Contribution of Familiarity and Recollection to Associative Recognition Memory: Insights from Event-related Potentials

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Abstract

■ Within the dual-process perspective of recognition memory, it has been claimed that familiarity is sufficient to support recognition of single items, but recollection is necessary for associative recognition of item pairs. However, there are some reports suggesting that familiarity might support associative recognition judgments when the items form an easy to access bound representation. In contrast, recollection seems to be required for the recognition of bindings that might be flexibly rearranged in novel situations. We investigated whether both forms of binding are mediated by different mechanisms as reflected by a qualitatively different spatiotemporal event-related potential (ERP) pattern. In a recognition memory experiment, subjects gave old/new judgments to words learned by focusing either on interitem associations or on size relation of word triplets. Results revealed higher hit rates in the relational condition as compared to the associative condition. In addition, the proportion of triplets from which all three items were remembered was significantly larger in the relational condition suggesting that memory retrieval in this condition relies primarily on bound representations of word triplets. The ERP revealed a late parietal old/new effect for both conditions, with relational processing resulting in a greater effect. In contrast, an early frontal old/new effect was solely present in the associative condition. Taken together, these data provide evidence that familiarity might support associative recognition if the associated components are coherently encoded into a bound representation. Recollection might foster the recognition of relational bindings among items. This indicates that the contribution of familiarity and recollection to associative recognition depends on the kind of binding operations performed on the items rather than on the single versus multiple item distinction. ■

INTRODUCTION

The idea that recognition memory is based on two distinct processes, recollection and familiarity, is central to dual-process theories of recognition (Mecklinger, 2000; Wilding & Rugg, 1996; for a review, see Yonelinas, 2002). Recollection refers to conscious retrieval of contextual details of the original study episode in which an item occurred. Thus, recollection provides information both about the prior occurrence of an item and about the context of that occurrence. By contrast, familiarity-based recognition is not accompanied by information from specific study episodes and therefore provides no means for making discriminations on the basis of contextual information.

An extensive amount of research has demonstrated that event-related potentials (ERPs) are sensitive to dissociate the contribution of familiarity and recollection to recognition memory (e.g., Curran, 2000; Friedman & Johnson, 2000; Rugg, Mark, Walla, Schloerscheidt, Birch, & Allan, 1998). In general, correct responses to old items elicit more positive-going ERPs than correctly rejected new items. This so called old/new effect can be subdivided into several subcomponents based on their spatiotemporal characteristics and sensitivity to experimental manipulations. For the present purposes, the most important effects are an early frontal old/new effect (300–500 msec) reflecting familiarity and a somewhat later effect (400–800 msec) maximal over (left) parietal regions thought to index recollection (e.g., Curran, 2000; Friedman & Johnson, 2000; Mecklinger, 2000). Furthermore, familiarity and recollection are dependent upon some subset of the structures typically damaged in amnesia such as the hippocampus and surrounding medial temporal cortex. There is evidence from several animal studies (Aggleton & Brown, 1999), studies on amnesic patients (Holdstock et al., 2002) and neurocomputational models (Norman & O'Reilly, 2003) suggesting that recollection is specifically dependent on the hippocampus, whereas familiarity is dependent on the nearby temporal cortex, that is, the perirhinal cortex.

From the dual-process perspective, it has been claimed that familiarity is sufficient to support recognition of single items, yet recollection is necessary for associative recognition involving pairs of items (Yonelinas, 1997). Most direct evidence comes from studies on associative

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recognition in which subjects study pairs of words followed by associative recognition tests requiring discrimination between same pairs of words, pairs of newly combined but studied words (rearranged pairs), and pairs of entirely new words. The late parietal ERP old/new effect is larger for correctly classified same than rearranged pairs (Donaldson & Rugg, 1998), indicating that the recognition of associations between words is mediated by recollective processes. Another recent study manipulated object–scene pairings during an associative recognition test (Tsivilis, Otten, & Rugg, 2001). Interestingly, in this study, although the ERPs elicited by same and rearranged pairs differed from those generated by new pairs, neither the late parietal nor the early frontal old/new effect differed between same and rearranged pairs. Thus, this study did not provide evidence for a differential contribution of recollection or familiarity to associative recognition. In addition, evidence for a contribution of familiarity to associative recognition has been provided by several patient studies (Mayes et al., 2004; Helmstaedter, Gleiner, Di Perna, & Elger, 1997). The amnesic patient, Y.R., investigated by Mayes et al. (2004) demonstrated well-preserved recognition of both intra-item associations and associations between items of the same kind. It has been suggested that the patient's familiarity memory for associations was mediated by the intact medial temporal lobe cortices and was preserved, whereas the hippocampally mediated recall/recollection of these kinds of information was impaired. Moreover, Yonelinas, Kroll, Dobbins, and Soltani (1999) tested associative recognition of facial stimuli, whereby the distractors during the test consisted of rearranged faces from the study list. Thus, the internal features (i.e., eyes, nose, mouth, etc.) of rearranged faces had been studied with another set of external features (i.e., hair, head shape, ears, etc.). Estimates of familiarity derived from receiver operating characteristics (ROCs) were significantly above zero and curvilinear for associative recognition when faces were presented upright but not when presented upside down. Based on these results, Yonelinas et al. have argued that associative effects on familiarity will occur to the extent to which the to-be-associated information can be bound into a single unitized representation.

