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Has the butcher on the bus dyed his hair? When color changes modulate ERP correlates of familiarity and recollection

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Recognition memory is usually thought of as comprising two distinct memory processes, namely familiarity and recollection. This distinction is reflected in specific event-related potential (ERP) components associated with both subprocesses. A mid-frontal attenuated negativity for correctly recognized old items relative to new ones around 400 ms has been typically linked to familiarity, whereas a parietally accentuated, more pronounced positivity for old items from 500 to 800 ms has been connected with recollection. Recently, this classification has been challenged by relating the mid-frontal old/new effect to conceptual priming mechanisms. Moreover, the perceptual sensitivity of both old/new effects is still under debate. The present study used a recognition memory task for visual objects and nonsense figures in order to investigate the functional significance of both ERP old/new effects. With respect to study presentation, all items were either presented in a perceptually identical or a color-modified version at test. Old nonsense figures, despite being meaningless, elicited a reliable mid-frontal old/new effect, thereby strongly suggesting a close relationship to familiarity processes rather than conceptual priming. Additionally, both the mid-frontal and the parietal old/new effect for real objects were graded with respect to the perceptual similarity between study and test. We argue that not only recollection, but also familiarity processes can provide information about perceptual atttributes, which is used in the course of recognition memory decisions.

Introduction

The example of the butcher on the bus is typically used to illustrate the experience of two distinct cognitive states associated with remembering. On seeing your butcher on the bus, you may experience a diffuse feeling of familiarity without being able to recollect any specific details about that person, thus left without a clue about his identity. This differentiation is well accounted for by two-process models of recognition memory (e.g., Jacoby and Dallas, 1981; Mandler, 1980; for review, see Yonelinas, 2002). Recollection usually refers to the effortful retrieval of detailed (e.g., contextual) information about individual episodes, whereas familiarity is thought of as an unspecific sense of having previously encountered a given event.

Accordingly, distinct spatiotemporal components of old/new effects in event-related potentials (ERPs) have been linked to the different subcomponents of recognition memory (Friedman and Johnson, 2000; Mecklinger, 2000; Rugg and Yonelinas, 2003). Recollection, on the one hand, has been related to a parietal positivity for correctly classified old items relative to correct rejections, from circa 400 to 800 ms (e.g., Allan et al., 1998; Düzel et al., 1997). Familiarity, on the other hand, has been associated with a mid-frontal old/new effect, emerging at around 300–500 ms (e.g., Nessler et al., 2001; Rugg et al., 1998; Tsivilis et al., 2001).

Descending to the butcher on the bus again, it may be assumed that the inability to retrieve specific details is, at least partially, due to the fact that the person you meet is separated from his/her common context. In experimental terms, this implies not only a shift in semantic context, but also a mismatch of perceptual details during ‘test’ compared to ‘study’ conditions (such as the fact that it seems rather implausible to assume that the butcher wears his apron outside the butchery). The critical question is whether your sense of familiarity is affected by such mismatching perceptual information. What if the butcher has dyed his hair?

Previous studies have usually demonstrated the mid-frontal old/new effect to be independent of perceptual manipulations (Curran, 2000; Curran and Cleary, 2003), thereby corroborating the conception of familiarity as a global matching process responding to the overall similarity between study and test (Gillund and Shiffrin, 1984; Hintzman and Curran, 1994). Interestingly, a recent study investigating the influence of modality changes on the mid-frontal old/new effect (Curran and Dien, 2003) yielded a slight but nonsignificant tendency towards a greater old/new effect for within-modality than for across-modality old items. The authors suggested that perceptual attributes may be included in the familiarity process but that they play only a minor role in the

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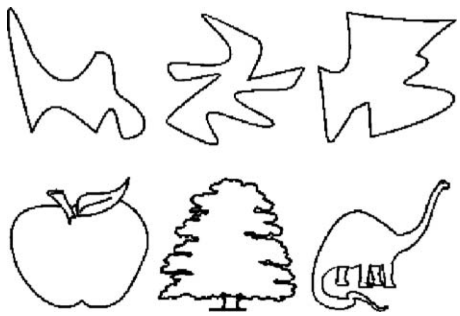

Fig. 1. Examples of objects (bottom row) and non-objects (top row) used in the present study.

global matching process compared to semantic attributes. In line with this suggestion, we recently presented data (Groh-Bordin et al., 2005) showing a mid-frontal old/new effect only for identically repeated pictures of common objects, but not for mirror-reversed repetitions. We attributed our results to the difficult perceptual conditions in this experiment, placing a stronger emphasis on the perceptual processing of the stimuli and thereby leading to an absence of the mid-frontal old/new effect for incongruent items.

Hence, the first goal of the present study was to further examine the sensitivity of familiarity processes for perceptual modifications of visual objects. We therefore manipulated the color of line drawings of common objects from study to test. To emphasize the relevance of the perceptual manipulation, subjects were told to intentionally encode the objects and their respective color (red or green). During a subsequent recognition memory test, all studied items along with completely new ones were presented. Critically, half of the old objects were shown in their identical colors, the other half were presented in reversed colors. According to the conception of familiarity as a mainly semantic matching process, congruent and incongruent items should elicit similar mid-frontal old/new effects during object recognition. If, however, familiarity processes can comprise perceptual attributes, then the mid-frontal old/new effect for incongruent stimuli should be attenuated or even eliminated.

Recently, a different position on the functional relevance of mid-frontal old/new effects has been brought forward (Yovel and Paller, 2004). In this study, investigating recognition memory for pre-experimentally unfamiliar face stimuli, familiarity and recollection were associated with topographically similar ERP correlates. Both memory processes elicited parietally accentuated brain potentials, merely with smaller amplitudes and a shorter duration for familiarity than for recollection. This finding led the authors to assume that familiarity 'may arise by virtue of a subset of the neural processing responsible for recollection' (Yovel and Paller, 2004, p. 797) and that the mid-frontal old/new effect, generally observed in studies using highly overlearned stimulus material, may not reflect familiarity, but verbally mediated conceptual priming (cf. Voss and Paller, 2006).

Hence, the second goal of the present study was to investigate whether the mid-frontal old/new effect indexes familiarity processes or conceptual priming mechanisms. To this end, subjects in our study also memorized colored line drawings of nonsense figures, for which no pre-existing knowledge was obtainable, which were hard to name and which elicited only rudimental semantic associations. If no semantic concept for such items exists, then any potential old/new effect in a recognition memory task cannot be based on conceptual priming but can only be due to an episodic memory entry. During a recognition memory test, participants judged the old/new status of new, old congruent (repeated with same color) and old incongruent (repeated with changed color) nonsense figures. If the mid-frontal old/new effect indeed reflects verbally mediated conceptual priming mechanisms, we should observe no such effect for meaningless, non-namable old nonsense figures. If, though, familiarity processes are involved in its generation, correctly recognized old nonsense figures should elicit a reliable mid-frontal old/new effect. As this effect can only be based on a rather perceptual memory entry, the additional comparison of congruent and incongruent items allows further inspection of the perceptual sensitivity of familiarity processes.

Materials and methods

Participants

Subjects were 26 right-handed students of Saarland University, which were paid for their participation. All subjects had normal or corrected-to-normal vision. Due to excessive EEG artifacts, 8 subjects had to be excluded from further analyses (a minimum of 20 trials per condition was considered necessary for inclusion into the Grand Average), leaving 18 subjects for behavioral and ERP analysis (mean age 26.8 years, range 20–42, 9 female).

