interrelated items subjectively appear "older" than objectively justified. This process reflects a bottom-up driven *retrieval* bias for semantically interrelated words, but manifests as a more liberal *response* bias in behavior. Alternatively, the shift of bias induced by the DRM word lists might indeed reflect a response strategy that is modulated by subject-controlled processes at the time of retrieval to facilitate judgments to categories of stimuli, studied or not (for more detailed discussions, see Gallo, 2006; Gallo, Roediger, & McDermott, 2001; Miller et al., 2011). The same two kinds of processes, automatic retrieval bias and subject-controlled decision bias, have also been proposed to underlie the emotion-induced recognition bias (Windmann & Chmielewski, 2008; Windmann et al., 2007).

Memory intrusions in the DRM paradigm occur more frequently after blockwise relative to random presentation of study words (Lampinen, Leding, Reed, & Odegard, 2006; Mather, Henkel, & Johnson, 1997; McDermott, 1996). At first blush, this finding might be taken as evidence for automatic priming effects based on spreading activation and neural summation, but direct evidence of the underlying evidence is lacking. ERPs have proven useful tools in investigations of the level of processing generating the DRM illusion (Beato, Boldini, & Cadavid, 2012; Chen, Voss, & Guo, 2012). In the case of the emotion-induced recognition bias, however, the existing evidence is sparse. At present, it is unclear whether the phenomenon would be subject to the same kind of study task context effects as the DRM illusion, and whether these effects relate to automatic or controlled processing.

The present study adopted subjective, objective, and correct perspectives onto ERP correlates of the emotion-induced recognition bias recorded during blockwise as compared to random presentation of study words. We aimed, first, to specify the mechanisms underlying the phenomenon, and second, to generally examine the potential of taking subjective as compared to objective and correct perspectives onto ERP correlates of cognitive illusions and biases. Emotionally negative and neutral word stimuli were presented in a recognition memory test either blockwise or randomly intermixed while ERPs were recorded. ERP old/new effects were then analyzed from subjective ("old" responses versus "new" responses), objective (old items versus new items), and standard correct perspectives (hits versus correct rejections). As typically done in ERP studies on recognition memory, we distinguished between early (300–500 ms poststimulus) and late old/new effects (500–800 ms poststimulus), yielding correlates of automatic familiarity and controlled recollection, respectively (Mecklinger, 2000, 2006; Rugg & Curran, 2007; Rugg et al., 1998).

We hypothesized, first, that ERP correlates of the emotion-induced recognition bias would be strongest in the subjective comparison, where "old" responses (of which some are containing illusory memory experiences) are compared with "new" responses, in analogy to the between-subject effects of bias reported by Windmann et al. (2002). By contrast, we expected the objective comparison to be most sensitive to input-driven differences between old and new items (whether or not these differences are recognized by subjects). Second, we investigated whether the emotion-induced bias effect is stronger in the blockwise study condition relative to random, as evidenced by both, behavioral and ERP data. Finally, we reasoned that if any bias-enhancing effect of blockwise presentation is based on automatic priming, ERP indices should be affected relatively early during stimulus processing (<500 ms poststimulus).

2. Methods

2.1. Participants

33 Right-handed participants (mean age 26.3, 22 female), mostly students of Psychology, participated either for course credit or were paid € 20 for participation.

2.2. Materials and procedures

Participants gave written informed consent prior to participation. They were presented lists of 60 emotionally neutral and 60 emotionally negative words (matched for frequency) in the center of the screen with the instruction to read the words silently. Participants saw words of one emotionally negative and one emotionally neutral study list in blocks of trials (with the order of negative/neutral words counterbalanced across subjects), and words from one other negative and neutral study list randomly intermixed (order of block-random presentation counterbalanced across subjects). At test, study words (old words) were presented plus an equal number of previously unpresented negative and neutral words (new words, again matched for frequency) in randomized order (480 words in total, old and new word lists counterbalanced across subjects). In both conditions, blockwise and random, study and test procedures were split into halves and performed alternatingly (study–test–study–test) with only a few minutes of retention interval between study and test blocks to warrant sufficiently high performance despite the large number of items. Participants were instructed to indicate as quickly and as accurately as possible via button-press with their right hand whether the item was old or new, or to guess when they could not remember. From these responses, Hits (correct "old" responses), Correct Rejections (correct "new" responses), and False Alarms (incorrect "old" responses) were taken. Recognition accuracy was computed as Pr = [Hit Rate – False Alarm Rate], and response bias as Br = [False Alarm Rate/(1 – Pr)], see Snodgrass and Corwin (1988).

2.3. EEG recordings and analyses

The EEG was recorded continuously with BrainAmp DC-amplifiers (BrainProducts, Gilching, Germany; sampling rate 250 Hz, resolution 0.1 μV/bit, input-impedance 10 MOhm) using an equidistant EasyCap (EasyCap GmbH, Herrsching-Breitbrunn, Germany, see Fig. 1) with sintered Ag/AgCl electrodes and built-in preamplifiers (BrainProducts ActiCap System). During recording, the vertex electrode was used as reference. Eye blinks and movements were monitored with supra- and infra-orbital electrodes and with electrodes at the external canthi.

