The Mechanism of Unitization in Facilitating Associative Memory: Familiarity and Recollection Processing

Authors: Liu Zejun, Liu Wei, Liu Zejun, Liu Wei

Date: 2022-05-26T14:15:20+00:00

Abstract

When two or more items are encoded in an integrated manner, familiarity can also support associative recognition—a viewpoint that has garnered substantial empirical support. However, disagreements persist regarding how integration influences both associative recognition and the recognition of individual items comprising the association. A review of existing research reveals that: (1) integration consistency serves as a crucial moderating factor in the relationship between integration and associative recognition; (2) limited cognitive resources and semantic relatedness between new and old items are important factors affecting the role of integration in item recognition; and (3) three theoretical accounts—the "item hypothesis," "schema hypothesis," and "elaborative processing hypothesis" —have been proposed to explain the underlying mechanism of integration. Future research should not only control for integration consistency but also compare the effect sizes of different integration methods and investigate the lifespan developmental trajectories of integration effects.

Full Text

The Mechanisms Through Which Unitization Promotes Associative Memory: Familiarity and Recollection Processes

Liu Zejun, Liu Wei
(College of Education, Shanghai Normal University, Shanghai 200234, China)

Abstract

The view that familiarity can support associative recognition when two or more items are encoded through unitization has received substantial empirical support. However, disagreements remain regarding how unitization affects asso-

ciative recognition and the recognition of individual constituent items. By reviewing existing research, we found that: (1) unitization congruence is a crucial factor moderating the relationship between unitization and associative recognition; (2) limited cognitive resources and semantic relatedness between new and old words are important factors influencing the effect of unitization on item recognition; and (3) three theoretical explanations may account for the mechanisms of unitization: the "item account,"the "schema account,"and the "semantic elaboration hypothesis." Future research should not only control for unitization congruence but also compare the magnitude of effects across different unitization methods and explore the lifespan developmental trajectory of unitization effects.

Keywords: Unitization, associative recognition, item recognition, familiarity, recollection

The human episodic memory system enables us to effectively encode, store, and retrieve past events and situations. As an important component of episodic memory, recognition serves as a key measure of memory performance. Dual-process theory posits that recognition judgments can be supported by two independent processes: familiarity and recollection. Familiarity refers to a sense of knowing for previously encountered items without retrieving specific detail information, whereas recollection enables retrieval of contextual details from the time of encoding (Mandler, 1980; Yonelinas, 2002; Yonelinas et al., 2010). Early research found that while both familiarity and recollection could support single-item recognition, associative recognition—the ability to judge whether relationships between items or between items and context had been previously encountered—could only be supported by recollection (Donaldson & Rugg, 1998; Rugg et al., 1998; Woodruff et al., 2006; Yonelinas, 1997, 2002). However, this view has been increasingly challenged over the past decade. Researchers have found that when two or more items are integrated into a new whole, familiarity can also support associative recognition (Ahmad & Hockley, 2014; Han et al., 2018; Li et al., 2019; Liu et al., 2020a; Parks & Yonelinas, 2015; Tibon et al., 2014a, 2014b; Zheng et al., 2015a). Graf and Schacter (1989) defined this operation as *unitization*. Based on the direction of association formation, Tibon et al. (2014b) distinguished between top-down unitization and bottom-up unitization. Subsequently, numerous behavioral studies (Ahmad & Hockley, 2014; Ahmad et al., 2014; Delhaye & Bastin, 2018a; Parks & Yonelinas, 2015; Robey & Riggins, 2017; Shao et al., 2016), electrophysiological studies (Bridger et al., 2017; Desaunay et al., 2017; Han et al., 2018; Hubbard, 2014; Kamp et al., 2016; Kriukova et al., 2013; Li et al., 2017, 2019; Lyu et al., 2017; Rhodes & Donaldson, 2007, 2008; Tibon et al., 2014a, 2014b; Wang et al., 2016; Zheng et al., 2015a, 2015b), fMRI studies (Bird, 2017; Borders et al., 2017; Haskins et al., 2008), amnesia patient studies (Giovanello et al., 2006; Kirwan et al., 2010; Mayes et al., 2002; Olsen et al., 2012; Quamme et al., 2007), and aging population studies (Ahamd et al., 2014; Badham et al., 2012; Bridger et al., 2017; Delhaye et al., 2018b, 2019; Naveh-Benjamin et al., 2003; Zheng et al., 2015b) have investigated the role of unitization in associative recognition and

its underlying processes. Relevant studies are summarized in Table 1.

1. The Effect of Unitization on Associative Recognition and Its Processing

As shown in Table 1, researchers have examined the effect of unitization on associative recognition and its processing by manipulating different unitization methods (top-down vs. bottom-up unitization), experimental materials (words, pictures, sounds, etc.), and assessment methods for familiarity and recollection (ROC curves, R/K procedure, and ERP components).

