Brain and Cognition 92 (2014) 19–31

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Associative recognition processes are modulated by the semantic unitizability of memoranda

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ARTICLE INFO

Article history:
Accepted 27 September 2014

Keywords:
Episodic memory
Familiarity
Recollection
ERP
Semantic memory
Unitization

ABSTRACT

Although memory of episodic associations is generally considered to be recollective in nature, it has been suggested that when stimuli are experienced as a unit, familiarity processes might contribute to their subsequent associative recognition. To investigate the effect of semantic relatedness during episodic encoding on the processes of retrieval of associative information, we had participants interactively encode pairs of object pictures, vertically arranged so as to suggest a functional or configural relationship between them. Half the pairs were independently judged to be of related objects (e.g., a lamp over a table) and half of unrelated objects (e.g., a key-ring over an apple). At test, participants discriminated between intact, recombined, and new pairs while event related potentials (ERPs) were recorded. In an early ERP marker of retrieval success generally associated with familiarity processes, differences related to associative memory only emerged for related pairs, while differences associated with item memory emerged for both related and unrelated pairs. In contrast, in a later ERP effect associated with recollection, differences related to associative memory emerged for both related and unrelated pairs. These findings may indicate that retrieval of episodic associations formed between two semantically related visual stimuli can be supported by familiarity-related processes.

1. Introduction

Remembering episodic associations – that several objects, people, or actions were experienced conjointly – is a vital cognitive function that enables us to reconstruct environments in which we have been present, and to relive events in which we have participated. In many cases, experiencing the conjoint presence of multiple items is shaped by our pre-existing knowledge of the world, such as the probability of finding two or more objects in certain settings and in specific spatial configurations. For example, when entering a kitchen we would expect to find a pot on a stove, but we may be surprised to see a bicycle on a stove, or to see a stove placed on top of a pot. Such expectations may not only shape our momentary experience, but may further affect the formation of episodic associations between objects in particular contexts (e.g., Henson & Gagnepain, 2010; Morris, 2006; Van Kesteren, Ruiter, Fernández, & Henson, 2012; Wang & Morris, 2010). Thus, it is possible that the processes that enable us to remember associations that are in accord with our expectations differ from those involved in remembering associations that diverge from our expectations. Indeed, it has been posited that schematic knowledge may affect the formation of contextually congruent and incongruent episodic memories via different neural mechanisms (e.g., Van Kesteren et al., 2012).

One method of accessing associative episodic memory is recognition, the judgment that currently presented items were previously experienced together in a specific episodic context. The widely accepted dual-process theory of episodic recognition posits that recognition might be supported by two functionally and neurally separable processes: familiarity and recollection. Familiarity refers to the basic feeling of having previously encountered something or someone without retrieval of additional information, while recollection provides additional contextual details about that encounter and integrates contextual details associated with a particular item (Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010). Although there is also evidence that recognition may be understandable in terms of a single mnemonic process (e.g., Slotnick, 2013) the dual process approach is supported by evidence from many behavioral, neuroanatomical and neurophysiological studies. These include event-related potential (ERP) studies showing that

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http://dx.doi.org/10.1016/j.bandc.2014.09.009
0278-2626/

two qualitatively distinct ERP components are associated with old/new judgments. The first is an early mid-frontal negative deflection associated with episodic novelty, arising between 300 and 500 ms post-stimulus presentation, which is often referred to as FN400 (or early mid-frontal effect). This effect has been widely described as the putative electrophysiological correlate of familiarity (reviewed by Mecklinger, 2000; Rugg & Curran, 2007; Wilding & Ranganath, 2011), although it might also reflect other rapid, automatic retrieval processes (see Paller, Voss, & Boehm, 2007; Tibon & Levy, 2014a, 2014b). In contrast, a late positive component (LPC; also called parietal old/new effect), prominent over left parietal scalp regions between 400 and 800 ms post-stimulus presentation, is considered to be a correlate of recollection (Mecklinger, 2000; Rugg & Curran, 2007; Wilding & Ranganath, 2011).

While it is generally agreed that recognition of single items can be supported by both recollection and familiarity, it has traditionally been asserted that in associative recognition tasks, recollection is required to retrieve novel episodic associations, and that such associative memory is not accessible via familiarity processes (e.g., Donaldson & Rugg, 1998; Hockley & Consoli, 1999; Yonelinas, 1997). Associative recognition tests typically require subjects to discriminate between intact (studied) and recombined (studied items in new combinations) stimulus pairs. As the individual members of intact and recombined pairs are equally familiar, it is argued that recollection is required to retrieve the newly formed associations between items. In recent years, however, a growing corpus of research has suggested that under certain circumstances familiarity might also contribute to associative memory – specifically, when the to-be-associated stimuli are bound together to form a unitized representation during study, and are thus perceived and encoded as a single unit entity (Jäger & Mecklinger, 2009; Jäger, Mecklinger, & Kipp, 2006; Quamme, Yonelinas, & Norman, 2007; Rhodes & Donaldson, 2007, 2008; Tibon & Levy, 2014a, 2014b; Tibon, Ben-Zvi, & Levy, 2014; Yonelinas, Kroll, Dobbins, & Soltani, 1999; for review, see Mecklinger & Jäger, 2009; Yonelinas et al., 2010).[1] Arguably, in such cases familiarity can contribute to associative recognition due to direct links between the components comprising the encoded representation (e.g., Mayes, Montaldi, & Migo, 2007).

While the notion of unitization as a characteristic of memory formation is appealing, the encoding conditions that might enable unitization require further specification. Two broad types of experimental strategies have been employed to promote unitization; these can be viewed as driven by either top-down or bottom-up cognitive processes. Top-down approaches to unitization focus on encoding instructions to process pairs of memoranda as a single unit (in high-unitization conditions) or as separate elements of the same episode (for low-unitization conditions). Unitizing instructions can take the form of compound definition versus use-in-sentence encoding of words (Bader, Mecklinger, Hoppstädter, & Meyer, 2010; Haskins, Yonelinas, Quamme, & Ranganath, 2008), or of encoding source and item information in an internal versus an external manner, thus forming intra- versus inter-item associations, e.g., "imagine each item in the color indicated by the background screen color" versus "imagine why the item would be associated with a stop sign or dollar bill" (Bastin et al., 2013; Diana, Van den Boom, Yonelinas, & Ranganath, 2011), or the "strategy type" manipulation employed by Rhodes and Donaldson (2008).

In contrast to these top-down manipulations that are based on explicit encoding instructions, bottom-up approaches are based on maximizing item features or associative information that might foster unitization. In this case, instructions are the same in all conditions, but inherent or presentation-related features of the memoranda are manipulated, so as to engender differential degrees of unitization. In one type of bottom-up approach, the manipulation is primarily perceptual. This may take the form of comparing encoding presentations of unimodal, within-domain associative memoranda (e.g., picture pairs) with those of crossmodal, between-domain associative memoranda (e.g., picture-environmental sound pairs; Tibon & Levy, 2014b; Tibon et al., 2014). Alternatively, simultaneous versus sequential presentation of associative memoranda may differentially engender unitization at encoding (Tibon & Levy, 2014a).

In the second type of bottom-up approaches, the high-unitization stimulus pairs differ from low-unitization pairs in the preexisting semantic or schematic relationships between them. This latter case includes the episodic encoding of a word compound such as "bus-stop" (i.e., two words comprising one unit), versus "bus–car" (two semantically related words that do not necessarily comprise such a unit), and versus "bus-pillow" (two unrelated words). It is asserted that in the first case, compared to the other two, the association is inherently unitized (as it corresponds to the traditional definition of unitization – "perceiving and encoding of several discrete stimuli as one single unit"). Furthermore, for two semantically related words that do not necessarily comprise a standard linguistic unit (e.g., "bus–car" pairs), unitization might still occur more readily than for two unrelated words (as the former would be grouped together more easily than the latter). This approach to unitization is of interest, as it bridges semantic and episodic aspects of associative memory, and can potentially explain how these two aspects interact during memory formation and retrieval.