Stimuli

Stimuli were 300 outline drawings of common objects (most of them taken from the standardized picture set by Snodgrass and Vanderwart, 1980) and nonsense figures (non-objects), respectively (see Fig. 1). The latter ones were generated by starting from three geometrical shapes (circle, square, triangle) and using freehand distortion, resulting in 100 nonsense figures from each original shape.

Stimuli were presented in the center of a 17″ Multiscan Color Monitor with a resolution of 800 × 600 dpi against a white background. Items had a size of 130 × 124 pixels, resulting in an angle of vision of 3°, approximately. In order to manipulate items' perceptual congruency, objects and non-objects were colored red and green, resulting in 300 red and 300 green objects and non-objects, respectively. For incongruent items, color was changed from study to test, that is, red items during study became green items during test and vice versa. Items were presented in a blocked design according to item class (object/non-object), and within each block, half the items were green and half were red, respectively. Assignment of stimuli to item color (green, red) and condition (new, congruent, incongruent) was counterbalanced across subjects.

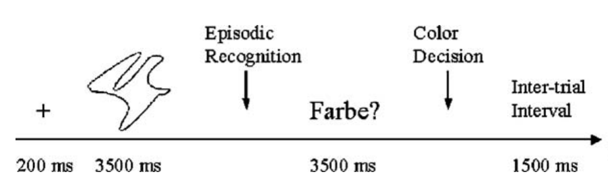

Fig. 2. Trial timing and procedure in the test phase of the present study (exemplified for a non-object trial); see text for further explanation.

Table 1
Recognition memory performance

	Objects			Non-objects		
	New	Congruent	Incongruent	New	Congruent	Incongruent
Reaction time (ms)	951 (34)	1249 (47)	1373 (60)	1457 (76)	1608 (73)	1619 (85)
Accuracy (% correct)	95 (02)	90 (02)	88 (02)	71 (03)	71 (04)	70 (03)

Mean reaction times and accuracy in the recognition memory task as a function of Item Class (object, non-object) and Condition (new, congruent, incongruent); values in parentheses indicate the standard error of means.

Design and procedure

All subjects were given 15 study test blocks (5 blocks for objects and 10 blocks for non-objects). To ensure that non-object performance would be above chance and similar to object performance, the number of to-be-remembered items in each non-object block was halved compared to the object blocks. Blocks were presented alternating, beginning with a block of objects, followed by two blocks of non-objects, and so on.

During study, subjects were told to memorize visually presented objects (30 study items) or non-objects (15 study items) and their respective colors. Items were presented for 3000 ms following a fixation cross (duration 200 ms); the inter-stimulus interval was 1000 ms (in all phases, trial timing was synchronized to the screen refresh rate). In the test phase, one half of the items from the preceding study phase were presented again in the same color (congruent), the other half in a changed color (incongruent).[1] Additionally, an equivalent number of new items were shown (i.e., 30 for objects, 15 for non-objects). Subjects had to accomplish a two-stage memory test concerning items and their corresponding color (see Fig. 2): first, subjects had to perform an old/new recognition task, in which congruent and incongruent items – regardless of their color – had to be accepted as 'old', and new items had to be rejected. When judging an item as old, subjects subsequently had to appraise its color ('identical' vs. 'changed'). This was done to control subjects' ability to recollect the perceptual feature at hand. Each test trial started with a fixation cross (200 ms) followed by the test item which was presented for 3500 ms. The old/new decision ended with subjects' response, or when the time limit of 3500 ms was reached. Subsequently, the color decision was signalized by presenting the word 'Farbe?' [color] in the center of the screen for 3500 ms. Subjects could make their choice immediately and the trial ended with their response or when the time limit (3500 ms) was reached. The inter-stimulus interval was 1500 ms. In both decisions, participants indicated their response by pressing the 'shift-left' or 'shift-right' button of the keypad with their index fingers (assignment of the buttons to response class was counterbalanced across subjects).

ERP recording and analyses

The experiment was run in a sound- and electromagnetically shielded chamber. EEG activity was recorded continuously from 64 Ag/AgCl electrodes mounted in a preconfigured cap (Electro-Cap International, Inc., Eaton, Ohio), arranged according to the extended international 10–20 system (American Electroencephalographic Society, 1994). Impedances for all electrodes were kept below 10 kΩ. Signals were digitized with a sampling rate of 250 Hz (50 Hz notch filter) by an AC coupled amplifier (Brain Amp MR, Brain Products, Munich; time constant 10 s) and referenced on-line to the left mastoid electrode. For further analysis, electrodes were re-referenced off-line to linked mastoids. Vertical and horizontal ocular artifacts were monitored and corrected off-line (Gratton et al., 1983).

ERPs with a 1200 ms duration were extracted during the old/new decision, beginning 200 ms prior to stimulus onset. Data were baseline-corrected with respect to the 200 ms pre-stimulus interval and digitally bandpass filtered at 0.1–20 Hz (slope 24 dB). Trials with incorrect responses in the recognition memory task and epochs containing artifacts (maximum amplitude in the recording epoch ±200 μV; maximum difference between two successive sampling points 50 μV; maximum difference of two values in the interval 300 μV; lowest allowed activity-change 0.5 μV in successive intervals of 100 ms) were excluded from averaging.

ERPs were computed for 6 different conditions (with the mean number of valid trials per condition given in parentheses): Object New (135), Object Congruent (62), Object Incongruent (62), Non-Object New (99), Non-Object Congruent (48) and Non-Object Incongruent (47). For statistical analysis, mean voltages were computed for each condition in two time windows: 250–450 ms and 450–700 ms (the choice of the time windows was based on previous studies, while taking into account visual inspection of the waveforms), and for each of the following nine regions of interest (ROIs): left frontal: F5, F7, FC5; left central: T7, CP5, TP7; left parietal: P5, P7, PO7; mid-frontal: Fz, FC1, FC2; mid-central: Cz, CP1, CP2; mid-occipito-parietal: Pz, O1, O2; and the right counterparts of left-sided electrode regions. This procedure resulted in a 3 (Anterior/Posterior) × 3 (Laterality) electrode arrangement.

Results

Behavioral data

Mean accuracy and reaction times in the *recognition memory task* (see Table 1) were analyzed by means of a repeated-measures analysis of variance (ANOVA), including Item Class (object, non-object) and Condition (new, congruent, incongruent) as within-subject factors. Accuracy was significantly better for objects than for non-objects ($F(1,17) = 195.14$, $P < .001$), but no main effect of Condition or interaction of Condition × Item Class was observed (P between .28 and .88). Recognition discrimination (Pr score, calculated as proportion of hits minus proportion of false alarms) was equivalent for both kinds of old objects (Pr = .86 for congruent stimuli, Pr = .85 for incongruent stimuli; $F(1,17) = 1.39$, $P = .26$) and non-objects (Pr = .44 for congruent stimuli, Pr = .43 for incongruent stimuli; $F < 1$), respectively. Subjects' discrimination

[1] Due to an odd number of study items in non-object blocks, a disparity between congruent and incongruent old items resulted at test (8 to 7 items), but this was counterbalanced across blocks.

