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Electrophysiological evidence for the effect of interactive imagery on episodic memory: Encouraging familiarity for non-unitized stimuli during associative recognition.

Running Head: Associative Recognition, Familiarity, Unitization and Interactive Imagery

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Abstract

Episodic memory depends upon multiple processes, including familiarity and recollection. Although associative recognition tasks are traditionally viewed as requiring recollection, recent research suggests a role for familiarity if to-be-remembered stimuli are perceived as unitized. Here we use Event-Related Potentials (ERPs) to examine the relationship between stimulus properties and encoding strategy on the engagement of familiarity during associative recognition. Participants studied word-pairs containing an association (e.g. traffic-jam) or an unassociated semantic relationship (e.g. violin-guitar), using either item or interactive imagery. At test, participants were required to recognize if word-pairs were presented in the same pairing as study, were rearranged, or new. We hypothesized that adopting a strategy of interactive imagery during encoding (i.e. encouraging unitization) would enhance familiarity for unassociated word-pairs, but would have no effect on association pairs because they are already perceived as unitized. As expected, overall recognition performance was better for word-pairs encoded with interactive imagery, and for association than semantic word-pairs. ERPs recorded at test revealed an interaction between encoding strategy and stimulus properties. Association word-pairs elicited similar bilateral frontal (familiarity) and left parietal (recollection) old/new effects following item and interactive imagery. By contrast, for semantic word-pairs, the left parietal effect was equivalent across conditions, but the bilateral frontal effect was enhanced for the interactive imagery condition. The ERP results suggest that an encoding strategy of interactive imagery can enhance familiarity during associative recognition, but this effect is ultimately dependent on the properties of the stimuli to-be-remembered and the nature of the representations that underlie them.

Introduction

Episodic memory, the conscious retrieval of previous events, is supported by familiarity, a relatively automatic process involving recognition without the retrieval of contextual information, and recollection, a more controlled process that supports retrieval of information and its context (for review see Yonelinas, 2002). Although familiarity and recollection can be clearly identified and dissociated as components of episodic retrieval, much less is known about the conditions that influence their use. In a previous study investigating this issue we (Rhodes and Donaldson, 2007) employed event-related potentials (ERPs) to provide an index of familiarity and recollection, demonstrating that the engagement of familiarity is influenced by the properties of to-be-remembered stimuli – namely whether or not the stimuli are 'unitized'. Here we extend this investigation, examining the influence of both stimulus properties and the specific strategy adopted at encoding on the engagement of familiarity. Below we outline the characteristics of familiarity and recollection, and discuss evidence that unitization does indeed influence their engagement. Following this, the present study investigates whether adopting an encoding strategy that encourages the formation of a unitized representation always differentially influences familiarity based responding, or if the effect of encoding strategy is dependent on stimulus properties, such that unitization only affects stimuli that are not already perceived to be a unit.

The ERP method provides strong support for dual process models of retrieval; ERP old/new effects, based on a contrast of activity for correctly recognized old and correctly rejected new stimuli, reveal clearly identifiable neural correlates of familiarity and recollection. The bilateral frontal old/new effect (circa 300 to 500 ms post stimulus) is typically correlated with familiarity, and for example, is elicited by 'Know' responses in the Remember/Know paradigm (Klimesch et al., 2001). The left parietal old/new effect (circa 500 to 900 ms post stimulus), provides a correlate of recollection, and is elicited by 'Remember' responses in the Remember/Know paradigm (Klimesch et al., 2001; Trott et al., 1999), and during associative recognition paradigms (Donaldson and Rugg, 1998; 1999).

The distinction between familiarity and recollection is particularly clear when item and associative recognition are compared. Whilst item recognition tasks require discrimination between single studied and unstudied stimuli, associative recognition tasks involve the presentation of pairs of stimuli at study (e.g., apple-car, bed-vase, house-pencil), and require discrimination between intact (e.g. apple-car) and rearranged (e.g. bed-pencil) pairs at test (Hockley, 1992). Importantly, ERP studies of associative recognition typically also employ a baseline condition of new pairs at test, to facilitate comparisons with the standard item recognition ERP old/new effects. Dual process accounts of associative recognition typically assume that the individual elements of a stimulus are represented and processed separately. By this view, individual elements of an event may be recognized on the basis of being familiar, but retrieval of the relationship between the elements necessarily requires recollection. Associative recognition tasks have therefore been thought to rely on recollection alone (c.f. Yonelinas, 1997, 2002, and see Donaldson and Rugg, 1998, 1999, for relevant ERP data); by this view familiarity cannot support performance because there is no specific representation of the stimulus relationship that can give rise to familiarity. More recently however, it has become clear that associative recognition tests may be performed on the basis of familiarity – at least under certain circumstances. According to the unitization account of associative recognition, familiarity can be engaged if to-be-remembered information is perceived as a single unit (cf. Mayes et al., 2007; Quamme et al., 2007; Rhodes and Donaldson, 2007; Yonelinas et al., 1999).

Behavioural evidence that unitization encourages familiarity can be found in studies of recognition memory for faces using receiver operating characteristics (ROC curves). Typically, item recognition tasks produce curvilinear asymmetrical ROC curves (reflecting familiarity and recollection) whereas associative recognition tasks produce linear ROC curves (reflecting recollection alone) (Yonelinas, 1997; although see Wixted, 2007). However, ROC curves for faces suggest that familiarity can support associative recognition under some circumstances. Yonelinas et al. (1999) reported that ROCs were curvilinear for faces presented in an upright position but linear for faces presented in an inverted orientation, suggesting that familiarity only supports associative recognition for upright faces. As face recognition is highly practiced and faces are normally processed holistically, the authors concluded that upright faces were encoded as a coherent entity (i.e., unitized) facilitating the use of familiarity at retrieval. Evidence that unitization encourages familiarity can also be found in neuropsychological data, comparing hypoxic patients who have impaired recollection but preserved familiarity, with medial temporal lobe damage patients who have impairments in familiarity and recollection (Quamme et al., 2007). Hypoxic patients showed superior performance on an associative recognition task under encoding conditions that encouraged unitization in contrast to a 'non-unitization' condition. In contrast, patients with medial temporal lobe damage showed no memory benefit from unitization. This pattern of findings is interpreted by the authors as support for the influence of unitization on familiarity based responding.

Electrophysiological evidence from recognition memory for word-pairs also provides support for the unitization account (Rhodes and Donaldson, 2007). Word-pairs can be constructed such that the relationship between the words varies in a wide variety of ways, effectively encouraging or discouraging unitization. For example, words can share a semantic relationship in common, reflecting activation of a semantic knowledge system in which information is organized categorically (e.g., cereal-bread). Alternatively words can simply be associated, whereby one item calls to mind the other (e.g. traffic-jam). Associations reflect word use rather than word meaning, and can exist either with (e.g. traffic-car) or without (e.g. traffic-jam) the presence of a semantic relationship. Rhodes and Donaldson (2007) investigated retrieval of word-pairs sharing an association, association + semantic relationship, and a semantic relationship. Behavioural ratings revealed that association pairs are perceived to be more 'unitized' than unassociated semantic pairs. In addition, ERP data revealed that the left parietal index of recollection was equivalent across conditions, but association pairs differentially elicited the bilateral frontal index of familiarity.

Although familiarity is traditionally associated with item recognition, the study by Rhodes and Donaldson (2007) demonstrates that familiarity can support retrieval on an associative recognition task. Just as the holistic processing of upright faces allows familiarity based responding, the existence of a pre-existing unitized representation (based on an association relationship between the members of a word pair) also allows familiarity based responding. Taken together, current findings suggest that whether or not associative recognition is supported solely by recollection is a product both of the demands of the task, and the properties of the information that is to be remembered. If this is the case, it raises the possibility that the requirement to engage recollection during episodic memory tasks could be reduced or possibly even circumvented – if the information to be retrieved is of the appropriate kind. In the present study we therefore address the question of whether unitization can be encouraged for nominally 'non-unitized' stimuli, using ERPs to assess the pattern of processing that supports behaviour. Specifically, we investigate whether instructions to adopt an encoding strategy of interactive imagery, which explicitly encourages the formation of a unitized representation, leads to the engagement of familiarity during the retrieval of unassociated word-pairs. At issue is the question of whether changes in unitization lead to changes in the underlying pattern of processes that support associative recognition memory.