EEG data were analyzed using the Vision Analyzer 1.05 software (BrainProducts, Gilching, Germany; www.brainproducts.com). EEG data were digitally filtered with a 30 Hz/24 dB Butterworth zero phase lowpass and a 0.2 Hz/12 dB highpass, segmented and baseline corrected (−200 ms to 0 ms). After removing segments with very large artifacts (exceeding ±500 μV) eye blinks were corrected using independent component analysis (ICA), further controlled by visual inspection, and baseline-corrected again. Furthermore, a semiautomatic procedure for artifact detection was applied (amplitude criterion ±50 μV, gradient 20 μV/sample), again controlled by visual inspection. Averages were then computed according to experimental stimulus and response conditions, rereferenced to linked mastoids, and the reconstructed vertex reference was added, resulting in 60 EEG channels for data analysis.

2.4. Data analyses

Behavioral measures Pr and Br were analyzed for effects of the repeated factors Emotion (negative, neutral) and Block (block, random). Mean ERP amplitudes were taken from standard early (300–500 ms poststimulus) and late (500–800 ms poststimulus) time-windows and analyzed using ANOVAs involving the repeated factors Old/New, Emotion (negative, neutral), Block (block, random), and Cluster of Electrodes (8 levels, see Fig. 1). Planned post hoc tests on individual clusters were performed to analyze the spatial distribution of the effects. To explore the temporal distribution of the effects beyond the predefined time-windows, running ANOVAs were performed on sliding 100 ms time-windows. Finally, we directly evaluated any observed differences between Subjective, Objective, and Correct perspectives in an overall ANOVA using Comparison Type as an additional repeated factor. For all results involving more than two repeated factor levels, Huynh–Feldt corrected p-values are reported.

3. Results

In behavior, we found the expected emotion-induced recognition bias as indexed by a significant main effect of emotion on the response bias measure Br, $F(1,32) = 9.48$, $p = .004$, $\eta_p^2 = .23$: Emotionally negative items were associated with a more liberal bias to respond "old" compared to emotionally neutral items (see Fig. 2B). No other effects were significant (interaction of Emotion × Block: $p = .32$). Analyses of recognition accuracy Pr showed no significant main effects of emotion or block, but a significant Emotion × Block interaction, $F(1,32) = 8.32$, $p = .007$, $\eta_p^2 = .21$. Post-hoc comparisons indicated a significant

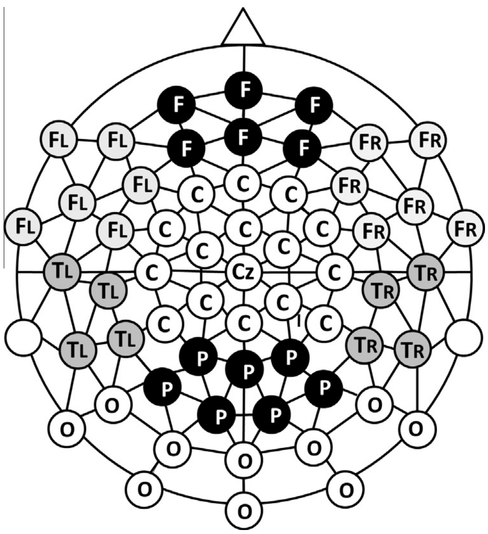

Fig. 1. Electrode array used for the ERP recordings and clusters of electrode sites as used in the analyses. F = Frontal, T = Temporal, C = Central, P = Parietal, O = Occipital; L = Left, R = Right.

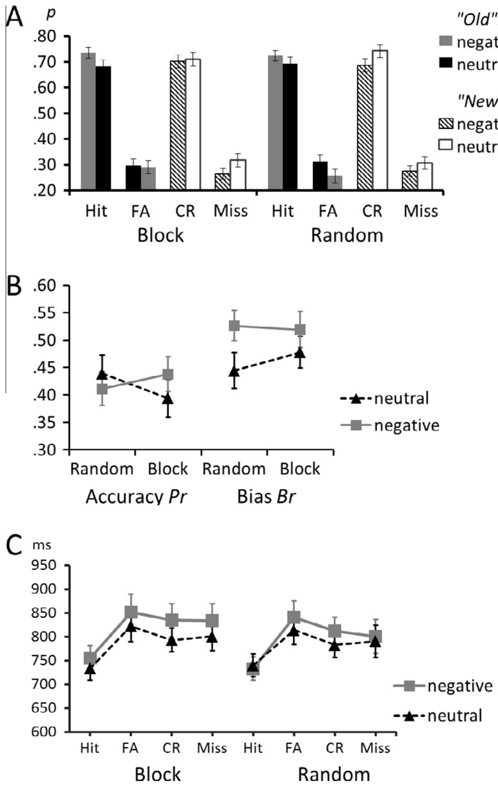

Fig. 2. Behavioral responses to emotionally negative and neutral items after blockwise compared to random study conditions. A: Rates of Hits, False Alarms (FA), Correct Rejections (CR), and Misses. B: Measures of recognition accuracy (*Pr*) and response bias (*Br*). C: Reaction times (ms).

effect of emotion in the blockwise study condition [$F(1,32) = 4.37$, $p = .04$, $\eta_p^2 = .12$], with negative > neutral, that was absent (even slightly reversed, $p = .12$) in the random condition (Fig. 2B). Fig. 2C also shows reaction times; these were in the expected range and slightly higher (<50 ms) for emotional items in some conditions.