Table 2
Color memory performance

	Objects		Non-objects	
	Congruent	Incongruent	Congruent	Incongruent
Reaction time (ms)	464 (34)	560 (37)	623 (42)	611 (48)
Accuracy (% correct)	83 (02)	72 (03)	57 (04)	50 (03)

Mean reaction times and accuracy in the color decision task as a function of Item Class (object, non-object) and Condition (congruent, incongruent); values in parentheses indicate the standard error of means.

performance differed significantly from chance-level performance in all conditions ($t(17) = 38.73$ for objects and $t(17) = 11.98$ for non-objects, $P < .001$, respectively).

Statistical analysis of reaction time data revealed main effects of Item Class ($F(1,17) = 75.50$, $P < .001$) and Condition ($F(2,34) = 41.37$, $P < .001$), as well as a significant interaction of these factors ($F(2,34) = 16.96$, $P < .001$). Planned comparisons clarified that responses to new items were made faster than to old items for objects ($F(1,17) = 87.24$ for congruent items, $F(1,17) = 104.55$ for incongruent ones, $P < .001$, respectively) and non-objects (congruent: $F(1,17) = 8.67$, $P < .01$; incongruent: $F(1,17) = 8.26$, $P < .011$). The critical difference between congruent and incongruent stimuli was significant for objects ($F(1,17) = 26.06$, $P < .001$), not for non-objects ($F < 1$).

In the *color decision task* (see Table 2), ANOVA on accuracy data of congruent and incongruent items for objects and non-objects revealed significant main effects of Item Class ($F(1,17) = 76.98$, $P < .001$) and Condition ($F(1,17) = 7.23$, $P < .05$), reflecting better color memory for objects as compared to non-objects and for congruent items compared to incongruent ones, respectively. Although the interaction of Item Class × Condition did not reach significance ($F(1,17) = 1.09$, $P = .31$), subsidiary paired contrasts revealed that congruent items differed significantly from incongruent ones for objects ($F(1,17) = 12.29$, $P < .01$), but not for non-objects ($F(1,17) = 2.23$, $P = .15$). Actually, subjects were able to remember the specific color of a previously seen item only for real objects since their accuracy differed from chance-level performance for objects (congruent: $t(17) = 21.22$, incongruent: $t(17) = 6.57$, $P < .001$, respectively), but not for non-objects (congruent: $t(17) = 1.94$, $P = .07$; incongruent: $t < 1$).

The accuracy advantage for congruent over incongruent objects in the color decision may reflect – at least partially – a response bias to judge old items as perceptually unmodified. We evaluated this possibility by inspection of the color decisions given to erroneously accepted new objects (false alarms). Assuming that subjects provide old color responses more frequently than new color responses to false alarms, then accuracy differences in color decisions to truly old items would have to be interpreted accordingly. Indeed, for real objects, subjects gave 55% old and 45% new color responses to false alarms. When using these values as baseline values in each condition (rather than 50% chance-level), accuracy would be about the same for congruent (83–55 = 28) and incongruent (72–45 = 27) objects. However, the reliability of this analysis is questionable since the proportion of false alarms made in the object class was quite low. Moreover, the same analysis for non-objects revealed 44% old color responses and 56% new color responses to false alarms. This result conflicts with a simple bias to respond 'old' in all cases of decision uncertainty. Nevertheless, it does not completely rule out the possibility that, for old items, subjects had a bias to judge the color as old, too.

Reaction time analysis revealed a main effect of Item Class ($F(1,17) = 11.63$, $P < .01$) and an interaction of Item Class × Condition ($F(1,17) = 24.37$, $P < .001$). Correspondingly, planned comparisons affirmed significantly slower responses to incongruent items relative to congruent ones for objects ($F(1,17) = 15.47$, $P < .01$), and no such difference for non-objects ($F < 1$).

ERP data

To examine whether differential old/new effects in the recognition memory test were observable for objects vs. non-objects (see Figs. 3 and 4), we initially conducted separate 2 × 3 × 3 × 3 multivariate analyses of variance (MANOVAs) within each time window, comprising the within-subject factors Item Class (objects, non-objects), Anterior/Posterior (anterior, central, posterior), Laterality (left, middle, right) and Condition (new, congruent, incongruent).[2]

In the 250–450 ms interval, MANOVA yielded a main effect of Item Class ($F(1,17) = 31.61$, $P < .001$), as well as significant interactions of Item Class with Anterior/Posterior ($F(2,16) = 25.12$, $P < .001$), Laterality ($F(2,16) = 8.36$, $P < .01$) and Condition ($F(2,16) = 5.96$, $P < .05$). Additionally, a significant interaction of Item Class × Anterior/Posterior × Condition ($F(4,14) = 3.69$, $P < .05$) was observed. In the later time window (450–700 ms), MANOVA revealed significant interactions of Item Class by Condition ($F(2,16) = 11.74$, $P < .001$) and Item Class by Anterior/Posterior ($F(2,16) = 6.17$, $P < .05$), along with a marginally significant interaction of Item Class with Laterality ($F(2,16) = 3.21$, $P = .07$).

This pattern of results suggests specific ERP effects for the two item classes in both time windows, which were further explored in separate 3 (Anterior/Posterior) × 3 (Laterality) × 3 (Condition) MANOVAs for objects and non-objects, respectively. As can be seen from Table 3, these analyses revealed significant main effects of condition as well as significant interactions of condition with electrode sites, which were further investigated by pairwise comparisons of new, congruent and incongruent objects and non-objects at single ROIs.

250–450 ms interval

Subsidiary analyses for *real objects* (see Fig. 3) in the early time interval revealed reliable old/new effects for congruent items at all ROIs (Fs(1,17) between 7.99 and 34.47, Ps between .012 and <.001). Incongruent items differed significantly from new ones at frontal and central ROIs (Fs between 9.18 and 44.88, all Ps < .01), and marginally so at left posterior sites ($F(1,17) = 3.45$, $P = .08$). Moreover, the critical difference between congruent and incongruent items was significant at all ROIs (Fs between 4.46 and 8.18, all Ps < .05) except right anterior ($F(1,17) = 2.06$, $P = .17$) and left posterior ($F(1,17) = 3.93$, $P = .06$) recording sites.

[2] Note that, due to the purpose of this analysis, only significant results including the factor Item Class are reported in this paragraph, with more specific reports of condition effects restricted to the following analyses concerned only with objects and non-objects, respectively.