The usefulness of imagery as an encoding technique for subsequent memory retrieval is well established (e.g. Bower, 1970; Paivio, 1969; Richardson, 1998) and there is evidence to suggest that the memory advantage of engaging in imagery arises from the formation of relationships between stimuli. Superior memory accuracy for word-pairs encoded with interactive imagery in contrast to item imagery has been reported on tasks of free recall (Bower, 1970) and recognition memory (McGee, 1980). The present experiment therefore directly compares the influence of interactive and item imagery; we test the prediction that the formation of a unitized representation arising from the use of interactive imagery at encoding will lead to familiarity based responding for otherwise 'non-unitized' semantic pairs, as reflected by a change in the magnitude of the bilateral frontal old/new effect at retrieval. Importantly, we will compare ERPs based on old (same) responses with both new and rearranged ERPs, enabling comparison with both behavioural and ERP studies, as the former have largely been restricted to the comparison of old/rearranged responses and the latter to old/new responses. We expect familiarity to support the retrieval of association word-pairs as these pairs are already perceived as a unit and therefore predict no further increase in familiarity as a result of interactive imagery.

Materials and Method

Participants

Twenty-four right-handed students participated in the experiment, paid at the rate of £5 per hour. Data from two participants were discarded due to there being insufficient artifact-free trials in the critical response categories. The mean age of the remaining 22 subjects was 21.09 (range 18-35), 11 of whom were female. All participants had normal or corrected to normal vision. Informed consent was collected in line with Stirling University Department of Psychology Ethics procedures.

Stimuli

The stimuli comprised 384 word-pairs selected from nouns, verbs, and adjectives (ranging from 3-9 letters in length) from the Kucera and Francis (1967) corpus. These stimuli comprised 192 word-pairs related by 'association', words that are associated but do not share a semantic relationship of a categorical or functional nature (e.g. traffic-jam), and 192 word-pairs sharing a 'semantic' relationship, words sharing a categorical or functional relationship independent of association (e.g. cereal-bread). Examples of the stimuli are provided in Table 1. The association and semantic word-pairs were each randomly allocated to the two encoding conditions, resulting in 4 stimuli conditions in the experiment: (1) association item imagery (2) association interactive imagery (3) semantic item imagery (4) semantic interactive imagery. No word-pair was repeated across encoding conditions.

Importantly, word-pairs of each relationship type were matched for word frequency (see Table 2) using the Kucera and Francis (1967) norms, and for both the presence and absence of association and semantic relationships (see Table 3). Word-pairs characterized by a semantic relationship shared category membership or a functional relationship. The semantic distance of these word-pairs was measured using a semantic space model; a method derived from the frequency distributions of the words occurring in the immediate context of a target word, computed over a large language corpus (containing millions of words) (McDonald, 2006; see Huettig et al., 2006, for further description). Mean frequency of contextual co-occurrence for semantic word-pairs is shown in Table 3. Association word-pairs shared a low frequency of contextual co-occurrence. Association ratings were taken from the Edinburgh Association Thesarus (EAT) which gives the proportion of participants who called to mind the second word on presentation of the first (i.e. association rank). The EAT was chosen based on its established use in the literature (e.g. Coulson et al., 2005) and because rank of association is regarded as a more optimal measure of association than association frequency (Anaki and Henik, 2003). Mean association strength for association word-pairs are shown in Table 3. Semantic pairs had no association relationship as indicated by this measure. The degree to which word-pairs in the association and semantic conditions were considered to reflect a single unit has previously been reported (Rhodes and Donaldson, 2007); a behavioural rating paradigm revealed that association pairs were perceived to be ‘unitized’ whereas unassociated semantic pairs received a low unitization rating.

Procedure

The experiment was designed using E-Prime (Psychology Software tools). Word-pairs were presented on a computer monitor in uppercase 18 point courier new font. Letters were displayed in white font against a black background and were displayed one above the other slightly above and below central vision. At the viewing distance of 97cm, the stimuli subtended a maximum horizontal visual angle of approximately 3.7˚, and a maximum vertical visual angle of approximately 1.4˚. Responses were made on a Psychology Software Tools Serial Response box. Prior to commencing the task, each participant completed a practice session which included 8 word-pairs at study and 12 at test. The experiment was divided into 16 blocks of study and test; 8 item imagery and 8 interactive imagery conditions. The order of item and interactive imagery conditions was counterbalanced across subjects. In the item imagery condition, participants were instructed to create a separate image for each individual word. In the interactive imagery condition, participants were instructed to create an image of the two items interacting together. Participants performed a practice block using the relevant encoding strategy before each experimental condition of 8 blocks commenced. Immediately following the practice block participants were verbally presented with one of the study pairs by the experimenter and were asked to describe the image they had created. All participants were found to be able to use the encoding strategy appropriately. Study blocks comprised 16 word-pairs. Test blocks comprised 24 word-pairs, 8 of which were the same as presented at study, 8 of which were in a different pairing from study (rearranged), and 8 of which were entirely new. Both study and test blocks involved equal proportions of association and semantic word-pairs in a randomized presentation.

In the study phase, each trial began with an initial fixation cross (+) displayed in the center of the screen for 1000ms. This cross was used to maintain participants' fixation on the center of the screen and to indicate the presentation of the next word-pair. A 1000ms blank screen then preceded the presentation of the word-pair which was presented for 1500ms. Test phases immediately followed study phases. Each test trial began with a fixation cross which was presented for 1000ms and which was followed by a blank screen also presented for 1000ms. Word-pairs were presented for 2000ms and followed by a 1500ms blank screen. Participants had to make a response of same, rearranged, or new during the presentation interval. The end of this interval began a new trial. Response hands for same and new were counterbalanced across participants.

Following the experiment, all participants completed the Vividness of Visual Imagery Questionnaire (Marks, 1973) to ensure participants were competent at vividly creating images.

Analysis revealed that no participants performed more than 1.5 standard deviations below mean performance (range of scores: 48-102; mean and s.d.: 71.7, 14.7).

ERP Recording

Scalp EEG was recorded from 61 standard sites based on an extension of the international 10-20 system (Jasper, 1958): FZ, FCZ, CZ, CPZ, PZ, POZ, Oz, FP1, FP2, AF7, AF8, AF3, AF4, F7, F8, F5, F6, F3, F4, F1, F2, FT7, FT8, FC5, FC6, FC3, FC4, FC1, FC2, T7, T8, C5, C6, C3, C4, C1, C2, TP7, TP8, CP5, CP6, CP3, CP4, CP1, CP2, P7, P8, P5, P6, P3, P4, P1, P2, PO7, PO8, PO5, PO6, PO3, PO4, O1, O2. An additional EEG channel was recorded from the right mastoid. All channels were referenced to the left mastoid, and ERPs were algebraically reconstructed off-line to represent recordings with respect to an average mastoid reference. Vertical and horizontal EOG was recorded from bipolar pairs of electrodes placed above and below the left eye, and on the outer canthi. Inter-electrode impedance levels were kept below 5k. EEG and EOG were filtered with a bandpass of 0.01 – 40 Hz and digitized (16 bit) at a rate of 8msec per point. Individual 1936ms epochs were formed (beginning with a 104ms pre-stimulus baseline) and epochs with baseline drift exceeding 75µv, or base-to-peak amplitude exceeded 100µv, were rejected. Averaged ERP waveforms were baseline corrected and smoothed over a 5 point kernel. A minimum of 16 artefact free trials in each critical response category was required from each participant to ensure an acceptable signal-to-noise ratio. The mean number of trials contributing to the grand average ERPs were: association item: same (25) rearranged (26) and new (27); association interactive same (27) rearranged (24) and new (27); semantic item: same (22) rearranged (26) and new (26); and semantic interactive: same (24) rearranged (25) and new (27). Analysis was performed on mean voltage data relative to the pre-stimulus baseline period using repeated measures ANOVA, and only main effects or interactions involving the factors of response (same, rearranged, new) are reported. The Geisser-Greenhouse correction for non-sphericity was applied as appropriate, and corrected df and F values are reported.