Table 1 shows significant and marginally significant ERP effects as revealed by the running ANOVA on mean amplitudes in 100 ms time steps for old/new comparisons associated with the correct, subjective, and objective old/new comparisons. Across all electrodes and independent of perspective, reliable old/new effects were observed between 200 and 1000 ms post-stimulus that interacted with electrode starting at about 300 ms in all three comparison types.

However, there were also differences between the three comparisons of ERPs. First, there were early effects of emotion starting at about 200 ms poststimulus in the objective and the subjective comparisons that appeared delayed by about 200 ms in the correct comparison (Table 1). Furthermore, and quite strikingly, there were effects of Old/New × Emotion × Block interacting with electrode site starting at about 500 ms in the objective comparison that were not nearly significant in the other two comparisons.

The main ANOVA of ERPs taken in early (300–500 ms poststimulus) and late (500–800 ms poststimulus) time-windows at the eight electrode clusters confirmed and sharpened this picture of results (Table 2). All three comparisons showed strong and robust old/new effects in both time-windows, and significant effects of emotion in the early time-window. However, there were two important specifics for the three comparisons. First, in the early time-window, the subjective comparison showed significant modulations of the ERP old/new differences by emotion and cluster (highlighted as bold in Table 2) that were not significant in the other two comparisons. As shown by Table 3 that lists the results of the post hoc ANOVAs at the level of individual electrode clusters, the significant impact of emotion on the old/new effect in the subjective comparison occurred at anterior frontal and left frontal electrode clusters (see Fig. 3). The effect was due to larger old/new difference for emotionally neutral compared to negative items, replicating the typical ERP correlate of the emotion-induced recognition bias (Johansson, Mecklinger, & Treese, 2004; Windmann & Kutas, 2001).

Second, another dissociation between the comparisons was the finding of a significant Cluster × Old/New × Emotion × Block interaction effect in the objective comparison in the late time-window (highlighted as bold in Table 2) that was not found in the other two comparisons (where all effects involving Block were $p > .35$). The post hoc ANOVAs listed in Table 3 located this effect at parietal ERPs. Visual inspection of the grand averages of parietal ERPs of the objective comparison in Fig. 4 confirms that the difference between emotional and neutral items with regards to the ERP old/new effect is smaller for the random condition compared to the block condition. What stands out in particular is the potential associated

Table 1
Results of the "running ANOVA" analyzing repeated effects of Old/New, Emotion (negative/neutral), and Block (blockwise, random) on ERP amplitude measures taken at 60 electrode sites (E) in 100 ms sliding time-windows.

Comparison Type	Correct (Hits versus Correct Rejections)								
Time Window (ms)	100–200	200–300	300–400	400–500	500–600	600–700	700–800	800–900	900–1000
E (Electrode)	***	***	***	***	***	***	***	***	***
Old/New		***	***	***	***	***	***	***	*
Emotion (Emo)		#		*	*	#			
Block									
E × Old/New			***	***	***	***	#	**	***
E × Emotion			*				#		
Old/New × Emotion		#					#	#	
E × Old/New × Emotion				*		***	***		
E × Block									
Old/New × Block									
E × Oldnew × Block									
Emotion × Block									
E × Emotion × Block									
Old/New × Emo × Block									
E × Old/New × Emo × Block									

Comparison Type	Subjective ("Old" versus "New" Decisions)								
Time Window (ms)	100–200	200–300	300–400	400–500	500–600	600–700	700–800	800–900	900–1000
E (Electrode)	***	***	***	***	***	***	***	***	***
Old/New		***	***	***	***	***	***	***	*
Emotion (Emo)		*	#	*	#	#			
Block									
E × Old/New		#	***	***	***	***		*	***
E × Emotion				*		*	*		
Old/New × Emotion							#		
E × Old/New × Emotion				***	*	***	*		
E × Block									
Old/New × Block									
E × Oldnew × Block									
Emotion × Block									
E × Emotion × Block	#								
Old/New × Emo × Block									
E × Old/New × Emo × Block									

Comparison Type	Objective (Old versus New Items)								
Time Window (ms)	100–200	200–300	300–400	400–500	500–600	600–700	700–800	800–900	900–1000
E (Electrode)	***	***	***	***	***	***	***	***	***
Old/New		***	***	***	***	***	***	***	*
Emotion (Emo)		**	#	*	#				
Block									
E × Old/New			***	***	***	***	*	***	*
E × Emotion			#	*		*	**		
Old/New × Emotion									
E × Old/New × Emotion						*	***		
E × Block									
Old/New × Block									
E × Oldnew × Block									
Emotion × Block									
E × Emotion × Block									
Old/New × Emo × Block									
E × Old/New × Emo × Block				#	*	*	**	*	

Note:
# $p < .10$.
* $p < .05$.
** $p < .010$.
*** $p < .001$; Huynh–Feldt corrected.

Table 2
Results of the main ANOVAs of ERP amplitudes.

