Published in final edited form as:

Int J Psychophysiol. 2015 March ; 95(3): 355–362. doi:10.1016/j.ijpsycho.2015.01.003.

The effects of unitization on the contribution of familiarity and recollection processes to associative recognition memory: Evidence from event-related potentials

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Abstract

Familiarity and recollection are two independent cognitive processes involved in recognition memory. It is traditionally believed that both familiarity and recollection can support item recognition, whereas only recollection can support associative recognition. Here, using a standard associative recognition task, we examined whether associative retrieval of unitized associations involved differential patterns of familiarity and recollection processes relative to non-unitized associations. The extent of engagement of familiarity and recollection processes during associative retrieval was estimated by using event-related potentials (ERPs). Twenty participants studied compound words and unrelated word pairs during encoding. Subsequently, they were asked to decide whether a presented word pair was intact, rearranged, or a new pair while electroencephalogram (EEG) was recorded. ERP results showed that compound words evoked a significant early frontal old/new effect (associated with familiarity) between ERPs to intact and rearranged word pairs, whereas this effect disappeared for the unrelated word pairs. In addition, the left parietal old/new effect (associated with recollection) between ERPs to intact and rearranged word pairs was greater for compounds than for unrelated word pairs. These findings suggest that unitization could enhance the contribution of both familiarity and recollection processes to associative recognition.

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Keywords

Unitization; Associative recognition; Familiarity; Recollection; Event-related potentials

1. Introduction

Recognition memory refers to the ability to identify previously experienced events. Dual-process theories propose that recognition memory is supported by familiarity and recollection (Mandler, 1980; Yonelinas, 2002). Familiarity is a fast-acting process that occurs without retrieval of the details of an event or stimulus. Recollection refers to a slower process which requires conscious retrieval of the details about an event or stimulus. Event-related potential (ERP) studies have provided support for the dual-process theory by identifying distinct ERP old/new effects that are independently associated with the effects of familiarity or recollection. Specifically, the early mid-frontal old/new effect from 300 to 500 ms has been thought to reflect familiarity-based recognition (Curran, 2000; Curran and Cleary, 2003; Rugg and Curran, 2007) while a later left parietal old/new effect from 500 to 800 ms is linked to recollection-based recognition (Rugg and Curran, 2007).

Associative recognition tasks and item recognition tasks are traditionally believed to be supported by different retrieval processes. Whereas both familiarity and recollection can support item recognition, only recollection can support associative recognition (Yonelinas, 2002). In a typical associative recognition task, the participants study unrelated word pairs during an initial study phase (e.g., umbrella-bread, map-rose, tiger-sand), and make a distinction between the intact pairs (e.g., umbrella-bread) and the rearranged pairs (e.g., map-sand) during a subsequent test phase. Using remember/know (R/K) procedure (Tulving, 1985), Hockley and Consoli (1999) found that associative recognition was associated with more “R” judgments (index of recollection), whereas item recognition was associated with more “K” judgments (index of familiarity). Receiver operating curves (ROCs) were curvilinear for item recognition, but were linear for associative recognition, suggesting that both familiarity and recollection contribute to item recognition, whereas only recollection contributes to associative recognition (Yonelinas, 1997). In ERP studies, Donaldson and Rugg (1998, 1999) found that associative recognition of word pairs evoked a parietal old/new effect associated with recollection.

Though these studies supported the proposal that associative recognition memory solely depended on recollection, recent studies have demonstrated that familiarity could also contribute to associative recognition when the to-be-remembered stimuli were perceived as a “unitized” representation (Mecklinger and Jäger, 2009; Yonelinas, 2002). This is referred to as the “unitization hypothesis” (Quamme, 2004). “Unitization” means the condition where two or more items are integrated into a single unit (Graf and Schacter, 1989).

Several ERP studies supported this hypothesis by revealing significant familiarity-related early frontal old/new effect only for unitized associations. For example, Jäger et al. (2006) asked participants to perform a forced-choice recognition task of face pairs, during which participants initially made an old/new judgment for the initially-presented face; if they made a correct “old” judgment, a follow-up forced-choice decision was required for the second

face. The results showed that the familiarity-related frontal old/new effect was only evoked in the unitized condition (i.e., both faces were from the same person); in contrast, the recollection-related parietal old/new effect was only significant in the non-unitized condition (i.e., the faces were from different persons), suggesting that familiarity is sufficient to support associative recognition when the to-be-remembered information can be unitized, but that only recollection could support non-unitized associative recognition.