Results

Behavioural Data

As can be seen from Figure 1a, recognition accuracy was generally lower for semantic than association word-pairs, and for word-pairs encoded with item imagery compared to interactive imagery. Analyses were conducted employing discrimination measures (Snodgrass and Corwin, 1988), based on subtractions of false alarms [1-correct rejections (i.e. new responses)] from hits (same, rearranged), providing a measure of P_r. The ANOVA was conducted with factors of response and condition (all 4 relationship/strategy types) rather than with separate 2x2 factors of relationship and strategy as this analysis structure obscures the reduced accuracy for same responses that can be observed for the semantic item condition in comparison to all other conditions (see Figure 1). An ANOVA with factors of response (same, rearranged) and condition (association item, association imagery, semantic item, semantic imagery) on P_r data revealed a significant response x condition interaction [$F(3,63) = 23.0$, $p<.001$]. A follow-up ANOVA on same responses revealed a significant main effect of condition [$F(3, 63) = 13.82$, $p<.001$]. Pairwise comparisons revealed that this interaction reflects reduced discrimination for the semantic item compared to all other conditions (all $p<.05$). ANOVA on rearranged responses revealed no significant main effect of condition [$F(3,63) = 1.92$, $p>.05$].

As can be seen from Figure 1b, slower response times were observed for semantic than association word-pairs, with semantic word-pairs encoded under item imagery eliciting the slowest response times. Repeated measures ANOVA on correct responses with factors of relationship (association, semantic), strategy (item, interactive), and response (same, rearranged, new) revealed a main effect of response [$F(2,42) = 36.96$, $p<.001$], along with interactions between relationship x response [$F(2,42) = 11.46$, $p<.001$], and relationship x strategy x response [$F(2,42) = 4.16$, $p=.02$]. As Fig 1b shows, for same responses, reaction times were faster for association than semantic pairs, and when encoding encouraged interactive rather than item imagery. By contrast, for rearranged responses, reaction times were equivalent for association and semantic pairs, but faster following interactive than item imagery. Finally, the reaction times to new responses are equivalent across word pair types, except for the slower responses to semantic word pairs in the item imagery condition.

Electrophysiological data

An example of frontal and parietal ERPs elicited by association item, association interactive, semantic item, and semantic interactive conditions is shown in Figure 2. The waveforms diverge approximately 250 ms post-stimulus onset, with the ERPs for 'same' responses becoming more positive than 'rearranged' and 'new' responses. As is clear from Figure 2, at electrode Fz the magnitude of the old/new difference is smallest for the semantic item condition during the 250-500 ms time window. The distribution of the difference between 'same' and 'new' ERPs is shown in Figure 4, illustrating that the old/new effect is maximal over frontal sites for association item, association interactive, and semantic interactive conditions. By contrast, whilst an old/new effect is present over frontal electrodes for the semantic item condition, this difference is maximal at left centro-parietal sites (see Fig. 4c). Divergence of 'same' and 'rearranged' ERPs can also be seen for all 4 conditions over frontal sites, but this effect is clearly weaker for the semantic item condition. In addition, positive activity is visible over parietal sites for 'same' responses in comparison to 'rearranged' and 'new' responses for all four conditions (see Fig. 2). This parietal activity appears to be maximal from approximately 500 to 800 ms. Consistent with previous investigations and visual inspection of the grand average waveforms, data was divided into time windows of 250-500 ms[1] and 500-800 ms relating to the bilateral frontal and left parietal effects respectively.

ERP Analyses

ANOVAs for the 250-500 and 500-800 time windows were conducted on chains of frontal and parietal electrodes (see Fig. 3). ANOVAs were designed to examine whether there were any significant differences between conditions (between relationship types and encoding strategies) during the time windows associated with the bilateral frontal and left parietal effects respectively. Initial ANOVAs were conducted with factors of response (same, rearranged, new), relationship (association, semantic), strategy (item, interactive), location (anterior, posterior), hemisphere (left, right) and site (superior, mid, inferior). The initial higher-level ANOVA is specifically intended to ask a) whether old/new effects are present, and if so, whether they b) are modulated by the manipulations of strategy and word-pair type, and c) exhibit distributions across the scalp that are appropriate given our expectation of eliciting the ERP correlates of familiarity and recollection.

Given our primary interest in the question of whether strategy effects produce different patterns of old/new effect depending on the nature of the relationship between the word pairs, significant interactions involving response, relationship and strategy were followed up by subsidiary analysis (using ANOVA or t-tests as appropriate) comparing the pattern of old/new effects found for each relationship type. These analyses compared ERPs to same pairs with, a) new pairs, providing an index of the pattern of old/new effects as typically used in ERP studies of associative recognition, and b) rearranged pairs, providing an additional insight into the pattern of ERP findings using the contrast that is typically employed in behavioural assessments of associative recognition. For completeness these analyses also compared ERPs to rearranged pairs with new pairs. Given our hypothesis, only significant main effects or interactions involving the factor of response are reported. Specific p values are reported in cases of significant differences where $p \geq .01$.

250-500 ms

ANOVA with factors of response (same, rearranged, new), relationship (association, semantic), strategy (item, interactive), location (anterior, posterior), hemisphere (left, right) and site (superior, mid, inferior) revealed a main effect of response [$F(1.4,30) = 64.81$, $p<.001$], along with interactions between response x location [$F(2,42) = 4.49$, $p=.01$], response x site [$F(2.3,47.3) = 24.8$, $p<.001$], response x relationship x strategy [$F(2,42) = 3.69$, $p=.03$], response x relationship x hemisphere

[F(2,42) = 3.06, p=.05], response x location x hemisphere [F(2,42) = 3.85, p=.03], response x location x site [F(2.2,45.9) = 3.47, p=.03], and importantly, response x relationship x strategy x location x site [F(2.2,46.9) = 3.085, p=.05]. These results demonstrate a) the presence of significant old/new effects, b) that the old/new effects are modulated by both encoding strategy and word-pair relationship type, and c) that the pattern of old/new effects varies across the scalp, consistent with a the presence of a bilateral-frontal old/new effect during this time window. As can be seen in Figure 2, the differences between conditions are largest at frontal scalp electrodes during this early time window, consistent with the presence of a bilateral-frontal old/new effect. The significant 5-way interaction was followed up with subsidiary ANOVAs conducted separately on each pair of responses at frontal and parietal locations. ANOVAs excluded the factor of hemisphere as the absence of significant response x relationship x strategy x location x hemisphere and response x relationship x strategy x location x hemisphere x site interactions in the original ANOVA revealed that response differences that interacted with location and relationship and/or strategy were bilaterally distributed.

Same vs. New

As can be seen from Figs. 2 and 4, comparison of same and new responses during the 250-500 ms time window reveals an old/new effect maximal over frontal electrode sites for the association item, association interactive, and semantic interactive condition. Whilst some positive activity can also be observed for the semantic item condition at frontal sites, the old/new difference is markedly reduced at frontal sites and actually maximal over left centro-parietal sites in this case. At the frontal location ANOVA with factors of response (same, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 68.69, p<.001], along with interactions between response x site [F(2.2,42.6) = 12.47, p<.001] and response x relationship x strategy x site [F(2,42.2) = 3.51, p=.03]. The 4-way interaction is of key interest because it reveals that the original 5-way interaction reflects a significant same/new difference at frontal sites, which gets larger towards the midline (reflecting the bi-lateral distribution of the effect), an effect that is modulated as a function of strategy and relationship type. The data that contributes to this interaction are illustrated in Figure 6, shown as difference scores (same minus new) for each relationship type and strategy (collapsed across the factor of electrode), and indicating a reduction in the size of the bilateral frontal effect for the semantic item condition. The 4 way ANOVA was followed up with an ANOVA using difference scores (same minus new), revealing a significant relationship x strategy x site interaction [F(2, 42.2) = 3.51, p=.039]. Subsidiary ANOVAs on separate sites revealed a significant relationship x strategy interaction at electrode site F2 [F(1,21) = 4.61, p=.04], although follow-up paired t-tests revealed that the difference between the semantic item and interactive condition was marginally non-significant [t(1,21) =-1.55, p=.07]. Most importantly for our hypothesis, it can be seen from Figures 4 and 6 that the interaction with the factors of relationship and strategy reflect the differential effects of item versus interactive imagery across semantic and association word pairs, with the magnitude of the bilateral frontal old/new effect reduced for the semantic condition under item imagery encoding.