This view bears some resemblance to memory binding, that is, processes by which distinct aspects of a memory are linked together to form a coherent episode (Curran, Tepe, & Piatt, 2006). There is general agreement that the hippocampus plays an important role in memory binding (O'Reilly & Rudy, 2001; Eichenbaum, Dudchenko, Wood, Shapiro, & Tanila, 1999). More precisely, recollective processes may benefit from higher order binding within the hippocampus. In contrast, familiarity may involve low-order binding in the perirhinal cortex by conjoining only a small number of features into a unitary representation (O'Reilly, Busby, & Soto, 2003).

In summary, familiarity seems to support associative recognition judgments when the items form an easy to access bound representation. Such representations arise when items occur together frequently in the environment, for example, hen and egg (see Carson & Burton, 2001, for a similar argument). In agreement with this proposal, a familiarity response has been observed in the medial temporal lobe cortex for repeatedly presented face–tool pairings (Düzel et al., 2003) or face–house pairings (Preston, Shrager, Dudukovic, & Gabrieli, 2004). Thus, for the purpose of the present report the preexperimentally existing semantic coherence of the to-be-remembered information will be referred to as rote association. In contrast, recollection plays a major role in recognition of bindings that might be flexibly rearranged in novel situations. Such effortfully formed bindings can be described in terms of relational operations (e.g., identity, greater than or earlier than) that link together and organize the individual elements of an event or episode (Eichenbaum, 2006; Engelkamp, Biegelmann, & McDaniel, 1998). For example, two words that were arbitrarily paired during the study phase of a memory experiment provide at test relational information about their identity with respect to the spatiotemporal context of the study episode. Such interitem bindings form proper relations.

The present experiment explored these hypotheses employing interitem bindings by focussing either on associative or on relational encoding of word triplets. Because the present study aims to assess the retrieval of bound information, the most direct test of this would be a recognition test of item pairings. Crucially, differences between identical and rearranged pairings, which are equated for item familiarity, would indicate that the underlying memory processes are sensitive to the binding between multiple items. However, within the experimental paradigm employed here, rearranged pairings could be easily identified because they are less semantically coherent than are identical pairings, thereby obscuring the expected binding effects. For this reason, the test requirements were old/new recognition judgments about single items. According to the reasoning outlined above, both forms of bindings should be mediated by different brain systems as reflected by a qualitatively different spatiotemporal pattern of the ERP. Thus, we hypothesize that if familiarity is sensitive to semantic coherence between items, an early frontal old/new effect should be observed for rote associations. In contrast, recognition memory for relational bindings should primarily be supported by recollection indexed in a late parietal old/new effect.

METHODS

Subjects

A total of 31 students from Saarland University participated in this study and were paid for their participation. The data from two participants were discarded because they failed to follow test instructions. The data from further six participants were excluded from all analyses because of excessive electrooculogram (EOG) artifacts. Of the remaining 23 participants (aged 20–30 years, 5 men), all were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971).

Materials

Stimuli consisted of 216 German words that were divided into 72 triplets. In a separate noun-generation experiment with a different sample (n = 34) of participants, each triplet was created by asking participants to write down two words that were associated to one given word (e.g., desert → camel, oasis). These triplets were randomly assigned to four lists of 18 triplets each. Two lists were used as study list; the two remaining constituted the recognition test list. The study test assignment of the four lists was counterbalanced across participants so that each list (and therefore each word) appeared equally often as study and test list. Each triplet was complemented with a fourth filler word required to complete the tasks at study (see below). All words were presented at a moderate contrast (black on white) and subtended a horizontal visual angle of 1.5° and a vertical angle of 0.4°.

Experimental Procedure

Each participant performed two study test cycles of an intentional item recognition memory experiment. During the study phase, participants were presented a word triplet together with a fourth filler item in randomized order (see Figure 1). In one cycle, they were asked to judge "Which word does not fit in the context of the other three?" (associative condition) for one of the two study lists, and in the other cycle, participants were required to decide "Which word denotes the smallest object?" (relational condition) for the other list. In this latter condition, words were recombined into new triplets to avoid any associative encoding strategy. List to task assignment was rotated. In every case, the filler item was the target to respond to by button press (numbers 1 to 4 on a computer keyboard). Because the filler item was only required to complete the study task, it was excluded from all analyses. Again, the order of study tasks was counterbalanced across participants.

During the test phase, participants saw single words (all previously encountered words and the two lists of unstudied distractors). Participants made an old/new recognition judgment. In case of an old response, a remember (R)/know (K) judgment followed 2200 msec after stimulus onset. Instructions for these judgments were adopted from Gardiner and Richardson-Klavehn (2000). An R response should be given when participants mentally reexperienced the previous presentation of a word, that is, recollected some specific contextual information pertaining to the study episode (with which words it was paired, study task), whereas a K response was required when they knew the word was seen in the previous study episode but could not recollect any contextual detail about its previous occurrence. The instructions for the old/new decision equally emphasized accuracy and speed, whereas the R/K response emphasized accuracy over speed.