Comparison type	Correct (Hits versus correct rejections)		Subjective (“Old” versus “New” responses)		Objective (Old versus new items)	
Time window (ms)	Early (300–500)	Late (500–800)	Early (300–500)	Late (500–800)	Early (300–500)	Late (500–800)
Old/New	$F(1,32) = 46.17$, $p < .001$, $\eta^2_p = .59$	$F(1,32) = 31.30$, $p < .001$, $\eta^2_p = .49$	$F(1,32) = 40.16$, $p < .001$, $\eta^2_p = .56$	$F(1,32) = 23.12$, $p < .001$, $\eta^2_p = .42$	$F(1,32) = 16.17$, $p < .001$, $^2_p = .37$	$F(1,32) = 26.44$, $p < .001$, $\eta^2_p = .45$
Emotion	$F(1,32) = 3.58$, $p = .067$, $\eta^2_p = .10$	$F(1,32) = 3.13$, $p = .09$, $\eta^2_p = .09$	$F(1,32) = 6.80$, $p = .014$, $\eta^2_p = .17$		$F(1,32) = 7.20$, $p = .011$, $\eta^2_p = .10$	
Block						
C × Old/New	$F(7,224) = 17.89$, $p < .001$, $\eta^2_p = .36$	$F(7,224) = 9.58$, $p < .001$, $\eta^2_p = .23$	$F(7,224) = 13.93$, $p < .\ 001$, $\eta^2_p = .30$	$F(7,224) = 8.56$, $p < .\ 001$, $\eta^2_p = .21$	$F(7,224) = 11.38$, $p < .001$, $\eta^2_p = .26$	$F(7,224) = 9.78$, $p < .001$, $\eta^2_p = .23$
C × Emotion			$F(7,224) = 3.06$, $p = .036$, $\eta^2_p = .09$	$F(7,224) = 2.88$, $p = .029$, $\eta^2_p = .08$	$F(7,224) = 3.09$, $p = .031$, $\eta^2_p = .09$	$F(7,224) = 3.67$, $p = .008$, $\eta^2_p = .10$
Old/New × Emotion	$F(1,32) = 3.49$, $p = .071$, $\eta^2_p = .10$					
C × Old/New × Emotion		$F(7,224) = 4.52$, $p = .003$, $\eta^2_p = .12$	**$F(7,224) = 2.70$, $p = .043$, $\eta^2_p = .08$**	$F(7,224) = 4.65$, $p = .002$, $\eta^2_p = .13$		$F(7,224) = 2.97$, $p = .025$, $\eta^2_p = .08$
C × Old/New × Emo × Block						**$F(7,224) = 3.74$, $p = .001$, $\eta^2_p = .11$**

Table 3
Results of post hoc ANOVAs analyzing mean ERP amplitudes at each of the 8 electrode clusters (see montage in Fig. 1).

Comparison type	Correct (Hits versus Correct Rejections)								Subjective (“Old” versus “New” Responses)								Objective (Old versus New Items)							
Electrode cluster	F_L	F	F_R	T_L	T_R	C	P	O	F_L	F	F_R	T_L	T_R	C	P	O	F_L	F	F_R	T_L	T_R	C	P	O
Early (300–500 ms)																								
Old/New	.100	.000	.007	.000	.000	.000	.000	.000	.033	.001	.009	.000	.000	.000	.000	.000	.001	.030		.004	.000	.001	.001	.001
Emotion	.005			.008			.095	.095	.000						.053	.075				.001			.025	.047
Block																								
Old/New × Emotion	.050	.023	.076	.059		.046			.096	.020										.078				
Old/New × Emo × Block																							.069	
Late (500–800 ms)																								
Old/New	.042	.004	.050	.000	.003	.000	.000	.000	.071	.010	.010	.000	.000	.000	.000	.000	.096	.041		.000	.001	.000	.000	.000
Emotion	.006			.010					.009			.004					.020			.002			.010	
Block									.069								.010							
Old/New × Emotion	.030	.016	.019						.039	.016	.032													
Old/New × Emo × Block																							.017	

Note: Only significant and marginally significant *p*-values are shown.

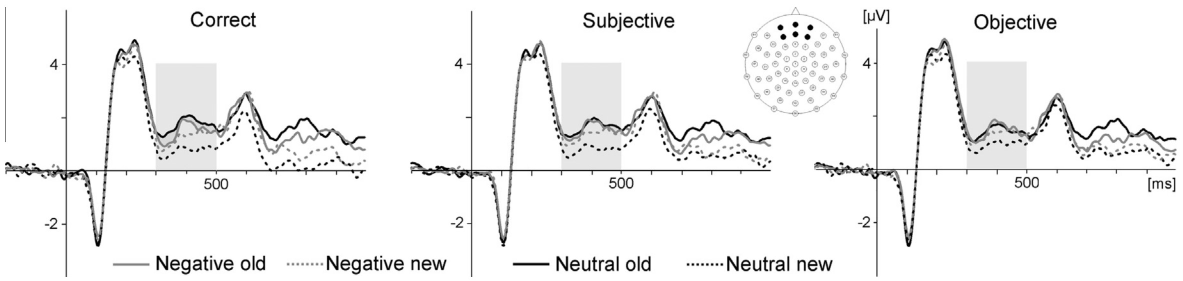

Fig. 3. Grand average ERPs recorded at frontal sites (electrode positions see insert and Fig. 1) for the correct, subjective, and objective comparisons. Data are collapsed across the two factor levels of Block (i.e., blockwise versus random presentation) as this factor had no significant impact. ERP old/new differences between 300 and 500 ms (shaded area) are smaller for negative compared to neutral items in the subjective and the correct comparison (relative to objective), but this effect survived correction of sphericity violation only in the subjective comparison. The difference between the three comparisons is subtle but of practical importance (see text).