1.1 The Effect of Top-Down Unitization on Associative Recognition and Its Processing

In top-down unitization studies, researchers manipulate unitization levels by instructing participants to either integrate two semantically unrelated items into a new whole or encode them as two independent representations (i.e., generating associations during the experiment). Common methods include interactive imagery versus item imagery, and concept definition versus sentence fill-in (see Table 1 for relevant studies). Specifically, interactive imagery versus item imagery controls unitization by manipulating the mental representation of two items, whereas concept definition versus sentence fill-in controls unitization by artificially assigning meaning to the items. Taking "milk-car" as an example, in the interactive imagery condition, participants imagine a scene containing both milk and car in interaction (e.g., milk spilled on a car), whereas in the item imagery condition, they imagine each item separately without interaction. In the concept definition condition, researchers create a definitional sentence that encodes two unrelated items as a new whole (e.g., defining "milk-car" as a vehicle specifically designed for milk transportation), while in the sentence fill-in condition, researchers create a sentence frame into which the two items are inserted separately to form two independent representations (e.g., "He spilled milk onto the car").

Han et al. (2018) and Murray (2014) used semantically unrelated words as materials and manipulated unitization through interactive versus item imagery. Results showed better associative recognition performance in the interactive imagery condition compared to the item imagery condition. ERP assessments of familiarity and recollection contributions revealed that interactive imagery elicited a larger early frontal old/new effect (FN400 effect) related to familiarity processing, with no significant difference in the late left-parietal old/new effect (LPC effect) related to recollection between the two conditions. Robey and Riggins (2017) were the first to investigate the effect of unitization on associative recognition in school-aged children (6- and 8-year-olds), using simple line drawings of objects with colored borders (e.g., an apple drawing with a red border). In the interactive imagery condition, children imagined a red apple, while in the non-unitized condition, they encoded the drawing and border separately.

During retrieval, single images were presented, and children reported the border color using a three-point confidence rating. Results showed better associative recognition in the interactive imagery condition for both age groups, with more familiarity-based processing contributing to associative recognition compared to the non-unitized condition. These three studies consistently demonstrate that top-down unitization increases familiarity' s contribution to associative recognition. However, Shao et al. (2016) attempted to match associative recognition performance between interactive and item imagery conditions by reducing trial numbers (by half) and increasing study repetitions (doubled) in the item imagery condition, then examining how familiarity and recollection contributed to associative recognition under matched performance. Results showed that interactive imagery produced less familiarity-based and more recollection-based processing than item imagery. Based on this, Shao et al. (2016) proposed that unitization might reduce familiarity' s contribution to associative recognition. Tibon and Henson (2015) subsequently challenged this conclusion, arguing that the item imagery condition in Shao et al.' s study may have inadvertently involved unitized encoding. In their item imagery condition, participants judged which of two items was "cleaner," while in the interactive imagery condition, they rated the plausibility of a combined image. Tibon and Henson argued that participants might have used interactive imagery strategies even in the item imagery condition. Indeed, compared to interactive versus item imagery that relies on participants' spontaneous imagination, concept definition versus sentence fill-in manipulates unitization more explicitly and concretely, with less influence from participants' individual strategies.

Three behavioral studies using concept definition versus sentence fill-in found better associative recognition in the concept definition condition. Analyses of familiarity and recollection contributions showed that concept definition increased both familiarity and recollection contributions to associative recognition (Haskins et al., 2008; Parks & Yonelinas, 2015; Shao et al., 2016). In two dissertations, Hubbard (2014) and Murray (2014) used the same paradigm with ERPs to assess familiarity and recollection. Despite better associative recognition in the concept definition condition, no significant differences emerged between conditions in familiarity or recollection measures. Furthermore, Bader et al. (2010) and Kamp et al. (2016) using the same paradigm found equivalent associative recognition performance between concept definition and sentence fill-in conditions. Familiarity/recollection dissociations showed that the FN400 effect (familiarity) appeared only in the concept definition condition, while the LPC effect (recollection) appeared only in the sentence fill-in condition. Based on these results, Bader et al. (2010) and Kamp et al. (2016) argued that when familiarity is sufficient to support associative recognition, recollection becomes unnecessary. This finding offers promise for populations with impaired recollection (e.g., older adults, hippocampal patients, school-aged children with immature hippocampal development).