Studies using a perceptual bottom-up unitization approach, such as those cited above, support the assertion that although associative retrieval in general requires recollection, when two items are unitized, their retrieval can be supported by familiarity. The studies that have explored semantic bottom-up unitization processes have commonly used verbal stimuli (Greve, van Rossum, & Donaldson, 2007; Kriukova, Bridger, & Mecklinger, 2013; Rhodes & Donaldson, 2007; and see also the relation factor in Rhodes & Donaldson, 2008). However, unitization of word pairs, in which the semantic knowledge is always mediated by verbal materials, may not generalize to the formation of associations in ecological conditions, in which we perceive combinations of objects in our visual environment. In one study that employed pictorial stimuli (Jäger et al., 2006), recognition memory for arbitrarily paired items (i.e., pairs of faces of two different persons, termed inter-item associations) were compared with recognition memory for pairs of highly overlapping stimuli that can be coherently unitized (i.e., two different face pictures of the same person; intra-item associations). In that study, the electrophysiological correlate of familiarity was significantly larger for successfully retrieved intra- than for inter-item associations, whilst the electrophysiological correlate of recollection was significantly larger for successfully retrieved inter- than for intra-item associations. Nonetheless, since faces form a specific class of visual stimuli (either because their processing is mediated by domain-specific mechanisms [e.g., Kanwisher, 2000], or due to the effects of expertise with such stimuli, [e.g., Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999]), the examination of face memory might not fully capture the processes used for visual memory. Furthermore, in two of the abovementioned studies (Bader et al., 2010; Rhodes & Donaldson, 2008) in which dissociations between recollection and familiarity processes were based on electrophysiological evidence, comparisons were

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[1] Though unitization arguably creates an integrated representation, the objects comprising the unitized representation do not necessarily lose their individual identity. This is the case for words (e.g., after encoding of "bus stop", it is possible to remember having seen the word "bus", and seemingly even more so for the visual objects employed in the present study (e.g., cup and saucer). Therefore, it is still appropriate to speak of associative memory even in cases of unitization.

made between components elicited by correct identification of studied (intact) stimulus pairs and those elicited by correctly identified pairs of completely new stimuli. However, for technical reasons the ERPs elicited by the recombined condition were not analyzed. This vitiates conclusions that may be drawn regarding associative recognition, as such memory is specifically expressed by distinguishing intact from recombined pairs.

Accordingly, the current study examines the effects of semantic unitization at encoding on retrieval processes supporting associative episodic memory, as indexed by differences in ERP correlates of retrieval. Memoranda were semantically associated object picture pairs presented in their canonical spatial configurations, or unrelated pairs created using the same component pictures. In both cases participants performed the same comparison encoding task, such that the only difference between the two conditions was the degree of their pre-existing semantic unitization. At test, participants discriminated intact, recombined and new pairs while EEG was recorded, enabling us to examine the time courses of retrieval of episodic associations of related and unrelated stimuli, and to differentiate between the processes subserving the retrieval of such associations.

Our main hypothesis was that related and unrelated pairs would elicit distinct patterns of neural activation, resulting from the effect of bottom-up unitization on associative recognition (indexed by activation for intact versus recombined pairs) and on item recognition (indexed by activation for intact and recombined versus new pairs). Specifically, we expected to observe an FN400 effect (i.e., a less negative deflection in response to intact pairs relative to recombined pairs, reflecting associative familiarity) for related pair associates, but not to see such an effect for unrelated pair associates. We also expected greater FN400 negativity for both related and unrelated new pairs compared with intact and recombined pairs, as the recognition of the single items in intact and recombined pairs can be supported by familiarity. The late recollection-related LPC was also expected to index item recognition for both semantically related and unrelated pairs. However, while some previous studies report that associative recognition elicits LPC regardless of the occurrence of earlier familiarity processes (e.g., Diana et al., 2011; Greve et al., 2007; Rhodes & Donaldson, 2007, 2008; Tibon et al., 2014), in other cases, modulation of this component was reduced, or even eliminated, when it followed familiarity-related activations (e.g., Bader et al., 2010; Jäger et al., 2006; Kriukova et al., 2013). The latter findings suggest that if familiarity is sufficiently mnemonically diagnostic to support recognition, recollection may be bypassed. We therefore hoped that modulation patterns of LPC in the current paradigm would provide further insights in this matter.

2. Methods

2.1. Participants

Participants were 35 healthy right-handed young adults (15 females; mean age = 22.8, *SD* = 2.7 years, range 18–30, all scored positively on the Edinburgh Handedness Inventory; Oldfield, 1971), with normal or adjusted-to-normal vision. All were undergraduate students who volunteered in return for academic requirement credit or payment. Informed consent was obtained from all participants for a protocol approved by the Interdisciplinary Center's Institutional Review Board. Three participants were excluded from the analyses: one participant due to very poor performance of the task, and two additional participants due to a very low number of trials ($n < 9$) in one bin after removing EEG artifacts, leaving 32 participants whose data was analyzed.

2.2. Materials

Candidate stimuli for the study – object pictures of furniture, tools, appliances, foods, clothes, etc. (see Fig. 1 for examples) – drawn from the Hemera Photo-Objects Collection (Hemera Photo Objects, Gatineau, Quebec, Canada) and a variety of internet sources, were subjected to screening for correct nameability. Five participants who did not take part in the main experiment rated 911 object pictures, presented for 100 ms each. Stimuli which were not correctly identified by at least four participants were removed from the stimulus pool. 532 of the correctly named stimuli were used to construct 266 semantically related pairs. Those same stimuli were then used to create an additional 266 unrelated pairs (see below). The assignment of pairs to relatedness conditions was confirmed in a second pilot test. In this pilot, ten additional participants who did not take part in the main study were presented with 266 picture pairs (half were pre-assigned to the related condition, and half to the unrelated condition). Importantly, two experimental lists were composed, such that each pilot participant viewed each object only once, either with its related or with its unrelated pair-associate. The lists were counterbalanced; thus, each pair was rated by five participants. They were asked to indicate how likely it is for the two objects to appear together ecologically as currently presented. Participants provided their responses on a scale ranging from 1 (very unlikely) to 4 (very likely). Pairs were presented on the screen until a response was given. Any pairs for which the relatedness assignment was not confirmed by the majority of the raters were removed from the pool. Of the remaining pairs, 94% were rated correctly by at least 4 of 5 participants. The rest were rated correctly by 3 of 5 participants. Following this procedure, 246 semantically related pairings and 246 semantically unrelated pairings of the objects remained for use.

During the experiment, the images were presented vertically on a gray background square, each subtending about 22 cm × 22 cm (corresponding to a visual angle of approximately 18° by 18° from a viewing distance of 70 cm). Objects image size varied, in order to account for scaling, with on-screen size ranging from 1 to 8 cm of length (visual angle of approximately 2.0–6.5°) and from 1 to 10 of height (visual angle of approximately 2.0–8.2°). Distance between stimuli comprising each pair was approximately 0.5 cm. As mentioned above, in order to allow full counterbalancing of all objects across experimental conditions, stimuli comprising related and unrelated pairs were drawn from the same stimulus pool, thus

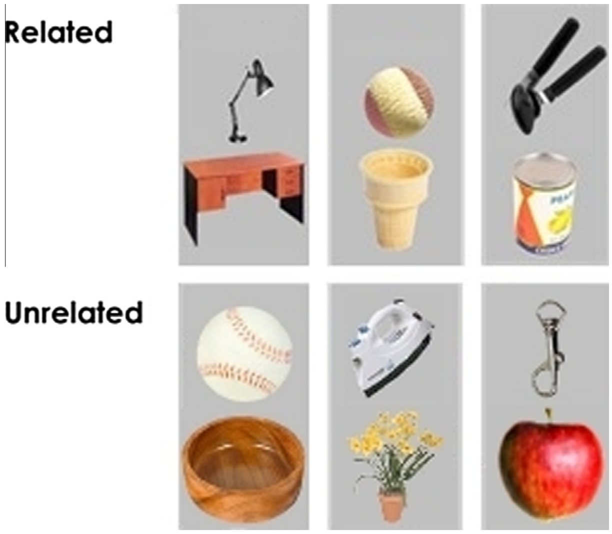

Fig. 1. Examples of related (top) and unrelated (bottom) stimulus pairs.

each stimulus was associated with one related and one unrelated pair (although each participant saw each stimulus in only one of these conditions). All object images were collected individually, rather than being taken from scenes comprising both objects, and were thus equally identifiable whether seen in the related or the unrelated conditions.

A total of 164 picture pairs were encoded, half related and half unrelated. An additional 82 stimulus pairs, comprising both relatedness types, were not presented at encoding, but rather served as novel distractors in the retrieval phase. At retrieval, stimuli could appear in one of six retrieval conditions, each comprising 41 pairs: (1) related-intact (related encoded pairs that recurred at retrieval); (2) unrelated-intact (unrelated encoded pairs that recurred at retrieval); (3) related-recombined (test pairs of related objects, constructed from stimuli which at encoding were presented with other, unrelated objects); (4) unrelated-recombined (test pairs of unrelated objects, constructed from stimuli which at encoding were presented with other, related objects); (5) related-new (related pairs that were not presented at encoding); (6) unrelated-new (unrelated pairs that were not presented at encoding). The assignment of stimuli to these conditions was fully counterbalanced across participants. Importantly, within the two recombined conditions, the "relatedness" factor of the pair referred to its status at retrieval. Thus, related recombined pairs were comprised of objects that were encoded as parts of unrelated pairs, and vice versa (see discussion below of the possible implications of this experimental design).