At the parietal location ANOVA with factors of response (same, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 75.67, p<.001] and a response x site [F(2.1,44.5) = 7.4, p<.004] interaction, but importantly no significant interactions involving the factor of response with either relationship or strategy [F<1.4]. In short, although differences exist over parietal scalp electrodes, most likely reflecting the early onset of the left parietal old/new effect, this effect is similar regardless of relationship and encoding strategy. Taken together, the pattern of results for same and new responses suggests differential effects of encoding strategy on association and semantic relationships. Adopting a strategy of interactive imagery at encoding had no effect on response differences for association word-pairs. In contrast, unassociated semantic word-pairs elicited larger bilateral frontal old/new differences following interactive in comparison to item imagery.

Same vs. Rearranged

As can be seen from Figure 2, comparison of same and rearranged responses during the 250-500 ms time window reveals an old/new effect maximal over frontal sites for the association item, association interactive, semantic item and semantic interactive condition – again, weakest for the semantic item condition. At the frontal location ANOVA with factors of response (same, rearranged), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 59.29, p<.001], along with a response x site [F(2.2,45.4) = 9.81, p<.001] interaction, and a marginally significant interaction between response x relationship x strategy [F(1,21) = 3.68, p=.06]. The data that contributes to this interaction are illustrated in Figure 7, shown as difference scores (same minus new) for each relationship type and strategy, indicating a reduction in the size of the bilateral frontal effect for the semantic item condition. The 3 way interaction was followed up with an ANOVA on difference scores (same minus rearranged) which revealed a significant relationship x strategy interaction [F(1,21) = 4.41, p=.048]. Follow up paired t-tests (collapsed across sites) revealed that this reflected a significant difference between the semantic item and interactive condition [t(1,21) = -1.67, p=.055]. As for the same/new contrast, examination of Figures 2 and 7 shows that the bilateral frontal effect is reduced for the semantic condition under item imagery encoding.

At the parietal location ANOVA with factors of response (same, rearranged), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) =23.83, p<.001] and a response x site [F(2.2,46.2) = 4.1, p=.02] interaction, but importantly, no significant interactions involving the factor of response with either relationship or strategy. As for the same/new contrast, differences exist over parietal scalp electrodes but this effect is similar regardless of relationship and encoding strategy. Overall, the analysis comparing same and rearranged responses reveals that for semantic word pairs a larger bilateral frontal effect was evoked following interactive than item imagery. In contrast, no such difference was present for association word pairs.

Rearranged vs. New

As can be seen from Figure 2, comparison of rearranged and new responses during the 250-500 ms time window reveals a rearranged/new difference for semantic pairs encoded under item imagery, with little sign of differences elsewhere. ANOVA with factors of response (rearranged, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) at the frontal location revealed a main effect of response [F(1,21) = 7.96, p=.01] and a response x relationship x site interaction [F(1.5, 32.5) = 3.9, p=.04]. As can be seen from Figure 2 this interaction reflects a greater rearranged/new difference for semantic in comparison to association pairs.

ANOVA with factors of response (rearranged, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) at the parietal location similarly revealed a main effect of response [F(1,21) = 15.25, p<.001] and a response x relationship x site interaction [F(1.8, 37.7) = 4.19, p<.03]. As can be seen from Figure 2 this interaction reflects a greater rearranged/new difference for semantic in comparison to association pairs. Importantly, unlike for the same/rearranged and same/new contrasts, comparison of the rearranged and new responses reveals no significant effects involving the factor of strategy.

500-800 ms

As can be seen from Figure 2, all four conditions elicited response differences over parietal sites, with the ERPs for correct same responses diverging from those for rearranged and new responses during the 500-800 ms time window. An initial ANOVA was conducted to directly compare response differences as a function of relationship type and encoding strategy from 500-800 ms. ANOVA with factors of response (same, rearranged, new), relationship (association, semantic), strategy (item, interactive), location (anterior, posterior), hemisphere (left, right) and site (superior, mid, inferior) revealed a main effect of response [F(2,42) = 51.8, p<.001], and interactions between response x location [F(2,42) = 3.24, p<.05], response x site [F(1.9,39.7) = 15.49, p<.001], response x strategy x relationship [F(2,42) = 4.18, p<.03], response x relationship x hemisphere [F(2,42) = 2.93, p<.05], response x location x hemisphere [F(2,42) = 6.55, p<.003], response x location x site [F(1.9,40.5) = 3.59, p<.04], and response x relationship x strategy x location x site [F(2.7,56.6) = 5.58, p<.003]. The 5-way interaction was of key interest, suggesting a pattern of old/new effects that is larger at parietal than frontal locations, and differs both across relationship type and encoding strategy. To investigate the effects, subsidiary ANOVAs were conducted separately on each pair of responses at frontal and parietal locations.

Same vs. New

As can be seen from Figs. 2 and 5, comparison of same and new responses during the 500-800 ms time window reveals an effect maximal over centro-parietal and parietal sites that is present for the association item, association interactive, semantic item and semantic interactive conditions. Analysis of data at the parietal location employed ANOVA with factors of response (same, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior), revealing a main effect of response [F(1,21) =81.27, p<.001] and a response x site interaction [F(1.8,38.7) = 5.74, p<.008], but no response interactions involving the factors of relationship or strategy. The data contributing to this analysis are illustrated in Figure 6, shown as difference scores (same minus new), revealing a significant parietal old/new effect for all four conditions, with no difference between them.

At the frontal location ANOVA with factors of response (same, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 32.41, p<.001], but no response interactions involving the factors of relationship or strategy. Overall, the pattern of results shows that the association and semantic item and interactive conditions elicited similar parietal old/new effects.

Same vs. Rearranged

As can be seen from Figure 2, comparison of same and rearranged responses during the 500-800 ms time window reveals an effect that is maximal over centro-parietal and parietal sites for all conditions. At the parietal location ANOVA with factors of response (same, rearranged), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 139.99, p<.001], along with interactions between response x site [F(1.5,31.3) = 3.56, p=.05], and response x strategy [F(1,21) = 6.01, p=.02]. The data contributing to this analysis are illustrated in Figure 7, shown as difference scores (same minus rearranged). In contrast to the old/new differences present between same and new ERPs which were equivalent across conditions, the parietal effect that distinguishes same and rearranged ERPs is significantly larger following an encoding strategy of interactive imagery compared to item imagery. Notably, this benefit of interactive imagery did not depend on the nature of the stimuli as there was no significant interaction with relationship.

At the frontal location ANOVA with factors of response (same, rearranged), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) revealed a main effect of response [F(1,21) = 16.06, p<.001], along with interactions between response x site [F(1.5,32.2) = 4.92, p=.02], and response x relationship x strategy [F(1,21) = 6.32, p=.02]. This pattern of effects appears to reflect ongoing activity relating to the early bilateral frontal effect, which is smaller for the semantic item condition than all other conditions. In sum, same/rearranged comparisons reveal greater parietal effects for interactive than item conditions but this effect is not specific to either relationship type.

Rearranged vs. New

As can be seen from Figure 2, comparison of rearranged and new responses during the 250-500 ms time window reveals a rearranged/new difference for semantic pairs. ANOVA with factors of response (rearranged, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) at the parietal location revealed a response x site interaction [F(1.8, 37.2) = 4.88, p<.02] but no significant interactions of response with the factors of relationship and/or strategy.