It is important to note that the same paradigm (concept definition vs. sentence fill-in) yielded different results, likely for two reasons. First, material construc-

tion: concept definition and sentence fill-in require researchers to create stimuli beforehand. While this ensures homogeneity, the novelty and artificial nature of materials may lead to individual differences in comprehension and acceptance, reflected in plausibility ratings during encoding (Kamp et al., 2016). These differences may contribute to divergent findings across studies. Second, measurement tools: behavioral studies using the "remember/know" procedure and ROC curves assess familiarity and recollection through hit and false alarm rates (Haskins et al., 2008; Parks & Yonelinas, 2015; Shao et al., 2016), whereas ERPs assess these processes by averaging amplitudes across individual trials. The former measures recognition outcomes based on familiarity and recollection, while the latter better captures processing dynamics and aligns with the consensus that familiarity operates earlier and faster than recollection (Liu et al., 2020b).

1.2 The Effect of Bottom-Up Unitization on Associative Recognition and Its Processing

Unlike top-down unitization that generates associations during encoding, bottom-up unitization manipulates unitization through inherent perceptual characteristics or intrinsic connections between items (i.e., pre-existing association properties in materials before the experiment), and can be divided into perceptual unitization and conceptual unitization. Perceptual unitization uses perceptual properties such as temporal relationships (simultaneous vs. sequential presentation) and sensory modalities (unimodal visual/auditory vs. cross-modal audiovisual) to manipulate unitization levels. Conceptual unitization relies on existing associative or semantic relationships between items. For example, common compound words (traffic-jam) and semantically/thematically/categorically related word pairs (violin-cello, violin-stage, violin-guitar) have higher unitization levels than unrelated word pairs (apple-hat) (see Table 1 for relevant studies).

Delhaye and Bastim (2018a), Giovanello et al. (2006), Liu et al. (2020a), and Zheng et al. (2015a, 2015b) manipulated unitization using compound versus non-compound words. Results showed that unitization might either not affect associative recognition performance (Delhaye & Bastim, 2018a; Giovanello et al., 2006; Liu et al., 2020a) or facilitate it (Zheng et al., 2015a, 2015b). Analyses of familiarity and recollection contributions revealed that unitization could increase familiarity processing, with recollection either remaining unaffected (Delhaye & Bastim, 2018a; Giovanello et al., 2006; Liu et al., 2020a) or increasing (Zheng et al., 2015a, 2015b). Greve et al. (2007) and Lyu et al. (2017) manipulated unitization using semantically related versus unrelated word pairs, finding that unitization increased familiarity' s contribution to associative recognition. Beyond verbal materials, some researchers investigated unitization effects on picture stimuli. Bridger et al. (2017) manipulated unitization through spatially plausible versus implausible picture pairs, while Lyu et al. (2015) used idiomatic versus non-idiomatic picture pairs, finding that unitization increased both familiarity and recollection contributions and improved associative recognition perfor-

mance. In contrast, studies by Delhaye et al. (2018b), Desaunay et al. (2017), Liu et al. (2021), and Tibon et al. (2014b) using semantically related versus unrelated picture pairs found that while unitization consistently increased familiarity and recollection contributions, it might either facilitate (Bridger et al., 2017; Liu et al., 2021; Tibon et al., 2014b) or not affect associative recognition performance (Delhaye et al., 2018b; Desaunay et al., 2017).

This review reveals that both top-down and bottom-up unitization can increase familiarity' s contribution to associative recognition, but substantial disagreement exists regarding unitization's effects on associative recognition performance and recollection. Specifically, 8 studies showed no effect on associative recognition performance, while 23 studies demonstrated facilitative effects. Fifteen studies found no effect on recollection' s contribution, 12 showed increased recollection contributions, and 4 even showed reduced recollection contributions. Why such divergent results? One intuitive speculation is that unitization methods may moderate these effects. Additionally, our analysis identified an uncontrolled extraneous variable across studies: whether unitization levels were matched between study and test stimuli. We next examine these two perspectives.

2.1 Comparing the Effects of Different Unitization Methods on Associative Recognition and Its Processing

Beyond examining single unitization methods, a few studies have compared the magnitude of effects across different approaches. Li et al. (2017) used compound and non-compound words combined with simultaneous versus sequential presentation to investigate two bottom-up methods (conceptual vs. perceptual unitization). Results showed that compound words yielded better associative recognition than non-compound words under both presentation modes, with non-compound words in simultaneous presentation showing better performance than non-compound words in sequential presentation. Familiarity/recollection analyses revealed significant FN400 effects (familiarity) for compound-simultaneous, compound-sequential, and non-compound-simultaneous conditions, but not for non-compound-sequential. No significant LPC differences emerged across the four conditions. Li et al. (2019) subsequently compared conceptual unitization (compound vs. non-compound words) with perceptual (modality) unitization (unimodal visual vs. cross-modal audiovisual). Results again showed better associative recognition for compound versus non-compound words in both presentation modes, with compound words eliciting significant FN400 and LPC effects regardless of modality, while non-compound words showed no such effects. These studies demonstrate that bottom-up unitization increases familiarity' s contribution, with conceptual unitization showing higher unitization levels than perceptual unitization.