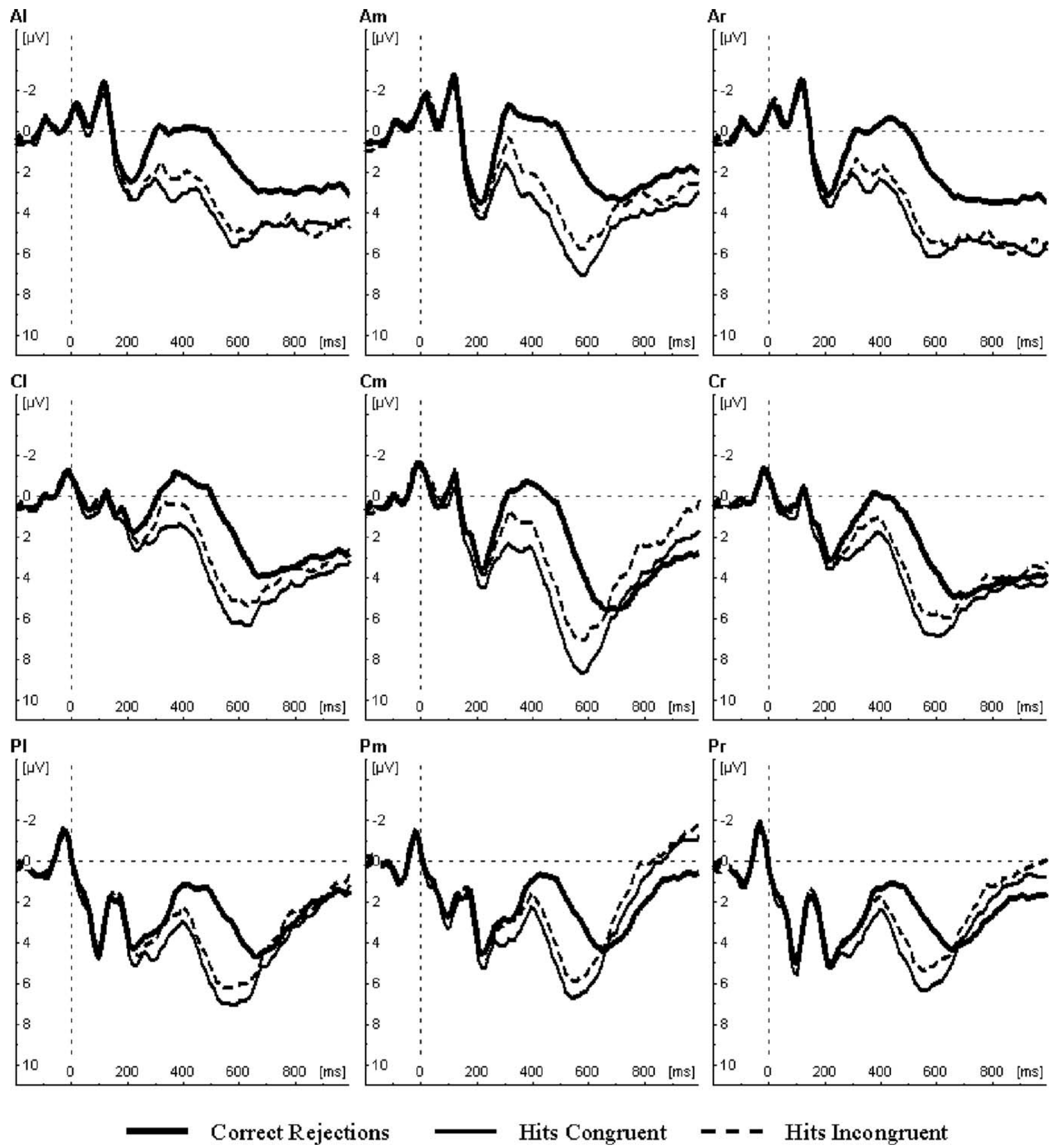

Fig. 3. Grand average waveforms for objects in the recognition memory test as a function of Condition (correct rejections, hits congruent, hits incongruent), depicted at the 9 regions of interest (A Anterior, C Central, P Posterior; l left, m middle, r right); positive values are displayed downwards.

Pairwise comparisons at individual ROIs for *non-objects* (see Fig. 4) exhibited reliable old/new differences for congruent items at left and mid-frontal as well as at left and mid-central recording sites (Fs(1,17) between 5.82 and 13.13, Ps between .027 and .002). Incongruent items as well differed significantly from new ones at mid-frontal electrode sites ($F(1,17) = 7.17$, $P < .05$), furthermore marginally so at left frontal ($F(1,17) = 3.93$, $P = .06$) and mid-central ($F(1,17) = 3.43$, $P = .08$) recording sites. No significant difference between congruent and incongruent non-objects was observable in this time window (Ps between .33 and .88).

Topographic analyses

Granted that non-objects indeed lack a corresponding conceptual representation, the comparison of ERP waveforms to objects vs. non-objects reflects the access to such semantic

Table 3
MANOVA results of ERP effects

Interval	Objects				Non-objects			
	Effect	*df*	*F*	*P*	Effect	*df*	*F*	*P*
250–450 ms	Cond	2,16	14.80	<.001	Cond	2,16	4.67	<.05
	Cond × AP	4,14	8.51	<.01	Cond × AP	4,14	<1	n.s.
	Cond × Lat	4,14	4.02	<.05	Cond × Lat	4,14	3.26	<.05
	Cond × AP × Lat	8,10	6.65	<.01	Cond × AP × Lat	8,10	1.18	n.s.
450–700 ms	Cond	2,16	29.53	<.001	Cond	2,16	2.71	=.10
	Cond × AP	4,14	2.82	=.07	Cond × AP	4,14	2.16	n.s.
	Cond × Lat	4,14	1.62	n.s.	Cond × Lat	4,14	3.39	<.05
	Cond × AP × Lat	8,10	3.19	<.05	Cond × AP × Lat	8,10	3.49	<.05

Results of the multivariate analyses of variance (MANOVAs) of ERP effects for objects and non-objects in the 250–450 ms and 450–700 ms time interval; Cond denotes Condition, AP stands for Anterior/Posterior, and Lat for Laterality; see text for further explanation.

memory entries. To separate these processes associated with semantic memory access from potential familiarity processes associated with old/new effects for non-objects, we compared the topography of the old/new difference for non-objects in the 250 to 450 ms range with the topography of the difference between objects and non-objects in the same time interval. As one can see, the old/new effect for non-objects (see Fig. 5, middle column) is frontally accentuated and resembles that for objects (although the latter one has a slightly broader distribution; see left-hand side of Fig. 5). In contrast, the object/non-object difference is accentuated at centro-parietal recording sites (see right-hand side of Fig. 5) and reminds of a more 'classical' N400 distribution (Kutas and Hillyard, 1980).

To elucidate these topographical differences, an additional MANOVA on ERP differences (old/new effect for non-objects vs. object/non-object difference) over the 3 × 3 ROIs was conducted. Besides a main effect of Condition ($F(1,17)$ = 53.53, P < .001), this analysis revealed significant two-way interactions of Condition × Anterior/Posterior ($F(2,16)$ = 24.26, P < .001) and Condition × Laterality ($F(2,16)$ = 15.08, P < .001); moreover, the three-way interaction of Condition × Anterior/Posterior × Laterality was significant ($F(4,14)$ = 7.87, P < .01), thereby substantiating discrete topographic distributions for the two contrasts.[3]

450–700 ms interval

Exploratory analyses for *objects* in the late time interval gave rise to reliable old/new effects for congruent and incongruent items at all ROIs (Fs(1,17) between 19.13 and 58.96, all Ps < .001). However, this old/new effect was graded with respect to perceptual congruency since congruent items differed significantly from incongruent ones at mid- and right central as well as at right posterior electrode sites (Fs(1,17) between 4.48 and 7.22, all Ps < .05). Additionally, the difference between congruent and incongruent items was marginally significant at mid-frontal (P = .06), left central (P = .06) as well as left posterior (P = .10) and mid-posterior (P = .08) sites.

Subsidiary comparisons for *non-objects* revealed reliable old/new differences for congruent items at left and mid-frontal as well as left and mid-central ROIs (Fs(1,17) between 5.71 and 16.62, Ps between .029 and <.001). Incongruent items differed only marginally from new ones at mid-frontal electrode sites ($F(1,17)$ = 4.07, P = .06). Again, no significant difference between congruent and incongruent non-objects was observed (Ps between .24 and .80).