Rhodes and Donaldson (2007) examined associative recognition using word pairs which included two types, namely associated word pairs (e.g., traffic-jam), and semantically related word pairs (e.g. violin-guitar). During the test phase, participants needed to discriminate between the intact, rearranged, and new word pairs. The results showed that only the associated word pairs, which were rated as more easily unitized into a single unit, evoked a significant bilateral frontal old/new effect, whereas the left parietal old/new effect was evoked equally by both word pairs. Further work from this group (Rhodes and Donaldson, 2008) found that the semantically-related word pairs could evoke a greater frontal old/new effect when encoded with a strategy encouraging unitization (i.e., interactive imagery) compared with the non-unitized strategy (i.e., item imagery); however, the strategy did not influence the recollection-related left parietal old/new effects.

Even arbitrary word pairs, when encoded with a unitized strategy, can engage familiarity in subsequent associative retrieval. Bader et al. (2010) asked participants to encode semantically unrelated word pairs either along with a definition combining the word pair into a new concept (unitized definition condition) or together with a sentence frame separating the word pair as disconnected components (non-unitized sentence condition). The results showed that the early old/new effect was only significant in the unitized condition, suggesting that familiarity could contribute to the associative recognition when the word pairs are unitized. Consistent with Jäger et al. (2006), the parietal old/new effect was only significant in the non-unitized condition.

These ERP studies consistently found a familiarity-related frontal old/new effect evoked by the unitized condition. However, it should be noted that all these ERP studies quantified the ERP old/new effects by comparing intact with new pairs. Whereas the associative recognition task should refer to the discrimination of intact from rearranged pairs, rather than that of intact from new pairs (Hockley, 1992; Speer and Curran, 2007). Thus, the old/new effects between ERPs to intact and new pairs may be confounded by item memory, and the observed frontal old/new effect evoked by unitized condition might not be related to associative memory, rather to item memory. Therefore, it is necessary to examine whether familiarity indeed can support associative recognition after unitized encoding, by comparing the ERPs evoked by intact with those evoked by rearranged pairs.

Reports of the left parietal old/new effect under the unitized condition have also shown some variability. On one hand, the recollection-related parietal old/new effect was equivalent for both unitized and non-unitized conditions (Rhodes and Donaldson, 2007, 2008), suggesting that recollection can support associative recognition of both conditions. On the other hand, this old/new effect was only observed for the non-unitized condition (Bader et al., 2010; Jäger et al., 2006), which was interpreted as evidence that the recollection process was not

necessary when the associations were unitized during encoding. The exact reason for the different patterns of the parietal old/new effect, however, remains unclear. Also, similar to the previous case, as these studies only analyzed the old/new differences between intact pairs and new pairs, these results could still be confounded by item recognition.

In the present study, we aimed to further examine the effects of unitization on the extent to which familiarity and recollection contribute to associative recognition. Based on previous studies (Giovanello et al., 2006; Rhodes and Donaldson, 2007), compound words were used in the unitized condition, and semantically unrelated word pairs were manipulated in the non-unitized condition. In a standard associative recognition task, we measured two types of old/new effects (i.e., both the intact vs. rearranged old/new effects and the intact vs. new old/new effects) to quantify the contributions of familiarity and recollection to associative retrieval. If familiarity can support associative recognition of unitized word pairs, the frontal old/new effect between ERPs to intact and rearranged pairs evoked by compounds should be greater than those of unrelated word pairs. It is traditionally thought that recollection contributes to discrimination of intact from rearranged pairs, so we expected that the parietal old/new effects between ERPs to intact and rearranged pairs would be similar for compounds and unrelated word pairs. We also performed analyses of old/new effects between ERPs to intact and new pairs for both compounds and unrelated word pairs, which may help to elucidate conflicting reports in the literature as previously described.

2. Methods

2.1. Participants

Twenty right-handed healthy university students (mean age 22 years, education levels 15.9 years) participated in the study. All participants were native Chinese speakers with normal or corrected-to-normal vision and were free from neurological and psychiatric disorders. Each participant signed informed consent documentation and was paid for participation. The study was approved by the Ethics Committee of the Institute of Psychology, Chinese Academy of Sciences.

2.2. Materials

The stimuli consisted of 144 compound words and 144 unrelated word pairs, the components of which were two-character Chinese nouns with low-to-high word frequency (range 1-472 occurrences per million) selected from the Dictionary of Modern Chinese words in Common Use (Liu, 1990). The mean word frequency for compounds and unrelated pairs was matched (58.6 and 61.5 per million, respectively).

Based on the protocol of previous studies (Kriukova et al., 2013; Rhodes and Donaldson, 2007), the degree to which word pairs could be unitized was assessed. Ten young adults (6 male, mean age 22.6 years, mean education 15.8 years) were asked to judge how well the two words could be bound into a single new concept using a scale from 1 (lowest ratings) - 7 (highest ratings); none of these raters subsequently participated in the formal ERP experiment. Pairwise contrasts revealed that compounds (6.52 ± 0.28) were rated more unitized than unrelated word pairs (1.62 ± 0.54 , $p < .001$).