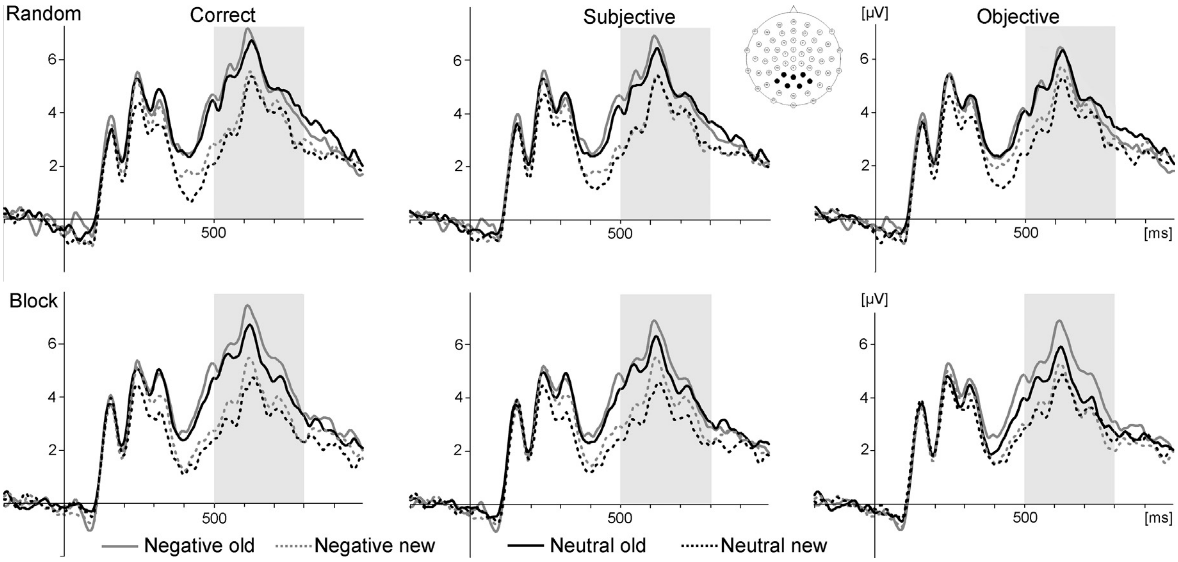

Fig. 4. Grand average ERPs recorded at parietal sites (electrode positions see insert) for the correct, subjective, and objective comparisons. In the time-window between 500 and 800 ms poststimulus (shaded), only the objective comparison shows pronounced ERP positivity associated with negative old items in the block condition (bottom right panel).

with old negative items as these are more positive going than those associated with all other item types. A post hoc test confirms that the ERP old/new difference in the objective comparison is significantly larger for the block condition relative to the average of the other three conditions (i.e., neutral block, neutral random, negative random); $t(32) = 2.05$; $p < .05$ (see Fig. 5). In the other two comparisons (subjective and correct), the ERP old/new differences are more homogeneous across the four conditions (block, random, negative, neutral), with no significant effects.

To statistically test the described overall differences between the three comparisons for significance, we performed an overall ANOVA with the repeated factors Comparison Type (Correct, Subjective, Objective) × Old/New × Emotion × Block × Cluster. Results showed that the dissociation between the comparisons in the late parietal effect was indeed significant; $F(14,448) = 5.03$, $p < .001$, $\eta_p^2 = .14$; see Fig. 5). By contrast, the other dissociation, the comparison-dependent modulation of the early ERP old/new effect at the frontal sites, did not reach significance ($p = .31$), indicating that although the relevant interaction appeared strongest in the subjective comparison, where it also exceeded the significance threshold, it went into the same direction in the other two comparisons. The grand averages plotted in Fig. 3 confirm that emotion-related differences (negative < neutral) in old/new effects are present in all three comparisons, and even comparable in size in the subjective and correct comparisons (not considering the variances). However, we suggest that the subtle differences between the comparisons are nonetheless of practical significance, first, because researchers tend to believe only results that exceed the significance threshold, and second, because researchers usually test only the correct comparison (hits versus

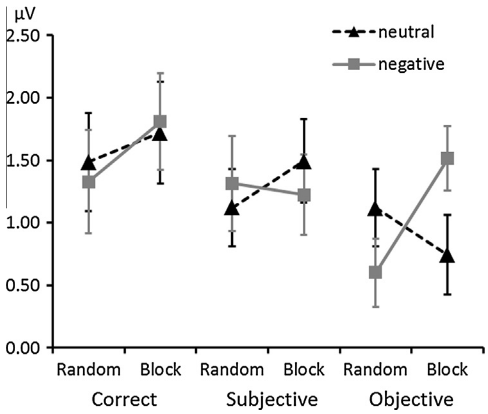

Fig. 5. Amplitude plots for the ERPs shown in the gray-shaded area of Fig. 4 Differences in ERPs to old minus new items (ERP old/new differences) taken between 500 and 800 ms poststimulus at parietal sites are shown for the correct, subjective, and objective comparisons. In the objective comparison, but not in the other two comparisons, the ERP difference is larger in the block condition relative to random for negative items, but not for neutral items.

correct rejections), which failed not only to meet that threshold in the main ANOVA, but also yielded a more widespread distribution of the emotion-induced recognition bias ERP effect. More specifically, the correct comparison showed a tendency toward a modulation of old/new by emotion across a number of frontal, temporal, and parietal clusters in the post hoc tests (see Table 3), including one significant result at frontal sites, but this modulation turned out only marginally significant in the main ANOVA (Table 2), with $p < .071$, again in agreement with earlier studies (Windmann & Kutas, 2001; Windmann et al., 2002). Had we tested only that classical comparison for significance with the usual threshold, we would have underestimated both the statistical significance of the effect and its frontal focus.