2.3. Procedure

Participants were tested individually in a quiet room. Upon arrival at the lab, they signed an informed consent form and filled out the Edinburgh Handedness Inventory (Oldfield, 1971). They were seated at a distance of ~70 cm from a 19 inch computer monitor with a 75-Hz refresh rate (LG Flatron L1953hm). Following EEG electrode cap preparation (described below), participants were told that they would be shown pairs of pictures, and were instructed to remember those pairs. They were further instructed to perform a comparison encoding task, namely, to judge which one of the two objects presented in each trial was more expensive. They were asked to press the 'up arrow' key on the keyboard if they thought that the upper object was more expensive, and to press the 'down arrow' if they thought that the lower one was more expensive. As mentioned above, 164 stimulus pairs were presented during encoding. In each trial, pairs were presented for a duration of 1500 ms. If a response was not provided prior to stimuli disappearance, a blank screen appeared for an additional 2000 ms, during which the participant could still provide a response. Next, a 1000 ms blank screen appeared, followed by a visual fixation cross, shown for 1000 ms. Three self-paced breaks were provided during the encoding phase.

Once the encoding phase was completed, a 10 min delay period was provided. During this period, participants rested for 5 min and then performed a distractor task (the Raven Progressive Matrices Test; Raven, Court, & Raven, 1996) for five additional minutes. During a subsequent retrieval phase, participants viewed stimulus pairs under the six retrieval conditions described above. They were instructed to indicate for each pair whether it was intact, recombined or new by pressing one of three adjacent keyboard keys, marked "1", "2" or "3", respectively. In each trial, a pair was presented until response was provided. Next, a blank screen appeared for 2000 ms, followed by a 1000 ms visual fixation cross, and then the next stimulus pair appeared. Five self-paced rest breaks were provided during the retrieval phase.

An encoding practice block of 16 trials was provided at the beginning of the experiment, prior to the encoding phase. An additional retrieval practice block of 21 trials was provided prior to the retrieval phase. During these practice sessions, the experimenter ascertained that the participants understood the task.

2.4. Electrophysiological recording parameters and data processing

2.4.1. EEG recordings

The EEG was recorded using the Active II system (BioSemi, The Netherlands) from 64 electrodes mounted in an elastic cap according to the extended 10–20 system. EOG (electro-oculogram) was recorded using four additional external electrodes, located above and below the right eye, and on the outer canthi of both eyes. Additionally, two electrodes were placed over the left and right mastoid bones, for reference purposes. The ground function during recording was provided by common-mode signal (CMS) and direct right leg (DRL) electrodes forming a feedback loop, placed over parieto-occipital scalp. The online filter settings of the EEG amplifiers were 0.16–100 Hz. Both EEG and EOG were continuously sampled at 1024 Hz and stored for offline analysis.

2.4.2. Preprocessing

Data was preprocessed using BrainVision Analyzer (Brain Products GmbH; www.brainproducts.com). Channels depicting drifts and other artifacts were replaced with interpolated data from adjacent electrodes. Raw EEG data were 0.5 Hz high-pass filtered with a notch filter at 50 Hz and were referenced off-line to the average of the left and right mastoid channels. Ocular artifacts were removed using the independent component analysis (ICA) method (Jung et al., 2000; as implemented in BrainVision Analyzer). Following ICA, performed on the un-segmented data, we detected and nullified the blink- and eye-movements- related components based on the typical scalp topography and on time course, which had to match the observable blink artifacts in the raw EEG. Segments contaminated by other artifacts were discarded visually. The remaining EEG data for correct responses were parsed into 1200-ms segments that included a 200 ms pre-stimulus period that was used for baseline correction. The waveforms were low-pass filtered with a cutoff of 30 Hz. For repeated measures ANOVA analyses, segments were averaged separately for each retrieval condition. The preprocessed data was converted to a MATLAB format (MathWorks, Inc.), for all further analyses.

2.5. Statistical analyses

2.5.1. Behavioral analyses

Accuracy level and reaction time (RT; for correct responses) were used as dependent behavioral measures, on which repeated measures ANOVAs were conducted, with relatedness at retrieval (related, unrelated) and retrieval category (intact, recombined, new) as repeated factors. Significant effects and interactions were further decomposed using subsequent repeated measures ANOVAs and pairwise comparisons. Here and in all other analyses, Holm–Bonferroni correction was applied to account for inflated type I error due to multiple comparisons. In order to ensure that differences between related and unrelated intact pairs did not result from a response bias (e.g., a tendency to respond "intact" to related pairs due to their familiar configuration), we calculated d' for each participant, using the distributions of the intact and the new conditions. Paired-samples t-tests were used to compare d' values for related and unrelated pairs.

The behavioral data was further subjected to analyses of error responses: For each participant, in each condition, we computed the number of error responses made in each of the two possible error types. For example, a failure to correctly identify a related-intact trial could lead either to a 'recombined' response or to a 'new' response. We then performed a 2 × 2 repeated-measures

ANOVA separately for each retrieval category, with the factors of relatedness (related, unrelated) and erroneous response (recombined/new for intact pairs; intact/new for recombined pairs; and intact/recombined for new pairs) as repeated factors. These analyses were performed separately for each condition, since the conditions differ in their erroneous response options.

2.5.2. ERP data segmentation

ERP waveforms were computed for the six retrieval conditions mentioned above (i.e., related-intact, related-recombined, related-new, unrelated-intact, unrelated-recombined, and unrelated-new). For data segmentation, we used 9 representative electrodes covering left anterior (AF3), mid anterior (AFz), right anterior (AF4), left central (C3), mid central (Cz), right central (C4), left posterior (PO3), mid-posterior (POz) and right posterior (PO4) locations. Following visual inspection of the averaged waveforms, the ERP data were analyzed in two time windows of 350–550 ms (early) and 550–750 ms (late) time windows, corresponding to the early mid-frontal and late parietal effects, respectively. These time windows are generally consistent with previous reports (e.g., Bader et al., 2010; Greve et al., 2007; Kriukova et al., 2013; Opitz, 2010; Wiegand, Bader, & Mecklinger, 2010), albeit falling in the later part of the range of effect latencies found in ERP recognition studies (reviewed by Mecklinger, 2000; Rugg & Curran, 2007; Wilding & Ranganath, 2011), seemingly due to increased demands posed by the retrieval of associative information, or due to the use of complex and perceptually rich stimuli, which characterize the present study in contrast to more common item recognition paradigms.

2.5.3. Mixed-effects models ERP analyses

To analyze the ERP data, we used a linear mixed-effects models approach that was performed separately for each time window. This analysis takes subject-specific variability into account in modeling effects, and can accommodate the repeated measures study design. Such models can be considered a generalization of ANOVA, but use maximum likelihood estimation instead of sum of squares decomposition. An advantage of such an approach over the standard repeated measures ANOVA is that mixed-effects models are better suited for complex designs (e.g., Bagiella, Sloan, & Heitjan, 2000; see also our previous reports, where we employed a similar approach: Tibon & Levy, 2014a, 2014b; Tibon et al., 2014). Moreover, such an approach is particularly recommended for unbalanced data, as in the current case in which the number of trials in each condition varied due to differences in accuracy rates between conditions (see Table 1). Inter-individual differences in EEG amplitude dynamics were modeled as a random intercept, which represents an individual "baseline," in addition to being affected by the fixed factors. In this mode of analysis, each observation serves as an element of analysis to be modeled; degrees of freedom represent the number of observations and not the number of participants, as is customary in grand average ANOVAs. These parameters result in increased degrees of freedom compared to traditional designs. Although at first glance this might appear to be an overly liberal approach, in this approach large intra-subject variance is not tempered by averaging within participants, which limits the number of effects that emerge as significant. Furthermore, effects that do emerge from the statistical analyses are reflected by robust differences in mean amplitudes. The fixed part of the model includes the relatedness factor (related, unrelated), the retrieval category factor (intact, recombined, new), and two spatial location factors: location (anterior, central, and posterior) and laterality (left, midline, and right). The fixed part of the model further included all possible interactions between these four fixed factors. Model parameters were estimated with the nlme package of the software R (Pinheiro, Bates, DebRoy, Sarkar, & the R Core team., 2007, freely available at http://www.R-project.org).