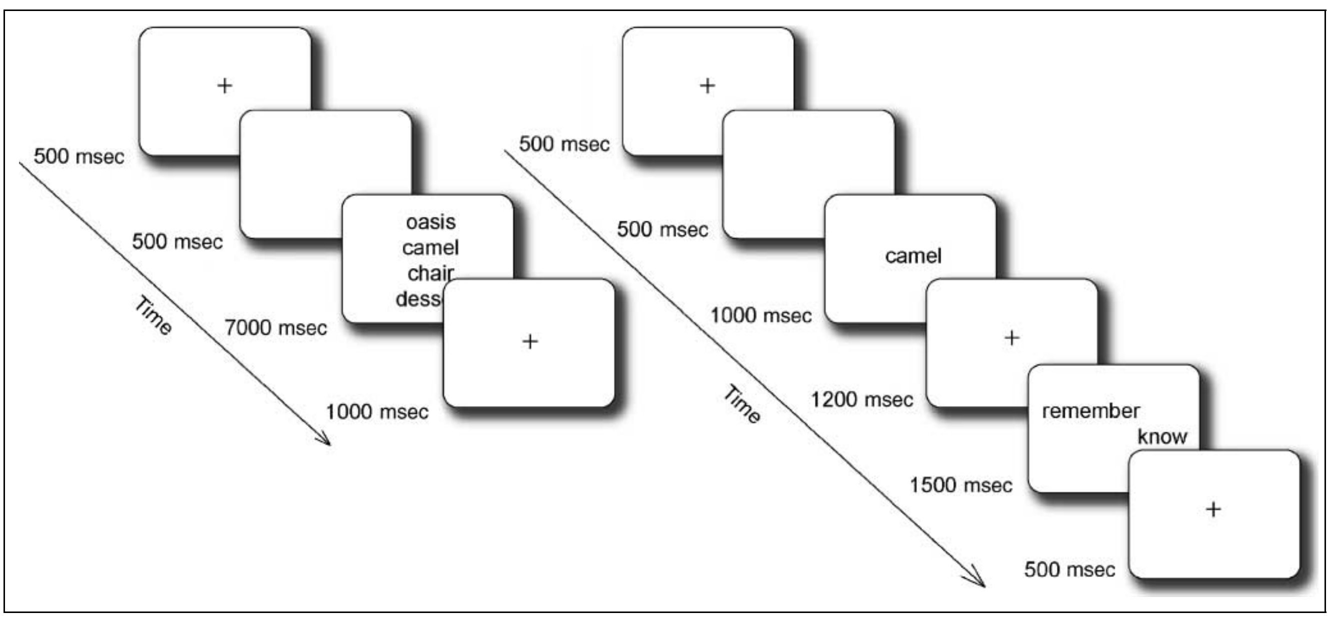

Figure 1. Trial structure of the study phase and the test phase. Duration of each event within a trial is noted on timeline. Note that during the study phase each triplet was presented along with a fourth item. The task at study in the associative condition was to decide "Which word does not fit in the context of the other three?" and in the relational condition was "Which word denotes the smallest object?" The figure depicts an example from the associative condition.

Data Acquisition

Electroencephalograms (EEGs) were continuously recorded from 61 Ag/AgCl scalp electrodes mounted in an elastic cap and labeled according to the extended 10–20 system (Sharbrough et al., 1994). The EEG from all sites was recorded with reference to the left mastoid electrode. An additional channel recorded EEG from the right mastoid, allowing the scalp recordings to be re-referenced off-line to linked mastoids. Vertical and horizontal EOGs were recorded bipolar with additional electrodes located above and below the right eye and outside the outer canthi of both eyes. All channels were amplified with a band pass from DC to 70 Hz and A/D converted with 16-bit resolution at a rate of 500 Hz. Interelectrode impedances were kept below 5 kΩ. Further off-line data processing included a digital high-pass filter set to 0.5 Hz (−3 dB cutoff) to eliminate low-frequency signal drifts. Recording epochs including eye movements were corrected by using a linear regression approach, and epochs with other recording artifacts were rejected before averaging whenever the standard deviation in a 200-msec time interval exceeded 30 μV in any EOG channel.

Data Analysis

Data were analyzed with repeated measures analyses of variance (ANOVA, α level = .05). The Greenhouse–Geisser adjustment for nonsphericity was used where appropriate and the corrected p values are reported together with the uncorrected degrees of freedom.

Behavioral Data

Measures of old/new discrimination, hits, false alarms and Pr[p(hit) − p(false alarm)] were calculated separately for the two conditions (two-high-threshold theory, Snodgrass & Corwin, 1988). Subsequently, hits were further classified as words given an R judgment and words given a K judgment. Reaction times were analyzed in an initial ANOVA using the factors item status (old vs. new), correctness (correct vs. incorrect), and condition (associative vs. relational).