Each of the 144 compounds was assigned an unrelated word pair as its complementary “partner” item. A compound and its complementary partner could be rearranged to form another compound and another unrelated word pair. For example, compound word A-B (e.g., ‘希腊-神话’ meaning ‘Greek-mythology’) and unrelated word pair C-D (e.g., ‘池塘-字母’ meaning ‘pool-letter’) could be rearranged to compound A-D (e.g., ‘希腊-字母’ meaning ‘Greek-letter’) and unrelated word pair C-B (e.g., ‘池塘-神话’ meaning ‘pool-mythology’). For this transformation, the position of each word component was kept unchanged. These newly formed pairs were designated to be rearranged pairs that would appear during the test phase.

The experiment was divided into 16 blocks, each including a study phase, a distracter task, and a test phase. Each study list comprised 14 word pairs including 2 untested buffers separately presented at the beginning and end of the list and 12 target pairs, in which 6 pairs (including 3 compounds and 3 unrelated pairs) appeared as intact pairs and 6 complementary pairs (also including 3 compounds and 3 unrelated pairs) formed rearranged pairs. Each test list comprised 20 word pairs including 2 fillers at the foremost and 18 target pairs, in which 6 pairs were presented in the same pairings as in the study phase (intact pairs), 6 pairs consisted of words not presented together in the study phase (rearranged pairs) and 6 pairs were not previously presented (new pairs). These pairs were pseudo-randomly presented, and the same type of pairs was not presented more than three times consecutively. The word pairs were rotated to ensure that every word pair was presented equally often as intact, rearranged, or new. The orders of study-test blocks were counterbalanced across participants. In total, there were 192 trials during the study phase (96 compounds and 96 unrelated word pairs) and 288 trials (48 intact, 48 rearranged, and 48 new pairs for compounds and unrelated word pairs, respectively) during testing. Participants first completed a practice session including 12 word pairs during the study phase and 18 items during testing to familiarize with the procedure prior to formal experimentation. None of the practice stimuli appeared subsequently.

2.3. Procedures

The experiment was designed using E-Prime (Psychology Software Tools). All word pairs were displayed in white font against a black background and were presented one above the other slightly above and below central vision on a LCD computer monitor at a viewing distance of approximately 100 cm with the stimuli subtended at a visual angle of $2.3^{\circ} \times 2.6^{\circ}$.

Figure 1 illustrates the procedures of study and test phases. During the study phase, each trial began with display of a fixation cross (+) in the center of the screen for 800 ms. The word pair was then presented for 5000 ms followed by a 500-800 ms blank screen. Participants were instructed to remember the words as an association for a subsequent test. There was a distracter task between study phase and test phase during which participants needed to count backward by threes for 60 seconds. During testing, each trial began with a fixation cross presented for 800 ms followed by a word pair with a maximum presentation time of 4000 ms. Participants were instructed to indicate whether the word pair was intact, rearranged, or new by pressing keys of a keyboard. Once they made a response, a blank screen was presented for 1500-1800 ms and the next trial began.

Participants were asked to respond as quickly and accurately as possible and the key-response mappings were counterbalanced between subjects (i.e., half of participants made responses of 'old' and 'rearranged' by pressing the key 'F' and 'D' under the index and middle fingers of left hand, and of 'new' by pressing the key 'J' under the index fingers of right hand, and the other half of participants responded 'old' and 'rearranged' by pressing the key 'J' and 'K' under the index and middle fingers of right hand, and 'new' by pressing the key 'F' under the index fingers of left hand). To minimize EEG artifacts, they were also instructed to maintain fixation, to relax, and to avoid making head motions and eye-movements other than blinks.

2.4. EEG recording

Electroencephalogram (EEG) was recorded from 62 Ag/AgCl electrodes embedded in an elastic cap based on an extended version of the international 10–20 system using Neuroscan 4.3 system (<http://www.neuroscan.com>). Vertical and horizontal electrooculogram (EOG) was recorded with electrodes placed above and below the left eye and on the outer canthi of both eyes. All scalp electrodes were referenced online to the left mastoid and re-referenced offline to the average of the left and the right mastoids. Data were digitized at a rate of 500 Hz and filtered with a band-pass of 0.05–100 Hz. Electrode impedance was kept below 5 k Ω .