2.5.4. Repeated-measures ANOVA ERP analyses

As explained above, a mixed-effects model analysis appears to be the appropriate mode of inspecting data in which bin size differs between the various conditions. However, since this type of analysis is not yet widespread, we also computed an average waveform for each participant in each condition and compared the results of the mixed-effects model approach with those of a conventional repeated measures ANOVA, using the same factors used as the fixed factors in our mixed-effects model analyses (i.e., relatedness, retrieval category, location, and laterality).

3. Results

3.1. Behavioral measures

Means and SDs for accuracy, and RTs for correct responses, are shown in Table 1. The results of the repeated measures ANOVA for accuracy rates revealed a significant main effect of retrieval category, $F(2,62) = 54.91$, $p < .001$, with no main effect of relatedness, $F(2,62) < 1$, yet a significant interaction between retrieval category and relatedness emerged, $F(2,62) = 74.61$, $p < .001$. Decomposition of the interaction revealed that it was driven largely by a greater hit rate for related versus unrelated intact pairs, $t(31) = 9.94$, $p < .001$, as predicted, but by a lower hit rate for related versus unrelated recombined pairs, $t(31) = -6.72$, $p < .001$, which was somewhat unexpected; we will discuss the reason for this divergence below. Differences between the accuracy of the two new conditions were marginal, $t(31) = 1.94$, $p < .07$. Paired-samples t-test comparing d' for related and unrelated pairs revealed a significant difference, $t(31) = 5.76$, $p < .001$, with d' significantly higher for related ($M = 2.7$, $SD = .51$) compared to unrelated ($M = 2.2$, $SD = .45$) pairs.

The analyses of RTs (for correct responses) revealed a significant main effect of relatedness, $F(1,31) = 10.89$, $p < .01$, a significant main effect of retrieval category, $F(2,62) = 29.06$, $p < .001$, and a significant interaction between the two factors, $F(2,62) = 18$, $p < .001$. Decomposition of the interaction revealed that in accordance with the accuracy findings, RTs for related-intact pairs were significantly shorter than for unrelated-intact pairs, $t(31) = -4.71$, $p < .001$, but RTs for related-recombined pairs were significantly longer than for unrelated-recombined pairs, $t(31) = 3.74$, $p = .001$.

Table 1
Mean performance indices (accuracy rates and RTs) for correct responses.

	Related			Unrelated		
	Intact	Recombined	New	Intact	Recombined	New
Accuracy (%)	75.8 (8.8)	49.8 (16.9)	84.1 (10.5)	56.6 (14.3)	67.2 (13.7)	81.3 (10.1)
RTs (ms)	1364 (341)	1813 (441)	1334 (342)	1618 (559)	1733 (469)	1419 (414)
Mean and range of trials per participant in ERP analyses	29.7 [22–40]	19.4 [9–34]	32.8 [20–40]	21.9 [12–34]	25.7 [12–37]	31.8 [16–40]

Note: Standard deviations are given in parentheses.

Table 2
Error distributions.

Condition	Intact		Recombined		New	
Incorrect response	Recombined	New	Intact	New	Intact	Recombined
% error responses for related trials	13.0 (6.3)	10.2 (8.3)	25.2 (12.3)	25.1 (11.4)	3.3 (4.6)	12.7 (7. 7)
% error responses for unrelated trials	29.7 (11.7)	12.3 (7.2)	12.6 (7.7)	19.7 (11.1)	2.1 (3.5)	15.9 (9.4)

Note: The percentage of error responses is calculated out of the total number of trials in each retrieval condition (i.e., 41). Standard deviations are given in parentheses.

Differences between the RTs of the two new conditions were marginal, $t(31) = -1.93$, $p < .07$.

We additionally analyzed the error responses within each retrieval category (see Table 2). In the intact condition, the analysis revealed a significant main effect of relatedness, $F(1,31) = 75.66$, $p < .001$, reflecting more errors in unrelated trials, a significant main effect of type of incorrect response, $F(1,31) = 34.22$, $p < .001$, and a significant interaction between these two factors, $F(1,31) = 31.08$, $p < .001$, stemming mainly from increased erroneous 'recombined' responses for unrelated compared to related pairs, $t(31) = -8.6$, $p < .001$. In the recombined condition, the analysis revealed a significant effect of relatedness (in an opposite direction than in the intact condition) $F(1,31) = 40.59$, $p < .001$, and a significant interaction between the two factors, $F(1,31) = 7.69$, $p < .01$. Decomposition of this interaction revealed that it stems predominantly from increased erroneous 'intact' responses for related compared to unrelated recombined pairs, $t(31) = 7.77$, $p < .001$, although the number of erroneous 'new' responses was also significantly greater for related compared to unrelated pairs, $t(31) = 2.47$, $p < .05$. In the new condition, the analysis revealed a significant effect of type of incorrect response, $F(1,31) = 69.32$, $p < .001$, and a significant interaction between the two factors, $F(1,31) = 12.12$, $p < .01$. This interaction was derived from increased erroneous 'recombined' responses for unrelated compared to related new pairs, $t(31) = 2.94$, $p < .01$; 'intact' responses to completely new pairs were in practice negligible.

Taken together, these behavioral analyses indicate that semantic relatedness has crucial effects on retrieval. The ANOVAs and analysis of d' revealed that unbiased retrieval of intact related pairs was both better and faster than for unrelated pairs. Unrelated intact pairs that were not recognized were likely to be judged as recombined, plausibly suggesting that associative reinstatement is less readily achieved for unrelated compared to related pairs. On the other hand, identification of recombined pairs was both better and faster for unrelated pairs. Analysis of erroneous responses in these conditions revealed increased intact and new responses for related compared to unrelated pairs. These observed patterns and their possible implications are broadly discussed in the discussion section.

3.2. ERP results

Fig. 2 shows averaged ERPs for each retrieval condition, for the nine representative electrodes averaged into anterior, central, and posterior loci of three electrodes each. As can be seen, in the early time window, for related pairs, differences related to associative memory (i.e., less negativity for intact versus recombined pairs in the FN400 time window) emerged at frontal locations, while differences related to item memory (i.e., less negativity for intact and recombined pairs relative to new pairs in the FN400 time window) were observed mostly in central locations. In contrast, for unrelated pairs, although less negativity for intact and recombined versus new items was observed at central locations, there were no differences related to associative recognition. In the late time window, for related pairs, an ERP effect that took the form of increased positivity to intact pairs compared to recombined and new pairs was observed, while for unrelated pairs, the ERP effect was associated with less positivity for recombined pairs compared to new pairs.

3.2.1. Mixed-effects models analyses

The topographic maps of the differences between the various conditions in the early time window are shown in Fig. 3. For the first time window (350–550 ms), the mixed-effects model analysis revealed significant main effects of relatedness, $F(1,46{,}373) = 46.42$, $p < .001$, retrieval category, $F(2,46{,}373) = 39.28$, $p < .001$, and location, $F(2,46{,}373) = 1063.89$, $p < .001$, and significant interactions between relatedness and retrieval category, $F(2,46{,}373) = 5.06$, $p < .01$, and between relatedness, retrieval category and location, $F(4,46{,}373) = 3.34$, $p < .01$. To further decompose the key 3-way interaction, we collapsed over the laterality factor, which did not play a part in this interaction, and ran the analyses separately for related and unrelated pairs, using subject as a random factor, and retrieval category, location, and retrieval category × location interaction as fixed factors. For related pairs, this analysis revealed a significant main effect of retrieval category, $F(2,23{,}531) = 39.17$, $p < .001$, a significant main effect of location, $F(2,23{,}531) = 482.89$, $p < .001$, and a significant interaction between these two factors, $F(4,23{,}531) = 3.05$, $p < .05$. We decomposed the latter interaction using pairwise comparisons with the subject as a random factor, and retrieval category as a fixed factor in each location group. These comparisons were subjects to Holm–Bonferroni correction. At anterior locations, this revealed a significant difference between related intact and recombined pairs, $F(1,4686) = 9.72$, $p < .01$, and between intact and new pairs, $F(1,5964) = 18.2$, $p < .001$, but not between recombined and new pairs. In central locations, there was a significant difference between related intact and new pairs, $F(1,5964) = 10.76$, $p < .01$, and between recombined and new pairs, $F(1,4977) = 16.71$, $p < .001$, but not between intact and recombined pairs. In posterior locations differences were revealed between intact and new pairs, $F(1,5964) = 21.55$, $p < .001$, and between recombined and new pairs, $F(1,4977) = 19.43$, $p < .001$, but not between intact and recombined pairs. For unrelated pairs, the analysis performed using condition and location as factors revealed a significant effect of retrieval category $F(2,22{,}811) = 7.58$, $p < .001$, and of location, $F(2,22{,}811) = 585.99$, $p < .001$, but no interaction between them. Pairwise comparisons revealed differences between intact and new pairs, $F(1,15{,}438) = 16.57$, $p < .001$, and between recombined and new pairs, $F(1,16{,}536) = 5.3$, $p < .05$, but not between intact and recombined pairs. The recombined versus new effect did not survive the correction for multiple comparisons. This analysis thus confirmed our hypothesis that in the early time window, for related pairs, differences related to associative memory (i.e., between intact versus recombined pairs) emerged at frontal locations, while for unrelated pairs, no differences related to associative recognition were observed. Additionally, differences related to item recognition (i.e., between intact/recombined versus new pairs) were more apparent at central and posterior scalp locations in the related condition, while in the unrelated condition they were more diffusely distributed.