ERP Data

In the test phase, ERP averages were computed for each participant at all recording sites with a duration of 1400 msec commencing 200 msec prestimulus baseline. The averages were low-pass filtered below 17 Hz to increase signal-to-noise ratio by eliminating those frequencies that were irrelevant to the measurements of interest (Picton et al., 2000). ERPs were formed for correct responses to old and new items separately for the two conditions. Because of insufficient trial numbers, an analysis of ERPs for R and K responses could not be performed. For statistical analysis, a hypothesis-driven approach was chosen. Based on prior studies examining ERPs in recognition memory tasks and visual inspection of the grand-average waveform, the mean amplitudes in two different time windows were used for the quantification of the ERP effects. The early frontal old/new effect was examined in a time window between 380 and 480 msec, whereas the parietal old/new effect was expected to be maximal between 550 and 650 msec. This analysis aimed primarily at tapping the old/new effects related to familiarity and recollection. To avoid a loss of statistical power that is implicated when repeated measures ANOVAs are used to quantify multichannel and multitime window data (Oken & Chiappa, 1986), electrode sites were pooled to six topographical regions of interest (ROIs): left anterior (F3, F5, FC3), middle anterior (F1, Fz, F2) right anterior (F4, F6, FC4), left posterior (P3, P5, PO3), middle posterior (P1, Pz, P2), and a right posterior region (P4, P6, PO4).

Two sets of statistical analyses were performed (1) to examine the effects of study condition on correct recognition memory and (2) to investigate associative and relational processing during recognition memory more specifically.

For each time window, an initial repeated measures ANOVA with the factors condition (associative vs. relational), item status (old vs. new), ROI (frontal vs. parietal), and hemisphere (left, middle, right) was performed. Only main effects or interactions including the condition factor are reported. In the case of significant interactions involving this factor, two-way ANOVAs with the factors condition and item status were performed to examine the effects of this factor in each of the topographical regions. Measures of effect size (ω^2, cf. Keppel, 1991) for the single effects are reported in combination with main effects of condition.

Relational processing effects were investigated by an examination of the ERPs elicited by old items as a function of retrieved items per triplet (i.e., binding). It was expected that if relational processing is driving the parietal old/new effect it should be larger for those items for which the complete triplet was remembered. In contrast, associative processing should be manifested in an increased frontal old/new effect that is dependent on the number of retrieved items per triplet. Thus, items were sorted whether or not the complete triplet was remembered. ERPs were quantified in the same ROIs and time windows as in the initial ANOVA.

Scalp potential maps were generated by using a two-dimensional spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989) and a radial projection from CZ, which respects the length of the median arcs.

RESULTS

Behavioral Data

Table 1 shows the probability of an old judgment to old items and the proportion of subsequent R and

Table 1. Mean Probability (±*SEM*) of an Old Response for the Initial Old/New Judgment and the Respective R and K Responses

	Hits			
Condition	*Total*	*Remembered*	*Know*	*Corrected Know*
Associative	.43 (.04)	.25 (.04)	.18 (.04)	.22 (.04)
Relational	.54 (.04)	.35 (.05)	.19 (.03)	.26 (.06)

Corrected Know refers to K responses that were corrected according to the assumption that recollection and familiarity operate independently (Yonelinas & Jacoby, 1995).

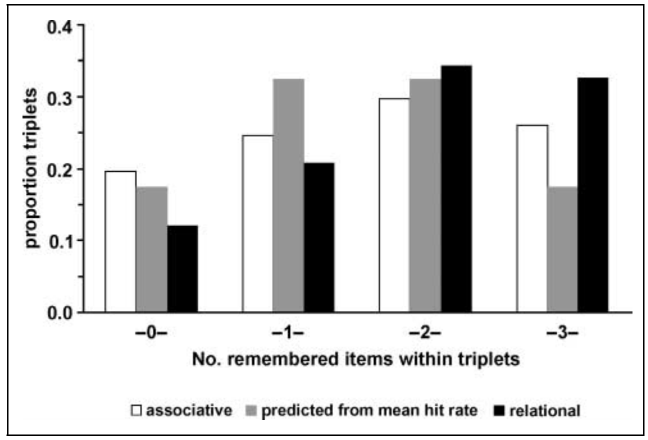

Figure 2. Proportion of triplets from which either 0, 1, 2, or 3 items were remembered from the associative condition (white bars) and from the relational condition (black bars). The control condition (gray bars) indicates the expected binomial probability distribution based on item memory. To simplify matters, the expected proportions based on the overall hit rate, collapsed across conditions, is depicted here. Note that in both conditions the proportion of completely remembered triplets (–3–) is significantly higher as compared to the control condition.

K responses. The ANOVA performed on the measures of discrimination accuracy (Pr) revealed a significantly more accurate discrimination of old and new words in the relational condition as compared to the associative condition, $F(1,22) = 16.34$, $p < .001$. This was due to more correct old responses in the relational condition, $F(1,22) = 12.19$, $p < .01$, whereas the false alarms did not differ between conditions, $F(1,22) = 3.34$, $p < .1$. The analysis of the R and K responses revealed no significant effect involving the condition factor (associative vs. relational; Fs < 1), suggesting that at the group level memory in both conditions differed only quantitatively.