Ocular artifacts with eye blinks were removed with the ocular artifact reduction procedure in Scan 4.3 software. EEG signals were digitally offline filtered with a bandpass of 0.05–40 Hz (24 dB/oct, zero phase shift). EEG data from the test phase were separated into 1700 ms epochs, including 200 ms prior to stimulus onset for baseline correction. Incorrect-response trials or trials with artifacts larger than $\pm 75 \mu\text{V}$ were rejected from ERP averages. A minimum of 16 artifact-free trials in each 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: compounds: intact (37), rearranged (34) and new (37); unrelated word pairs: intact (37), rearranged (36) and new (38).

2.5. ERP analyses

Based on visual inspection of the grand average waveforms and previous studies (Jäger et al., 2006; Rhodes and Donaldson, 2007, 2008), the ERP of old/new effects were quantified by calculating the mean amplitudes over two consecutive time windows of 250–400 ms, 400–700 ms. These time windows were chosen to characterize the early bilateral frontal old/new effect and the left parietal old/new effect, respectively. The repeated-measures analyses of variance (ANOVAs) of these old/new effects were performed over four scalp regions: left frontal (F1, F3, F5), right frontal (F2, F4, F6), left parietal (P1, P3, P5) and right parietal (P2, P4, P6). The electrodes sites used for the analyses were illustrated in Figure 2.

As noted in the introduction, two types of old/new effects were explored: one is analyzed by comparing ERPs to intact with rearranged pairs; another is analyzed by comparing ERPs to intact with new pairs. For each time window, the mean amplitude of ERP waveforms was subjected to ANOVA with the factors of response (intact vs. rearranged or intact vs. new), location (frontal vs. parietal), hemisphere (left vs. right) and site (superior vs. mid vs. inferior) for compounds and unrelated word pairs separately in order to quantify the old/new

effects for each condition. Significant interactions involving the factor of response were followed up with subsidiary ANOVAs. In addition, ANOVAs were conducted on difference waveforms (intact minus rearranged or intact minus new) employing the factors of condition (compounds vs. unrelated), location (frontal vs. parietal), hemisphere (left vs. right) and site (superior vs. mid vs. inferior) in order to compare the magnitude of the old/new effects across conditions. Topographic analyses were conducted on the difference waveforms rescaled by the vector length method (McCarthy and Wood, 1985; Wilding, 2006). Topographical maps depicting old/new effects were formed by subtracting ERPs of rearranged or new pairs from ERPs of intact pairs.

Greenhouse-Geisser correction for non-sphericity of data was applied as necessary. The uncorrected degrees of freedom, corrected p -values, and effect size are reported. For all analyses, the significance level was set to .05.

3. Results

3.1. Behavioral results

The accuracy and response times were separately subjected to repeated-measures ANOVA with the factors of response (intact, rearranged, and new) and condition (compounds, unrelated word pairs).

3.1.1. Accuracy data—Mean accuracy for each condition as a function of three response categories are presented in Figure 3A. The ANOVA revealed a main effect of condition [$F(1,19) = 6.64, p = .018, \eta^2_p = .26$], a main effect of response [$F(2,38) = 19.19, p < .001, \eta^2_p = .50$], and a two-way condition $\times$ response interaction [$F(2,38) = 6.48, p = .009, \eta^2_p = .25$]. As the Figure 3A shows, follow-up analyses revealed that the intact pairs were better recognized for compounds than for unrelated word pairs [$F(1,19) = 5.15, p = .035$]. By contrast, rearranged and new pairs were more difficult to reject for compounds than for unrelated word pairs [$F(1,19) = 7.61, p = .013$ and $F(1,19) = 4.80, p = .041$, respectively].

3.1.2. Response times—Concerning response times (see Figure 3B), the ANOVA revealed a main effect of condition [$F(1,19) = 8.73, p = .008, \eta^2_p = .32$], a main effect of response [$F(2,38) = 86.75, p < .001, \eta^2_p = .82$], and a two-way condition $\times$ response interaction [$F(2,38) = 23.90, p < .001, \eta^2_p = .56$]. As the Figure 3B shows, follow-up analyses revealed that the intact pairs were responded to more quickly for compounds than for unrelated word pairs [$F(1,19) = 38.71, p < .001$]; in contrast, the response times of rearranged pairs were slower for compounds than for unrelated word pairs [$F(1,19) = 16.99, p < .001$]. There were no significant differences across conditions for new pairs.

3.2. ERP results

The grand average ERPs evoked by correct responses to intact, rearranged, and new word pairs for compounds and unrelated word pairs are shown in Figures 4 and 5, respectively. The “intact” and “rearranged” ERPs waveforms diverge beginning about 250 ms post-stimuli onset for the compounds with more positive-going waveforms for intact pairs compared to rearranged pairs. As is illustrated by the distribution maps shown in Figure 6B,

this early old/new effect evoked by compounds is maximal at bilateral frontal regions during the 250-400 ms time window. However, the early bilateral frontal old/new effects are not apparent for unrelated pairs. The more positive-going waveforms for intact pairs extend from anterior to posterior sites compared with rearranged pairs during 400-700 ms time window for both conditions, but the parietal positivity is greater for compounds than for unrelated word pairs (see Figure 7B). As seen from the distribution maps, both conditions evoked bilateral frontal and left parietal old/new differences between “intact” and “new” ERPs waveforms. These two old/new effects are equivalent for compounds and unrelated word pairs.