900–1300 ms interval

The reader may have noticed the polarity reversal of the old/new effect for objects at around 700 ms (cp. Fig. 3). Although not in the original focus of our attention, we got granular on this component by extending the time interval to 1300 ms post-stimulus onset. Fig. 6 (left-hand side) shows the negative shift of waveforms for congruent and incongruent objects at one of the most representative electrodes (Oz), as well as the corresponding effect for non-objects (right-hand side).

A MANOVA on mean amplitudes in the 900–1300 ms interval for new, congruent, and incongruent *objects* over 9 ROIs yielded significant interactions of condition with electrode sites (see left-hand side of Table 4). Post hoc comparisons identified two discriminable foci of old/new effects: First, mean amplitudes for both types of old objects were more positive than new ones at right frontal electrodes (Tukey HSD: Ps < .001). Second, both congruent and incongruent items elicited more negative-going waveforms than new ones at mid-central, mid-posterior and right posterior electrode sites (all Ps < .001). Additionally, this negativity was even more pronounced for incongruent than for congruent objects (all Ps < .01).

A corresponding MANOVA for *non-objects* gave rise to marginally significant interactions of condition with electrode sites (see right-hand side of Table 4). Post hoc analyses detected the sustained positivity for congruent and incongruent items at frontal electrodes (mid-frontal: congruent P = .09, incongruent P < .05; right frontal: incongruent P = .05). Moreover, the posterior negativity was marginally significant for incongruent non-objects at the mid-posterior ROI, only (P = .06).

Semantic associativity

Non-objects were designed to convey as little meaning as possible and to be hard to verbalize. However, it is possible that some of the nonsense figures elicited rudimental semantic associations. Hence, it might be argued that the mid-frontal old/new effect for non-objects is based on conceptual priming mechanisms for the very figures with rudimental conceptual associations rather than on familiarity processes. To rule out this argument, we conducted an additional rating study, in which 20

[3] The reliability of this topographic analysis was confirmed in an additional analysis on vector-scaled ERP data (McCarthy and Wood, 1985; see also Dien and Santuzzi, 2004).

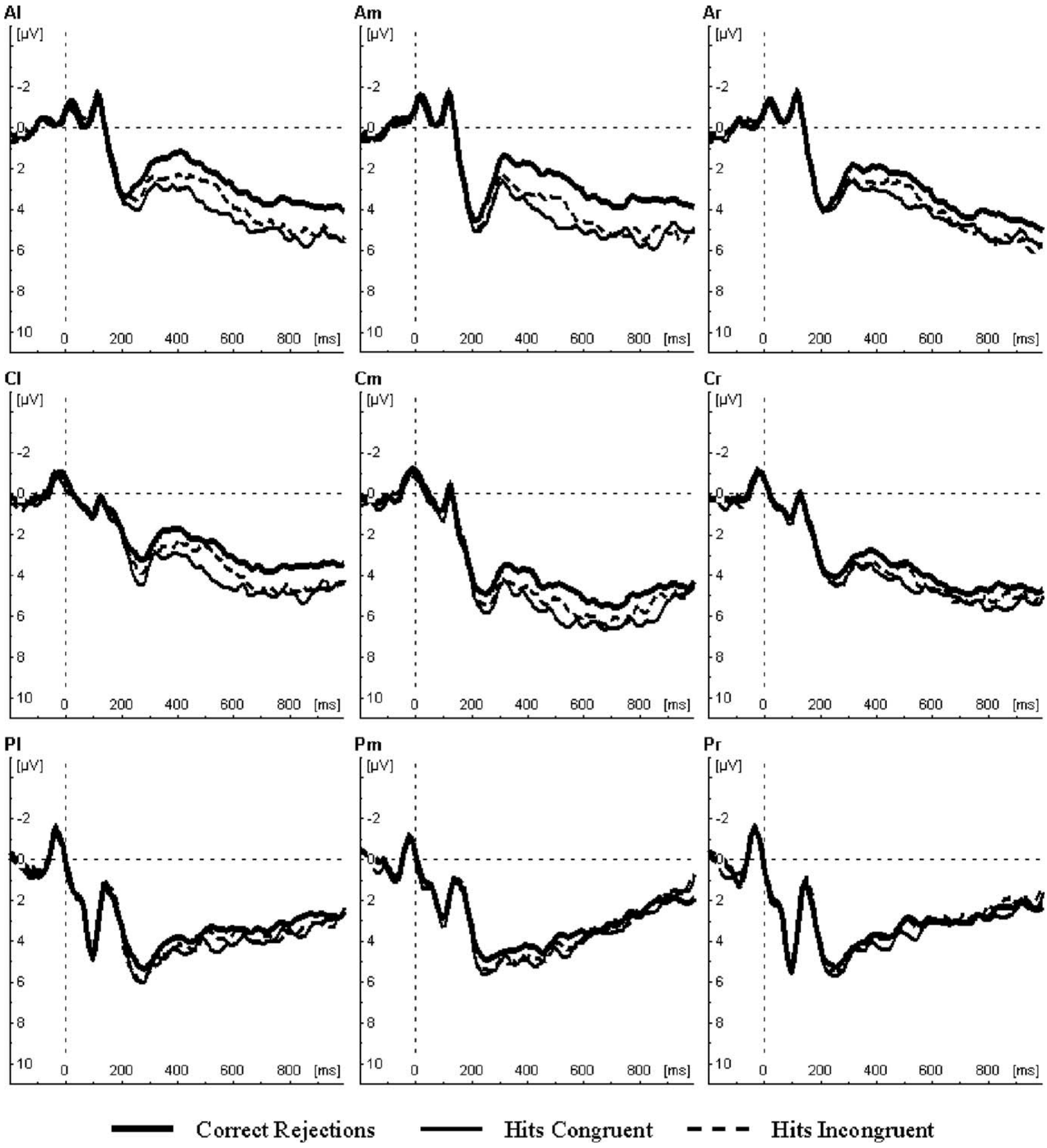

Fig. 4. Grand average waveforms for non-objects in the recognition memory test as a function of Condition (correct rejections, hits congruent, hits incongruent), depicted at the 9 regions of interest (A Anterior, C Central, P Posterior; l left, m middle, r right); positive values are displayed downwards.

participants (mean age 25.6, range 20–40, 12 female) judged the semantic associativity of the nonsense figures (10 participants rated half of the figures, respectively) on a four-point rating scale, ranging from '1' ('no meaning') to '4' ('reminds me of' or 'looks like'). This procedure resulted in an average rating for each item, indicating the 'semantic content' of each figure. We then conducted a median-split (median = 1.5, mean = 1.59, SD = .42) of item ratings and classified each figure according to 'low' (below median; mean = 1.31, SD = .15) or 'high' (above median; mean = 1.93, SD = .39) semantic associativity. This additional factor was then included in the analysis of behavioral and ERP data for non-objects in the present study. If the mid-frontal old/new effect is related to conceptual priming, then the size of this effect should vary with the level of semantic associativity: the effect should be larger for non-objects with 'high' than for those with 'low' conceptual meaning. If, however, the size of the mid-

