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The importance of unitization for familiarity-based learning

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Abstract

It is often assumed that recollection is necessary to support memory for novel associations, whereas familiarity supports memory for single items. However, the levels of unitization (LOU) framework assumes that familiarity can support associative memory under conditions in which the components of an association are unitized (i.e., treated as a single coherent item). In the current study we test two critical assumptions of this framework. First, does unitization reflect a specialized form of learning or is it simply a form of semantic or elaborative encoding, and, second, can the beneficial effects of unitization on familiarity be observed for across-domain associations or are they limited to creating new associations between items that are from the same stimulus domains? Unitization was found to increase associative recognition but not item recognition, it affected familiarity more so than recollection, it increased associative but not item priming, and it was dissociable from levels of processing effects. Moreover, unitization effects were found to be particularly effective in supporting face-word and fractal-sound pairs. The current results indicate that unitization reflects a specialized form of learning that supports associative familiarity of within- and across-domain associations.

Keywords

unitization; associative recognition; recollection; familiarity

Understanding how we form new associations is one of the core questions that has dominated memory research since the time of Ebbinghaus. One effective strategy for forming new associations is to ‘unitize’ or ‘chunk’ the items such that they are treated as a single coherent item rather than as two separate items that are simply linked together in memory (Graf & Schacter, 1989; Yonelinas, 1997; Yonelinas, Kroll, Dobbins, & Soltani, 1999; Gobet et al., 2001). A growing body of research from behavioral, neuropsychological, electrophysiological and neuroimaging studies has indicated that unitization is particularly important in forming memories that can be supported by subsequent familiarity-based recognition responses as compared to recollection-based responses (e.g., Quamme, Yonelinas, & Norman, 2007; Haskins, Yonelinas, Quamme, & Ranganath, 2007; Rhodes & Donaldson, 2007). However, this research is controversial because the scientific construct of

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unitization is not yet well understood. That is, it is not clear how unitization differs from other theoretical constructs such as memory strengthening or levels of processing, and there is debate about whether unitization can be effectively applied to a broad set of materials or whether it is only useful in forming associations between items that are from the same stimulus type or processing domain. In the current paper, we aim to clarify the nature of unitization and its effects on familiarity by determining how it differs from levels of processing effects and determining whether it is domain limited.

We address the controversy by first clarifying how the construct can be used and applied to empirical studies of memory, and we review the existing empirical support for the approach. We then consider the two main criticisms of this approach and report on a series of experiments designed to address both of these challenges. The first is that unitization may simply reflect a memory strengthening or levels of processing effect, and thus it is not specific to promoting associative familiarity. If this is true then it suggests that unitization is an unnecessary construct, at least within studies of recognition, and that it can be replaced with older better understood constructs such as simple memory strengthening or levels of processing. The second criticism is that effects of unitization on familiarity only apply to a very restricted set of conditions in which the materials are from the same stimulus types or processing domains (e.g., Mayes, Montaldi, & Migo, 2007). Determining the conditions over which unitization is effective is essential in determining the scientific utility of this construct.

Associative Recognition and Dual Process Models

In recognition memory, dual process models posit that overall performance reflects the contribution of recollection and familiarity (e.g., Atkinson & Juola, 1974; Jacoby, 1991; James, 1890; Mandler, 1980; Yonelinas 1994; but see Gillund and Shiffrin, 1984; Dunn, 2004). Recollection reflects the retrieval of episodic information about a past event whereas familiarity reflects the assessment of a quantitative memory strength signal. Behavioral research (see Yonelinas, 2002 for a review), event-related potential (ERP) research (e.g., Rugg & Curran, 2007), neuroimaging research, and lesion and animals studies (e.g., Eichenbaum, Yonelinas, & Ranganath, 2007; Aggleton & Brown, 1999) have supported the distinction between recollection and familiarity.

Early dual process theories of recognition assumed that tests of associative recognition rely on recollection, whereas tests of item recognition rely on a combination of recollection and familiarity (e.g., Mandler, 1980). That is, in associative recognition tests, subjects are required to remember which items were previously paired together, and so recollection of qualitative information about the study event is particularly useful in supporting this discrimination whereas familiarity is thought to be unhelpful because all items at test should be equally familiar. In contrast, in item recognition, which requires subjects to distinguish between studied and novel items, performance can rely on recollection, but it can also rely quite heavily on familiarity because the studied items are expected to be more familiar on average than new items.