ANOVA with factors of response (rearranged, new), relationship (association, semantic), strategy (item, interactive), and site (superior, mid, inferior) at the frontal location revealed a significant response x relationship x site interaction [F(2.4, 49.4) = 4.45, p<.02]. As can be seen from Figure 2 this interaction reflects greater positive going activity for semantic in comparison to association pairs. This interaction appears to reflect ongoing activity from the early time window of 250-500 ms.

Discussion

The present study investigated the question of whether or not performance on associative recognition tasks can be based in part on familiarity, despite traditionally being viewed as reliant primarily on recollection. We employed words as stimuli, comparing association word pairs and semantic word pairs, which have previously been shown to differ in how 'unitized' they are perceived to be. We then manipulated the encoding strategy adopted by participants, comparing interactive and item imagery, predicting that facilitating the perception of a unit for semantic word-pairs would differentially encourage familiarity based retrieval for these stimuli. We also predicted that no such effect would be seen for association pairs because they are already perceived as unitized, and in addition, that no differences would be found in the degree of recollection across relationship types. We used ERPs to measure the engagement of retrieval processes, with the bilateral frontal and left parietal old/new effects providing an index of familiarity and recollection respectively, and these results are summarized in Figures 6 and 7.

Our ERP findings reveal that the strategy adopted at encoding does influence the pattern of processes engaged during episodic retrieval. Most strikingly, the ERP data suggest that an encoding strategy of interactive imagery can selectively encourage familiarity based responding during associative recognition. The results reveal differential effects of the use of item and interactive imagery at encoding on subsequent episodic memory retrieval of unassociated semantic relationships. The ERP findings revealed that the bilateral frontal old/new effect, typically associated with familiarity, was larger for semantic word-pairs encoded with interactive imagery than for semantic word-pairs encoded with item imagery. Importantly, we provide evidence for increased engagement of the bilateral frontal effect following unitization from comparisons of both same/rearranged and same/new ERPs. We note however that the outcome of the same/new comparison is marginally non-significant (p=.07). In multi-condition experiments of this type it is of course difficult to achieve reliable outcomes at the level of paired t-tests. Nonetheless the overall pattern of results for the same/rearranged and same/new comparisons in relation to the increased size of the early bilateral frontal effect is consistent with our prediction that the encoding technique of interactive imagery would lead to an enhancement of familiarity based remembering for these pairs. This pattern of findings suggests that the individual elements of an event can, when encoded with a technique that encourages unitization of the pair, be sufficiently related that there is a separate unitized representation of the relationships itself. Below we address the theoretical significance of our findings, the influence of interactive imagery at encoding on the engagement of familiarity, as well as discussing our ERP findings relating to recollection.

The influence of interactive imagery on familiarity appears to be dependent on stimulus properties. The association item and association interactive conditions elicited similar bilateral frontal and parietal old/new effects to those reported in our previous paper for association word-pairs (Rhodes and Donaldson, 2007), with no significant difference in the size of the effect between the two conditions. This pattern of data suggests that the strategy of interactive imagery adopted to encourage unitization differentially influenced the semantic word-pairs. As we have previously reported (Rhodes and Donaldson, 2007) association word-pairs are already perceived as a unit and further encouragement of a unitized representation appears not to increase familiarity during retrieval. However, the behavioural evidence suggests that such a conclusion should be made with caution. As is shown in Figure 1, accurate rearranged responses were reduced when encoding encouraged interactive rather than item imagery for association word pairs. One interpretation of this finding is that encoding with interactive imagery enhanced unitization for association word-pairs, but that this in turn leads to impaired recognition of these pairs when they are presented in a rearranged format. From the opposite perspective, encoding association word-pairs with item imagery did not lead to a reduction in recognition accuracy over interactive imagery. This pattern of results could be taken as evidence that a unitized representation is difficult if not impossible to break up once established. Further investigation of conditions under which unitized representations can be broken would therefore be of interest. One route - unusual processing demands - is suggested by the findings of Yonelinas (1999), who showed that familiarity does not support associative recognition memory when faces are processed upside down.

One potential difficulty for interpreting the findings of the present study is that, whilst the analysis of the bilateral frontal old/new effect revealed significant interactions between stimulus type and encoding strategies (for both comparison of same/rearranged and same/new responses), the behavioural data was conducted on discrimination measures with data collapsed across the four conditions (i.e. across stimulus type and encoding strategy) because the use of separate factors of stimulus type and encoding strategy did not produce a significant interaction. The analysis strategy we adopted enabled us to maximize the ability to detect differences, revealing reduced accuracy for same responses for the semantic item condition in comparison to all other conditions. Nonetheless, the absence of an equivalent interaction between stimulus type and strategy in the behavioural and ERP data could be taken as being inconsistent with (even contrary to) the proposal that the benefits of interactive imagery over item imagery are greater for semantic than association word pairs. In the present case, however, the neuroimaging data likely enables the detection of underlying differences in memory that are obscured in the behavioural data. The ERP data provide separate estimates of familiarity and recollection, demonstrating no significant difference in the magnitude of recollection across conditions, along with a difference in the magnitude of familiarity across conditions. By contrast, behavioural performance reflects the summation of the contributions of familiarity and recollection, and because of the nature of the associative recognition task, recollection is the major contributor to the overall behavioural scores. It is therefore unsurprising that the differential effect on familiarity that is seen in the ERP data is not as clear in the behavioural data. The ERP data reveals differences in an underlying process that contributes to, but is not the only determinant of, performance.

Whilst the present findings replicate those of Rhodes and Donaldson (2007), this previous study only reported the ERPs elicited by correct same and new responses, whereas here we also compared same and rearranged responses. As noted above, examination of the same/rearranged ERPs adds support to our characterization of the engagement of familiarity. By contrast, the pattern of left parietal effects found in the same/rearranged contrast differs somewhat from that found for the old/new contrast; unlike for the same/new comparison, activity measured over left parietal electrodes was modulated by encoding strategy in the same/rearranged comparison (i.e. it was larger following interactive imagery). This finding is important for two reasons. First, it strongly suggests that the use of interactive imagery facilitated participants' ability to discriminate between same and rearranged pairs overall; this is consistent with behavioural differences in performance as a function of encoding strategy that are typically viewed as resulting from increases in recollection following a strategy that encourages deep processing (Yonelinas, 2002). Unlike for the bilateral frontal effect however, there was no interaction with stimulus type, consistent with our prediction that no differences would be found in the degree of recollection across relationship types. Second, the findings clearly illustrates the fact that the pattern of old/new effects revealed during associative recognition is dependent on the choice of conditions being compared; whilst a same/new contrast suggests that interactive imagery has no effect on recollection at all, this is clearly not the case when the same/rearranged contrast is examined.

The findings presented here for the bilateral frontal old/new effect is very clear, and does not depend on the choice of contrast employed. Although familiarity is traditionally associated with item recognition, the present study reinforces the idea that familiarity can be used to support retrieval during an associative recognition task, consistent with recent behavioural evidence of face recognition (Yonelinas et al., 1997), behavioural evidence from amnesic patients (Quamme et al., 2007), electrophysiological evidence for pre-existing associations between words (Rhodes and Donaldson, 2007), and for pairs of faces (Jager et al., 2006). We interpret this finding as showing that the use of interactive imagery at encoding successfully encouraged unitization of these word-pairs in memory, and this in turn leads to familiarity becoming a viable retrieval route. The present findings contribute to dual process accounts of recognition memory, suggesting that the operation of familiarity and recollection is, at least in part, dependent upon the representations underlying to-be-remembered information. Importantly, whilst previous studies that have investigated stimulus-based properties that facilitate unitization, the present findings build on this to show that unitization, and consequently the use of familiarity, can in fact be encouraged by participant led strategies.

Although we assume a dual process perspective, it is worth highlighting that this is not the only framework within which recognition memory can be considered. Global matching models (e.g., Murdock, 1997; Humphreys, Bain and Pike, 1989; Clark and Gronlund, 1996) propose that recognition memory is supported by a single process, reflecting the overall strength of an item in memory. The models differ in their exact implementation, but they typically combine all available information about an item (including related contextual information) into a measure of memory strength, and no distinction is drawn between recollection and familiarity as different bases for recognition. Thus, during associative recognition, the familiarity of the members of a pair is combined with familiarity for the pair itself, and with any contextual information that could support retrieval. From this perspective, forming a unitized representation would produce a change in memory performance by producing an increase in memory strength, in the same way that any other manipulation of memory would do. Although the global matching models can account for the effects of unitization on memory performance per se, it is hard to reconcile the models with the wider range of data that supports the dual process distinction between familiarity and recollection. In particular, it is unclear how studies examining the ERP correlates of recollection and familiarity as measures of retrieval processing can be reconciled with such a single process view.