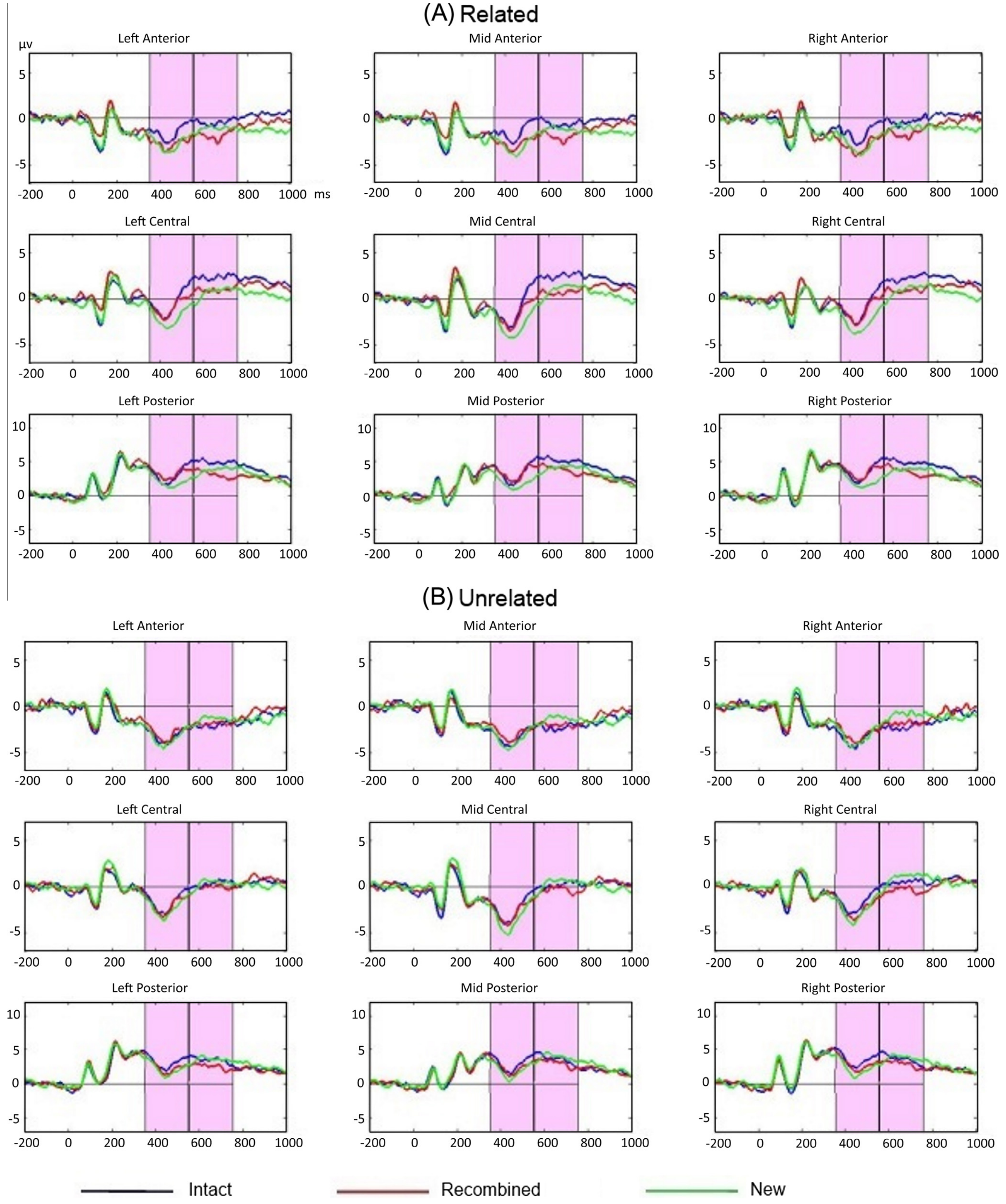

Fig. 2. Averaged ERP waveforms elicited by correct recognition of related (A) and unrelated (B) stimulus pairs. Data are shown for the nine electrodes used in all statistical analyses. Shadings indicate the two time windows used for statistical analyses.

The topographic maps of the differences between the various conditions in the late time window are shown in Fig. 4. For the later time window (550–750 ms), the analysis revealed significant main effects of relatedness, $F(1,46,373) = 82.74$, $p < .001$, of retrieval category, $F(2,46,373) = 22.63$, $p < .001$, of location, $F(2,46,373) = 757.26$, $p < .001$, and a significant relatedness × retrieval category interaction, $F(2,46,373) = 16.97$, $p < .001$. Decomposition of the 2-way interaction for related pairs revealed

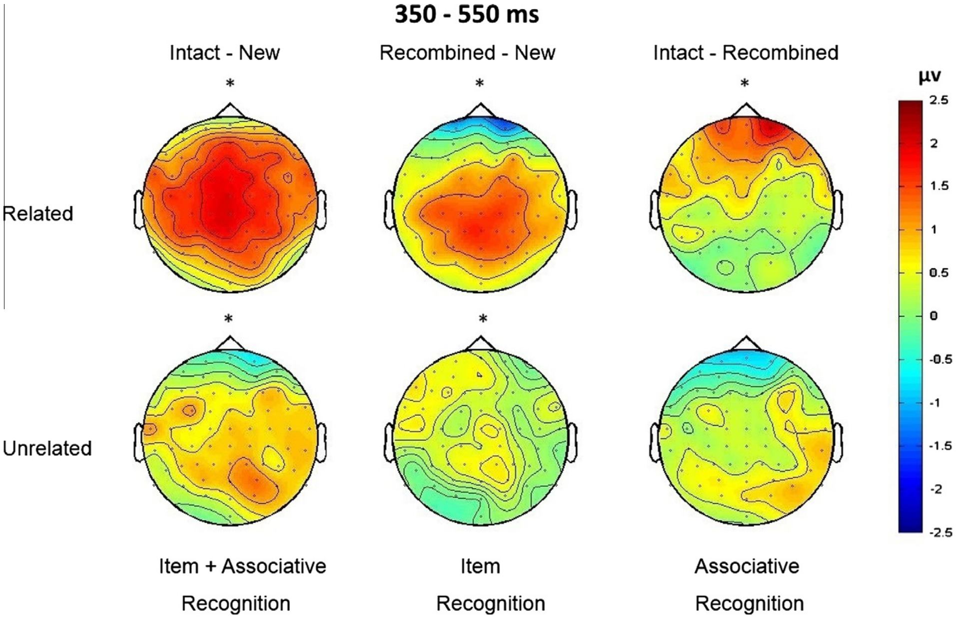

Fig. 3. Topographic maps of differences between retrieval conditions for related and unrelated pairs in the early time window (350–550 ms). Captions appearing below the topographic maps correspond to the types of recognition reflected by each comparison. Asterisks indicate topographical mnemonic differences significant at $p < .05$.