The levels of unitization framework

In contrast to earlier models, we have argued that familiarity *can* contribute to accurate associative recognition judgments, when pairs of items are unitized (i.e., treated as a single item rather than as a pairing of two separate items; Parks & Yonelinas 2009; Quamme, Yonelinas, & Norman, 2007; Yonelinas, Kroll, Dobbins, Soltani, 1999; Yonelinas, Aly, Wang, & Koen, 2010). The core assumption underlying this approach is that the familiarity of a test item can be used to support familiarity-based recognition, whereas recollection serves to retrieve associations between items or between an item and its episodic context. As such, familiarity should not be particularly useful in supporting memory for arbitrary associations between two separate items, unless individuals treat the pair as a single item (or unit) rather than as two separate items. When a pair of items is encoded as a single item then the newly encoded item can become familiar and this can be useful in discriminating between studied pairs and re-arranged pairs.

Whether a pair of items will be encoded as a single unit or as two separate items will depend critically on the manner in which the items are processed during encoding. This in turn will be influenced by the individual's goals and encoding strategies as well as by their past experience with the specific materials. For example, when asked to remember the arbitrary word pair CLOUD-LAWN, one might adopt a unitization strategy in which the two items are fused to create a single coherent item such as "A CLOUD-LAWN is a yard used for sky-gazing". In this way, the word pair is no longer an arbitrary association between two separate items but rather it becomes an item in its own right. Alternatively, one might use a strategy of encoding the items such that they are related to one another but they are not treated as a single item, such as "He watched the CLOUD float by as he sat on the LAWN". The latter approach is still quite elaborative and can reflect a very effective encoding strategy, but the word pair is less unitized in the sense that the individual words are processed largely independently of one another.

We have used the term levels of unitization (LOU) to refer to the idea that there is a continuum along which associations can be unitized. At the lower end of the continuum, two items may be treated as two separate objects, and the only way in which they are associated is that they have occurred in the same episodic context. At the higher end of the continuum, the two items may not even be perceived as two separate items at all, but rather are processed as a single coherent entity or object. We doubt that either extreme exists in a pure form and therefore refer to higher and lower unitized associations or high and low unitization strategies[1]. The construct, as such, is a relative one, in the sense that there is no absolute level of unitizing that is required before one would call a pair unitized. Rather conditions can be contrasted that vary in the degree to which the components of the association are treated a single or separate units (e.g., as two separate words vs. as a compound word).

[1]It should also be noted that whether associations are processed as single units or as separate items will also be influenced by the individual's prior experience with those types of materials. For example, the word pair "CELL-PHONE", may have been treated as an arbitrary association in the 1950s, but it is sure to be treated as a single unit today. Thus, existing compound words and common phrases (e.g., traffic jam) are more likely to be unitized than new word pairs (e.g., Giovanello, Keane, & Verfaellie, 2006; Rhodes & Donaldson, 2007). Our main focus, however, has been on the utility of unitization in learning new arbitrary associations.

Evidence that unitization allows familiarity to support associative recognition comes from a number of behavioral, ERP, neuroimaging and patient studies using a range of different methods to manipulate levels of unitization. For example, in a behavioral ROC study of associative recognition, participants studied faces and were later tested with intact faces and rearranged faces in which rearranged faces consisted of the eyes, nose, and mouth of one studied face with the hair and shoulders of a different studied face (Yonelinas et al. 1999). The key manipulation was whether the faces were studied and tested in their upright orientation or upside down. Face processing research has demonstrated that faces are processed holistically when upright, but as the conjunction of a number of different features when inverted (e.g., for review see Searcy & Bartlett, 1996). Thus, the associations between different facial features should be highly unitized when presented upright, but should be less unitized when inverted. Associative recognition was tested by presenting old and rearranged faces and requiring subjects to indicate their recognition confidence, which was used to plot ROCs and derive estimates of recollection and familiarity. The ROC method involves plotting hits against false alarms cumulatively across levels of response confidence and fitting that to a nonlinear function to derive parameter estimates of recollection (i.e., y-intercept) and familiarity (i.e., degree of curvilinearity; for detailed discussion of the method see Yonelinas 1994; Parks & Yonelinas, 2007). The results of that study showed that when faces were upright, familiarity contributed significantly more to the associative recognition decisions than when faces were upside down, indicating that unitization promotes familiarity-based associative recognition.