Lu et al. (2020) first compared two top-down methods (interactive imagery vs. concept definition). Encoding tasks included concept definition, interactive imagery, and item comparison. Results showed better associative recognition

for interactive imagery than concept definition, with both outperforming item comparison. Familiarity/recollection analyses revealed significant FN400 effects for both concept definition and interactive imagery (with no difference between them), but not for item comparison. Based on equivalent old/new effects yet superior recognition performance for interactive imagery, Lu et al. (2020) concluded that interactive imagery may achieve higher unitization levels than concept definition.

Only Rhodes and Donaldson (2008) have compared top-down (compound vs. semantically related word pairs) and bottom-up (interactive vs. item imagery) unitization. Results showed equivalent associative recognition for compound-interactive imagery and compound-item imagery conditions, followed by semantically related-interactive imagery, with semantically related-item imagery showing the poorest performance. Familiarity/recollection analyses revealed larger FN400 and LPC effects for the first three conditions compared to semantically related-item imagery. Integrating behavioral and ERP findings, for compound words, interactive and item imagery showed equivalent recognition performance and equivalent FN400/LPC effects; for semantically related words, interactive imagery showed better recognition and larger FN400/LPC effects than item imagery. For interactive imagery, compound words showed better recognition than semantically related words, but equivalent FN400/LPC effects; for item imagery, compound words showed better recognition and larger FN400/LPC effects than semantically related words. Comparing the two high-unitization conditions, for stimuli with inherently high unitization (bottom-up), top-down unitization did not affect associative recognition or its processing; for experimentally created high-unitization conditions (top-down), bottom-up unitization facilitated recognition performance. This suggests bottom-up unitization may achieve higher levels than top-down unitization, consistent with unitization' s definition—integrating multiple items into a whole. Compared to top-down unitization that generates associations through instructions, bottom-up unitization formed through everyday co-occurrence naturally possesses higher unitization levels.

In summary, different unitization methods are comparable: conceptual unitization shows higher levels than perceptual unitization and interactive imagery, while interactive imagery may surpass concept definition. However, direct comparisons between conceptual unitization and concept definition, and between perceptual unitization and interactive imagery/concept definition, are lacking. Based on existing research, we predict conceptual unitization may exceed concept definition, and both interactive imagery and concept definition may surpass perceptual unitization in unitization level.

2.2 The Moderating Role of Unitization Congruence on the Relationship Between Unitization and Associative Recognition

Liu et al. (2020a) first proposed the variable of unitization congruence, referring to whether the unitization level changes between encoding and retrieval stimuli. For example, in bottom-up unitization, participants study high-unitization pairs (Greek-mythology, English-letter) and low-unitization pairs (Paris-living room, pond-commune) during encoding. At test, these words are recombined into new pairs (high-unitization: Greek-letter, Paris-commune; low-unitization: English-mythology, pond-living room). Compared to Greek-letter and pond-living room pairs where unitization levels remain unchanged, English-mythology and Paris-commune pairs show changed unitization levels. In top-down unitization, pre-experimentally unrelated stimuli have low unitization; encoding tasks differentiate high vs. low unitization conditions, and stimuli are recombined into new unrelated pairs at test. Thus, for low-unitization conditions, encoding-retrieval unitization levels remain unchanged, but for high-unitization conditions, they change. Due to difficulties matching encoding-retrieval unitization levels in high-unitization conditions, most researchers have not adequately controlled this variable (24 of 31 studies), with only 7 studies doing so. Among these, 4 studies forewent higher-unitization compound words in favor of less unitized semantically related stimuli to match encoding-retrieval unitization levels (picture pairs: Delhaye et al., 2018b; Desaunay et al., 2017; Liu et al., 2021; word pairs: Greve et al., 2007), providing new material selection strategies.

Delhaye et al. (2019) used categorically related and unrelated word pairs to examine how categorical relatedness at encoding and retrieval affected associative recognition. Results showed that both encoding and retrieval relatedness jointly determined recognition performance. When categorically related pairs were studied and recombined into unrelated pairs at test, performance was better than when recombined into related pairs. When categorically unrelated pairs were studied, recombination into related versus unrelated pairs at test yielded equivalent performance. This indicates that matching encoding-retrieval relatedness levels indeed affects how relatedness influences associative recognition. Reanalysis by matching status showed equivalent recognition for related and unrelated pairs under matched conditions (1.7 ± 0.87 vs. 1.42 ± 1.04), but better performance for related than unrelated pairs under mismatched conditions (2.21 ± 0.77 vs. 1.22 ± 1.07). However, Delhaye et al. (2019) did not further explore the processing mechanisms (familiarity and recollection).