To further examine interitem binding effects on recognition memory following associative and relational encoding, we calculated the expected binomial probability distribution of recognizing a set number of items in a triplet based on item memory alone (hit rate) and compared this to the observed frequency of recognizing triplets separately for each condition (Figure 2). This analysis assumes memory for each individual item to be independent of memory for every other item of the same triplet. Thus, any deviation from the expected distribution would reflect recognition that includes a memory component due to item binding. A sign test on these data revealed that the distribution of remembered items per triplet was different from that expected from item memory alone in both conditions (relational encoding, $\chi_{(3)} = 9{,}78$, $p < .05$, associative encoding, $\chi_{(3)} = 9{,}54$, $p < .05$). In addition, participants were more likely to remember two or three items from a triplet studied relationally relative to associatively encoded triplets, $t(22) = 3.41$, $p < .01$.

The ANOVA performed on reaction times showed a main effect of correctness, $F(1,19) = 12.65$, $p < .01$, and a Correctness × Item Status interaction, $F(1,19) = 6.17$, $p < .05$ (because of missing values for false alarms in three cases, only 20 subjects entered this analysis). Planned pairwise comparisons revealed that false old judgments (i.e., false alarms) took longer than any other response, $F(1,19) = 12.78$, $p < .01$. All other contrasts were not significant.

ERP Data

Grand averages for correct responses to old and new words in each condition are depicted in Figure 3, together with topographic maps showing the distribution of the old/new effects across the two time windows. As expected, correctly recognized old words elicited more positive-going ERPs than correctly rejected new words, beginning approximately 350 msec poststimulus onset and lasting until the end of the epoch at anterior electrode sites. More importantly, the scalp distribution of these old/new effects seems to differ as a function of time and condition. Whereas relationally encoded words elicited an old/new difference that was largest at parietal sites, associatively encoded words, in addition to the parietal effect, were associated with an old/new difference maximal over midfrontal regions. The temporal characteristics of these effects correspond well with the old/new effects associated with familiarity and recollection (Mecklinger, 2000; Curran, 1999). The midfrontal old/new effect occurred early (around 400 msec), whereas the parietal effect was evident at around 600 msec.

An omnibus ANOVA with the factors condition (associative vs. relational), item status (old vs. new), ROI (frontal vs. parietal), and hemisphere (left, middle, right) contrasted the ERPs to old and new words for both conditions. This analyses revealed no significant main effect of hemisphere nor an interaction with this factor (all p values $> .2$). Thus, all subsequent analyses were applied to data obtained at the two ROIs—midfrontal and parietal—predicted a priori to be most sensitive to familiarity and recollection effects. In the early time window (380–480 msec), a significant interaction of

