Research

Under the condition of unitization at encoding rather than unitization at retrieval, familiarity could support associative recognition and the relationship between unitization and recollection was moderated by unitization-congruence

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It is widely accepted that associative recognition can be supported by familiarity through integrating more than two stimuli into a unit, but there are still three unsolved questions: (1) how unitization affects recollection-based associative recognition; (2) whether it is necessary to match the level of unitization (LOU) between original and rearranged pairs, which was term as unitization-congruence (UC); (3) whether unitization can occur at encoding or at retrieval. The purposes of this study are to try to answer these questions. During the encoding phase, the participants were asked to learn compound words and unrelated word pairs, and during the retrieval phase, they needed to distinguish intact pairs from rearranged consistent and rearranged inconsistent pairs with "remember/know" paradigm. The results showed that (1) the role of unitization in recollection was moderated by UC; (2) Under the consistent UC condition, unitization could improve familiarity-based associative recognition without affecting recollection-based associative recognition, while under the inconsistent UC condition, unitization could improve familiarity-based and recollection-based associative recognition simultaneously, these results indicated that it was necessary to match the LOU between original and rearranged pairs; (3) unitization at encoding could support familiarity-based associative recognition, while unitization at retrieval did not. In briefly, unitization at encoding could improve associative recognition and this effect was moderated by UC, while unitization at retrieval did not affect associative recognition.

Recognition memory is the ability to realize whether we have encountered an event before (Curran 2000; Yonelinas 2002; Curran and Cleary 2003). The dual-process theory of recognition posits that recognition can be supported by two processes: familiarity and recollection (Mandler 1980; Jacoby 1991; Hintzman and Curran 1994; Yonelinas 1994). Familiarity is a relatively automatic process which occurs without retrieval of any details about studied stimuli, while recollection refers to a slower process which can retrieve additional contextual details (for review, see Yonelinas 2002). A considerable amount of research from behavioral and Event-related potential (ERP) has provided support for the dual-process theory (Curran 2000; Yonelinas 2002; Curran and Cleary 2003). In behavioral studies, "Remember/Know" (R/K) paradigm is usually adopted to estimate familiarity and recollection. Participants are instructed to respond "remember" when they can recollect some specific detailed information about the studied stimuli, or to respond "know" when they only feel familiar without the retrieval of specific information. The receiver operating characteristics (ROCs) procedure is another way to measure familiarity and recollection. Participants are instructed to rate the confidence of their judgments, and then we estimate the contribution of familiarity and recollection to recognition by examining the effect of varying response confidence on hits and false alarms (Yonelinas 1997). Also, some ERP studies reveal that there are two distinct ERP old/new effects that are independently correlated with familiarity and recollection. Specifically, the early bilateral frontal old/new effect (FN400 effect), which occurs at 300–500 msec after stimulus onset and is maximal over bilateral frontal electrodes, has been associated with familiarity, while a later left-parietal old/new effects (LPC effect), which occurs at 500–700 msec and is maximal over left parietal electrodes, has been associated with recollection (Rugg and Nagy 1989; Curran 2000; Curran and Cleary 2003).

A number of studies have found that both familiarity and recollection can contribute to item recognition, whereas only recollection can support associative recognition (Rugg et al. 1998; Yonelinas 2002; Woodruff et al. 2005). However, more and more evidence has challenged this viewpoint by demonstrating that familiarity can also contribute to associative recognition when the to-be-associated stimuli are unitized into a whole representation (Yonelinas et al. 1999; Rhodes and Donaldson 2007, 2008; Bader et al. 2010; Quamme et al. 2010; Diana et al. 2011). Evidence from behavioral (Opitz and Cornell 2006; Shao and Weng 2011; Delhaye et al. 2017), ERPs (Bader et al. 2010; Tibon et al. 2014a,b; Zheng et al. 2015; Kamp et al. 2016) and neuroimaging studies

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Article is online at http://www.learnmem.org/cgi/doi/10.1101/lm.051094.119.

(Haskin et al. 2008; Borders et al. 2017), as well as from studies of older adults (Bastin et al. 2013; Ahmad et al. 2015; Zheng et al. 2015b; Overman et al. 2018) and amnesic patients (Giovanello et al. 2006; Quamme et al. 2010) have provided support for this new phenomenon (see Table 1).

The effect of unitization on familiarity-based and recollection-based associative recognition

Unitization refers to the manipulation of integrating two or more stimuli into a single unit (Graf and Schacter 1989). According to the direction of information flow, there are two categories of manipulation to promote unitization: top-down unitization which utilizes explicit instruction to bind two unrelated items into a whole (high-unitization) or into separate parts (low-unitization) (e.g., interactive imagery vs. item imagery, concept definition vs. sentence framing) and bottom-up unitization which mainly relies on preexisting semantic or perceptual association between to-be-learned items to form a united representation (e.g., compounds/related pairs vs. unrelated pairs, uni-modal vs. cross-modal) (Tibon et al. 2014a,b). The biggest difference between top-down and bottom-up unitization is that the former uses unrelated items as experimental materials and controls the level of unitization (LOU) through explicit instruction, while the latter uses related (or compound words) and unrelated pairs to control the LOU.

Parks and Yonelinas (2015) has used the term LOU to describe the viewpoint that there is a continuum along which associations can be unitized. At the lower end of this continuum, two items are treated as two separate items, and the only association is that they have appeared in the same episodic context. At the higher end of this continuum, the two items are unitized as a single unit. They doubt that either extreme exists in a pure form and therefore refer to high and low LOU. As such, the LOU is a relative variable and varies in different levels. For example, the LOU of compound words is higher than that of unrelated word pairs.

Although previous studies have used a variety of stimuli (e.g., compound words, unrelated word pairs), unitization manipulations (e.g., concept definition, interactive imagery), and measuring methods (e.g., "R/K" paradigm, ROCs, ERPs) to explore the effect of unitization on associative recognition and to estimate the contribution of familiarity and recollection, the results congruously

Table 1. The summary of previous studies which focus on the effect of unitization on familiarity-based and recollection-based on associative recognition