3.2.1. 250-400 ms

Intact vs. rearranged: As can be seen in Figures 4 and 5, comparison of intact and rearranged responses during this time window revealed that only the compounds evoked significant frontal old/new effects. ANOVA of compounds revealed a response $\times$ site interaction [$F(2,38) = 3.94, p = .04, \eta^2_p = .17$]. Follow-up analyses revealed significant old/new differences at all three sites, with more positive waveforms for intact pairs than for rearranged pairs ($p < .001$). There was a trend that the magnitude of old/new effects tended to be larger at frontal region (an average of data from F1/3/5/2/4/6) than that at parietal region (an average of data from P1/3/5/2/4/6; 1.65 μV vs. 0.88 μV), although the interaction of response $\times$ location did not reach significance ($F(1,19) = 2.81, p = .11, \eta^2_p = .13$). ANOVAs of unrelated word pairs revealed no significant main effect of response or interactions involving response ($p > .05$), revealing no old/new differences at any scalp regions.

Between-condition contrasts in the magnitude of difference waveforms (intact minus rearranged) revealed a main effect of condition [$F(1,19) = 5.23, p = .034, \eta^2_p = .22$], revealing a greater old/new effect for compounds than for unrelated word pairs. The mean amplitude of bilateral frontal old/new effect (intact minus rearranged; collapsed over F1/3/5/2/4/6) for compounds and unrelated word pairs is shown in Figure 6A. The topographic maps of the ERPs old/new effects during this time window for compounds and unrelated word pairs are illustrated in Figure 6B.

Intact vs. new: As can be seen in Figures 4 and 5, comparison of intact and new responses during this time window revealed that compounds and unrelated word pairs evoked equivalent frontal old/new effects. ANOVAs of compounds revealed a response $\times$ location $\times$ site interaction [$F(2,38) = 4.48, p = .021, \eta^2_p = .19$]. Following the interaction, follow-up analyses of both frontal and parietal locations revealed significant old/new effects at all sites ($p < .001$). ANOVAs of unrelated word pairs only revealed a main effect of response [$F(1,19) = 41.02, p < .001, \eta^2_p = .68$], revealing widely distributed old/new differences.

Between-condition contrasts in the magnitude of difference waveforms (intact minus new) revealed no significant main effect of condition or interactions involving condition, revealing that early old/new effects did not differ in magnitude for compounds and unrelated word pairs at any locations. The mean amplitude of bilateral frontal old/new effect (intact minus new; collapsed over F1/3/5/2/4/6) for compounds and unrelated word pairs is shown in

Figure 6A. The topographic maps of the ERPs old/new effects during this time window for compounds and unrelated word pairs are illustrated in Figure 6B.

3.2.2. 400-700 ms

Intact vs. rearranged: As can be seen in Figures 4 and 5, comparison of intact and rearranged responses during this time window revealed that compounds evoked greater left parietal old/new effects compared with unrelated word pairs. ANOVAs of compounds revealed a main effect of response [$F(2,38) = 27.84, p < .001, \eta^2_p = .59$] and a response $\times$ site interaction [$F(2,38) = 8.25, p = .003, \eta^2_p = .30$]. Follow-up analyses revealed significant old/new differences at all three sites, with more positive waveforms for intact pairs than for rearranged pairs ($ps < .001$). No significant interactions involving the factors of location indicated widely distributed old/new effects at both parietal and frontal locations. ANOVAs of unrelated word pairs revealed a response $\times$ location interaction [$F(1,19) = 4.61, p = .045, \eta^2_p = .20$]. Follow-up analyses revealed significant old/new differences at both parietal and frontal locations [$ps < .05$].

Between-condition contrasts in the magnitude of difference waveforms (intact minus rearranged) revealed a main effect of condition [$F(1,19) = 7.36, p = .014, \eta^2_p = .28$], and a marginally significant condition $\times$ hemisphere interaction [$F(1,19) = 4.02, p = .06, \eta^2_p = .17$]. Follow-up analyses revealed greater old/new effect for compounds than for unrelated word pairs at left hemisphere [$F(1,19) = 4.61, p = .045$] and right hemisphere [$F(1,19) = 9.18, p = .007$]. The mean amplitude of left parietal old/new effect (intact minus rearranged; collapsed over P1/3/5) for compounds and unrelated word pairs is shown in Figure 7A. The topographic maps of the ERPs old/new effects during this time window for the compounds and unrelated word pairs are illustrated in Figure 7B.