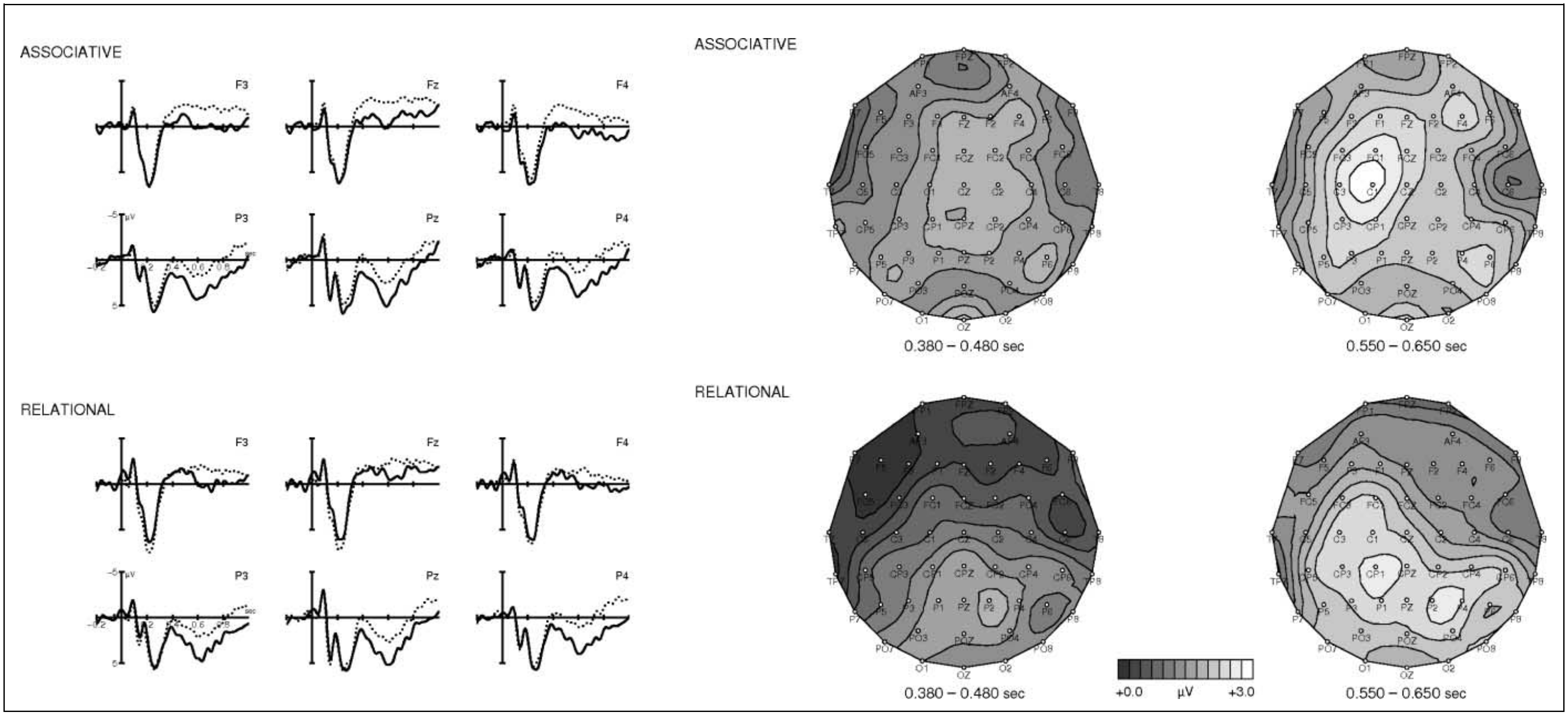

Figure 3. Grand-average ERPs elicited by correctly judged old (solid trace) and new (dotted trace) items depicted separately for the associative (top row) and the relational (bottom row) condition. The topographic maps show the scalp distribution of the old/new effects in the two time windows used in the analyses.

Condition × Item Status × ROI, $F(1,22) = 4.57, p < .05$, was observed. Subsidiary analyses indicated significant old/new effects at frontal sites only for the associative condition, $F(1,22) = 19.62, p < .001, \omega^2 = 0.437$, but not for the relational condition ($F < 1, \omega^2 = 0.029$). The ANOVA for the late time window (550–650 msec) revealed a three-way Condition × Item Status × ROI interaction, $F(1,22) = 4.39, p < .05$. Based on this interaction, separate tests for each ROI were conducted. For the associative condition, there were significant old/new effects for both ROIs, but the parietal ROI showed the larger effect size ($\omega^2 = 0.502$). For the relational condition, only in the parietal ROI was a reliable old/new effect found, $F(1,22) = 15.03, p < .001$. The magnitude of this effect ($\omega^2 = 0.564$) was even higher as compared to the associative condition, indicating a larger contribution of recollective processes to the recognition of relationally as compared to associatively encoded words.

The contribution of associative processing to familiarity, and relational processing to recollection, was further examined by examining the R and K responses conditional on whether or not the complete triplet was remembered (i.e., all three items were remembered vs. one or two items were remembered). Furthermore, the ERPs elicited by old items were sorted according to the number of retrieved items (Figure 4). To achieve an acceptable signal-to-noise ratio, this analysis was conducted for those participants completely retrieving at least four triplets. Thus, data from 16 participants with at least 10 artifact-free trials in each condition entered this analysis. Due to the reduced statistical power caused by the limited number of data, the alpha level for accepting the alternative hypothesis was set to $p < .1$ in this analysis.

Associative processing led to an increased proportion of R and K responses for fully retrieved triplets, whereas relational processing gave rise to an increase of R responses only (Table 2). This differential response pattern was confirmed by an ANOVA with the factors condition (associative vs. relational), item status (number of remembered items per triplet), and response type (R/K responses), revealing a significant three-way interaction of Condition × Item Status × Response Type, $F(1,15) = 3.56, p < .1$. This was caused by a differential contribution of familiarity and recollection to the recognition of items from fully retrieved triplets in both conditions (Significant Condition × Response Type interaction), $F(1,15) = 2.96, p < .1$. Planned pairwise comparisons revealed an increased familiarity contribution in the associative condition when all three items from a triplet were remembered compared to items for which at most one other item from the same triplet was remembered, .26 versus .09, $F(1,15) = 3.16, p < .1$. In contrast, in the relational condition, the recognition of such items was predominantly based on recollection as indicated by significantly more R responses for fully retrieved triplets, .40 versus .13, $F(1,15) = 4.38, p < .1$.

For the ERP data, the repeated measures ANOVA with the factors condition and item status was estimated in the same ROIs (midfrontal vs. left parietal) and time windows (early vs. late) as in the previous analyses. Items for which the complete triplet was remembered elicited a larger old/new effect as compared to items for which at most one other item from the same triplet was remembered in both conditions: main effect item status, $F(1,15) = 20.45, p < .001$. Crucially, this old/new effect had different spatiotemporal characteristics in both conditions as indicated by a significant four-way Condition × Item Status × ROI × Time Window interaction, $F(1,15) = 5.06, p < .05$. Tests performed separately for each time window revealed a significant Condition × Item Status × ROI interaction for both time windows: early time window, $F(1,15) = 10.82, p < .01$; late time window, $F(1,15) = 4.25, p < .06$. The early effect was caused by a larger frontal old/new effect for those items in the associative condition for which the complete triplet was remembered, $F(1,15) = 15.78, p < .01$. In contrast, only in the relational condition items from fully retrieved triplets elicited a late parietal old/new effect, $F(1,15) = 15.67, p < .01$.