				Parameter estimation		
Authors (years)	**High vs. Low LOU**	**Method**	**Behavioral result**	**Familiarity**	**Recollection**	**UC**
Unitization increase familiarity and decrease recollection processing						
Bader et al. (2010)	Def vs. Sen	ERPs	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} < R_{(l)}$[a]	
Kamp et al. (2016)	Def vs. Sen	ERPs	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} < R_{(l)}$[a]	
Kriukova et al. (2013)	The vs. Cat	ERPs	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} = F_{(l)}$	$R_{(h)} < R_{(l)}$[a]	com
Opitz and Cornell (2006)	Ass vs. Rel	ERPs	$Hit_{(h)} = Hit_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} < R_{(l)}$	
Unitization increase familiarity and have no effect on recollection processing						
Delhaye and Bastin (2016)	Com vs. Unrel	R/K	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	con
Giovanello et al. (2006)	Com vs. Unrel	R/K	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	con
Greve et al. (2007)	Rel vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	con
Han et al. (2018)	Item vs. inter	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	
Haskin et al. (2008)	Def vs. Sen	ROCs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	
Li et al. (2017)	Com vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	com
	Sim vs. Seq		$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} = F_{(l)}$	$R_{(h)} = R_{(l)}$	
Lyu et al. (2018)	Rel vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	com
Murray (2014)	Def vs. Sen		$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} = F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	com
	Item vs. inter		$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	
Rhodes and Donaldson (2007)	Ass vs Rel	ERPs	$Hit_{(h)} > Hit_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	
Rhodes and Donaldson (2008)	Ass vs Rel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	com
	Item vs. inter		$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} = R_{(l)}$	
Hubbard (2014)	Def vs. Sen	ERPs	$Hit_{(h)} = Hit_{(l)}$	$F_{(h)} = F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	
Tibon et al. (2014a)	Uni vs. cross	ERPs	$Hit_{(h)} > Hit_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	
Wang et al. (2016)	Rel vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} = R_{(l)}$	com
Unitization increase familiarity and recollection processing simultaneously						
Bridger et al. (2017)	Pla vs. Impla	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} > R_{(l)}$	con
Desaunay et al. (2017)	Rel vs. Unrel	ERPs	$Hit_{(h)} = Hit_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} > R_{(l)}$	con
Delhaye et al. (2017)	Rel vs Unrel	R/K	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	com
Parks and Yonelinas (2015)	Def vs. Sen	ROCs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	
Robey and Riggins (2017)	Item vs. inter	ROCs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	
Shao ans Weng (2011)	Ass vs. Unrel	R/K	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} = F_{(l)}$	$R_{(h)} > R_{(l)}$	com
	Def vs. Sen	R/K	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} = F_{(l)}$	$R_{(h)} > R_{(l)}$	
Shao et al. (2016)						
EXP1	Com vs. Unrel	R/K	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	com
EXP2	Com vs. Unrel	R/K	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} < R_{(l)}$	
EXP3	Item vs. inter	R/K	$Pr_{(h)} = Pr_{(l)}$	$F_{(h)} = F_{(l)}$	$R_{(h)} > R_{(l)}$	com
Tibon et al. (2014b)	Rel vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$[b]	$R_{(h)} > R_{(l)}$	com
Zheng et al. (2015a)	Com vs. Unrel	ERPs	$Hit_{(h)} > Hit_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	com
Zheng et al. (2016)	Com vs. Unrel	ERPs	$Pr_{(h)} > Pr_{(l)}$	$F_{(h)} > F_{(l)}$	$R_{(h)} > R_{(l)}$	com

Def, compound definition; Sen, sentence frame; The, thematic related pairs; Cat, categorical related pairs; Ass, associative pairs; Rel, related pairs; Com, compound words; Urrel, unrelated word pairs; Item, item imagery; Inter, interactive imagery; Pla, plausible spatial arrangement; Uni, uni-model; cross, cross model; Impla, implausible spatial arrangement; com, combined, means that the researchers had not consider the consistence between original and rearranged pairs; con, consistent, means that the researchers matched the consistence between original and rearranged pairs.

[a]There is no recollection in high LOU.

[b]There is no familiarity in low LOU.

indicate that unitization can facilitate familiarity-based associative recognition. However, there are still three questions that have not been solved.

The first question is: how does unitization effect recollection-based associative recognition?

What's the effect of unitization on recollection-based recognition is still under debate, with some studies showing weakened effect of unitization (Opitz and Cornell 2006; Bader et al. 2010; Kriukova et al. 2013; Kamp et al. 2016), some showing no effect (Haskin et al. 2008; Hubbard 2014; Wang et al. 2016; Li et al. 2017; Lyu et al. 2018), and some showing enhanced effect (Shao and Weng 2011; Parks and Yonelinas 2015; Delhaye et al. 2017; Desaunay et al. 2017). A summary of previous studies is showed in Table 1. For top-down unitization, Bader et al. (2010) and Kamp et al. (2016) controlled the LOU through concept definition and sentence frame encoding. The results showed that unitization could enhance familiarity-related FN400 effect and decrease recollection-related LPC effect. Haskin et al. (2008) and Hubbard (2014) used the same research paradigm and found that unitization could support familiarity-based associative recognition without affecting recollection-based associative recognition. Parks et al. (2015) and Shao and Weng (2011) even found that unitization could increase familiarity-based and recollection-based associative recognition simultaneously. Similarly, for bottom-up unitization, participants were asked to learn compound words and unrelated pairs in encoding and then distinguish intact pairs from rearranged pairs in retrieval. Some studies revealed that unitization could enhance familiarity-related FN400 effect at the cost of recollection-related LPC effect (Kriukova et al. 2013; Opitz and Cornell 2006), some studies revealed that unitization had no effect on recollection-related LPC effect when it facilitated familiarity-related FN400 effect (Li et al. 2017; Lyu et al. 2018; Wang et al. 2016), and some studies even revealed that unitization could increase the contribution of familiarity and recollection simultaneously (Shao et al. 2011; Tibon et al. 2014b; Parks et al. 2015; Zheng et al. 2015a, 2016; Shao et al. 2016; Delhaye et al. 2017; Desaunay et al. 2017; Robey and Riggins 2017). These differences indicated that the role of unitization in recollection was varied and that studies on this question in the future would be meaningful.

Why is the role of unitization in recollection so varied? Based on the literature, we put forward an assumption that whether the match of LOU between original and rearranged pairs, termed as unitization-congruence (UC), is an important factor which can explain the discrepancy (see the last column in Table 1). In the studies of bottom-up unitization, most researchers who matched the UC between original and rearranged pairs found that unitization could increase familiarity without affecting recollection (Delhaye and Bastin 2016; Giovanello et al. 2006; Greve et al. 2007). Other researchers who did not match the UC between the two pairs found that unitization could increase familiarity without affecting recollection (Rhodes and Donaldson 2008; Murray 2014; Wang et al. 2016; Li et al. 2017; Lyu et al. 2018), or that unitization could increase familiarity and recollection simultaneously (Tibon et al. 2014b; Zheng et al. 2015a,b; Delhaye et al. 2017). The difference might be dependent on the ratio of the number of consistent pairs to inconsistent pairs. Beyond that, in the studies of top-down unitization, this question was insoluble. The researchers used unrelated items as materials and controlled the high and low LOU through concept definition (high LOU) and sentence frame encoding (low LOU). However, in retrieval, they rearranged these items to form new unrelated pairs (low LOU), the UC was not matched between original and rearranged pairs. Therefore, we need to explore whether it is necessary to match the UC between original and rearranged pairs.