Regardless of whether one takes a single process or dual process view, empirically, clear differences in engagement of the bilateral frontal effect were observed between the semantic item and interactive conditions. Our interpretation of this difference is that the use of interactive imagery has served to create the perception of a unit between the items to such a degree that the pairs were represented as a single coherent item in memory. Importantly, we believe that the use of interactive imagery at encoding created the perception of a unit rather than the perception of an association, and that it is the perception of a unit that leads to the use of familiarity in support of retrieval. Furthermore, previous evidence demonstrates that familiarity based responding is not encouraged by employing either word-pairs related by an association + semantic relationship (Rhodes and Donaldson, 2007) or an encoding strategy that encouraged the formation of an association (Ferlazzo et al., 1993; Weyerts et al., 1999) per se. Thus, on the basis of current data, it appears that an association between items is not sufficient to encourage the use of familiarity; the perception of a unitized representation appears to be critical.

In relation to the current findings, it is of course questionable whether participants created a unitized representation for semantic word-pairs encoded with interactive imagery for every individual word-pair, and what participants did do is highly likely to have varied across trials. It would be interesting therefore to investigate the influence of an encoding technique on retrieval processes that in one condition encourages the formation of an association and in another the perception of a unit. As noted above, our view is that the formation of an association between items would encourage recollection while the facilitation of the perception of a unit would encourage familiarity. In associative recognition memory studies participants are frequently encouraged to create a sentence that includes the two words (for the purpose of deeper encoding to boost recognition performance). The creation of a sentence that combines two words could lead to a process of placing the two items in the same context thus creating an association (e.g. while shopping the lady bought a vase and a bed) or imagining the two items as one image thus forming a unitized representation (e.g. while cleaning the lady left the vase on the bed). Direct comparison of the retrieval processes engaged following use of an encoding strategy which systematically encourages either association or unitization of items is clearly warranted.

One important question that follows from the present study is whether ‘unitization’ should simply be considered synonymous with ‘binding’. We take binding to refer to processes supported by the hippocampus (Cohen and Eichenbaum, 1995; Mecklinger et al., 2004), whereby individual elements of an episode are related to one another, such that one element can be used as a cue to retrieve the other. From this perspective binding is a mechanism that specifically supports recollection (i.e. the retrieval of associations). By contrast, familiarity does not require binding – and is not supported by the hippocampus per se. Familiarity is a product of the processing of an individually represented element of an episode, without reference to other elements. Thus, by our view, associative recognition requires recollection when one word in a pair is used as a cue to retrieve the relationship that was formed at encoding, but may be performed on the basis of familiarity if the two words have been unitized.

These findings also have implications for understanding the role of imagery in aiding memory during learning. The present findings provide electrophysiological evidence to support previous behavioural reports that the memory advantage of engaging in imagery arises from the encoding of a unitized representation rather than the use of imagery per se (Bower, 1972; McGee, 1980). The current findings, alongside those reported in Rhodes and Donaldson (2007), raise the possibility that other encoding techniques that encourage unitization will aid memory retrieval. Future research is necessary to investigate what other techniques can encourage unitization to the extent that familiarity is encouraged during retrieval. For example, would the use of repetition as an encoding strategy, or the repeated presentation of stimuli during encoding, encourage familiarity based responding?

In conclusion, we build on our previous report that a pre-existing association between words influences the pattern of processes engaged during episodic retrieval by showing a unitized relationship can also be created in memory. The findings presented here suggest that the assumption that familiarity will not contribute to performance on associative recognition tasks is questionable if there is a unitized representation between the items. Whether recollection or familiarity is engaged ultimately depends on the representation that underlies the information that is to-be-remembered.

[1] The same analyses conducted during the more traditional 300-500 ms time window produce the same outcomes.

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Figure Legends

Fig. 1: Panel a displays accuracy data showing mean percentage of correct responses for each relationship type across three responses. Panel b displays mean reaction time for each relationship type across three responses. Error bars represent the standard error of the mean.

Fig. 2: Grand average ERPs for the correct same, rearranged, and new responses for association item, association interactive, semantic item, and semantic interactive conditions, shown from –104 to +1000 ms. Two electrodes are shown, from frontal (FZ) and parietal (PZ) scalp. Vertical bar shows stimulus onset (0 ms), and the scale bar indicates that data is displayed positive up.

Fig. 3: Schematic Map of 61 electrodes sites, highlighting the sites included in analyses during 250-500 ms and 500-800 ms time windows. LF: left frontal; RF: right frontal; LP: left parietal; RP: right parietal.

Fig. 4: Topographic maps illustrating the difference between same and new ERPs during the 250-500 ms time window for (a) association pairs encoded using item imagery, (b) association pairs encoded using interactive imagery, (c) semantic pairs encoded using item imagery, and (d) semantic pairs encoded using interactive imagery. Crucially, a larger bilateral frontal old/new effect was elicited for the semantic interactive condition than the semantic item condition, and the old/new effect for the semantic item condition is maximal across centro-parietal scalp. Maps are based on subtraction of hits to same pairs from correctly rejected new pairs.

Fig. 5: Topographic maps illustrating the difference between same and new ERPs during the 500-800 ms time window for (a) association pairs encoded using item imagery, (b) association pairs encoded using interactive imagery, (c) semantic pairs encoded using item imagery, and (d) semantic pairs encoded using interactive imagery. For each condition there is a clear positive going effect over left parietal electrodes. Maps are based on subtraction of hits to same pairs from correctly rejected new pairs.

Fig. 6: The mean magnitude of the same-new old/new effect at frontal and parietal electrodes, during the 250-500 and 500-800 ms time windows respectively. The pattern of old/new effects is show for association and semantic word pairs encoded using item and interactive imagery. The bilateral frontal old/new effect is smallest for the semantic item condition, whereas the left parietal effect is equivalent in magnitude across conditions. The old/new effects are measured using the same/new contrast from 250-500 and 500-800 ms post-stimulus onset. Error bars represent the standard error of the mean.

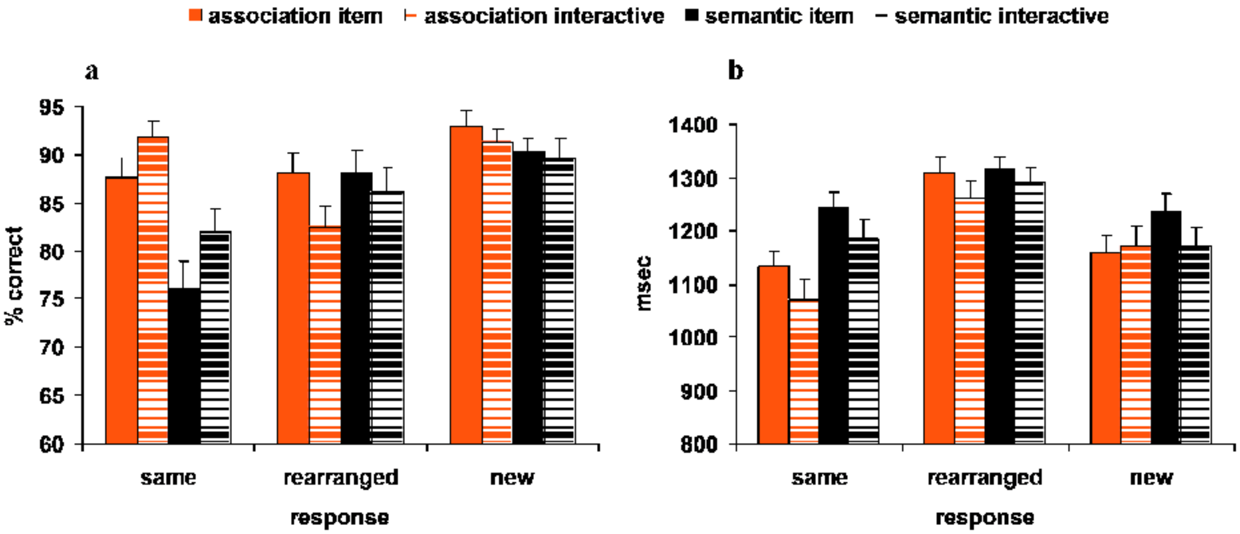
Fig. 7: The mean magnitude of the same-rearranged old/new effect at frontal and parietal electrodes, during the 250-500 and 500-800 ms time windows respectively. The pattern of old/new effects is show for association and semantic word pairs encoded using item and interactive imagery. Both the bilateral frontal and left parietal old/new effects are smallest for the semantic item condition. Error bars represent the standard error of the mean.