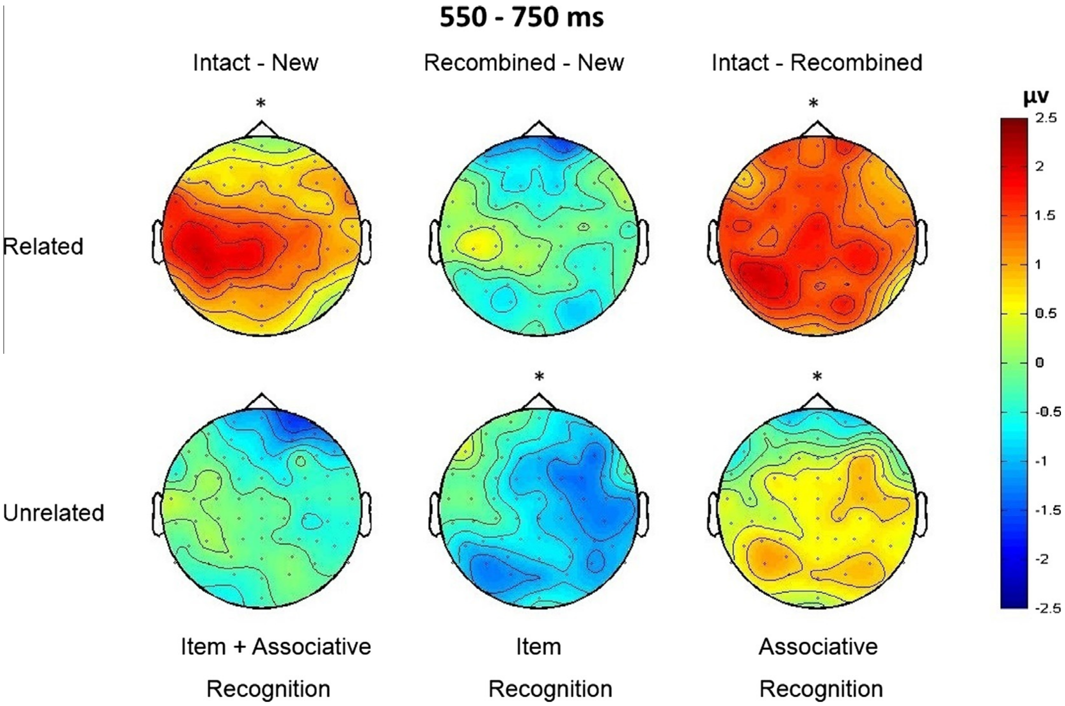

Fig. 4. Topographic maps of differences between retrieval conditions for related and unrelated pairs in the late time window (550–750 ms). Captions appearing below the topographic maps correspond to the types of recognition reflected by each comparison. Asterisks indicate topographical mnemonic differences significant at $p < .05$.

significant differences between intact and recombined pairs, $F(1,14,124) = 48.45$, $p < .001$, and between intact and new pairs, $F(1,14,124) = 44.45$, $p < .001$, with more positive deflections in both cases for intact pairs (e.g., an intact > new = recombined pattern), but not between recombined and new pairs. For unrelated pairs, this analysis revealed a significant difference between intact and recombined pairs, $F(1,13,665) = 4.34$, $p < .05$, with a more positive deflection for the former (however, this trend did not survive the correction for multiple comparisons), and between recombined and new pairs, $F(1,16,536) = 19.11$, $p < .001$, with more positive deflection for the latter, but not between intact and new pairs. These analyses provide some support to our hypotheses that in the late time window an intact > recombined pattern emerged for both related and unrelated pairs (but was more pronounced in the former). Nonetheless, since the effect was only marginal for unrelated pairs, this conclusion should be treated with caution. Additionally, for related pairs, the ERP effect was associated with less positivity for new pairs compared to intact pairs. However, contrary to our expectations, for unrelated pairs, increased positivity was found for new pairs versus recombined pairs.

3.2.2. Mixed-effects models analysis versus repeated measures ANOVA

For the early time window, repeated measures ANOVA revealed significant main effects of relatedness, location, and laterality, and significant interactions between relatedness × location, relatedness × laterality, and location × laterality (all $ps < .05$). Most critical to the goal of our study, the ANOVA further revealed a marginal 3-way relatedness × retrieval category × location interaction, $F(4,124) = 2.23$, $p = .069$. We further used pairwise comparisons to decompose the 3-way interaction, in the same manner it was decomposed in the mixed effects analysis. For related pairs, pairwise comparisons revealed a significant difference between intact and recombined pairs at anterior locations, $t(31) = 2.07$, $p < .05$, between intact and new at central $t(31) = 3.11$, $p < .01$, and posterior locations, $t(31) = 2.55$, $p < .05$, and between recombined and new at central, $t(31) = 2.06$, $p < .05$, and posterior locations, $t(31) = 2.95$, $p < .01$. For unrelated pairs, this analysis only revealed a significant difference between intact and new pairs at posterior locations, $t(31) = 2.6$, $p < .05$. Thus, the pattern of results in the early time window identified by the mixed-effects models analysis was replicated, to a large degree, in a standard repeated measures ANOVA.

For the later time window, the analysis only revealed a significant main effect of relatedness, $F(1,31) = 8.23$, $p < .01$, and of location, $F(2,62) = 38.56$, $p < .001$. Nonetheless, pairwise comparisons revealed more positive deflection for related intact versus recombined pairs at central, $t(31) = 2.14$, $p < .05$, and posterior locations, $t(31) = 2.1$, $p < .05$, and for related intact versus new pairs, in central locations, $t(31) = 2.41$, $p < .05$. In this time window, no significant differences emerged for unrelated pairs. Note that the differences in results between the different methods of analysis (i.e., mixed-effects versus ANOVA) are likely a function of the overweighting of participants with smaller numbers of trials per condition in the standard ANOVA.

3.3. Additional analyses

3.3.1. Interactions between semantic and episodic effects

In order to relate the present findings to semantic congruency effects for pictorial stimuli, reported in previous studies (e.g., Ganis & Kutas, 2003; Hamm, Johnson, & Kirk, 2002; McPherson & Holcomb, 1999; Mudrik, Lamy, & Deouell, 2010), we ran an additional analysis for the 350–550 ms time window at the central electrode location (Cz), which according to those reports best captures such effects. We used the new conditions, for which only semantic effects were expected to occur (i.e., since this is the first exposure to these pairs, there should be no episodic retrieval), as baseline, and differences between related and unrelated intact pairs as an indication of interaction between semantic and episodic effects (since for these pairs, which are presented for the second time, both effects might occur). We first examined a mixed effects model that was constrained to the new condition, with relatedness (related, unrelated) as a fixed factor and the subject number as a random factor. We then examined another model with the same parameters, but now constrained to the intact condition (note that we did not examine the recombined conditions, since those stimuli were presented in different relatedness relationships at study and test). These analyses revealed no difference between related and unrelated new pairs, but did reveal significant differences between related and unrelated intact pairs, $F(1,1618) = 9.75$, $p < .01$, with waveforms for unrelated-intact pairs being more negative-going than those for related-intact pairs. This interaction between semantic relatedness and episodic status will be discussed below.

3.3.2. Analysis of early effects

As indicated by Fig. 2, in related pairs, an unpredicted early effect (100–250 ms) emerged, in which ERPs for the recombined condition were more positive-going than ERPs for the intact and new conditions. We analyzed this effect, using retrieval category factor (intact, recombined, new), location (anterior, central, and posterior) and laterality (left, midline, and right) as fixed factors, and the subject number as a random factor. This analysis revealed significant main effects of retrieval category, $F(2,23,531) = 11.61$, $p < .001$, location, $F(2,23,531) = 278.2$, $p < .001$, and laterality, $F(2,23,531) = 6.95$, $p < .01$. Decomposition of the retrieval category effect confirmed that ERPs in the recombined condition were significantly more positive-going than ERPs in the intact condition, $F(1,14,124) = 19.94$, $p < .001$, and in the new condition, $F(1,14,124) = 13.21$, $p < .001$. Below, we will comment on possible interpretations of this effect.

3.3.3. Topographic analysis

As indicated by Fig. 3, associative recognition and item recognition effects for related pairs in the early time window exhibited a different topographical distribution, with more anteriorly distributed differences in the former. We therefore extended our ROI analysis by examining topographical differences in the amplitude normalized distributions of these effects using the entire montage of electrodes in the early time window. Differences in scalp topography after amplitude normalization suggest that these effects might be mediated by distinct mechanisms (e.g., Allan, Robb, & Rugg, 2000; Wilding, 2006; but see caveats in Urbach & Kutas, 2002, 2006). To directly compare the topographies of associative versus item recognition effects, we first calculated the difference waves for related pairs (intact minus recombined for associative recognition and recombined minus new for item recognition) for the averaged data of each subject. Difference amplitudes were then normalized according to the vector scaling procedure described by McCarthy and Wood (1985), applied within-subjects, as was suggested by Haig, Gordon, and Hook (1997). The comparison of the normalized difference amplitudes at 350–550 ms in a repeated measures ANOVA with recognition (associative, item) and location (64 electrodes) as repeated factors, revealed a significant interaction between these factors, $F(63,1953) = 2.13$, $p < .001$. This finding may be taken as an indication that for semantically related pairs, different processes contributed to item and associative recognition.