The second question is: whether it is necessary to match the unitization-congruence (UC) between original and rearranged pairs?

This is the first study to examine the effect of UC on the relationship between unitization and associative recognition. In addition to answering the above questions, this study has another important significance for materials selection. The reason why some researchers do not consider the role of UC is that it can reduce the number of materials and the difficulty of materials selection. Under the consistent UC condition, in order to match the UC, they need to discard half of the items. For example, they rearrange two compound words ("Greek-mythology" and "phonetic-alphabet") to form a new compound words ("Greek-alphabet") and discard the remaining items ("phonetic" and "mythology"). In contrast, the researchers who do not match the UC can rearrange two compound words ("Greek-mythology" and "phonetic-alphabet") to form two new word pairs ("Greek-alphabet" and "phonetic-mythology") without considering the LOU of rearranged pairs, this reduced not only the number of materials but also the difficulty of material selection. However, they neglect the role of UC in associative recognition. Whatever the results, solving this problem is meaningful and important. If we find that UC plays a role in the relationship between LOU and associative recognition, this study provides the first empirical support for us to consider the role of UC in associative recognition when constructing rearranged word pairs. Then, the previous studies of top-down unitization need to be explained carefully because of the inconsistent UC. Conversely, if we find that UC has no effect on this relationship, then we need not pay much attention to the construction of rearranged word pairs in future studies, which greatly simplifies the selection of experimental materials.

Although no study has directly explored the role of UC in relationship between unitization and associative recognition, there are two similar studies. Patterson et al. (2009) aimed to illustrate whether semantic relatedness could improve the ability of young and older adults to discriminate preexperimental associations (semantic association) from experimental associations (episodic association). In encoding, participants were required to learn 20 related word pairs and 30 unrelated word pairs. In retrieval, there were seven different list conditions: (1) S+E+: Semantically related pairs that were previously studied together; (2) S−E+: Semantically unrelated pairs that were previously studied together; (3) S−E−r: Semantically unrelated pairs whose left and right members were studied as members of different related pairs (the UC of original and rearranged pairs was inconsistent); (4) S+E−u: Semantically related pairs whose left and right members were studied as members of different unrelated pairs (the UC of original and rearranged pairs was inconsistent); (5) S−E−u: Semantically unrelated pairs whose left and right members were studied as members of different unrelated pairs (the UC of original and rearranged pairs was consistent); (6) New−u: Semantically unrelated pairs that were previously not studied; (7) New−r: Semantically related pairs that were previously not studied. The results showed that both young and older adults had higher hits for S+E+ pairs than for S−E+ pairs, and higher FAs for S+E−u than for S−E−u pairs, followed by S−E−r pairs. By comparing S+E−u and S−E−u pairs, we found that UC had different role in FAs. However, the researchers missed out on vital rearranged pairs–S+E−r pairs: Semantically related pairs whose left and right members were studied as members of different related pairs (the UC of original and rearranged pairs was consistent). Therefore, we could not predict how LOU and UC worked together on associative recognition.

Peterson et al. (2017) believed that there was a schematic support when the age category between face and name was matched (e.g., younger face-younger name pairs, older face-older

name pairs). During a continuous recognition task, participants were required to learn face-name pairs and then test face-name pairs which either were rearranged within the same age categories (e.g., older face-older name or younger face-younger name) or between two different age categories (e.g., older face-younger name or younger face-old name), the former was defined as "no change" condition and the latter as "change" condition. The results suggested that both younger and older could benefit from change in schematic support and that the accuracy was significantly higher in the change condition compared to the no change condition. In experiment 2, they used "R/K" paradigm to estimate the contribution of familiarity and recollection to recognition. The results revealed that these benefits of schematic support for recognition were moderated by the accessibility of recollection in the change condition, there was higher recollection-based CRs in the change condition than in the no change condition. Drawing an analogy between schematic support and unitization, we assumed that the no change condition might correspond to consistent UC condition and the change condition corresponded to inconsistent UC condition, we predicted that the CRs would be higher in inconsistent UC condition than in consistent UC condition.

In sum, the second question aims to answer whether UC can moderate the role of unitization in associative recognition and whether it is necessary to match the UC between original and rearranged pairs. This is the most important and interesting question of this study.

The third question is: whether unitization can occur at encoding or at retrieval?

In this experiment, when we introduce the variable of UC, we rearrange not only two compound words to form new compound words and new unrelated word pairs but also two unrelated word pairs to form new unrelated pairs and new compound words, why do we distinguish between high and low LOU only based on the pairs' status at encoding, but not based on the pairs' status at retrieval? In some studies, the researchers who matched the UC between original and rearranged pairs had found that when participants learned the association existing in compound words in encoding and tested intact and rearranged pairs in retrieval, the preexisting association could improve the ability of participants to distinguish intact pairs from rearranged pairs. This was a simple case because of the consistent UC. In other studies, the researchers did not match the UC between original and rearranged pairs, because we could not judge the high or low LOU of rearranged pairs, the case was more complicated. For example, if these researchers rearranged two unrelated pairs to form new related pairs, whether the association only presented in retrieval could also help participants to distinguish intact pairs form rearranged pairs. That was whether the association presented in retrieval could also contribute to associative recognition.

In addition, in one study of Tibon et al. (2014b), they rearranged one related and one unrelated picture pair to form a new related and a new unrelated picture pair, and the "relatedness" factor of the pairs referred to its status at retrieval. In another study of Zheng et al. (2015a), they rearranged one compound word and one unrelated pair to form a new compound word and a new unrelated pair, and the "unitization" factor of the pairs referred to its status at encoding. Although both studies had shown higher familiarity-related FN400 effect and recollection-related LPC effect for high LOU pairs than for low LOU pairs, there was a different definition for pairs' LOU. Therefore, we wanted to examine whether the results would happen in one experiment and whether unitization could occur at encoding or at retrieval.

What are the research questions in this study?

Taking the above into consideration, we aimed to explore three questions in this study: (1) how unitization effected recollection-based associative recognition; (2) whether it was necessary to match the UC between original and rearranged pairs; (3) whether unitization could occur at encoding or at retrieval. During the encoding phase, participants were instructed to learn compound words and unrelated word pairs, and during the retrieval phase, word pairs were divided into six retrieval conditions: (1) compound-intact (studied compound words and tested old compound words, C–C–o); (2) unrelated-intact (studied unrelated word pairs and tested old unrelated word pairs, U–U–o); (3) compound-rearranged-consistent (studied compound words and tested rearranged compound words, C–C–r); (4) compound-rearranged-inconsistent (studied compound words and tested rearranged unrelated word pairs, C–U–r); (5) unrelated-rearranged-consistent (studied unrelated word pairs and tested rearranged unrelated word pairs, U–U–r); (6) unrelated-rearranged-inconsistent (studied unrelated word pairs and tested rearranged compound words, U–C–r). Based on previous studies, we predicted that: (1) there were higher hits and FAs for compound words than for unrelated word pairs; (2) under the inconsistent UC condition, there would be higher CRs for compound words than for unrelated word pairs; (3) UC might moderate the role of unitization in associative recognition.