Table 1: Examples of word-pairs for each relationship type.

Association	**Semantic**
traffic-jam	cereal-bread
fountain-pen	violin-guitar
mars-bar	cow-goat
spark-plug	prince-duke
glow-worm	pig-chicken
grave-digger	fork-plate
dolly-bird	broom-floor

Table 2: Mean (and standard error) word frequency, semantic distance, and association strength shown separately for each relationship type. Both association strength and semantic distance can range from .0 to 1.0.

	Association	**Semantic**
Frequency Word 1	32.93 (2.53)	31.32 (3.26)
Frequency Word 2	56.82 (4.99)	56.06 (6.95)
Semantic Distance	.175 (.005)	.509 (.006)
Association Strength	.20 (.01)	0 (0)


association item
association interactive
semantic item
semantic interactive
a
95
90
85
80
75
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65
60
% correct
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900
800
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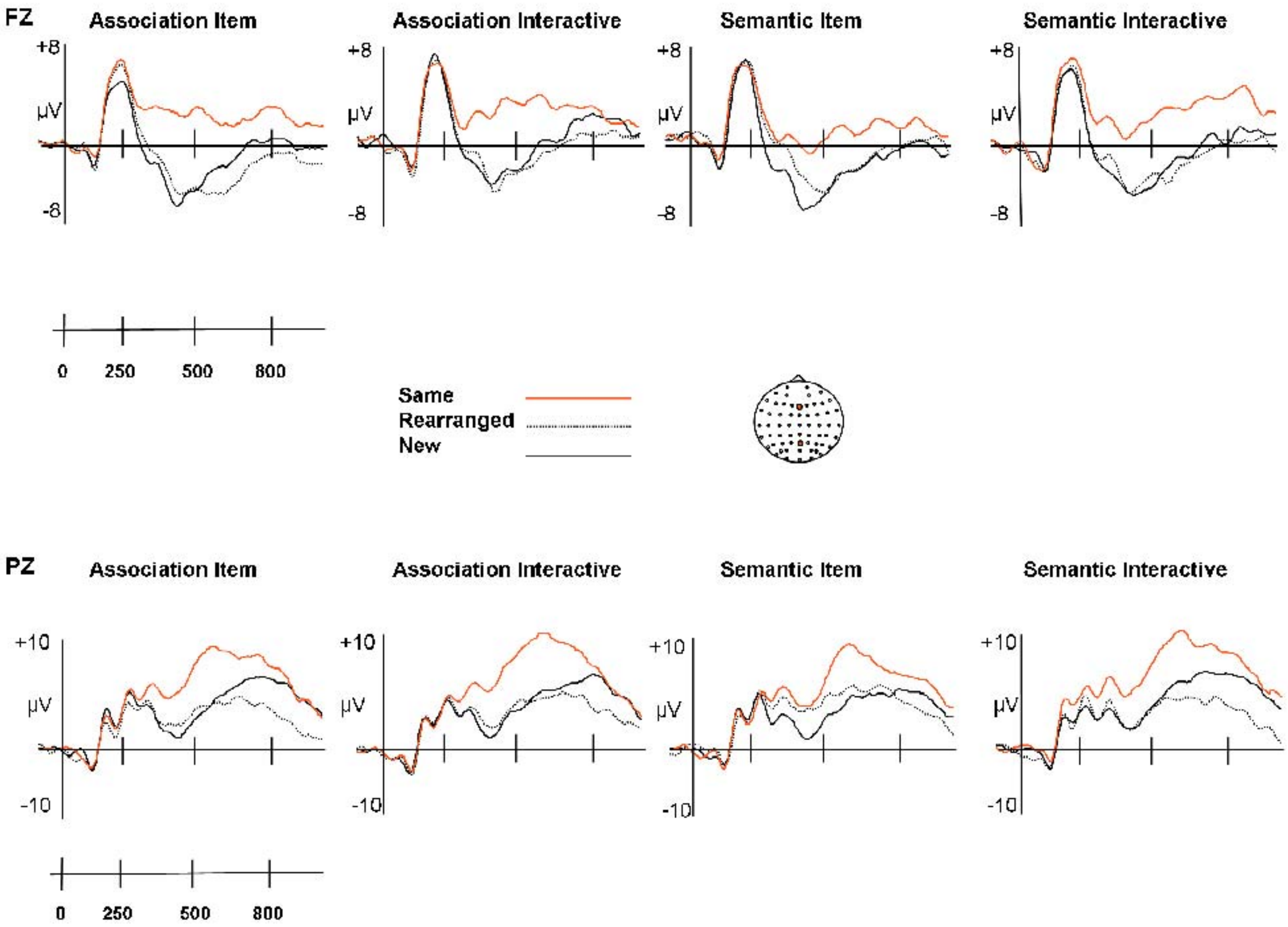
rearranged
new
response