Intact vs. new: As can be seen in Figures 4 and 5, comparison of intact and new responses during this time window revealed that both conditions evoked equivalent left parietal old/new effects. ANOVAs of compounds only revealed a significant main effect of response [$F(1,19) = 33.15, p < .001, \eta^2_p = .63$], revealing more positive waveforms for intact pairs than for new pairs at widely distributed scalp regions. ANOVAs of unrelated word pairs revealed a response $\times$ location $\times$ hemisphere interaction [$F(1,19) = 12.07, p = .003, \eta^2_p = .39$]. Subsidiary ANOVAs revealed widely distributed old/new differences ($ps < .001$).

Between-condition contrasts in the magnitude of difference waveforms (intact minus new) revealed no significant main effect of condition or interactions involving condition, revealing that old/new effects did not differ in magnitude for compounds and unrelated word pairs at any locations. The mean amplitude of left parietal old/new effect (intact minus new; collapsed over P1/3/5) for compounds and unrelated word pairs are shown in Figure 7A. The topographic maps of the ERPs old/new effects during this time window for compounds and unrelated word pairs are illustrated in Figure 7B.

3.2.3. Topographic analyses—Topographic analyses were conducted on the rescaled difference waveforms to examine topographic differences of both types of old/new effects during the 250-400 ms and 400-700 ms time windows. The topographic maps of the old/new

ERP effects during these time windows for compounds and unrelated word pairs are illustrated in Figures 6B and 7B.

For each word pair condition, ANOVAs were performed with the factors of time window (250-400 vs. 400-700 ms), location (frontal vs. parietal), hemisphere (left vs. right), and site (superior vs. mid vs. inferior) to examine the topographic differences between early frontal and left parietal old/new effects. For the intact vs. rearranged old/new effect, there were significant time window $\times$ location $\times$ hemisphere [$F(1,19) = 5.65, p = .028, \eta^2_p = .23$] and time window $\times$ location $\times$ site [$F(2,38) = 7.55, p = .004, \eta^2_p = .28$] interactions for compounds, and a significant time window $\times$ location $\times$ hemisphere interaction [$F(1,19) = 7.42, p = .013, \eta^2_p = .28$] for unrelated word pairs. For the intact vs. new old/new effect, there was a significant time window $\times$ location $\times$ hemisphere interaction [$F(1,19) = 23.24, p < .001, \eta^2_p = .55$] for compounds, and a significant time window $\times$ location $\times$ hemisphere interaction [$F(1,19) = 13.64, p = .002, \eta^2_p = .42$] for unrelated word pairs. These results reveal different topographic distribution between early and late old/new effects for both conditions, with the early old/new effects were more anteriorly distributed, but the late old/new effects were more widespread, without a focused distribution.

4. Discussion

The present study was designed to examine whether unitized compound words and non-unitized unrelated word pairs involved differential patterns of familiarity and recollection during associative recognition. The old/new effects were quantified by comparing intact with rearranged pairs, compared with old/new effects quantified by comparing intact with new pairs as commonly used in previous studies. For the old/new effects between ERPs to intact and rearranged pairs, the compounds evoked a significant early frontal old/new effect, whereas this effect was absent for unrelated word pairs. In addition, the left parietal old/new effect was greater for compounds than for unrelated words. Whereas the early frontal and late parietal old/new effects between ERPs to intact and new pairs were equivalent for both compound and unrelated pairs. The findings that the two analyzing approaches produced different results suggest that it is needed to adopt intact vs. rearranged old/new difference analysis to examine associative memory.

4.1. The early frontal old/new effect

The associative recognition task mainly examines the ability to discriminate intact from rearranged pairs, not intact from new pairs. Thus, it is reasonable to examine the old/new ERP differences between intact and rearranged pairs in ERPs studies of associative recognition. Intriguingly, in the present study, we found that the frontal old/new effect between ERPs to intact and rearranged pairs was significant for compounds, but not significant for unrelated word pairs, suggesting that familiarity can support associative retrieval of unitized associations. The present findings are consistent with the results of previous behavioral associative recognition study. Giovanello et al. (2006) confirmed that compounds could induce more familiarity-based judgments compared with unrelated word pairs with the R/K paradigm when participants need to distinguish between intact and rearranged pairs. In addition, our findings were also consistent with previous ROC analyses

and ERP studies of unitization effects on source memory (Diana et al., 2011; Diana et al., 2008, 2010), which found that familiarity can support source retrieval when the item (e.g., a word) and source information (e.g., background color) were encoded with unitized strategies during the study phase. In sum, in accordance with the unitization hypothesis, we extend previous findings and provide new ERP evidence that familiarity is involved in associative recognition if the associative information was unitized during the study phase.