Results

Study phase

A paired-samples *t*-test with LOU revealed that there was higher LOU rating and faster RTs for compound words than for unrelated word pairs [LOU: 4.78 (0.04) vs. 1.69 (0.08), $t_{(32)} = 38.81$, $P < 0.001$, Cohen's $d = 6.86$; RTs: 1325.11 (71.18) vs. 1813.50 (79.97), $t_{(32)} = -7.55$, $P < 0.001$, Cohen's $d = -1.33$], indicating that the participants could distinguish the compound words from the unrelated word pairs well.

The analyses of accuracy and FAs based on LOU-at-encoding

In this part, we analyzed the hits to intact pairs, the CRs to rearranged pairs, and the FAs to rearranged pairs under each condition. The results are shown in Table 2.

In overall process, a paired-samples *t*-test with LOU (compound words vs. unrelated word pairs) on hits revealed a higher hits for compound-intact pairs than for unrelated-intact pairs [$t_{(32)} = 5.09$, $P < 0.001$, Cohen's $d = 0.90$]. A 2 (LOU: compound words vs. unrelated word pairs) × 2 (UC: consistent vs. inconsistent) ANOVAs on CRs revealed a main effect of LOU [$F_{(1,32)} = 7.72$, $P = 0.009$, $\eta_p^2 = 0.19$], a main effect of UC [$F_{(1,32)}$=7.37, $P = 0.011$, $\eta_p^2 = 0.19$], and a LOU × UC interaction [$F_{(1,32)} = 36.10$, $P < 0.001$, $\eta_p^2 = 0.53$]. Decomposition of the interaction revealed that CRs for C–C–r pairs was significantly lower than for U–U–r pairs [$t_{(32)} = -4.02$, $P < 0.001$, Cohen's $d = -0.71$], but CRs for C–U–r pairs was higher than for U–C–r pairs [$t_{(32)} = 6.78$, $P < 0.001$, Cohen's $d = 1.20$]. A 2 × 2 ANOVAs on FAs revealed a main effect of LOU [$F_{(1,32)} = 6.31$, $P = 0.017$, $\eta_p^2 = 0.17$], a main effect of UC [$F_{(1,32)} = 8.32$, $P = 0.007$, $\eta_p^2 = 0.21$], and a LOU × UC interaction [$F_{(1,32)} = 34.82$, $P < 0.001$, $\eta_p^2 = 0.52$]. Decomposition of the interaction revealed that FAs for C–C–r pairs was higher than for U–U–r pairs [$t_{(32)} = 4.02$, $P < 0.001$, Cohen's $d = 0.71$], but FAs for C–U–r pairs was lower than for U–C–r pairs [$t_{(32)} = -6.77$, $P < 0.001$, Cohen's $d = -1.20$].

In the recollection process, the analysis of hits revealed higher hits for compound words than for unrelated word pairs [$t_{(32)} = 4.97$, $P < 0.001$, Cohen's $d = 0.88$]. A 2 × 2 ANOVAs on CRs revealed a

Table 2. The descriptive statistics of accuracy and FAs for each condition

		Compound words			Unrelated word pairs		
		Intact	Rearranged-consistent	Rearranged-inconsistent	Intact	Rearranged-consistent	Rearranged-inconsistent
Overall	Accuracy	0.82(0.02)	0.59(0.04)	0.85(0.03)	0.63(0.03)	0.75(0.03)	0.60(0.03)
	FAs		0.41(0.03)	0.15(0.03)		0.25(0.03)	0.39(0.03)
Recollection	Accuracy	0.74(0.03)	0.40(0.04)	0.61(0.05)	0.55(0.03)	0.38(0.04)	0.36(0.04)
	FAs		0.28(0.03)	0.08(0.03)		0.14(0.03)	0.26(0.03)
Familiarity	Accuracy	0.28(0.05)	0.32(0.04)	0.64(0.05)	0.17 (0.04)	0.58(0.05)	0.38(0.03)
	FAs		0.13(0.02)	0.06(0.01)		0.11(0.02)	0.13(0.02)

main effect of LOU [$F_{(1,32)} = 22.81$, $P < 0.001$, $\eta_p^2 = 0.42$], a main effect of UC [$F_{(1,32)} = 17.93$, $P < 0.001$, $\eta_p^2 = 0.36$], and a LOU × UC interaction [$F_{(1,32)} = 19.39$, $P < 0.001$, $\eta_p^2 = 0.38$]. Decomposition of the interaction revealed that CRs were equivalent for C–C–r and U–U–r pairs [$t_{(32)} = 0.34$, $P = 0.74$], but CRs for C–U–r pairs were higher than for U–C–r pairs [$t_{(32)} = 6.62$, $P < 0.001$, Cohen's $d = 1.17$]. A 2 × 2 ANOVASs on FAs revealed a main effect of UC [$F_{(1,32)} = 5.88$, $P = 0.021$, $\eta_p^2 = 0.16$] and a LOU × UC interaction [$F_{(1,32)} = 32.07$, $P < 0.001$, $\eta_p^2 = 0.50$]. Decomposition of the interaction revealed that FAs for C–C–r pairs was higher than for U–U–r pairs [$t_{(32)} = 4.50$, $P < 0.001$, Cohen's $d = 0.80$], but FAs for C–U–r pairs were lower than for U–C–r pairs [$t_{(32)} = -5.35$, $P < 0.001$, Cohen's $d = -0.95$].

In familiarity process, The analysis of hits revealed a higher hits for compound words than for unrelated pairs [$t_{(32)} = 2.08$, $P = 0.045$, Cohen's $d = 0.37$]. A 2 × 2 ANOVA on CRs revealed only a significant interaction between LOU and UC [$F_{(1,32)} = 39.55$, $P < 0.001$, $\eta_p^2 = 0.55$]. Decomposition of the interaction revealed that CRs for C–C–r pairs were lower than for U–U–r pairs [$t_{(32)} = -5.25$, $P = 0.002$, Cohen's $d = -0.93$], but CRs for C–U–r pairs were higher than for U–C–r pairs [$t_{(32)} = 5.31$, $P = 0.002$, Cohen's $d = -0.94$]. A 2 × 2 ANOVA on FAs revealed a main effect of LOU [$F_{(1,32)} = 9.29$, $P = 0.005$, $\eta_p^2 = 0.23$] and a LOU × UC interaction [$F_{(1,32)} = 4.39$, $P < 0.001$, $\eta_p^2 = 0.12$]. Decomposition of the interaction revealed that FAs were equivalent for C–C–r and U–U–r pairs [$t_{(32)} = 0.61$, $P = 0.55$], but FAs for C–U–r pairs were lower than for U–C–r pairs [$t_{(32)} = -3.37$, $P = 0.002$, Cohen's $d = -0.60$].