No other interaction effects involving comparison type were significant in the overall ANOVA, except for a significant interaction of Comparison Type × Cluster × Old/New in the early time-window; $F(14,448) = 3.05$, $p = .017$, $\eta_p^2 = .09$, that continued to be marginally significant in the late time-window; $F(14,448) = 2.09$, $p = .055$, $\eta_p^2 = .06$. These two results indicate that the ERP old/new effects showed a somewhat different spatial distribution across the three comparisons. As can be seen from the grand averages of the frontal and parietal ERPs displayed in Figs. 3 and 4, as well as from the p-statistics reported in Table 1, the old/new effects were largest in the correct comparison, where input-driven and subjectively experienced memory effects conjoin; however, the significant interaction involving the factor cluster suggest that this pattern does not hold true to the same degree for all clusters of electrode sites.

4. Discussion

In investigating an emotion-related processing effect on recognition memory judgments that resembles the DRM memory illusion, we adopted a subjective perspective onto the study status of test items as opposed to an objective and the correct perspective. We found that the subjective perspective was indeed most sensitive to emotion-induced modulations of response bias, as expected: Between 300 and 500 ms poststimulus, ERP differences to items classified as "old" relative to "new" were larger for emotionally negative items compared to neutral items, particularly at anterior frontal and left frontal sites, with the left-lateral distribution emerging presumably because the stimuli were verbal. The result not only replicates previous findings regarding the temporal and spatial distribution of the correlates of the emotion-induced recognition bias, but also regarding the specific sensitivity of the subjective comparison to variations of decision bias (Windmann et al., 2002). In the standard old/new comparison associated with correct responses, such early effects of emotion (<500 ms poststimulus) on frontal ERPs were statistically less robust and spatially less focused; they were visible in the grand average, but subject to high individual variation. In the objective comparison that reflects true differences between old and new items, the emotion-related ERP effects were clearly too small to become significant.

Topography and time-course of the emotion-induced bias effect found in the subjective comparison qualify it as an FN400, a well-known ERP component that is driven by automatic retrieval of semantic familiarity, quite independent of episodic recollection (Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012; Curran, 2004; Curran & Hancock, 2007; Mecklinger, 2006; Rugg & Curran, 2007; Woodruff, Hayama, & Rugg, 2006). If interpreted in such terms of semantic familiarity, the emotion-induced recognition bias would not be attributable to the effects of emotions *per se*, but to the higher semantic associatedness of the negative test items relative to neutral, just like the memory intrusions induced by the DRM paradigm (Maratos et al., 2000; McNeely et al., 2004; White, Kapucu, Bruno, Rotello, & Ratcliff, 2014). The belief is that representations of emotionally negative words coactivate each other more during encoding and retrieval relative to emotionally neutral items as the negative items are semantically more interrelated. Consequently, negative test items, old or not, feel more familiar than neutral test items and prompt participants to respond "old" when unsure, thereby increasing the response bias and its ERP correlates in a similar vein as direct manipulations of bias via instructions (Azimian-Faridani & Wilding, 2006; Miller & Wolford, 1999). Whether emotions are particularly subject to such semantic-categorical effects, perhaps due to arousal-enhanced spreading activation or other effects of emotions on network dynamics, is difficult to determine experimentally with word lists whose semantic features are virtually impossible to balance out between emotional and neutral, especially when a large number of items is needed for averaging as is the case in ERP studies. However, it is worthwhile noting that studies using pictures of facial expressions have found similar effects of emotions on the bias, both positive and negative, albeit somewhat weaker (Johansson et al., 2004; Sergerie et al., 2007; Windmann & Chmielewski, 2008). Since the semantic structure of these picture lists can be considered matched between the neutral and any specific emotion category, the finding of an emotion-related shift of the bias suggests that it is indeed the emotional meaning, and more specifically, the emotional arousal, expressed by the face that must have caused the emotion-induced recognition bias, above and beyond effects of semantic association. Studies using functional magnetic imaging suggest that the underlying neuronal mechanism involves emotion-related activation of the amygdala leading to an enhanced subjective sense of remembering (Sergerie et al., 2007; Sharot et al., 2004; for review see Phelps & Sharot, 2008). At present, it remains puzzling why the brain fails to make the behaviorally important distinction between emotional arousal and memory strength. Nonetheless, the present results confirm that the emotion-induced recognition bias arises during early retrieval processes, thereby generating an illusory sense of familiarity, before any recollection of specific item information sets in.