Three studies using compound and non-compound words examined unitization effects while controlling encoding-retrieval unitization levels (Delhaye & Bastin, 2018a; Giovanello et al., 2006; Liu et al., 2020a). Due to material scarcity, Delhaye and Bastin (2018a) and Giovanello et al. (2006) had very few trials ($n1 = 22$, $n2 = 12$), with only Liu et al. (2020a) reaching 48 trials. Liu et al. (2020a) first introduced unitization congruence. During encoding, participants studied compound words (religion-faith, logic-operation, mass-relation)

and non-compound words (kung fu-lipstick, Paris-living room, pond-commune). At test, six pair types were presented: compound-old (studied compound, religion-faith), compound-recombined-congruent (studied compound, recombined compound, logic-relation), compound-recombined-incongruent (studied compound, recombined non-compound, mass-operation), non-compound-old (studied non-compound, same non-compound, kung fu-lipstick), non-compound-recombined-congruent (studied non-compound, recombined non-compound, pond-living room), and non-compound-recombined-incongruent (studied compound, recombined compound, Paris-commune). Participants made "old" judgments for old pairs and "new" judgments for recombined pairs, followed by remember/know judgments. Results showed a significant interaction between unitization and unitization congruence: when encoding-retrieval unitization levels were congruent, compound and non-compound words showed equivalent recognition performance; when incongruent, compound words showed better performance. Familiarity/recollection analyses revealed more familiarity for compound than non-compound words under congruent conditions, with no recollection difference; under inconcongruent conditions, compound words showed more familiarity and recollection. Our ongoing ERP study found equivalent recognition and LPC effects for compound and non-compound words under congruent conditions, but better recognition and larger FN400/LPC effects for compound words under incongruent conditions. The only discrepancy was the absence of significant FN400 effects under congruent conditions in our study. Examining Liu et al. (2020a) revealed that although compound words showed more familiarity than non-compound words under congruent conditions, familiarity' s contribution was minimal (0.15 ± 0.30 vs. 0.06 ± 0.24). We therefore propose that under congruent conditions, familiarity may not support associative recognition because old pairs and recombined-congruent pairs have similar pre-experimental familiarity, preventing discrimination. Under incongruent conditions, old pairs and recombined-incongruent pairs have distinct pre-experimental familiarity, facilitating discrimination. Consistent with this, our ERP results showed significant FN400 for compound words and reversed FN400 for non-compound words under incongruent conditions. For recollection, because compound words have stronger associations, participants could rely on individual constituent words to recall studied pairs. Under congruent conditions, although compound-old pairs showed more recollection than non-compound-old pairs, compound-recongruent pairs also showed more recollection than non-compound-recongruent pairs, resulting in equivalent LPC effects. Under incongruent conditions, compound-reincongruent pairs showed less recollection than non-compound-reincongruent pairs, yielding larger LPC effects for compound words. In summary, for bottom-up unitization, materials' inherent familiarity and associative strength determine familiarity and recollection contributions to associative recognition (Liu et al., unpublished data).

Integrating Delhaye et al. (2019), Liu et al. (2020a), and Liu et al. (unpublished data), we conclude that unitization congruence is a critical variable mod-

erating the relationship between unitization and associative recognition. When encoding-retrieval unitization levels are congruent, unitization neither affects recognition performance nor recollection' s contribution. When incongruent, unitization facilitates recognition performance and increases both familiarity and recollection contributions. This conclusion explains divergent findings in the literature and identifies the boundary condition for unitization' s facilitative effect: when high-unitization stimuli are recombined into low-unitization pairs, unitization enhances recognition by increasing familiarity and recollection.

3. The Effect of Unitization on Item Recognition and Its Processing

While the view that unitization facilitates familiarity' s contribution to associative recognition is widely accepted, most studies have overlooked an important question: How does unitization affect recognition of individual constituent items? Research on this topic is scarce and yields mixed results. The "benefits-only account"proposes that unitization promotes associative recognition without impairing item recognition, whereas the "benefits and costs account" suggests that unitization enhances associative recognition at the expense of item recognition (Liu & Guo, 2019).

Liu et al. (2020b) used compound and non-compound words, and Liu et al. (2021) used related and unrelated pictures to examine bottom-up unitization effects on item recognition. Results showed equivalent item recognition for compound and non-compound words (Liu et al., 2020b), but better item recognition for related than unrelated pictures (Liu et al., 2021). However, both studies found that high-unitization conditions (compound words, related pictures) elicited smaller LPC effects than low-unitization conditions (non-compound words, unrelated pictures), indicating that participants achieved equivalent or better recognition with less neural activity—supporting the benefits-only account. Pilgrim et al. (2012) manipulated unitization through interactive versus item imagery to examine top-down effects on item recognition. Although recognition performance was equivalent between conditions, interactive imagery elicited smaller FN400 effects. Pilgrim et al. (2012) concluded that unitization incurred costs (reduced FN400), supporting the benefits and costs account. However, we argue that although unitization reduced FN400 contributions, recognition accuracy remained equivalent. Achieving equal memory performance with less neural activity represents a facilitative effect, supporting the benefits-only account. Parks and Yonelinas (2015) manipulated unitization through concept definition versus sentence fill-in, finding better associative recognition for concept definition with equivalent item recognition between conditions. Familiarity/recollection analyses showed that concept definition increased both processes for associative recognition but left them unchanged for item recognition, supporting the benefits-only account.