The analyses of associative recognition based on LOU-at-encoding

In this part, we defined the LOU based on the pairs' status at encoding. The associative recognition performance (probability of true recognition, Pr) was equal to $hits_{(intact)}$ minus $FAs_{(rearranged)}$. Three ANOVAs were conducted for overall, recollection, and familiarity separately. The results are shown in Figure 1.

In overall process, a 2 (LOU: compound words vs. unrelated word pairs) × 2 (UC: consistent vs. inconsistent) ANOVA revealed a significant main effect of LOU [$F_{(1,32)} = 27.15$, $P < 0.001$, $\eta_p^2 = 0.46$], a main effect of UC [$F_{(1,32)} = 8.32$, $P = 0.007$, $\eta_p^2 = 0.21$], and an interaction between LOU and UC [$F_{(1,32)} = 34.82$, $P < 0.001$, $\eta_p^2 = 0.52$]. Post hoc analyses showed that under the consistent UC condition, the associative recognition performance was equivalent for compound words and unrelated pairs ($t_{(32)} = 0.60$, $P = 0.66$), and under the inconsistent UC condition, there was better associative recognition performance for compound words than for unrelated pairs [$t_{(32)} = 6.95$, $P < 0.002$, Cohen's $d = 1.23$].

In recollection process, a 2 ANOVA revealed a main effect of LOU [$F_{(1,32)} = 23.66$, $P < 0.001$, $\eta_p^2 = 0.43$], a main effect of UC [$F_{(1,32)} = 5.88$, $P = 0.021$, $\eta_p^2 = 0.16$], and a significant interaction between LOU and UC [$F_{(1,32)} = 32.07$, $P < 0.001$, $\eta_p^2 = 0.50$]. Follow-up analyses showed that under the consistent UC condition, the recollection-based associative recognition performance was equivalent for compound words and unrelated pairs [$t_{(32)} = 1.18$, $P = 0.25$], and under the inconsistent UC condition, there was better associative recognition performance for compound words than for unrelated pairs [$t_{(32)} = 6.29$, $P < 0.001$, Cohen's $d = 1.11$].

In familiarity process, a 2 × 2 ANOVAs revealed only a main effect of LOU [$F_{(1,32)} = 9.23$, $P = 0.005$, $\eta_p^2 = 0.24$]. Follow-up analyses revealed that there was better performance for compound words than for unrelated pairs under both the consistent UC condition [$t_{(34)} = 2.08$, $P = 0.046$, Cohen's $d = 0.37$] and the inconsistent UC condition [$t_{(32)} = 3.00$, $P = 0.005$, Cohen's $d = 0.53$].

Based on the analyses of Pr, there was no significant difference between compound words and unrelated pairs in overall associative recognition performance under the consistent UC condition. Distinguishing the contribution of recollection and familiarity, the results showed that LOU could improve familiarity-based associative recognition without affecting recollection-based associative recognition. In contrast, under the inconsistent UC condition, we found LOU could improve overall associative recognition performance through increasing the contribution of recollection and familiarity. Based on the different result patterns between the consistent and inconsistent UC condition and the significant interaction between LOU and UC, we believed that UC could affect associative recognition and moderate the relationship between LOU and associative recognition.

The analyses of associative recognition based on LOU-at-retrieval

In this section we distinguished high and low LOU based on the pairs' status at retrieval. For example, two compound words were rearranged to form new unrelated pairs, the new pairs were high

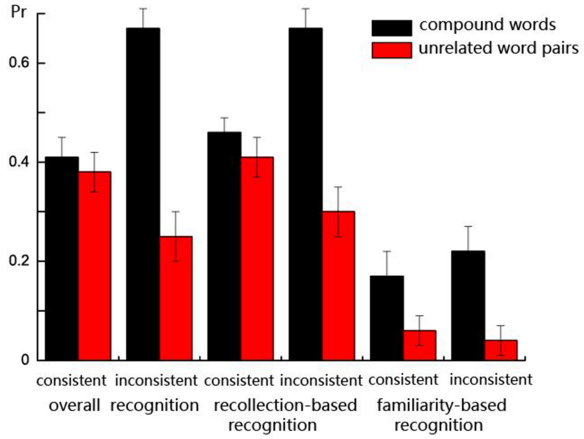

Figure 1. Mean performance indices (Pr) for each condition across three processes, based on LOU-at-encoding.

LOU when we distinguished LOU based on its status at encoding, but it was low LOU when we defined LOU based on its status at retrieval. Similarly, two unrelated pairs were rearranged to form a compound words which was low LOU at encoding but high LOU at retrieval. The rest was the same as the previous analyses. The results are shown in Figure 2.

In overall process, a 2 × 2 ANOVAs revealed a main effect of UC [$F_{(1,32)} = 8.32$, $P = 0.007$, $\eta_p^2 = 0.21$] and a LOU × UC interaction [$F_{(1,32)} = 6.32$, $P = 0.017$, $\eta_p^2 = 0.17$]. Decomposition of the interaction revealed that unrelated pairs induced worse recognition performance under the consistent UC condition than under the inconsistent UC condition [$t_{(32)} = -3.39$, $P = 0.002$, Cohen's $d = 0.60$], but there was no difference between the two conditions for compound words [$t_{(32)} = -0.89$, $P = 0.38$]. Critically, there was no significant difference between compound words and unrelated word pairs, whether under the consistent UC [$t_{(32)} = 0.60$, $P = 0.56$] or the inconsistent UC conditions [$t_{(32)} = -1.43$, $P = 0.16$].

In the recollection process, a 2 × 2 ANOVA revealed only a main effect of UC [$F_{(1,32)} = 5.88$, $P = 0.021$, $\eta_p^2 = 0.16$]. Follow-up analyses revealed a better associative recognition performance under the inconsistent UC condition than under the consistent UC condition.

In the familiarity process, a 2 × 2 ANOVAs revealed that there was neither main effect nor interaction effect.

To summarize, when we defined LOU based on the pairs' status at retrieval, there was no main effect of LOU in overall, recollection-based, and familiarity-based associative recognition. These results indicated that LOU-at-retrieval did not affect associative recognition, nor did it affect the estimate of familiarity and recollection.