In addition, we also performed analyses of old/new effect between intact and new pairs, and found that the familiarity-related early frontal old/new effect was equally involved in associative recognition of compounds and unrelated word pairs. Presumably, the contribution of familiarity found under non-unitized condition may be resulted from the confounding of item memory.

4.2. The left parietal old/new effect

For the left parietal old/new effect between ERPs to intact and rearranged pairs, our results revealed that both conditions evoked significant left parietal old/new effect, and this effect was greater for compounds than for unrelated word pairs. This putative recollection-based old/new effect is commonly observed in previous ERP studies of associative memory tasks (Bader et al., 2010; Donaldson and Rugg, 1998, 1999; Mecklinger and Jäger, 2009).

The present study may suggest that recollection processes make more contribution to the discrimination of intact from rearranged pairs for unitized associations than for non-unitized associations. That is, accurately accepting intact pairs and rejecting rearranged pairs for compounds require more effortful recollection-related process to retrieve details about the study episodes. The rearranged pairs of compounds were also pre-experimentally existing associations (e.g., 'Greek-letter'), which may have high-overlapping representations with the original pairs (e.g., 'Greek-mythology') relative to those of unrelated word pairs, for which the relational representations are different between rearranged pairs and original pairs. Thus, the familiarity of rearranged pairs is also high for compounds such that recollection is more necessary to support the comparison of intact with rearranged pairs (Kriukova et al., 2013). The behavioral results echo this suggestion by showing that rearranged pairs were more difficult to reject for compounds than for unrelated word pairs, reflected by the lower accuracy and slower response times for rearranged pairs for compounds than for unrelated word pairs.

These results suggest that recollection supports the discrimination of intact from rearranged pairs despite familiarity being involved in the associative recognition of unitized representations. In addition, the present finding that the engagement of familiarity in recognition did not lead to less contribution of recollection to unitized associative retrieval was consistent with the proposal that familiarity and recollection are independent processes (Yonelinas, 2002). In a word, we demonstrated that the unitization can also influence the contribution of recollection to associative recognition.

For the old/new effects between ERPs to intact and new pairs, the compounds evoked similar left parietal old/new differences as the unrelated word pairs, consistent with previous studies of associative recognition (Rhodes and Donaldson, 2007, 2008). This is probably

because the intact-new judgment used in present as well as previous studies (Rhodes and Donaldson, 2007, 2008) was not as demanding as the intact-rearranged judgment, so that no extra recollection resources were required to make associative recognition under unitized condition. There are also studies in which significant parietal old/new effect was not found at all under the unitized condition (Bader et al., 2010; Jäger et al., 2006). The null results about the parietal old/new effect in these studies may be associated with stimulus properties (i.e., face pairs with a high degree of similarity or a new concept created by a definition), which make recollection unnecessary for retrieving the associations that are unitized during encoding because familiarity may be sufficient for retrieval of high-level unitized associations. However, because the compounds employed in the present study were also relatively high-level unitized associations, these assumptions may now be less likely. In addition, other aspects may need to be considered, such as when the unitization actually takes place. In the present study, the unitization was based upon the pre-existing semantic knowledge; while for some previous studies, the unitization was created by encoding strategies during experiment.

4.3. Implications for future studies

Amnesic patients with hippocampal lesions and normal older adults have been found with greater declines in associative memory relative to item memory, which may be associated with their impaired recollection (Giovanello et al., 2003; Holdstock et al., 2005; Mayes et al., 2004; Old and Naveh-Benjamin, 2008; Turriziani et al., 2004). Fortunately, their familiarity is relatively preserved (Daselaar et al., 2006; Yonelinas, 2002). Studies have demonstrated that these groups performed better at the associative memory test following the encoding strategies encouraging unitization (e.g., interactive imagery), indicating that they could benefit from enhanced engagement of familiarity in retrieval due to unitization (Bastin et al., 2013; Diana et al., 2010). Future studies are necessary to examine whether these unitized encoding strategies could improve associative memory performance in the patients with Alzheimer's disease (AD) and amnesic mild cognitive impairment (aMCI), who have also shown impaired recollection but preserved familiarity (Gallo et al., 2004; Serra et al., 2010; Westerberg et al., 2006; but see Hoppstädter et al., 2013; Wolk et al., 2008), and to apply those strategies to cognitive training and rehabilitation in these special populations.