Jin (2021) examined how bottom-up (Experiment 1: compound vs. unrelated word pairs) and top-down (Experiment 2: unitized vs. elaborative encoding) uni-

tization affected item and associative recognition in older and younger adults. Experiment 1 showed that bottom-up unitization did not affect younger adults' performance but improved older adults' item and associative recognition. Familiarity/recollection analyses for item recognition (recollection for associative recognition was not measured) revealed that for younger adults, compound words elicited smaller LPC effects than unrelated words, consistent with Liu et al. (2020b, 2021); for older adults, compound words elicited significant LPC effects while unrelated words did not, though the difference was not statistically significant. Experiment 2 similarly found that top-down unitization did not affect younger adults' item or associative recognition but impaired item recognition while facilitating associative recognition in older adults. Familiarity/recollection analyses for item recognition showed smaller FN400 effects for unitized than elaborative encoding in both age groups. LPC effects were equivalent for younger adults (consistent with Pilgrim et al., 2012) but absent for older adults. Overall, Jin' s (2021) findings support the benefits-only account for younger adults (both unitization types preserved item recognition) and for older adults in bottom-up unitization (improved both recognition types), but support the benefits and costs account for older adults in top-down unitization (enhanced associative recognition at the expense of item recognition).

We initially attempted to explain the benefits-only versus benefits and costs discrepancy from a limited cognitive resources perspective. Cognitive resources are finite, and associative encoding competes with item encoding for these resources, but the relationship is not purely zero-sum and depends on material properties. In top-down unitization, the lack of pre-existing associations requires allocating more resources to generate holistic representations, leaving fewer resources for item encoding, potentially impairing item recognition. Conversely, bottom-up unitization leverages existing associations without requiring additional resource expenditure for association generation, leaving sufficient resources for item encoding and thus preserving item recognition. This account explains older adults' results but seems inconsistent with younger adults' findings, possibly because older adults require more cognitive resources to generate associations (Badham et al., 2012), leaving fewer resources for item encoding. This is reflected in LPC effects: younger adults showed significant LPC for both unitization types, whereas older adults showed significant LPC only for compound words in bottom-up unitization, with no LPC in the other three conditions lacking pre-experimental associations.

When does unitized encoding impair younger adults' item recognition? Ahmad and Hockley (2014) used compound and non-compound words to examine unitization effects on both recognition types. Results showed better associative recognition but poorer item recognition for compound words, supporting the benefits and costs account. A key difference from other studies (Liu et al., 2020b, 2021; Pilgrim et al., 2012; Parks & Yonelinas, 2015) is that Ahmad and Hockley (2014) used two sets of new words: compound-new words (constituents of compound words) and non-compound-new words (constituents of non-compound words). False alarm analyses showed higher false alarms for compound-new than non-

compound-new words. Liu et al. (2021) similarly distinguished new pictures as semantically related lures versus unrelated new pictures, requiring participants to discriminate old/lure/new pictures (Experiment 3). Results showed better item recognition for related than unrelated pictures when discriminating old/new, but poorer performance for related than unrelated pictures when discriminating lure/old. These studies demonstrate that new stimulus properties affect unitization' s impact on item recognition, primarily through higher false alarm rates for semantically related new stimuli. In summary, limited cognitive resources and semantic relatedness between old and new stimuli may be important factors explaining the discrepancy between benefits-only and benefits and costs accounts.

4. Possible Theoretical Explanations for Unitization' s Effects on Associative and Item Recognition

Despite nearly a decade of research on unitization's effects on associative recognition, few studies have examined its underlying mechanisms. Parks and Yonelinas (2015) initially proposed that unitization might be a deep processing mechanism. In their Experiment 3, they directly compared unitization level and processing level effects on both recognition types. Results showed a dissociation: processing level facilitated both associative and item recognition, while unitization level only facilitated associative recognition. Familiarity/recollection analyses showed that processing level increased both processes for both recognition types, whereas unitization level only increased familiarity' s contribution to associative recognition. Based on these results, Parks and Yonelinas (2015) concluded that unitization is not deep semantic elaboration but may form a new holistic representation.