The different roles of LOU-at-encoding and LOU-at-retrieval in associative recognition

Based on the intuitive comparison between the two analyses mentioned above, we thought the role of LOU in associative recognition might be moderated by LOU status. Accordingly, we merged data from preexperiment ($N = 25$) and formal experiment (25 participants were randomly selected from 33 participants). The preexperiment was exactly the same as formal experiment except that the participants only needed to make an "old/new" judgment. The results are shown in Figure 3.

The associative recognition performance (Pr) were subjected to ANOVAs with the between-subjects factor of LOU status (LOU-at-encoding vs. LOU-at-retrieval) and the within-subjects factors of LOU (compound words vs. unrelated word pairs) and UC (consistent vs. inconsistent). The results showed a main effect of LOU [$F_{(1,32)} = 7.52$, $P = 0.009$, $\eta_p^2 = 0.14$], a main effect of UC [$F_{(1,48)} = 14.01$, $P < 0.001$, $\eta_p^2 = 0.23$], a LOU × UC [$F_{(1,48)} = 20.71$, $P < 0.001$, $\eta_p^2 = 0.30$], a LOU × LOU status [$F_{(1,48)} = 21.42$, $P < 0.001$, $\eta_p^2 = 0.31$], and a LOU × UC × LOU status [$F_{(1,48)} = 32.98$, $P < 0.001$, $\eta_p^2 = 0.41$]. Decomposing the variable of UC, we illustrated the different role of LOU status in associative recognition.

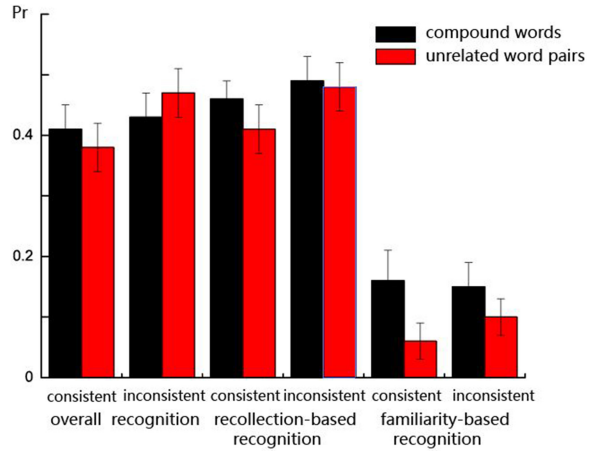

Figure 2. Mean performance indices (Pr) for each condition across three processes, based on LOU-at-retrieval.

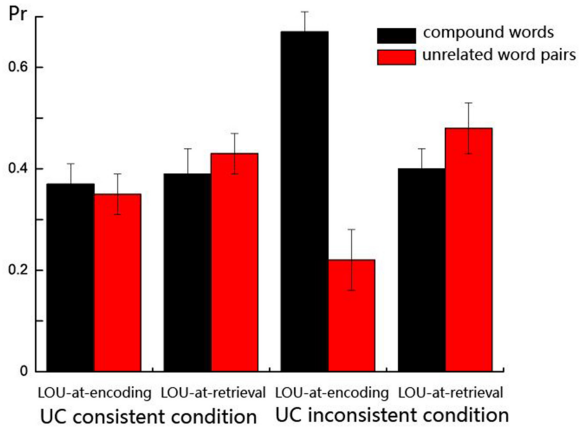

Figure 3. Mean performance indices (Pr) for each condition, based on LOU-at-encoding and LOU-at-retrieval.

Under the UC consistent condition, a 2 (LOU: compound words vs. unrelated word pairs) × 2 (LOU status: LOU-at-encoding vs. LOU-at-retrieval) ANOVAs revealed neither a significant main effect of LOU or LOU status nor a significant interaction. Under the UC inconsistent condition, a 2 × 2 ANOVAs revealed a main effect of LOU [$F_{(1,48)} = 18.97$, $P < 0.001$, $\eta_p^2 = 0.28$] and a LOU × LOU status interaction [$F_{(1,48)} = 40.72$, $P < 0.001$, $\eta_p^2 = 0.46$]. Follow-up analyses showed that when we defined LOU based on the pairs' status at encoding, the compound words occurred better associative recognition than did the unrelated pairs [$t_{(24)} = 6.32$, $P < 0.001$, Cohen's $d = 1.26$]. In contrast, when we defined LOU based on the pairs' status at retrieval, the associative recognition performance was equivalent for compound words and unrelated pairs [$t_{(24)} = -1.92$, $P = 0.066$].

The correlation analyses of LOU rating and associative recognition

To examine the correlation between LOU rating and associative recognition, the high and low LOU rating were merged and Pearson correlation analysis was conducted between LOU rating and associative recognition under 2 (LOU status: LOU-at-encoding vs. LOU-at-retrieval) × 2 (UC: consistent vs. inconsistent) × 3 (processes: overall vs. familiarity vs. recollection) conditions. The results showed that only under the LOU-at-encoding × inconsistent UC condition, there were significant correlations between LOU rating and overall ($r = 0.63$, $P < 0.001$), recollection-based ($r = 0.58$, $P < 0.001$), and familiarity-based ($r = 0.34$, $P = 0.006$) associative recognition. In contrast, under other conditions, there was no significant correlations (all $r < 0.24$, $P > 0.113$). These results coincided with those of ANOVAs and showed a significant correlation under the condition that the associative recognition was better for high LOU than for low LOU pairs.

Discussion

This experiment was designed to explore whether LOU and UC could affect associative recognition. The results indicated that:

(1) when we defined the LOU based on the pairs' status at encoding, both LOU and UC affected associative recognition performance and the effect of LOU on associative recognition was moderated by UC. Decomposition the contribution of recollection and familiarity, the results showed that under the consistent UC condition, LOU could increase familiarity without affecting recollection, and under the inconsistent UC condition, LOU could improve associative recognition through increasing recollection and familiarity simultaneously; (2) according to the significant LOU-at-encoding × UC interaction, we thought it was necessary to match the UC between original and rearranged pairs; (3) when we defined the LOU based on the pairs' status at retrieval, it had no effect on overall, recollection-based, and familiarity-based associative recognition, indicating that unitization could only occur at encoding but not at retrieval.