Importantly, however, in the present study, the finding of early emotion effects on the frontal ERP correlates of bias failed to reach statistical significance in both, the objective comparison of old versus new items, and in the correct comparison of hits versus correct rejections (referring to the early effects of C × Old/New × Emotion depicted in Table 2). In the objective comparison, the relevant interaction was insignificant at all levels of analysis. In the correct comparison, emotion did appear to modulate old/new differences in a relatively widespread manner, as reflected in the results of the post hoc ANOVAs (referring to effects of Old/New × Emotion at frontal, left temporal, and central sites in Table 3). However, these effects did not survive correction of sphericity violation in the main ANOVA (Table 2, referring to the early effect of Old/New × Emotion with $p = .071$). As post hoc tests are usually performed only when the main results are significant, the finding would have been missed if only standard ERP analyses had been performed.

The differential robustness of the three comparisons against corrections of statistical violations illustrates another advantage of the subjective and objective comparisons relative to correct: Because they are based on higher trial counts, they provide more reliable results. Although in the present case, the correct comparison involved mean trial counts of about 40 (range 17–59) per condition, which is quite high for ERP studies (and thus cannot account for the different results obtained by the three comparisons), averaging across more trials helps further to meet the statistical requirements of parametric tests. For that same reason, analyzing the subjective perspective onto old/new differences in investigations of the ERP correlates of biases and illusions is a viable alternative to the analyses of incorrect trials, as performed, e.g., in the seminal study by Rugg et al. (1998) investigating implicit/unconscious components of memory, or other studies investigating the neural correlates of recognition failures, namely misses and false alarms (Walla, Endl, Lindinger, Deecke, & Lang, 1999, 2000). Sampling a sufficient number of incorrect trials for averaging, while maintaining a reasonable level of task difficulty, can be a dilemma for ERP studies. In addition, incorrect response trials are just as ambiguous as are hits and correct rejections: They can be incorrect either because of biases and illusions, or because of sheer error, e.g., due to lack of ability, motivation or attention. By contrast, the subjective perspective is straightforwardly defined by the participant's responses, correct or not, and should therefore most validly reflect the subjective view onto stimulus differences. These differences should be low and insignificant in the case of random errors, but clear and systematic in the case of biases and illusions.

Notably, in investigating ERP correlates of the emotion-induced response bias effect, we compared ERPs to items evoking a relatively liberal response threshold (negative items) with ERPs to items evoking a more conservative response threshold (neutral items). What we found is that at the liberal threshold (i.e., for negative items), the difference in ERPs to items above the decision threshold ("old") and items below the decision threshold ("new") is smaller relative to that same difference at the more conservative threshold (i.e., for neutral items). On the one hand, this result of an interaction of decision bias with ERP old/new differences is consistent with earlier findings (Azimian-Faridani & Wilding, 2006; Windmann & Kutas, 2001; Windmann et al., 2002), and straightforwardly suggests that "old"/"new" identifications are made differently at the two different decision thresholds. On the other hand, one could have expected a *main* effect of decision threshold in this set up (an "ERP liberal/conservative difference" as it were, regardless of response type) rather than an interaction with "old"/"new". Such main effects of bias on frontal amplitudes around 400 ms post stimulus have indeed been reported (Hill & Windmann, in press; Windmann et al., 2002). We suggest that these may be indicative of subject-controlled differences in bias, in contrast to the present bias effects that are bottom-up driven by stimulus features (i.e., semantic meaning). Another possibility is that such interactions of decision threshold with "old"/"new" item status emerge in ERP correlates when item distributions are not normal, for instance, when "old" items in the conservative condition are more often recollected (as opposed to automatically recognized on the basis of familiarity) than in the liberal condition. While this possibility does not threaten our current interpretations about the early frontal effects, it should be a matter of further investigation. ERP studies on recognition memory usually refer only to average response rates and reaction times, and rarely consider differences in variance and other qualitative differences between conditions. The second goal of our study was to investigate, again by contrasting correct, subjective and objective perspectives, whether blocked as compared to randomly interspersed presentation of emotional items in the test list would influence the effects of emotional word meaning on recognition memory as has previously been reported for the famous DRM word lists (Lampinen et al., 2006; Mather et al., 1997; McDermott, 1996). In behavior, we found that blockwise as compared to random presentation increased recognition memory performance *Pr* for emotional items, but not for neutral items, whereas the bias measure *Br* was not significantly affected by the manipulation. Since all prior investigations of the effects of emotions on bias have used random stimulus presentations, our finding is unprecedented in the literature, although some of the studies with random presentations have also found significant effects of negative emotions on *Pr* (Johansson et al., 2004; Maratos et al., 2000).

The effects of blockwise presentation in the behavioral accuracy measure went along with a highly significant ERP amplitude modulation in the late time-window of the objective old/new comparison that was quite far from significant in both, the subjective and correct comparisons: Emotion-related modulations of old/new effects were larger at parietal sites in the blockwise study condition relative to random. The parietal locus and the relatively late time-course of the effect, modulating the LPC, do not speak for automatic priming effects as the underlying mechanism as we had expected, but rather for controlled retrieval processes associated with episodic recollection (Curran, 2004; Rugg et al., 1998; Woodruff et al., 2006). Recollection processes are typically reflected in ERPs between 500 and 800 ms poststimulus at parietal sites, as in the present case. These processes are increased by depth of processing manipulations and decreased by hippocampal lesions associated with anterograde amnesia (Addante, Ranganath, Olichney, & Yonelinas, 2012; Rugg & Curran, 2007; Rugg et al., 1998). Thus, contrary to common opinion, we conclude that not all effects of blockwise compared to random encoding are due to automatic semantic priming (c.f., Lampinen et al., 2006; Mather et al., 1997; McDermott, 1996), but can instead be driven by recollection processes.