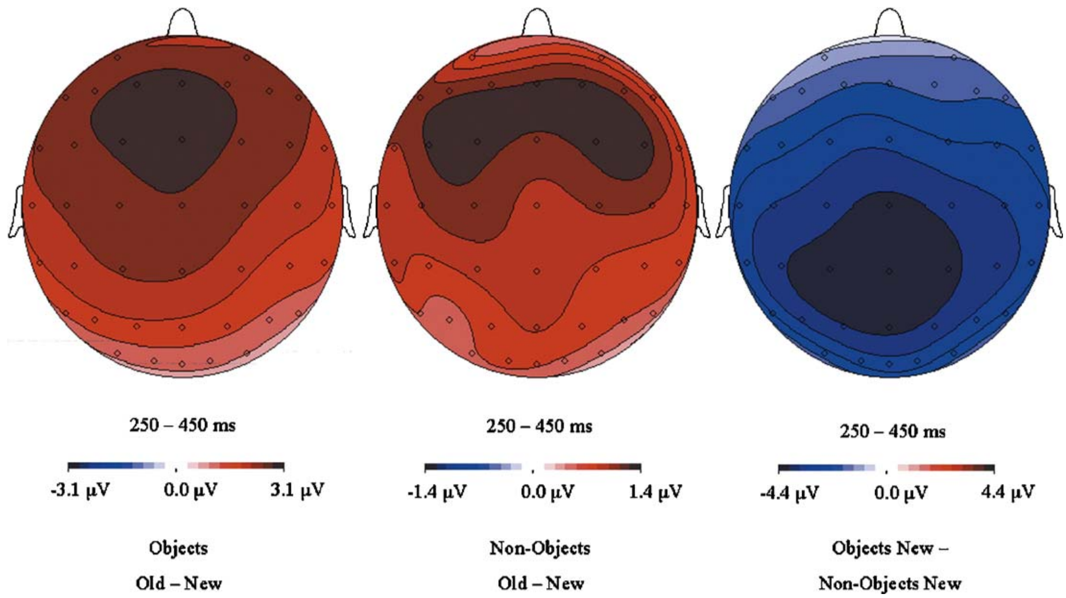

Fig. 5. Spherical-spline interpolated topographical maps of ERP differences in the 250–450 ms interval. The left-hand side shows the old/new effect for objects: correct responses to new items were subtracted from correct responses to old items, which were collapsed over congruent and incongruent conditions; the middle column shows the corresponding old/new effect for non-objects; the right-hand side depicts the difference between correct rejections to new objects and correct rejections to non-objects. The head is depicted from above (with the front facing up, left on left, etc.).

frontal effect is not affected by semantic associativity, this result would substantiate the familiarity-based account of the early old/new effect.

Accuracy rates were higher for 'high' than for 'low' semantic non-objects in the recognition (Pr = .46 vs. .37; $F(1,17) = 10.65$, $P < .01$; see Table 5) and in the color decision task (proportion correct .56 vs. .51; $F(1,17) = 6.06$, $P < .05$; see Table 6).[4] Reaction times, then again, were not affected by semantic associativity (all Ps > .26).

A MANOVA on ERP mean amplitudes from the recognition task in the 250–450 ms time interval (see Fig. 7) was conducted and comprised a 2 (Semantic Associativity) × 3 (Anterior/Posterior) × 3 (Laterality) × 3 (Condition) design. This analysis yielded a marginally significant main effect of Semantic Associativity ($F(1,17) = 3.84$, $P = .07$), reflecting overall more positive-going waveforms for 'high' semantic non-objects compared to 'low' ones. However, no interaction of Semantic Associativity with Condition or any other higher-order interaction was observed (Ps between .21 and .42). Additionally, the old/new effect (collapsed over congruent and incongruent items) was not influenced by Semantic Associativity ($F(1,17) < 1$). For 'low' semantic non-objects, post hoc comparisons revealed that the mid-frontal old/new effect for congruent and incongruent items was still present at frontal sites (Tukey HSD: all Ps < .01). For 'high' semantic non-objects, congruent items elicited statistically reliable old/new effects at frontal and central ROIs (all Ps < .05 except right frontal), whereas incongruent stimuli showed only a marginally significant old/new difference at mid-frontal ($P = .06$) and mid-central ($P = .07$) recording sites.

[4] Note that, in the color task, the difference between high and low non-objects dated from accuracy for congruent items only. Although the interaction of Semantic Associativity and Condition was only marginally significant ($F(1,17) = 3.39$, $P = .08$), this was the only condition in which performance differed significantly from chance-level ($t(17) = 17.63$, $P < .001$).

Discussion

Above-chance-level discrimination performance was observed for both item classes, indicating that subjects were well able to discriminate old from new items in the episodic recognition task. However, a reaction time effect of perceptual specificity, i.e., slower response times for incongruent relative to congruent stimuli, was found only for real objects (namely in the recognition task and in the color decision). This finding is in accordance with previous studies investigating the influence of perceptual modifications on explicit memory tasks (Biederman and Cooper, 1992; Snodgrass et al., 1996; Zimmer, 1995; Zimmer and Steiner, 2003). We have argued (Ecker et al., 2004) that these perceptual specificity effects speak for an involuntary reactivation of a previously engendered object representation during test. This representation includes all sensory features, hence leading to a mismatch with a perceptually changed item and thereby hampering object recognition.

The failure to observe such an effect for non-objects cannot unambiguously be attributed to the specific item class since results from the color decision showed that subjects were not able to recall the specific colors associated with old non-objects. As indicated also by accuracy differences in the recognition memory test between the two item classes, the memory task obviously was much more difficult for non-objects than for objects, presumably due to their (intended) meaninglessness (cf. the higher accuracy in the item and color decision for 'high' than for 'low' semantic non-objects). In line with the behavioral data, ERPs showed no statistically significant difference between congruent and incongruent non-objects (despite a slight tendency for a somewhat more distinct old/new effect for congruent items), thereby providing no meaningful information about the perceptual sensitivity of memory processes associated with nonsense figures in the present study. Nevertheless, subjects' performance for non-objects in the recognition memory task was sufficiently high to allow for the investigation of ERP old/new effects.