The effect of unitization on hits and FAs

Under the consistent UC condition, the analyses of hits and FAs revealed that there was higher hits and FAs for compound words than for unrelated pairs, resulting an equivalent associative recognition performance. This was consistent with some studies (Kriukova et al. 2013; Ahmad and Hockley 2014, 2016). Under the inconsistent UC condition, there was higher hits and lower FAs for compound words than for unrelated pairs. This result seemed to be inconsistent with previous studies. A pairwise comparison revealed that FAs was equivalent for C–C–r and U–C–r pairs, but higher following U–U–r pairs than C–U–r pairs. We assumed that the preexisting association might induce FAs. Decomposition of the estimate of familiarity and recollection, we found the hits were mainly supported by recollection, although familiarity could also support it. In the recollection process, a pairwise comparison on CRs revealed higher CRs for C–U–r pairs than for C–C–r, U–U–r, and U–C–r pairs. Critically, there was no significant difference among the last three pairs, this was consistent with the study of Peterson et al. (2017). One possibility was that when the participants studied compound words in encoding and tested unelated pairs in retrieval, they could better recollect the pairs based on its components and then correctly rejected it. For C–C–r pairs, although the participants could recollect the pairs based on its components, the rearranged compound words which had high semantic relevance to original compound words could also induce a false sense of remembrance, which resulted in higher recollection-based FAs. The analyses of FAs showed that the C–C–r and U–C–r pairs led to higher FAs than did the C–U–r and U–U–r pairs and provided support for this possibility. In the familiarity process, the hits were higher for compound words than for unrelated pairs. The analyses of CRs showed higher CRs for C–U–r and U–U–r pairs than for C–C–r and U–C–r pairs, which was a little unusual. The FAs were equivalent for the C–C–r and U–C–r pairs, which were larger than C–U–r and U–U–r pairs. Also we assumed that the preexisting association might induce a false sense of knowing which led to higher FAs for compound words than for unrelated pairs. Briefly, the compound words in retrieval might induce a false sense of remembrance and knowing, leading to higher FAs than the unrelated word pairs.

The role of unitization in recollection-based associative recognition was moderated by UC

The first question was how unitization influenced recollection-based associative recognition, the results indicated its role in recollection-based associative recognition was moderated by UC. When we defined the LOU based on the pairs' status at encoding, UC could moderate the role of unitization in recollection-based associative recognition. Under the consistent UC condition, we found unitization had no effect on recollection-based associative recognition, while under the inconsistent UC condition, unitization could improve recollection-based associative recognition. A pairwise comparison on recollection-based Pr revealed that there was higher recognition performance for C–U–r pairs than for C–C–r and U–U–r pairs, and higher than for U–C–r pairs. Together with the results of recollection-based hits and FAs, we assumed the benefits of unitization for recollection-based associative recognition came from the preexisting association. After learning compound words in encoding, whether compound words or unrelated pairs were tested in retrieval, the participants could recollect the original pairs based on its components and then correctly distinguished intact pairs from rearranged pairs. However, when they learned unelated word pairs, there was no existing association to help them recollect the pairs. In addition, when they learned unrelated pairs and tested compound words, because the association existing in U–C–r pairs could induce a false sense of remembrance, there would be higher FAs and lower discrimination for U–C–r pairs than for U–U–o pairs. That was to say, it was more difficult for participants to distinguish the intact pairs from U–C–r pairs.

It was necessary for researchers to match the unitization-congruence between original and rearranged word pairs

This was the first study which aimed to examine the effect of UC on the relationship between unitization and associative recognition. We controlled the UC through matching the LOU between original and rearranged word pairs. For instance, participants were required to learn two compound words (A–B, C–D) and two unrelated pairs (E–F, H–G) in encoding, and then these pairs were rearranged to form two new compound words (A–D, consistent UC; H–F, inconsistent UC) and two new unrelated pairs (C–B, inconsistent UC; E–G, consistent UC) in retrieval. The results showed that the main effects of UC and LOU were significant and moderated by UC × LOU interaction. In overall associative recognition performance, we found that under the consistent UC condition, LOU did not affect associative recognition, while under the inconsistent UC condition, LOU could improve associative recognition performance. Estimating the familiarity and recollection, we found that under the consistent UC condition, the compound words induced higher familiarity-based and equivalent recollection-based associative recognition than did the unrelated word pairs, demonstrating that unitization could support familiarity-based associative recognition and had no effect on recollection-based associative recognition. Under the inconsistent UC condition, we found compound words induced higher familiarity-based and recollection-based associative recognition than did the unrelated word pairs, indicating that unitization could enhanced familiarity-based and recollection-based associative recognition. When the UC was emerged, we also found that unitization could enhance familiarity-based and recollection-based associative recognition simultaneously. To some extent, these results could explain the divergence of existing studies. Beyond that, this study provided the first empirical support for the claim that we needed to match the UC between original and rearranged pairs when constructing rearranged pairs. Also, the existing studies about top-down unitization needed to be explained carefully because of the inconsistent UC. In future studies, investigators must take into account the UC when constructing rearranged word pairs to ensure that the LOU between original and rearranged pairs was matched.

Unitization could only occur at encoding but not at retrieval

This was the first study which aimed to examine whether unitization could occur at encoding or at retrieval. The results showed that

only when we defined the LOU based on the pairs' status at encoding, could familiarity support associative recognition. This might be due to the fact that the two items were unitized as a coherent item (compound words) and that item recognition could be supported by familiarity. When we defined the LOU based on the pairs' status at retrieval, familiarity could not support associative recognition, indicating that unitization could not occur at retrieval. Why did this happen? We assumed it was mainly due to the false sense of knowing which led to a confusion between intact and rearranged compound words. The analysis of FAs also revealed that when we defined LOU based on the pairs' status at retrieval, there was higher familiarity-based FAs for compound words than for unrelated pairs.

In summary, this study showed that (1) the role of unitization in recollection-based associative recognition was moderated by UC. Under the consistent UC condition, unitization could improve familiarity-based associative recognition without affecting recollection-based associative recognition, while under the inconsistent UC condition, unitization could improve familiarity-based and recollection-based associative recognition simultaneously; (2) it was necessary for researchers to match the UC between original and rearranged pairs; (3) unitization could only occur at encoding but not at retrieval.

Materials and Methods

Participants

On the basis of effect size in preexperiment, we calculated the sample size on Gpower 3.1 (LOU × UC interaction effect size = 0.58, $\alpha = 0.05$, and $1-\beta = 0.95$, total sample size = 22). Thirty-five undergraduate students (14 males; mean age = 22.83 ± 3.20, range 18–32) participated in this experiment. All of them were native Chinese speakers with normal or adjusted-to-normal vision. Two participants were excluded from the analyses because of the outliers in FAs for "know" response, the remaining participants volunteered to participate in this study and were paid for ¥50/in total. The study was approved by the Ethics Committee of the Institute of Psychology, Capital Normal University.

Materials and procedures

The stimuli consisted of 144 compound words and 144 unrelated pairs were selected from Zheng et al. (2015a) and Dictionary of Modern Chinese Words in Common Use (Liu 1990). Ten participants who did not participate in main experiment rated the level of familiarity and unitization with five Likers scale, the bigger the number, the higher the LOU, and the higher the familiarity. The results showed that there was higher LOU for compound words than for unrelated pairs [4.83(.08) vs. 1.29(.07), $t = 31.27$, $P < 0.001$] and that the level of familiarity was equivalent for compound words and unrelated pairs [4.63(.14) vs. 4.73(.11), $t = -1.29$, $P = 0.23$] in encoding. Similarly, in retrieval, there was higher LOU for compound words than for unrelated pairs [4.85(.06) vs. 1.23(.03), $t = 47.61$, $P < 0.001$] and the level of familiarity was equivalent for compound words and unrelated pairs [4.68(.12) vs. 4.67(.13), $t = 0.28$, $P = 0.79$]. It was indicated that our materials were well matched.