In our data, the effect was mostly based on enhanced positivity associated with negative old items (c.f., Figs. 4 and 5), as would be typical for depth-of processing manipulations (Rugg et al., 1998). It is possible that some specific features of the negative items (such as semantic meaning, source information or verbatim information) may have been better encoded in the blockwise study condition relative to random which later facilitated episodic recollection and therefore increased accurate old/new discrimination. After all, blockwise presentation of emotionally negative items is more likely than the random condition to actually induce emotional experiences rather than just briefly and relatively superficially activate information processing networks.

Interestingly, the effect was far from significant in the correct comparison of hits and correct rejections ($p > .89$; with or without interaction by Cluster), and in the subjective comparison of "old" and "new" decisions ($p > .62$), suggesting that the effect may relate to differences in old/new stimulus processing that are not subjectively realized, or otherwise do not significantly influence participant's decision-making, despite their relatively late reflection in the ERPs. It is thus possible that modulations of the late parietal old/new effect in the objective comparison may reflect potions of *unconscious recollection*, at least more so than in the other two comparisons. Currently, for lack of additional evidence, this interpretation is speculative, but it is derived from the fact that the objective comparison, where the effect was strongest and statistically significant, is the only one among the three comparisons that ignores the subjective view of participants by contrasting the differences between actually old and new items, recognized or not. In fact, the objective comparison of old and new items is quite similar to the contrasting of misses and hits performed by Rugg et al. (1998) who interpreted the associated ERP differences as correlates of implicit and potentially unconscious memory.

At first sight, the suggestion seems counterintuitive that blockwise presentation of emotional words with the higher potential of inducing subjectively experienced emotions (relative to the random presentation) should enhance old/new discrimination performance via *unconscious* routes and yet be reflected in *late* parietal ERP old/new differences. Indeed, that late parietal correlate can also be interpreted in light of the results by Sharot et al. (2004): Subjectively experienced emotions at study (activating the amygdala) might unconsciously and inadvertently activate the hippocampus, which at later retrieval suggest to the brain that the studied item is recollected. This alternative interpretation would be more in line with the existing ERP recognition memory literature because hippocampus-driven recollection is typically understood to be reflected in the late parietal ERP old/new effect. What remains unclear from this interpretation, however, is why the effects show in the objective comparison only, and in behavioral accuracy as opposed to the bias. For that reason, we prefer the above interpretation that the late parietal positivity in response to old negative items reflects unconscious recollection. Clearly, more research is needed to clarify under what conditions blockwise item presentations as compared to random alter conscious or unconscious memory processes.

What does it mean generally when experimental manipulations selectively impact on measures reflected in objective, subjective, or correct comparisons? We suggest that the objective perspective yields traces of input-driven stimulus processing that are relatively independent of subjective experiences, at both early and late stages of processing. By contrast, the subjective perspective should be indicative of the kinds of processes that drive participants' decisions, whether these processes root in actual stimulus differences (in which case responses are correct), or in biased beliefs, expectations, preferences, or illusions. As mentioned, we think that the latter processes may be closer to conscious representations of stimulus attributes than the former. Finally, the comparison of correct responses reflects the intersection of the subjective and objective comparisons, and is therefore likely to represent the degree to which actual stimulus differences are picked up by subject-driven information processing.

In general, measures associated with any kind of behavioral response, correct or incorrect, to a given stimulus input provides only indirect and incomplete evidence of the mediating cognitive and brain processes. Behavioral reactions can result from accurate input processing, from random errors, from biases and illusions, or any mixture of these factors. When trials are sorted into bins, researchers cannot know exactly what response results from which underlying process, and will therefore misclassify trials to the degree that task performance is less than perfect. One cannot solve this problem principally, but one can try to estimate the relative contribution of subject-related versus stimulus-related processing by using appropriate criteria for trial sorting. Our results illustrate that the conventional analysis of trials associated with correct responses alone may not be the most powerful one. In our data, the comparison of ERPs associated with hits and correct rejections was insufficiently sensitive to variations in both, biased and accurate stimulus processing. Although yielding the largest ERP old/new effects (descriptively), the analysis of correct response trials failed to show the two experimental effects of central interest.

In conclusion, we recommend routine comparison and systematic contrasting of subjective and objective perspectives alongside analyses of correct and incorrect response trials for tasks invoking less-than-perfect discrimination performance, particularly for investigations of biased stimulus processing due to, e.g., expectations, preferences, or prior experiences (e.g., Rahnev, Lau, & de Lange, 2011a; Rahnev et al., 2011b; Sohoglu, Peelle, Carlyon, & Davis, 2012). The strategy proposed here is only one way of dissociating the subjective and objective perspectives, albeit one that is easy to implement; alternatives include comparison of stimulus-locked with response-locked brain correlates (e.g., Curran, DeBuse, & Leynes, 2007) and the use of ambiguous or bistable stimuli (Knapen, Brascamp, Pearson, van Ee, & Blake, 2011).

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