DISCUSSION

We used behavioral and electrophysiological measures to examine the subprocesses mediating recognition memory for associatively and relationally encoded word triplets. Although the performance data showed that participants were able to discriminate between old and new words at a level well above chance in both conditions, they do significantly better in the relational condition. At first sight, this might be caused by a more elaborative encoding due to different task demands in the relational as compared to the associative condition. This is consistent with the levels-of-processing effect that memory is superior following deep elaborative encoding relative to shallow encoding (Rugg, 1998; Craik & Lockhart, 1972). However, enhancement of episodic memory retrieval is usually observed following semantically meaningful encoding as compared to structural encoding. Moreover, the binomial distribution analysis suggested that interitem binding rather than depth of processing is the major source of enhanced memory performance in the relational condition. It has been previously argued that recognition of interitem bindings is based solely on recollection, as the recovery of information about item pairings (i.e., word triplets in the present experiment) is only available if memory for the original study episode is retrieved (Donaldson & Rugg, 1998; Hockley, 1992). Thus, these behavioral data suggest that memory in the relational condition depends on recollective processes, whereas the associative condition might bear on familiarity-based recognition.

This argument is also supported by the different spatiotemporal characteristics of the ERP. Only associatively

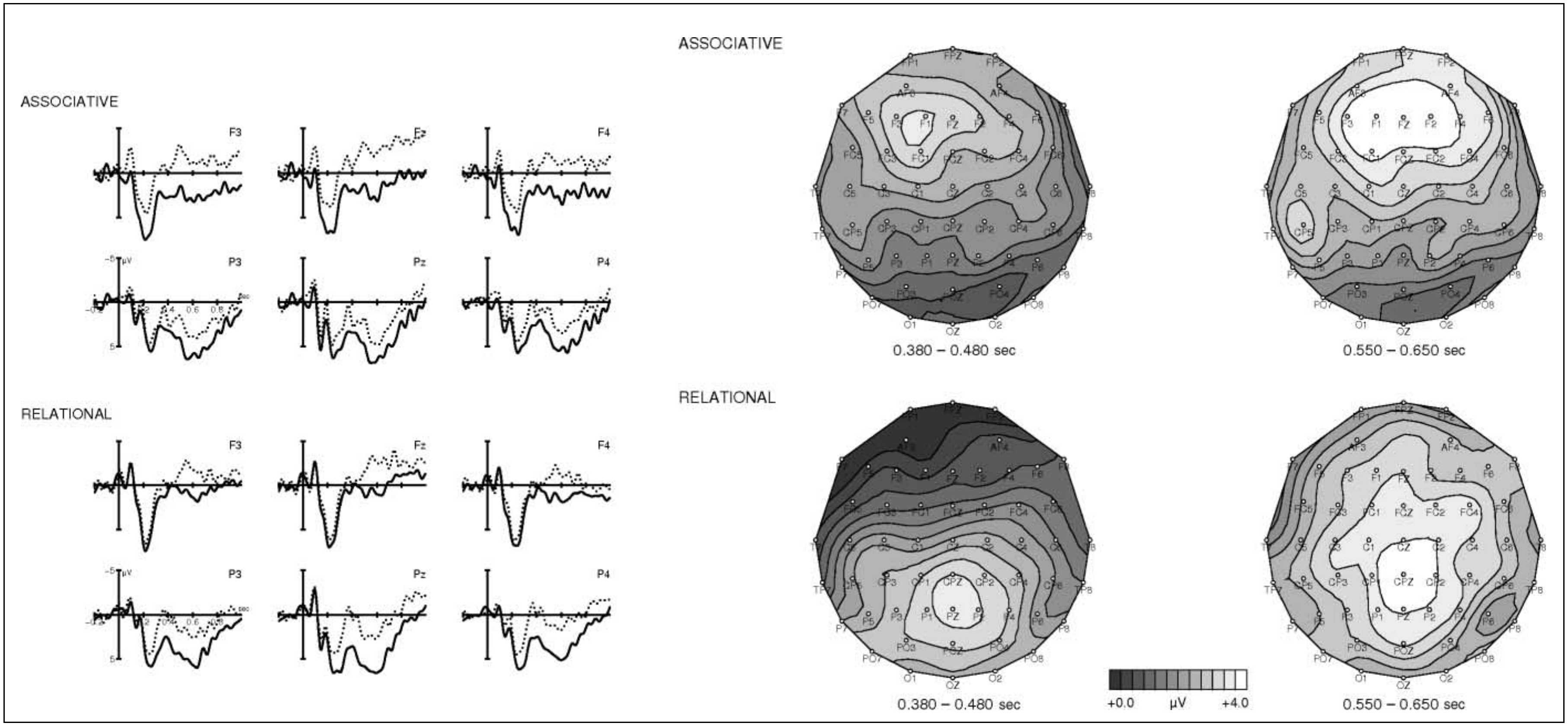

Figure 4. Grand-average ERPs elicited by old items for which the complete triplet was remembered (solid trace) and old items for which at most one other item from the same triplet was remembered (dotted trace) depicted separately for the associative (top row) and the relational (bottom row) condition. The topographic maps show the scalp distribution of the old/new effects in the early and late time windows.