During the study phase, the participants were required to learn compound words (e.g., "逻辑-运算" meaning "logical operation," "群众-关系" meaning "masses relationship," "宗教-信仰" meaning "religious belief") and unrelated word pairs (e.g., "池塘-公社" meaning "pool Commune," "巴黎-客厅" meaning "Paris parlor," "功夫-口红" meaning "Kong Fu lipstick"). These stimuli were randomly presented in white against a black background by Presentation software and on the left and right side of the center. A cross fixation was presented in central screen for 900 ~ 1100 msec and then word pairs were presented for 4000 msec, during which the participants needed to rate the LOU from 1 (low unitization) to 5 (high unitization) with 1/2/3/4/5 key in number pad, followed by another cross fixation. The word pairs were presented in a pseudorandom order to ensure that no more than three consecutive trials came from the same condition. The stimuli subtended a maximum visual angle of 7.36° × 1.47°.

During the retrieval phase, word pairs were divided into six subgroups: (1) compound-intact (studied compound words and tested old compound words, C–C–o, e.g., "religious belief"); (2) unrelated-intact (studied unrelated pairs and tested old unrelated word pairs, U–U–o, e.g., "Kong Fu lipstick"); (3) compound-rearranged-consistent (studied compound words and tested rearranged compound words, C–C–r, e.g., "logical relationship"); (4) compound-rearranged-inconsistent (studied compound words and tested rearranged unrelated word pairs, C–U–r, e.g., "masses operation"); (5) unrelated-rearranged-consistent (studied unrelated pairs and tested rearranged unrelated word pairs, U–U–r, e.g., "pool parlor"); (6) unrelated-rearranged-inconsistent (studied unrelated pairs and tested rearranged compound words, U–C–r, e.g., "Paris Commune"). Each trial began with a fixation cross presented randomly between 900 and 1100 msec, and then word pairs was presented for 2000 msec, during which the participants were required to make an "old/new" judgment. After that, an instruction of "remember (C) know (M)" was displayed for 2000 msec, during which the participants were instructed to respond "remember" if they could recollect some specific details about the studied word pairs or to respond "know" if they felt familiar to the word pairs, but could not recollect any details. In this study, "remember" and "know" responses were collected for both "old" and "new" pairs to assess the contribution of recollection and familiarity, because the "new" pairs were composed of two old components which had been learned in encoding. In addition, we also wanted to know which process could support false alarms. The experiment procedures are showed in Figure 4.

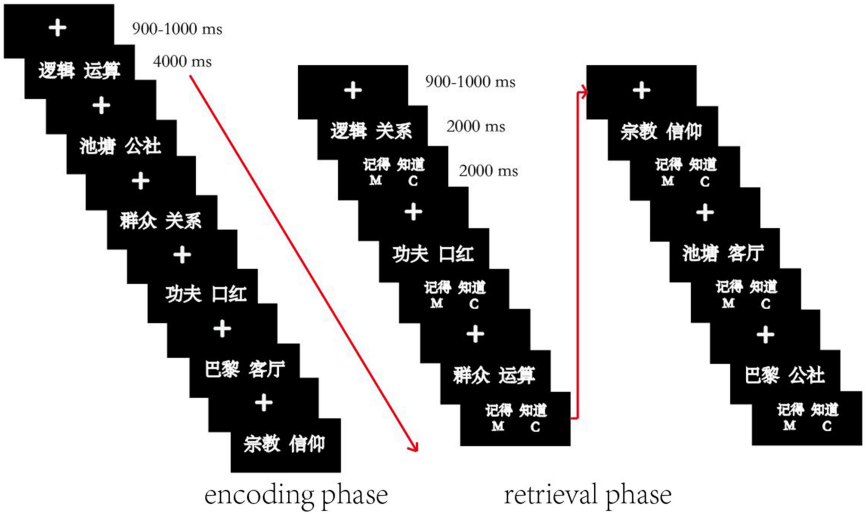

Figure 4. Time course of events in encoding and retrieval phase. In encoding, participants were instructed to rate the LOU of compound words and unrelated word pairs. In retrieval, participants had to discriminate old pairs form new pairs and reported remember or know judgments. The order of the retrieval conditions was: compound-rearranged-consistent, unrelated-intact, compound-rearranged-inconsistent, compound-intact, unrelated-rearranged-consistent, and unrelated-rearranged-inconsistent.

Data analyses

According to R/K paradigm, the participants were asked to respond "remember" when they could recollect any details, so the probability of correct "remember" response was used as the index of recollection [$hit_{(Remember)}$ = Recollection]. In contrast, they were asked to respond "know" when they felt familiar to the pairs but could not recollect any details [$hit_{(Know)}$ = Familiarity × (1 − Recollection)], the probability that a pair was familiar would be equal to the probability that it received a "know" response given it was not recollected [Familiarity(IRK) = $hit_{(Know)}$/(1 − Recollection)]. Because of the independence assumption of ANOVAs and the interdependence between familiarity and recollection, we could not compare familiarity and recollection directly. Therefore, we analyzed the overall, familiarity, and recollection results, respectively.

Before analyzing associative recognition, we first analyzed the hits for intact pairs, CRs for rearranged pairs, and FAs for rearranged pairs under each condition. Then, we examined the effect of LOU and UC on associative recognition based on the pairs' status at encoding. Overall associative recognition, recollection-based associative recognition, and familiarity-based associative recognition were calculated by $overall_{(hits)}$ minus $overall_{(FAs)}$, $R_{(hits)}$ minus $R_{(FAs)}$, and $IRK_{(hits)}$ minus $IRK_{(FAs)}$, respectively. Three ANOVAs were conducted to illustrate the effect of LOU and UC on overall, recollection-based, and familiarity-based associative recognition, respectively.

In addition, we examined the effect of LOU and UC on associative recognition based on the pairs' status at retrieval. This was very similar to the previous analyses, except for that the LOU factor of the pairs referred to its status at retrieval.

Competing interest statement

The authors report no conflict of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (31671127), the Beijing Municipal Commission of Education Key Program of Science and Technology (KZ201410028034) and the Beijing Advanced Innovation Center for Imaging Technology (BAICIT-2016018). We thank Roni Tibon for their experimental materials and Xiaohuan Li and Chenyuan Zhao for their research assistance.

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Received October 25, 2019; accepted in revised form November 22, 2019.