4. Discussion

In the current study, an associative recognition memory task was employed to explore whether episodic associations between related and unrelated picture pairs differentially recruit familiarity- and recollection-based recognition, as indexed by their putative electrophysiological signatures. The key finding was that in a time window of activity associated with familiarity-based recognition, associative recognition of intact stimulus pairs was accompanied by a larger frontal positive deflection compared to recombined pairs – but only in the related pairs condition. A temporally similar deflection accompanied the successful identification of intact and recombined pairs, compared to correct identification of new pairs (i.e., reflecting item familiarity); this deflection, which was most pronounced at central scalp locations, was apparent for both related and unrelated pairs. In a later time window, associated with recollective recognition processes, discrimination between intact and recombined pairs elicited a stronger positive deflection for the former in both related and unrelated conditions (albeit with a stronger effect for the related condition). These data provide novel evidence for a multiplicity of processes supporting associative recognition of semantically related and unrelated picture pairs, under conditions that model ecological perception and memory. They suggest that while the recognition of episodic associations formed between related objects might recruit both familiarity- and recollection-based processes, associative recognition of unrelated pair associates necessitates recollection. These findings are notable as they are based on directly contrasting responses to recombined pairs with responses to intact and new pairs, which has not characterized most earlier studies. Furthermore, the topographical electrophysiological patterns of responses herein reported suggest possible process dissociations between associative recognition and item recognition.

The critical hypothesis underlying the current study was that the ability of associations between related object-picture pairs to be processed in a unitized fashion may promote the contribution of familiarity to associative recognition. In accordance with this prediction, a mid-frontal effect, conventionally interpreted as the putative ERP correlate of familiarity, was selectively observed for related stimulus pairs. A number of studies employing both top-down or bottom-up unitization procedures (Bader et al., 2010; Diana, Yonelinas, & Ranganath, 2008; Diana et al., 2011; Ford, Verfaellie, & Giovanello, 2010; Giovanello, Keane, & Verfaellie, 2006; Jäger et al., 2006; Kriukova et al., 2013; Quamme et al., 2007; Yonelinas et al., 1999) support the notion that enhanced familiarity enables memory for unitized associations. However, no previous reports examined this issue using object picture pairs, which form a unitized perceptual and conceptual compound.

Ample evidence from the visual perception literature has documented the importance of semantic and spatial object-to-object relations to online unitization or to "perceptual grouping" processes (e.g., Auckland, Cave, & Donnelly, 2007; Davenport, 2007; Green & Hummel, 2006; Gronau & Shachar, 2014; Oppermann, Hassler, Jescheniak, & Gruber, 2012; Roberts & Humphreys, 2011). More relevant to the present research, several studies have demonstrated the significance of such unitization processes for visual memory encoding and retrieval processes (e.g., Hollingworth, 2006; Mandler & Parker, 1976; Mandler & Ritchey, 1977). The current study, however, is a first attempt to link such visual perceptual and contextual processes, which underlie bottom-up unitization, to specific episodic associative recognition (i.e., familiarity) processes.

As noted above, bottom-up unitization is of particular interest, since it may be seen as a bridge between episodic and semantic memory, two dissociable forms of declarative memory (e.g., Schacter & Tulving, 1994; Tulving, 1972) that typically function together during normal cognition. One type of influence of semantic memory on episodic retrieval is associated with the level of processing (LOP) of stimuli during encoding (Craik & Lockhart, 1972). The LOP theory posits that when stimuli are encoded in a semantically meaningful manner (such as semantic categorization) their subsequent retrieval will be enhanced relative to shallow non-semantic encoding (e.g., letter discrimination). As shallow processing can engender subsequent familiarity (Yonelinas, 2002), the differential benefit of deep encoding, in which prior semantic knowledge is brought to bear, is sometimes asserted to result primarily from stronger subsequent recollection (Craik & Lockhart, 1972; Greve et al., 2007). According to that approach, to the extent that related pairs undergo meaningful semantic processing more efficiently than do unrelated pairs, that semantic relatedness would influence episodic retrieval largely by promoting recollection. The present study adds to a growing body of literature challenging this notion (e.g., Bader et al., 2010; Greve et al., 2007; Jäger & Mecklinger, 2009; Jäger et al., 2006; Rhodes & Donaldson, 2007, 2008) by providing evidence that semantic factors may augment episodic retrieval by enhancing familiarity as well, as indexed by the FN400, the putative electrophysiological correlate of episodic familiarity.

In the current study, associative-familiarity effects for related pairs were more anteriorly distributed than the item-familiarity effects (i.e., the comparison between conditions in which individual stimuli had been seen previously and the new condition in which individual stimuli were episodically novel) observed for both related and unrelated pairs. This topographical distribution difference implies that multiple processes might engender familiarity. Several recent studies have examined the manifold nature of familiarity by exploring the contribution of relative and absolute familiarity to recognition memory judgments (Bader et al., 2010; Bridger, Bader, & Mecklinger, 2014; Coane, Balota, Dolan, & Jacoby, 2011; Stenberg, Hellman, & Johansson, 2008; Wiegand, Bader, & Mecklinger, 2010). Following Mandler (1980), these researchers draw a distinction between absolute familiarity, i.e., baseline knowledge of an item, and relative (or incremental) familiarity, i.e., the relative increase of the familiarity signal compared to the pre-experimental baseline as a result of an episodic encounter. In episodic memory tasks involving completely novel stimuli (such as unfamiliar faces or abstract drawings), the assessment of absolute familiarity is mnemonically diagnostic, whereas in tasks with pre-experimentally familiar stimuli (such as words), relative familiarity is required for recognition judgments. It is suggested (Bader et al., 2010; Wiegand et al., 2010) that this distinction is reflected in differences in the topographical distribution of the early old/new ERP effect, with a mid-frontal effect associated with the assessment of relative familiarity, and a more posteriorly distributed effect associated with absolute familiarity. In the current study, an early associative-recognition effect was observed solely for related pairs. Associations between semantically related objects are 'absolutely familiar', in the sense that the image of a lamp on a table, e.g., is consonant with our prior conceptual experience. Therefore, such absolute semantic familiarity would not be diagnostic for the episodic recognition of studied versus unstudied related pairs. Accordingly, associative recognition of semantically related pairs would more likely be determined by relative familiarity, indexed by the mid-frontal FN400 ERP effect. On the other hand, early item-recognition effects, obtained when pairs of completely new pictures were discriminated from the other two conditions, were observed in both related and unrelated pairs. In this case of item recognition, the absolute familiarity of the component items was equated across relatedness conditions, as items comprising related and unrelated pairs were drawn from the same stimulus pool. However, the fact that the items were processed as pairs, which involve a rarer presentation format than for individual objects, might have engendered a sense of low absolute familiarity for the studied component items, and therefore a more posterior distribution of the item familiarity effect.

An alternative understanding of the early anterior ERP divergence between responses to intact and rearranged related pairs is that they reflect not familiarity processes, but rather processing fluency associated with conceptual implicit memory (Paller et al., 2007; Voss, Lucas, & Paller, 2012). In that view, the current results would be interpreted thus: the intact related pairs are processed more fluently when seen the second time, compared to the rearranged related pairs, which were not studied together. Such fluency is reflected in the reduced negative deflection for intact pairs. This difference is limited to the related condition, as the presence of pre-existing semantic representations in related pairs at encoding might be required to engender conceptual priming. Since the current experiment was designed to address the contribution of semantic relatedness to unitization, the data do not enable us to adjudicate between the proposed associative familiarity account and the alternative conceptual fluency account. However, as there were no differences in the ERPs elicited by new pairs in both conditions, there is no evidence that pre-existing semantic relations do indeed modulate the ERPs in the critical time interval. Furthermore, it may be argued that even if fluency factors did modulate the early anterior ERP divergence, such unitization-related processing fluency contributes to the recognition judgment that those fluent pairs had been studied, and therefore on the whole we believe that the episodic familiarity account is preferable.