Table 2. Mean Probability of R and K Responses (±*SEM*) Conditional on the Number of Items Recognized within a Triplet

	No. Items per Triplet	*Remembered*	*Know*	*Corrected Know*
Associative	–1/2–	.11 (.02)	.09 (.02)	.10 (.02)
	–3–	.25 (.06)	.26 (.11)	.35 (.09)
Relational	–1/2–	.13 (.02)	.11 (.04)	.13 (.04)
	–3–	.40 (.12)	.10 (.01)	.16 (.05)

See Table 1 for details.

encoded items elicited a frontal old/new effect during recognition, whereas relational encoding led to a late parietal old/new effect, indicating recollective processes. Although these results are consistent with our view that rote associations can be recognized based on familiarity, whereas relational bindings require recollection, there are other possible accounts for these findings. It is conceivable that the frontal old/new effect reflects item memory of the individually presented words because familiarity is sufficient to support recognition of single items. However, as the associative and the relational condition were equated for item familiarity one would expect a similar frontal old/new effect in both conditions. Furthermore, the deep encoding, as in the associative condition, would augment recognition by enhancing recollection, that is, the parietal old/new effect (Rugg et al., 1998; Paller & Kutas, 1992). In the study by Rugg et al. (1998), a level-of-processing manipulation required subjects to study words with either a semantically deep or a shallow encoding task. The late parietal old/new effect was greater for correctly recognized words following deep rather than shallow encoding, but the frontal old/new effect did not differentiate between shallow and deep conditions. Thus, item memory alone cannot be the driving factor of the early frontal old/new effect observed in the associative condition.

The present results rather suggest that recognition of rote associations is partly based on familiarity, whereas recognition of relational bindings requires recollection. Evidence for this notion is provided by a study on patients suffering from temporal lobe epilepsy (Helmstaedter et al., 1997). These patients with circumscribed temporomesial lesions (hippocampal sclerosis) showed improved memory performance for highly associated words, that is, words from well-defined and limited categories learned together as compared to loosely related words. Given an involvement of the hippocampus in recollection and of the surrounding cortex in familiarity (cf. Mecklinger, 2000; Aggleton & Brown, 1999), these data suggest that high binding requirements imposed by loosely related study material depend on the integrity of the hippocampus and, therefore, might facilitate recollection. Contrary to this, a close semantic association of the items, possibly implicating bound representations, is likely to foster a familiarity contribution to associative recognition that is spared after hippocampal sclerosis. This is supported by a recent study demonstrating that the recognition of objects (e.g., cow, barn, hay bale) that are associated with a particular scene (farm in this case) lead to increased hemodynamic activity in the medial temporal cortex (Bar & Aminoff, 2003).

In addition, there are reports of recollection being necessary for relational recognition memory involving pairs of items (e.g., Yonelinas, 1999, 2002). For example, Donaldson and Rugg (1998) observed a larger late parietal ERP old/new effect for correctly classified same than for rearranged pairs of words. This suggests that the correct binding of words into an arbitrary pair supports recollective processes. Indeed, much of the conditions eliciting the late parietal ERP old/new effect reflecting recollection can be conceptualized as requiring binding. When subjects are asked to recollect the modality (Wilding, Doyle, & Rugg, 1995), speaker's voice (Wilding & Rugg, 1996), or temporal source (Trott, Friedman, Ritter, & Fabiani, 1997) of studied words, the judgment requires binding between the words and these specific attributes. In all cases, the late parietal ERP old/new effect has been shown to depend upon arbitrary bindings of these attributes.

This line of arguments is also confirmed by previous neuroimaging studies demonstrating differential involvement of various substructures of the medial temporal lobe in binding (Preston et al., 2004). During study, face–house pairings, each presented four times, had to be learned. Recognition judgments on repeatedly learned face–house pairs, thereby forming bound representations (Norman & O'Reilly, 2003; Eichenbaum et al., 1999), lead to increased activity in the medial temporal cortex. Pairs of faces whose relationship was not explicitly learned but could be mediated through an overlapping relation with an explicitly learned common house elicited selective hippocampal activation. More recently, increased hippocampal activity for infrequent cue–target associations was observed (Amso, Davidson, Johnson, Glover, & Casey, 2005). In this study, the same target was preceded by two different cues, one with which it was highly associated and one with which it had a more novel or less frequent association. The hippocampus was preferentially active in the infrequent association, suggesting involvement in learning of new associations or linking a cue with a novel target. This is consistent with our view stressing the role of the hippocampus in relational processing, that is, binding together into one memory multiple features of an experience (O'Reilly & Rudy, 2001; Eichenbaum et al., 1999; Cohen, Poldrack, & Eichenbaum, 1997).

Taken together, the present results suggest that familiarity can support associative recognition judgments if the associated components are coherently encoded into a bound representation. This might indicate that the contribution of familiarity and recollection to recognition memory depends on the kind of binding operations performed on the items rather than on the single versus multiple-item distinction. Thus, recognition based on familiarity requires items be integrated into a coherent bound representation, whereas recollection might be based on flexible bindings of the relationship among items.

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