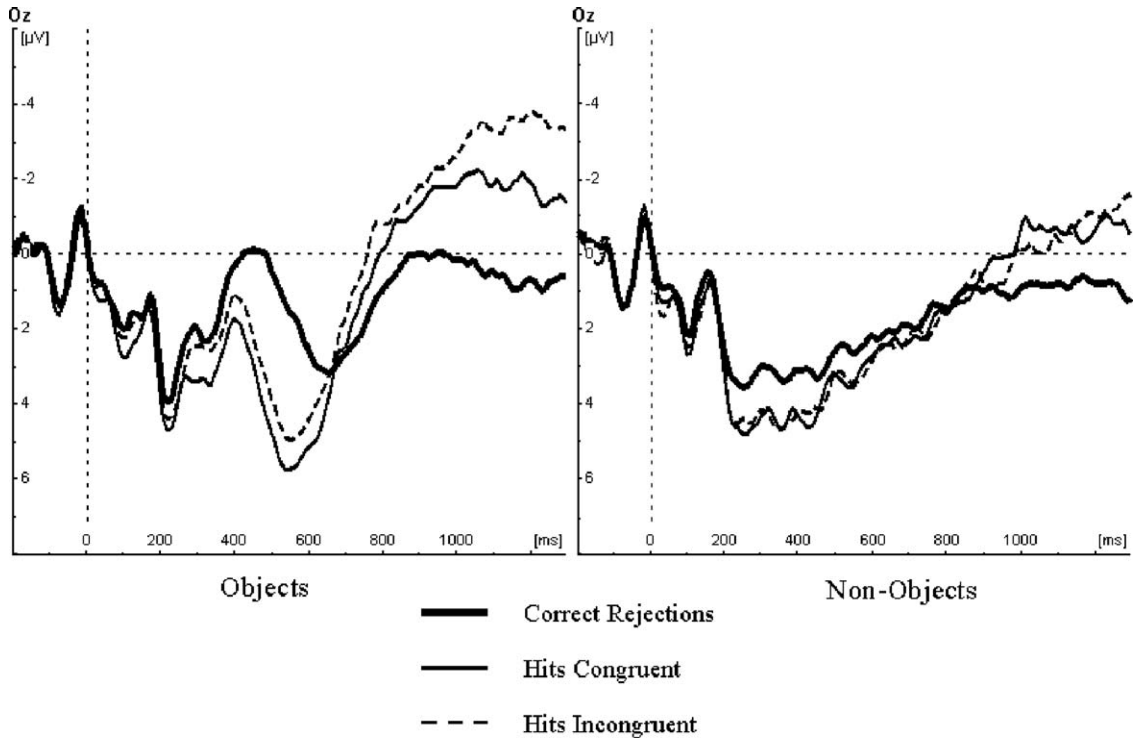

Fig. 6. Grand average waveforms for objects (left-hand side) and non-objects (right-hand side) in the recognition memory test as a function of Condition (correct rejections, hits congruent, hits incongruent); waveforms are shown at electrode Oz in the time interval ranging from −200 ms to 1300 ms around stimulus' onset; positive values are displayed downwards.

Meaningless non-objects, being hard to name, elicited a reliable old/new effect at fronto-central electrodes in the early time window, thereby resembling the old/new difference for objects in the present study as well as previously described mid-frontal old/new effects (cf. Friedman and Johnson, 2000; Mecklinger, 2000) both in their spatial and temporal characteristics. We are aware of only three previous studies investigating ERP old/new effects for novel visual patterns in a recognition memory paradigm. Penney et al. (2000) did not find any old/new effects for structurally impossible visual objects. Following the framework provided by Rugg and colleagues (Rugg and Doyle, 1994; Rugg et al., 1995), they attributed this failure to the fact that impossible objects cannot be represented in a 'unitized code', that is, they are not encoded at a level of abstraction beyond that of their surface features (e.g., lexically, semantically or episodically). However, accuracy for impossible objects in the recognition memory task was well above chance, and it is unclear why this access to apparently existing (perceptual) memory traces was not reflected in corresponding ERP correlates. According to this consideration, Van Petten and Senkfor (1996) reported that hits to novel patterns elicited a more positive-going waveform compared to correct rejections at fronto-central electrodes from 300 to 700 ms. As this old/new effect was interpreted as reflecting episodic retrieval, it may support the results from the present experiment. However, one constraint has to be considered insofar as, in the Van Petten and Senkfor study, waveforms to old patterns comprised items shown once or twice during study. A dual presentation during study might have enhanced subjects' ability to semantically code the patterns, thus possibly increasing the contribution of conceptual processes during test. The same argument holds for a recent study on visual categorization by Curran et al. (2002), in which the authors reported a mid-frontal old/new effect for novel visual patterns in an early time window; however, subjects underwent an extensive training session with several families of novel patterns prior to the recognition memory test, thereby raising the possibility that the patterns were verbally and/or semantically recoded within a conceptual frame of reference. The present experiment deals with these arguments by revealing a distinct old/new effect for nonsense figures even following a single study presentation.

Table 4
MANOVA results of ERP effects

Interval	Objects				Non-objects			
	Effect	*df*	*F*	*P*	Effect	*df*	*F*	*P*
900–1300 ms	Cond	2,16	3.98	<.05	Cond	2,16	<1	n.s.
	Cond × AP	4,14	9.24	<.001	Cond × AP	4,14	2.96	=.06
	Cond × Lat	4,14	9.33	<.001	Cond × Lat	4,14	1.32	n.s.
	Cond × AP × Lat	8,10	3.28	<.05	Cond × AP × Lat	8,10	2.88	=.06

Results of the multivariate analyses of variance (MANOVAs) of ERP effects for objects and non-objects in the 900–1300 ms time interval; Cond denotes Condition, AP stands for Anterior/Posterior, and Lat for Laterality; see text for further explanation.

Table 5
Recognition memory and semantic associativity

	Low			High		
	New	Congruent	Incongruent	New	Congruent	Incongruent
Reaction time (ms)	1470 (80)	1621 (84)	1612 (95)	1443 (73)	1601 (62)	1620 (79)
Accuracy (% correct)	69 (02)	68 (02)	68 (02)	74 (01)	74 (02)	72 (01)

Mean reaction times and accuracy for non-objects in the recognition memory task as a function of Semantic Associativity (low, high) and Condition (new, congruent, incongruent); values in parentheses indicate the standard error of means.

In our view, the ERP correlate of recognition memory for nonsense figures found in the present experiment can be interpreted as a rather pure correlate of familiarity. No remembrance of specific perceptual information in the color decision could be obtained, hence the probability for recollection processes (at least referring to color information) contributing to the old/new difference is quite low. Accordingly, statistical analysis revealed the old/new effect in the later time interval to be significant only at left and mid-frontal and central electrode sites, respectively, representing the temporal extension of the early old/new effect and lacking the parietal focus typically associated with recollection processes. Critically, no semantic associations to non-objects were available, so no semantic memory representation – usually considered the basis of conceptual priming – could be addressed during test. When controlling the amount of semantic associativity connected with non-objects (see our rating study), the mid-frontal old/new effect was still observable for 'low' semantic items and, in addition, was not influenced by conceptual associativity. In our judgment, the data of the present study strongly suggest a close relationship of the mid-frontal old/new effect to familiarity processes rather than conceptual priming mechanisms.

In contrast to the frontally accentuated old/new effect for non-objects, the topography of the object/non-object comparison resembled a 'classical' visual N400 with its centro-parietal maximum (cf. Kutas and Federmeier, 2000). Following Kutas and Federmeier, the N400 reflects the retrieval of information from long-term semantic memory, and the N400 amplitude is sensitive to the ease of accessing such semantic information. Such an access to semantic memory representations – and hence the elicitation of an N400 – is possible for "potentially meaningful stimuli" only (ibid., p. 468), just as the real objects used in the present study. In line with this suggestion, it has been shown that phonologically legal pseudowords elicit N400 responses, whereas non-words (i.e., non-pronounceable pseudowords) do not (e.g., Bentin et al., 1999; Friedrich and Friederici, 2005). On this note, it makes sense that non-objects in our study did not elicit such a negative component since there are no meaningful representations accessible. However, if one considers the broader distribution of the early old/new effect for objects compared to non-objects and additionally assumes that priming mechanisms are not strictly tied to implicit memory tests, it might be the case that, in a typical recognition memory test using words or namable pictures, a superposition of a more frontally accentuated portion of the old/new effect, reflecting a neural correlate of familiarity, and a more centro-parietally distributed portion, reflecting a neural correlate of conceptual priming, is observable (cf. Curran and Dien, 2003 for a similar idea).