The interrelationship between episodic and semantic factors during the retrieval task was manifest in an additional aspect of the electrophysiological data. Ancillary analysis revealed that at Cz in the 350–550 ms time window, there was an interaction between semantic relatedness and episodic status, such that for studied test probes, unrelated pairs elicited greater negativity than related pairs, but for unstudied test probe pairs, there was no such difference. Greater negativity related to semantic incongruity of pictures in various presentation conditions in comparable scalp location and latency has been reported in several prior studies (e.g., Ganis & Kutas, 2003; Mudrik, Shalgi, Lamy, & Deouell, 2014; Mudrik et al., 2010 – incongruence of objects in complex visual scenes; Hamm et al., 2002 – incongruence of object pictures with previously presented name labels; McPherson & Holcomb, 1999 – incongruence relative to object picture primes; and even Sitnikova, Holcomb, Kiyonaga, & Kuperberg, 2008; Sitnikova, Kuperberg, & Holcomb, 2003 – incongruence in short movie clips depicting everyday events). In the current study, object pictures that were unrelated (and arguably somewhat incongruous relative to the other half of the pairs presented that were semantically related) elicited greater negativity. However, that effect only emerged for studied materials (intact-condition test probes). In initial presentation of the picture pairs (i.e., for the new-condition test probes), there was no difference between relatedness conditions. We speculate that this pattern of results might be a factor of the more dominant negative deflection elicited by novel stimuli in an episodic recognition test in this time window, which might have masked the semantic processing correlates for the new probe trials. For the intact probes, there is no such episodic novelty-related negative deflection, which enables the semantically-related negative deflection to be exposed. Since the current study was designed to study episodic memory effects rather than semantic processing, we cannot reach strict conclusions regarding this congruity effect, which may be profitably explored in future research.

In addition to the early anterior effect, a posterior ERP modulation was observed for both related and unrelated pairs. This took the form of a somewhat typical LPC pattern in terms of associative recognition, with increased positivity for intact versus recombined associations, for both related and unrelated pairs (although in the latter case, the effect was marginal). It therefore seems that regardless of the occurrence of early familiarity-related processes, late recollective processes may also contribute to the retrieval of associative information. This notion is supported by previous reports of recollection-based retrieval and their physiological correlates, irrespective of the presence or absence of familiarity and its effects (e.g., Diana et al., 2011; Greve et al., 2007; Rhodes & Donaldson, 2007, 2008; Tibon et al., 2014). This would be expected by the dual-processes model of recognition memory, which proposes that the two processes are orthogonal. Nonetheless, some recent studies have suggested that in certain cases familiarity can be sufficiently mnemonically diagnostic, to the extent that it may eliminate (or reduce) the need for recollection (e.g., Bader et al., 2010; Kriukova et al., 2013). Seemingly, when memoranda are picture pairs (which may yield more vivid representations than word pairs), recollective information might be more accessible. Therefore, even though familiarity may support associative recognition judgments, recollection of the encoding event still occurs and is expressed electrophysiologically. Aside from the expected LPC modulation, elicited by associative recognition judgments (i.e., intact > recombined), an unexpected pattern of intact = new > recombined for unrelated pairs emerged. This pattern is inconsistent with previous reports of decreased positivity for new materials (e.g., Bader et al., 2010; Greve et al., 2007; Kriukova et al., 2013; Mollison & Curran, 2012; Opitz, 2010; Rhodes & Donaldson, 2007, 2008); the reason for this discrepancy is unclear. A comparable finding is noted by Addante, Ranganath, and Yonelinas (2012), who describe an ERP in this time window elicited by correct but low-confidence item memory accompanied by correct source judgment that is less positive than the ERP elicited by correct rejection of foils. Those authors similarly note that the discrepancy requires further investigation.

Another effect that emerged in the post hoc ancillary analyses was a difference between recombined pairs and the other two conditions in an unexpectedly early time window (100–250 ms). The only associative memory ERP effect of which we are aware which emerges that early is reported by Tsivilis, Otten, and Rugg (2001), in a context effects paradigm. Those authors speculate that the early effect is related to priming or represents "the emergence of information about prior occurrence that contributes to recognition judgments". However, unlike the present pattern, that early effect was elicited by totally new object picture-scene context pairs compared to other conditions in which at least one element had been studied. It is difficult to understand how differentiation between intact and rearranged pairs which we have observed could emerge so quickly. We therefore defer the interpretation of this effect pending its replication in additional studies.

In the current study, the recombined retrieval condition was characterized by a full cross-over in the relatedness status of stimuli. That is, recombined unrelated pairs were composed of stimuli that had been studied as members of related pairs, and vice versa. We used this cross-over approach because attempts to create a sufficient number of recombined related combinations were not successful. For testing the endorsement of intact pairs, this approach provided an effective foil condition: neither an item's oldness nor its associative relatedness (at retrieval) were sufficient criteria for associative oldness, and remembering the specific pairings was required. Unrelated intact pairs similarly needed to be endorsed in contrast to unrelated recombined pairs in which the component items had been previously studied individually. However, due to this cross-over approach, several different processes might have led to the endorsement of recombined pairs as such. As mentioned above, the most basic process involves the participant experiencing one or both of the component pictures to be old (requiring item familiarity), but having no memory of studying them together (i.e., no associative familiarity or recollection). However, there is the possibility of an alternate route, in which the participant actively remembers having studied one of the component pictures with a different picture. This represents a "recollect-to-reject" process for excluding the alternatives. Arguably, such recollection may be easier in recombined-unrelated than in the recombined-related condition, as in the former case the component pictures were each studied as parts of related pairs, which are easier to remember. However, the electrophysiological data do not appear to support this interpretation. If recollection played a greater role in the correct identification of recombined-unrelated pairs than in those of the recombined-related pairs, we would expect larger LPC responses (in absolute terms, and also relative to correctly identified new pairs) in the former case than in the latter. However, such a pattern was not obtained: as noted above and as can be seen in Fig. 4, recombined-unrelated pairs actually elicited a smaller LPC component than new pairs, while for recombined-related pairs there were no overall differences between the conditions. We may therefore suggest that the recombined pairs were most likely discriminated from the new pairs by the presence of item familiarity (as indexed by early frontal recombined versus new differences in both related and unrelated conditions, Fig. 3), and the absence of associative familiarity or recollection.

The current study also provides some interesting behavioral results, demonstrating the effects of semantic congruency on associative recognition memory. Our main finding was that retrieval of semantically related intact stimulus pairs was enhanced relative to that of semantically unrelated pairs. This enhanced endorsement of related pairs does not appear to be a function of a relatedness response bias, as there was a significant relatedness difference in d' for intact pairs relative to new pairs. As mentioned above, this result indicates that our semantic knowledge can affect the formation of long-term episodic associations between objects within a certain context. A less intuitive finding is the reversal of relatedness effects in the recombined condition, in which unrelated pairs were more likely to be endorsed as such than related pairs (Table 1). In this condition, misidentified pairs could be marked as either new or intact. Related recombined pairs were equally likely to be marked as intact or new pairs, while unrelated recombined pairs were more likely to be marked as new pairs. However, both types of errors were more frequent in the related condition (Table 2). This pattern of responses may have resulted from two complementary reasons. One is that relatedness may cause a fluency-based associative response bias (even though, as noted above, it does not engender an item response bias), especially when both stimuli in the test pair are familiar items. That would yield a greater number of 'intact' responses for related recombined pairs. The second effect – more misses in the direction of 'new' responses for related than unrelated recombined pairs – may arise because the stimulus members of pairs in the related recombined retrieval condition were all encoded as members of unrelated pairs, which might have yielded a less effective associative encoding than for stimuli encoded as parts of related pairs. Therefore, their component items might have been less strongly remembered, yielding more item misses and therefore more 'new' responses.

An additional insight is afforded by the analysis of error responses. As mentioned above, intact related pairs were more readily correctly endorsed than intact unrelated pairs. Mislabeling of intact pairs might occur due to failure to retrieve associative information (which will result in mislabeling an intact pair as a recombined one), or from failure to retrieve item information (which will result in mislabeling an intact pair as a new one). In the current case, the type of failure in identification of intact pairs differed between relatedness conditions. Specifically, Table 2 shows that misidentification of intact pairs as recombined was significantly more likely for unrelated pairs than for related pairs. In contrast, the number of 'new' responses for unrelated intact pairs was not larger than for related intact pairs. The finding that participants were more prone to mislabeling intact unrelated pairs as recombined indicates that unitization affected associative rather than item memory.

In summary, examining the electrophysiological correlates of episodic associative recognition of semantically and spatially related versus unrelated object picture pairs, we report evidence suggesting that recognition of related stimulus pairs amenable to unitization can be differentially supported by associative familiarity. This finding reinforces the importance of semantic relationships between episodically associated memoranda in determining the way that their co-occurrence is experienced and subsequently remembered.

Acknowledgments

This work was supported by the German-Israeli Foundation for Scientific Research and Development Grant 1083-5.4/2010 to A.M. and D.A.L. We thank Rotem Amar, Anna Izoutcheev, Yam Goddard, and Nava Traschanski for assistance with stimulus preparation and data collection, and David Anaki for facilitating the analyses.

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