Tibon et al. (2018) first proposed the item account and schema account to reveal unitization' s mechanisms. The item account posits that familiarity only supports single-item recognition; if familiarity supports memory for relationships between multiple items, they must form a new single-item representation. The schema account proposes that when two semantically unrelated items are presented simultaneously with a semantic context applicable to both, the context provides a new structure (schema) that accommodates both items even without forming a pre-existing concept (e.g., items: sugar-towel; semantic context: sweet cloth). Exploiting the schema account' s key feature—generalizability across associations—Tibon et al. (2018) conducted three experiments to test the schema account. The experiments included: initial learning of unrelated word pairs (cloud-grass) under concept definition or sentence fill-in; relearning where studied words were rematched with either semantically related (moon-grass) or unrelated (tea-grass) new words; and final testing of relearning pairs (moon-grass, tea-grass). Tibon et al. (2018) predicted that if the schema account held, related pairs in the concept definition condition would benefit from generalization, showing better recognition than unrelated pairs (i.e., concept definition > sentence fill-in for related pairs, but no difference for unrelated

pairs). However, all three experiments showed equivalent recognition between concept definition and sentence fill-in for both related and unrelated pairs, contradicting the schema account. Does this mean unitization truly creates a new single-item representation (item account)?

We believe this question should be addressed by simultaneously examining unitization' s effects on both associative and item recognition. Based on the effects reviewed above (Section 1 for associative recognition, Section 3 for item recognition), unitization facilitates associative recognition without facilitating item recognition (Ahmad & Hockley, 2014; Liu et al., 2020b; Parks & Yonelinas, 2015; Pilgrim et al., 2012), contradicting the semantic elaboration hypothesis. Familiarity/recollection analyses consistently show that unitization increases familiarity' s contribution to associative recognition while reducing familiarity or recollection contributions to item recognition (Liu et al., 2020b, 2021; Pilgrim et al., 2012). That is, unitization increases familiarity for associations but decreases familiarity and recollectability for constituent items, supporting the item account. Liu et al. (unpublished data) compared ERP amplitudes for compound and non-compound words during both encoding and retrieval. Results showed that compound words always elicited more positive amplitudes than non-compound words (300-800 ms, right frontal and bilateral parietal regions), regardless of whether they were studied or recombined, consistent with holistic processing in Tu et al. (2017). We therefore speculate that holistic encoding necessarily occurs early in unitization (especially bottom-up), supporting the item account. However, theoretical explanations for unitization mechanisms remain in early stages, primarily inferring encoding processes from retrieval results. Future research requires more sophisticated designs.

5.1 Future Research Directions

First, although unitization' s facilitation of familiarity in associative recognition is widely accepted, disagreement persists regarding its effects on associative recognition performance and recollection. Unitization congruence is a key factor contributing to this disagreement. Constrained by material selection and associative memory load, most studies have not adequately controlled this variable. Three studies examining it demonstrate that unitization' s effects are clearly moderated by congruence (Delhaye et al., 2019; Liu et al., 2020a; Liu et al., unpublished data). Therefore, previous conclusions about unitization' s effects should be generalized cautiously, and future research should incorporate this variable for more accurate understanding of unitization effects. Particularly for top-down unitization, material properties prevent matching encoding-retrieval unitization levels in high-unitization conditions. Could related word pairs help simultaneously examine top-down unitization, bottom-up unitization, and unitization congruence effects? For example, encoding could include semantically related word pairs, concept definition, and sentence fill-in conditions; at test, related pairs could be recombined into related-recombined-congruent and related-recombined-incongruent pairs, while concept definition and sentence

fill-in conditions could include concept-recombined-related, concept-recombined-unrelated, sentence-recombined-related, and sentence-recombined-unrelated conditions. This design would allow direct comparison of concept definition versus conceptual unitization and provide preliminary estimates of congruence effects on top-down unitization.

Second, most research has focused on single unitization methods rather than comparing two or more approaches, leaving results from different methods independent and lacking direct comparison. Li et al. (2017, 2019) examined effects of simultaneous vs. sequential and unimodal vs. cross-modal presentation on compound and non-compound word recognition, showing higher unitization levels for conceptual than perceptual unitization. Rhodes and Donaldson (2008) compared conceptual unitization (compound vs. non-compound) with top-down unitization (concept definition vs. sentence fill-in), finding higher unitization levels for the former. Lu et al. (2020) directly compared two top-down methods (interactive imagery vs. concept definition), suggesting higher unitization levels for interactive imagery. Although these four studies examined different unitization levels, no research has directly compared conceptual unitization vs. interactive imagery, or concept definition/interactive imagery vs. perceptual unitization. Determining the relative positions of these methods on a unitization continuum would enable more direct comparison and prediction of facilitation magnitudes, helping select optimal strategies to improve memory.