The old/new effect for real objects in the early time window was graded according to the perceptual congruency between study and test. Reliable old/new differences were observed for both perceptually identical and modified items, but this old/new effect was attenuated for incongruent compared to congruent stimuli. This finding additionally challenges Yovel and Paller's (2004) position on the functional significance of the mid-frontal old/new effect since conceptual priming should not be affected by perceptual manipulations from study to test (cf. Roediger and McDermott, 1993; Roediger and Srinivas, 1993). If, then, familiarity comes into play, our finding also conflicts with previous reports in which the familiarity component has been found to be insensitive to perceptual feature manipulations (Curran, 2000; Curran and Cleary, 2003). Rather, it is in accordance with results from our own laboratory (Groh-Bordin et al., 2005) in showing that familiarity processes can indeed encompass perceptual attributes. Recent studies by Rugg and colleagues revealed a comparable sensitivity of the mid-frontal

Table 6
Color memory and semantic associativity

	Low		High	
	Congruent	Incongruent	Congruent	Incongruent
Reaction time (ms)	605 (40)	635 (55)	624 (51)	583 (47)
Accuracy (% correct)	52 (02)	50 (01)	61 (02)	51 (02)

Mean reaction times and accuracy for non-objects in the color decision task as a function of Semantic Associativity (low, high) and Condition (congruent, incongruent); values in parentheses indicate the standard error of means.

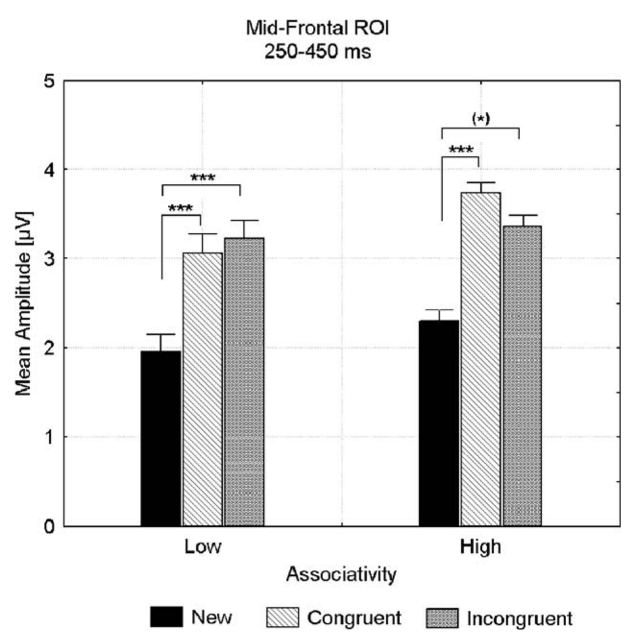

Fig. 7. Mean ERP amplitudes from the recognition memory task for non-objects at the mid-frontal ROI in the 250–450 ms time range as a function of Semantic Associativity (low, high) and Condition (new, congruent, incongruent); error bars indicate the standard error of mean; $***P < .001$, $(*)P = .06$.

component for context changes (Tsivilis et al., 2001) and stimulus format changes (Schloerscheidt and Rugg, 2004), respectively. Following their results, the authors attributed the mid-frontal old/new effect to a novelty detection mechanism, assessing the relative novelty of a stimulus within an experimental context. With respect to our neurocognitive memory model (Ecker et al., 2004), assuming that the memory representation underlying familiarity binds all perceptual item features and is reactivated during episodic retrieval, a higher degree of 'novelty' (or lower degree of familiarity) may result from the perceptual mismatch between reactivated features of the stored representation and the perceived features of the incongruent item at hand.

Considering the diverse effects of perceptual manipulations on the mid-frontal old/new effect, it is supposable that familiarity is neither strictly tied to perceptual processes nor acting exclusively on the overall semantic similarity of items between study and test (for similar considerations, see Curran and Dien, 2003). We rather assume that both perceptual and conceptual information contribute to familiarity-based episodic recognition, the ratio depending on specific properties of the stimuli (including, for instance, a substantial perceptual mismatch from study to test) and the task at hand (as in the present study, focusing subjects' attention on the perceptual feature by study instruction).

Similar to the old/new effect in the early time interval, the late parietal old/new effect was also attenuated for incongruent compared to congruent objects. We argued recently (Groh-Bordin et al., 2005) that a critical variable moderating perceptual specificity effects emerging in the late parietal component may be the relevance of the perceptual feature for the memory task to be performed. Accordingly, studies using inclusion tasks (Curran and Dien, 2003; Groh-Bordin et al., 2005; Tsivilis et al., 2001), in which identical and modified items have to be accepted as 'old', observed similar parietal old/new effects for congruent and incongruent stimuli. In contrast, studies employing exclusion tasks (Curran, 2000; Curran and Cleary, 2003; Ranganath and Paller, 1999), where modified items have to be rejected as 'new', yielded remarkable differences in the parietal old/new effect between congruent and incongruent items. This pattern points to the influence of strategic processes on episodic retrieval (cf. Rugg and Wilding, 2000; Wilding et al., 2005). On this note, it is reasonable to assume that, due to the sequential testing procedure in the present study, subjects may have been engaged in an evaluation of perceptual features during the recognition memory test, yet, and that this may have contributed to the observed difference in the late parietal old/new effect between congruent and incongruent items.

However, an important caveat has to be considered: whereas subjects usually show similar recognition memory accuracy for both types of old items in inclusion tasks (e.g., Groh-Bordin et al., 2005; or even worse performance for congruent stimuli, Curran and Dien, 2003), they often perform better for congruent compared to incongruent items in exclusion tasks (e.g., Curran, 2000; Curran and Cleary, 2003). Since the late parietal old/new effect is normally associated with successful episodic retrieval (Smith, 1993; Wilding and Rugg, 1996; Wilding et al., 1995), differences in ERP old/new effects between congruent and incongruent items (also in the present experiment) may reflect a differential degree of successful access to consisting memory representations. A direct comparison of an inclusion vs. an exclusion task, controlling for subjects' accuracy levels for congruent and incongruent items, would be necessary to disentangle the amalgamation of strategic components related to the memory task, on the one hand, and processes related to successful memory retrieval, on the other.

In line with the suggestion of upstream feature retrieval processes, a late (i.e., 900–1300 ms) negative shift for old items over posterior electrodes was observable in the present study that resembles the previously described late posterior negativity (LPN; for a review and discussion, see Johansson and Mecklinger, 2003). According to Johansson and Mecklinger, the LPN may reflect retrieval processes "that act to reconstruct the prior study episode when task-relevant attribute conjunctions are not readily recovered by the test probe or need continued evaluation" (p. 112). Since the LPN is usually not observed in pure item recognition tasks, but rather in source memory tasks (e.g., Friedman et al., 2005), it is sensible to assume that subjects in the present study continuously evaluated the perceptual attribute (i.e., color) during the recognition memory phase, already, as they had to withhold their responses until the color cue appeared on the screen. Similar to the parietal old/new effect, the LPN for non-objects was hardly observable, and this may be due to subjects' difficulties to retrieve any detailed information at all for this type of stimulus. Regarding real objects, we can only speculate why the LPN was even more pronounced for incongruent items than for congruent ones. Possibly, the reactivation of contextual features and their binding into an internal cognitive representation are more demanding for incongruent items because they lack an additional retrieval cue due to their mismatching perceptual information. Alternatively, the LPN has been related to action monitoring processes associated with response conflict (cf. Johansson and Mecklinger, 2003), and it is conceivable that incongruent items lead to higher levels of response conflict than congruent items, again on the basis of their mismatching features. However, the exact functional significance of the LPN is far from being solved (cf. Johansson and Mecklinger, 2003), and further research is needed to enlighten the cognitive operations associated with this memory-related component.

Acknowledgments

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