4.4. Limitations

Some limitations should be noted. Firstly, the manipulation of rearranged pair was one word from the compound pair, and the other from the unrelated pair. This arrangement may cause the participant to reject a type of rearranged pair (say rearranged compounds) as intact by only recalling that part of the pair was from the other condition (i.e., unrelated condition). Therefore, creating the rearranged pairs within one word pair condition (either compound or unrelated) is a better strategy for future studies. Secondly, although it is necessary to include rearranged pairs in associative memory task, and the ERP comparison between old and rearranged pairs is a better approach than widely used contrast between old and new to capture the nature of association, it should be noted that the rearranged pairs may have the potential to be associated with successful retrieval of the original study phase partner. Thirdly, the presentation of one word above the other may be more unusual for compound

than unrelated pairs. The presentation of one word next to the other for pairs needs to be considered for future studies. Finally, the late old/new effect used to index recollection process usually has a typical left parietal distribution, while our ERP results showed pronounced old/new differences with a widespread topography. The exact reason remains unclear. Thus, the relevant findings need to be explained with caution.

In summary, the present findings extend previous results by showing that the unitization could enhance the contribution of both familiarity and recollection to associative recognition. These findings have important implications for memory training and rehabilitation in healthy older adults and the patients with AD and aMCI, who have impaired recollection and relatively preserved familiarity.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (31070916, 31271108 and 31470998), the Knowledge Innovation Project of the Chinese Academy of Sciences (KSCX2-EW-J-8), the CAS/SAFEA International Partnership Program for Creative Research Team (Y2CX131003), and the National Center for Advancing Translational Sciences, National Institutes of Health (TL1TR00115).

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Highlights

The effects of unitization on associative recognition memory were examined.

Retrieval processes were assessed by comparing ERPs to intact with rearranged pairs.

Familiarity was only involved in associative recognition of compound words.

Recollection was more involved in associative recognition of compound words.

Figure 1. Stimuli and Experimental design. During the study phase, the examples of word pairs ‘家庭-教师’, ‘希腊-神话’, and ‘池塘-字母’ mean ‘Family-Teacher’, ‘Greek-Mythology’, and ‘Pool-Letter’, respectively; during the test phase, the examples of word pairs ‘家庭-教师’, ‘希腊-字母’, and ‘手表-香蕉’ mean ‘Family-Teacher’, ‘Greek-Letter’, and ‘Watch-Banana’, respectively.

Figure 2.

Schematic maps of 62 electrodes sites with the highlighted sites used for analyze the old/new effects of 250-400 ms and 400-700 ms time windows. LF: left frontal (F1, F3, F5); RF: right frontal (F2, F4, F6); LP: left parietal (P1, P3, P5); RP, right parietal (P2, P4, P6). S: superior; M: middle; I: inferior.

Figure 3.

Panel A shows the mean accuracy of each word pairs condition across three responses. Panel B shows the mean response time (ms) of each word pairs condition across three responses. Error bars represent within-subject 95% confidence intervals (Loftus and Masson, 1994).

Figure 4.

Grand average ERPs for correct responses to intact (black line), rearranged (red line) and new (blue line) word pairs for compound words at selected electrodes which are indicated by the insert, showing from -200 to 1000 ms. Scale bars indicate the time windows used for statistical analyses (250-400 ms, and 400-700 ms windows). Positive voltages are plotted upwards.

Figure 5.

Grand average ERPs for correct responses to intact (black line), rearranged (red line) and new (blue line) word pairs for unrelated word pairs at selected electrodes which are indicated by the insert, showing from -200 to 1000 ms. Scale bars indicate the time windows used for statistical analysis (250-400 ms, and 400-700 ms windows). Positive voltages are plotted upwards.

Figure 6.

Bilateral frontal old/new effect (250-400 ms). Panel A shows the mean amplitude of the early bilateral frontal old/new effects (correct intact minus correct rearranged and correct intact minus correct new) under compounds and unrelated word pairs conditions, which represent collapsed activity over six frontal electrodes. Error bars represent within-subject 95% confidence intervals (Loftus and Masson, 1994); Panel B shows the topographical maps of old-rearranged and old-new old/new effects for compound words and unrelated word pairs conditions, which were formed by subtracting ERPs of correct rejected rearranged and new pairs from ERPs of hits to intact pairs, respectively. The scale bar shows amplitude range.

Figure 7.

Left parietal old/new effect (400-700 ms). Panel A shows the mean amplitude of the left parietal frontal old/new effects (correct intact minus correct rearranged and correct intact minus correct new) under compounds and unrelated word pairs conditions, which represent collapsed activity over three left parietal electrodes. Error bars represent within-subject 95% confidence intervals (Loftus and Masson, 1994); Panel B shows the topographical maps of old-rearranged and old-new old/new effects for compound words and unrelated word pairs conditions, which were formed by subtracting ERPs of correct rejected rearranged and new pairs from ERPs of hits to intact pairs, respectively. The scale bar shows amplitude range.