Finally, research has primarily used healthy young adults (with intact familiarity and recollection) or older adults (with intact familiarity but impaired recollection), with less investigation of school-aged children, adolescents, or middle-aged adults. What is the lifespan developmental trajectory of unitization effects? Based on current knowledge, we speculate that familiarity and recollection may follow developmental patterns similar to fluid and crystallized intelligence. Shaped by both knowledge experience and brain maturation, familiarity develops well in early childhood and approaches maturity by adolescence, potentially showing steady growth throughout life. Recollection develops later than familiarity, being difficult to rely on for new associative learning in early childhood (Robey & Riggins, 2017). With brain development, recollection rapidly improves during adolescence, matures, then declines in older adulthood with hippocampal atrophy and gray matter reduction (potentially showing an inverted U-shaped trajectory). Combining these developmental patterns, future research should examine the lifespan trajectory of unitization' s facilitative effects to determine strategy applicability for specific populations.

5.2 Research Significance

Research on unitization' s facilitative effects first emerged in studies of older adults, who show markedly poorer associative recognition than younger adults —a phenomenon termed age-related associative memory deficit. Studies using compound vs. non-compound words (Ahamd et al., 2014; Zheng et al., 2015b), categorically related vs. unrelated pairs (Delhaye et al., 2018b), and semantically

related vs. unrelated pairs (Naveh-Benjamin et al., 2003) found that whereas older adults showed poorer associative recognition than younger adults under low-unitization conditions, they showed equivalent or even better performance under high-unitization conditions. Badham et al. (2012), Bridger et al. (2017), and Delhaye et al. (2019) also found that younger adults outperformed older adults in both high- and low-unitization conditions, but the difference was significantly smaller under high-unitization conditions. These findings demonstrate that unitization can mitigate age-related associative memory deficits, offering a new approach to addressing upcoming aging challenges in China.

Furthermore, top-down unitization is essentially no different from the chunking strategies we use in daily learning—an effective but often unconscious learning strategy. Particularly for populations with limited prior knowledge or for unrelated information lacking intrinsic connections, unitization is highly effective for improving memory (Robey & Riggins, 2017). For example, when primary and secondary students (a population with limited prior knowledge) learn ancient poetry or idioms (“半亩方塘一鉴开，天光云影共徘徊” [a half-acre square pond opens like a mirror, with light and cloud shadows shimmering]; “米珠薪桂” [rice as precious as pearls, firewood as expensive as cassia]), the words lack direct connections before learning. Students can use interactive imagery (imagining the poetic scene) to understand the verse, or concept definition (interpreting the idiom’ s meaning) to understand “米珠薪桂.” In short, thoroughly understanding this strategy’ s applicable conditions and internal processes can help us select appropriate encoding strategies for special populations (older adults with impaired recollection, amnesic patients, young school children) or specific tasks (multiple-choice/judgment questions relying on familiarity; short-answer/essay questions relying on recollection), thereby applying laboratory research to daily life to improve knowledge acquisition more targeted and efficiently.

Finally, beyond using unitization alone, combining it with other strategies such as repeated study, retrieval practice (testing), or distributed learning could develop more ecologically valid learning methods. For example, combining unitization with retrieval practice, our ongoing study has participants learn compound and non-compound words during initial study (bottom-up unitization), then re-study half the words and practice retrieval (using cued recall) for the other half during restudy, followed by an associative recognition test after two days. Results show that compound words outperform non-compound words in both restudy and retrieval practice conditions, but the difference is significantly smaller in the retrieval practice condition. Moreover, compound words show equivalent recognition in both conditions, whereas non-compound words show better recognition in retrieval practice than restudy. This research simultaneously examines unitization and retrieval practice effects from both encoding and retrieval perspectives, approximating real-world learning patterns and holding both theoretical and practical significance. Future research should further explore combinations of unitization with other strategies to develop more efficient and ecologically valid learning methods.

In summary, both top-down and bottom-up unitization can facilitate familiarity' s contribution to associative recognition without impairing item recognition, supporting the benefits-only account and demonstrating that unitization is an effective learning strategy for improving associative memory. Specifically: (1) unitization' s effects on associative recognition are moderated by unitization congruence—facilitating performance when high-unitization stimuli are recombined into low-unitization pairs; (2) unitization' s effects on constituent item recognition are influenced by both limited cognitive resources and semantic relatedness between old and new stimuli; and (3) despite a decade of research, unitization' s mechanisms remain unclear, with three possible theoretical accounts (item, schema, and semantic elaboration hypotheses), though current evidence seems to favor the item account. Finally, we look forward to examining unitization' s effects in special populations and its lifespan developmental trajectory, aiming to bridge laboratory research and everyday learning.

Note: Figure translations are in progress. See original paper for figures.