FZ
Association Item
Association Interactive
Semantic Item
Semantic Interactive
+8
µV
-8
0
250
500
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Same
Rearranged
New
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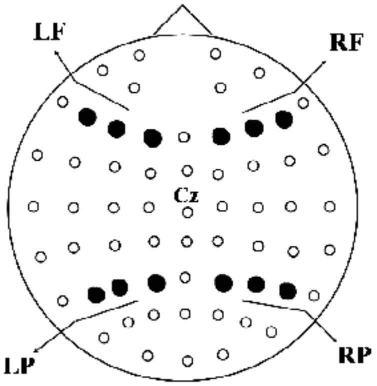
Association Interactive
Semantic Item
Semantic Interactive
+10
µV
-10
0
250
500
800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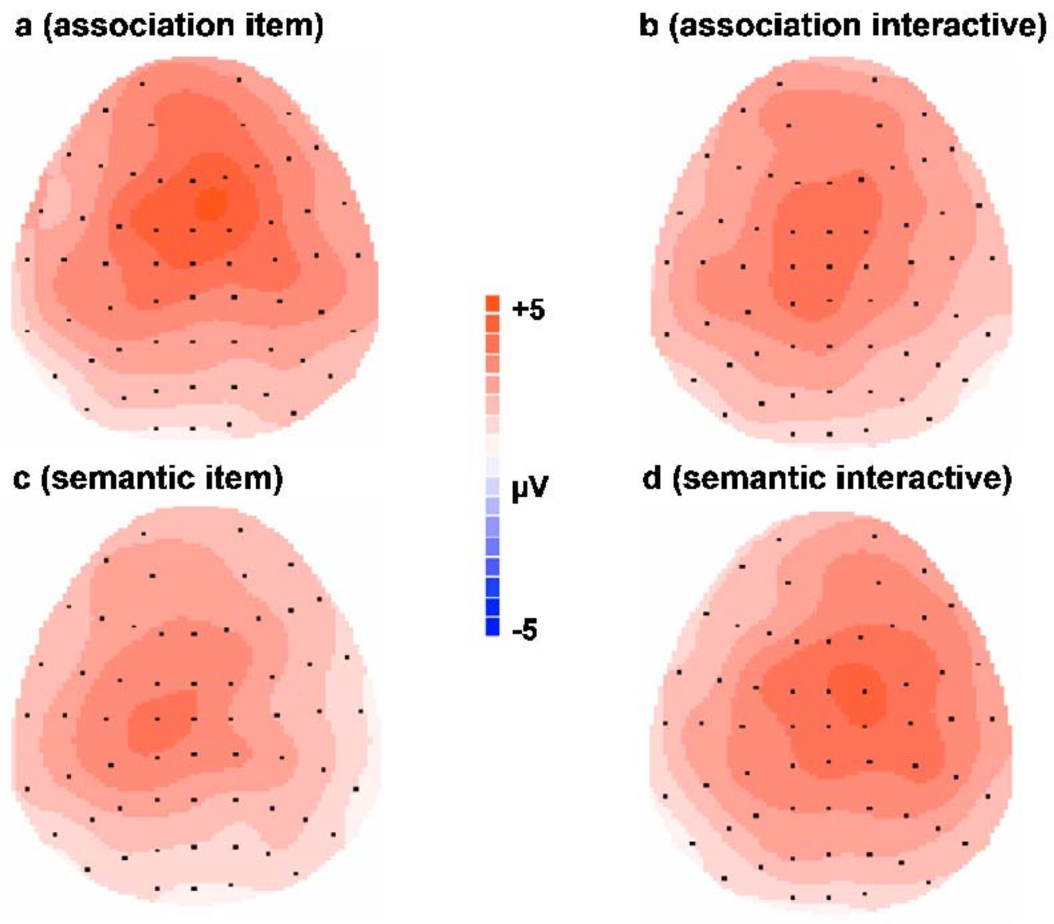
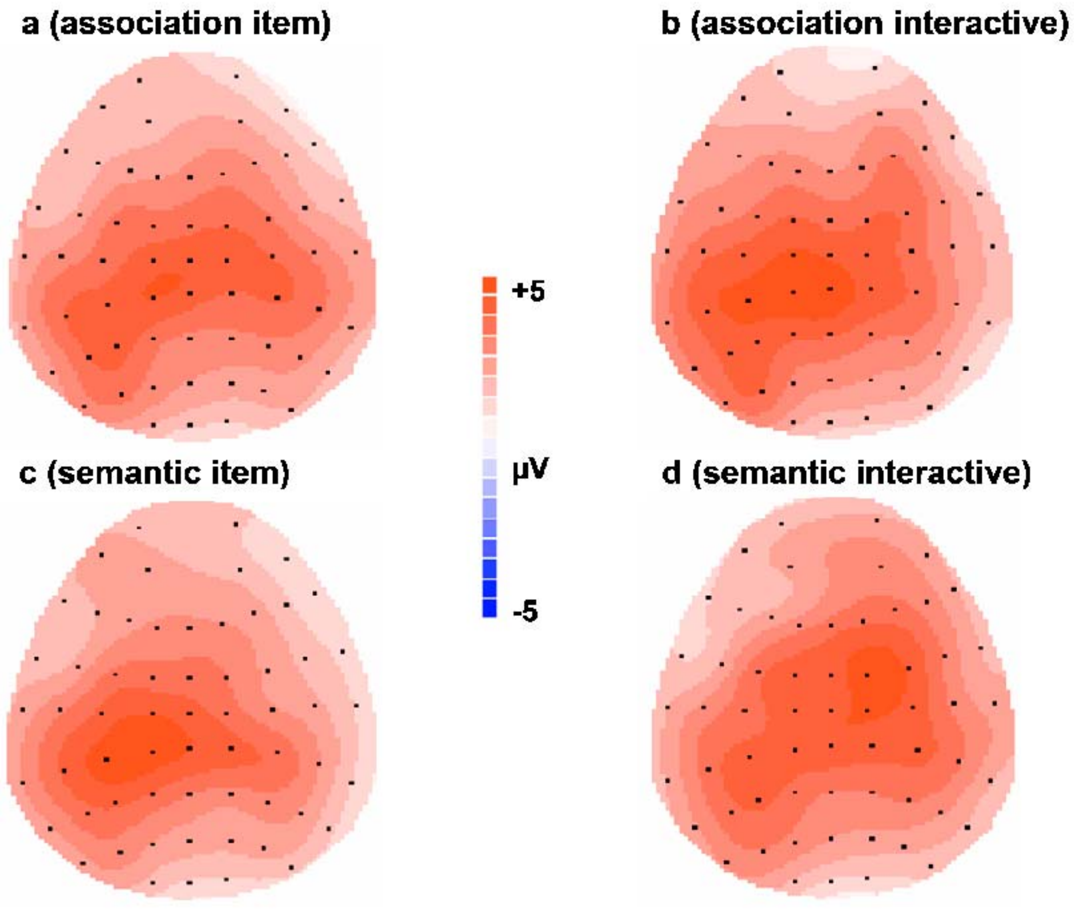
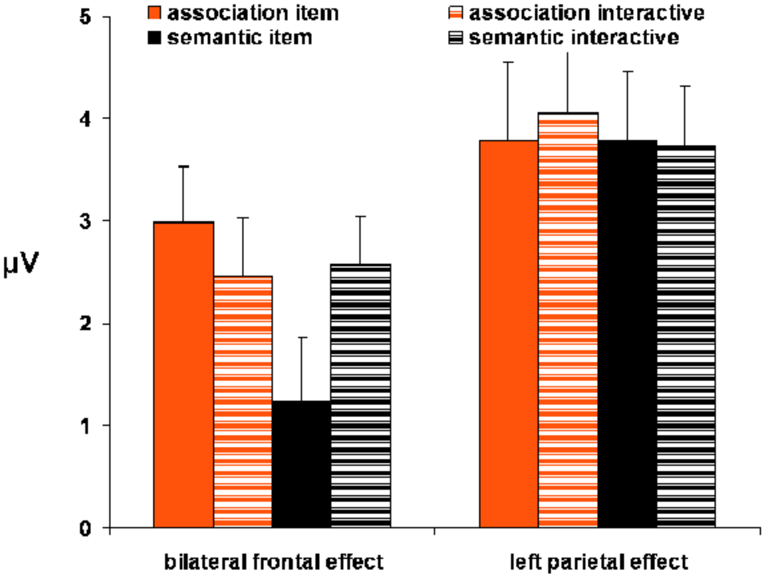
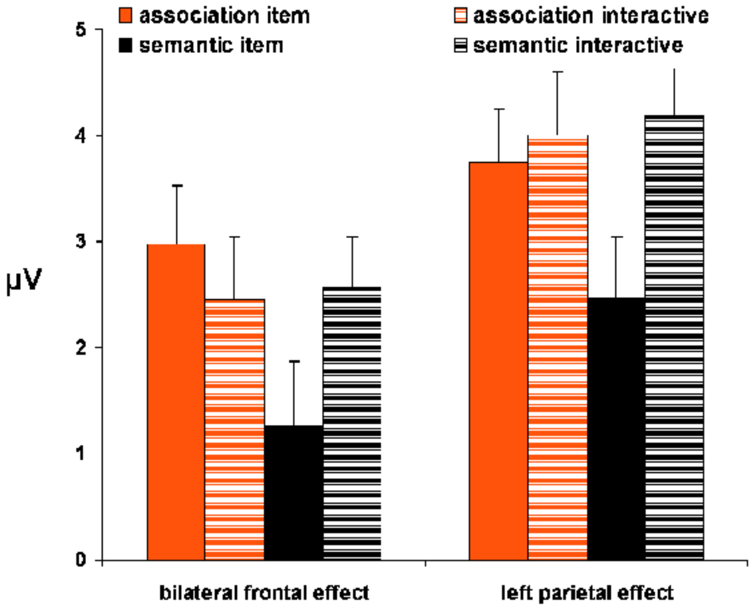

a (association item)
b (association interactive)
+5
μV
-5
c (semantic item)
d (semantic interactive)


a (association item)
b (association interactive)
+5
µV
-5
c (semantic item)
d (semantic interactive)


association item
semantic item
association interactive
semantic interactive
µV
0
1
2
3
4
5
bilateral frontal effect
left parietal effect


association item
association interactive
semantic item
semantic interactive
μV
5
4
3
2
1
0
bilateral frontal effect
left parietal effect