Several other studies have examined unitization by examining associative recognition ROCs for random word pairs using a different unitization manipulation (e.g., Haskins et al., 2008; Parks & Yonelinas, 2009; Quamme et al., 2007). For example, in one study (Haskins et al.), random word pairs were encoded under high unitization conditions in which subjects encoded them by treating them as novel compound words (e.g., CLOUD-LAWN: A yard used for sky-gazing). In contrast, in a low unitization condition the words were treated as separate items such that the meanings of the two words remained relatively separate (e.g., He watched the CLOUD float by as he sat on the LAWN). Parameter estimates showed that high unitization led to a significant increase in familiarity estimates but did not affect recollection (for similar results also see Parks & Yonelinas, 2009; Quamme et al., 2007). Similar effects of unitization have been found in tests of source memory (e.g., was the word studied earlier in red or green?), where familiarity estimates are greater when items and sources were encoded as a single unit (e.g., the ELEPHANT was RED because it had a sunburn) compared to when items and sources were encoded as different objects (e.g., the ELEPHANT stood by the RED stop sign; Diana et al., 2008; Diana et al., 2011).Results from studies using methods other than the ROC methods of estimating recollection and familiarity (e.g., a familiarity-only procedure (Quamme et al. 2007) and a second-choice procedure (Parks & Yonelinas, 2009)) have led to similar conclusions about the effects of unitization on familiarity, indicating that these conclusions about unitization are quite general.

Evidence from implicit memory studies also indicates that unitization facilitates familiarity of associations by forming fused representations. Prior work has shown that fluent processing can support both familiarity-based recognition and implicit memory (e.g., Wang

& Yonelinas, 2010; 2012; Wang, Ranganath, & Yonelinas, 2014;Wang, Lazzara, Knight, Ranganath, Yonelinas, 2010; but see Voss, Lucas, & Paller, 2010) and studies have shown that priming for associative information can be facilitated by high-unitization conditions, similar to the effects on familiarity. For instance, Graf and Shacter (1985) found that associations between unrelated words could be primed, but only when those words were elaborately processed in a sentence-generation task. Thus, priming of associations was shown to depend on the integration of the words. Later work showed that stimuli unitized pre-experimentally could have similar effects. Schacter and McGlynn (1989) compared American and British idioms(e.g., sour grapes and curtain lecture, respectively) expecting that American subjects would have unitized representations of the American idioms and not of the British idioms. They found associative priming for American idioms regardless of how they were processed at study but only found priming of British idioms when they were processed in the context of a definition (i.e., a high-unitization condition).

Several electrophysiological studies also indicate that unitization increases associative familiarity (Pilgrim, Murray, & Donaldson, 2012; Bader, Mecklinger, Hoppstadter, & Meyer, 2010; Jager, Mecklinger, & Kipp, 2006; Kounios et al., 2001; Rhodes & Donaldson, 2007, 2008; Diana, et al., 2011). For example, Diana et al. found that unitization increased the amplitude of the ERP correlate of familiarity when items were unitized with their source. In addition, manipulating unitization with pre-experimentally high- and low-unitization phrases (e.g., traffic jam versus cereal bread, respectively), Rhodes and Donaldson (2007; 2008) found the ERP correlate of familiarity for unitized word pairs, but not for other (non-unitized) pairs.

Studies of amnesic patients have also shown that unitization facilitates familiarity-based associative memory. For example, if unitization enables familiarity to support associative recognition, then unitization should attenuate the associative memory impairments of amnesics who have severe recollection deficits but relatively spared familiarity. This prediction was tested by Quamme et al. (2007) who showed that patients with selective deficits in recollection had pronounced associative recognition deficits when the encoding conditions did not promote unitization, but they showed relatively preserved associative memory when encoding conditions promoted unitization. In contrast, patients with larger lesions and deficits in both recollection and familiarity showed pronounced impairments in associative memory regardless of the encoding conditions. Importantly, in the control subjects performance was matched for the high and low-unitization conditions, so it is not the case that unitization simply led to stronger memories. Similar findings of relatively preserved associative memory in amnesics after high- compared to low-unitization encoding have also been observed in the source memory for color paradigm (Diana et al., 2010). In addition, Giovanello, Keane, and Verfaellie (2006) found that amnesics' associative recognition memory impairments were significantly reduced if the word pairs had preexisting associations, and thus presumably were more easily unitized than random word pairs.

Finally, converging evidence that unitization promotes familiarity-based recognition is also provided by neuroimaging studies. For example, unitized encoding of word pairs is associated with increased perirhinal cortex activation during encoding (one of the putative substrates of familiarity) compared to encoding that promoted processing of the individual items (Haskins et al., 2008), and activation in this region was directly related to accurate associative memory for the unitized pairs, suggesting that unitization facilitates familiarity for associations. Moreover, Diana et al. (2010) found perirhinal cortex activity at test correlated with source recognition accuracy in the high- but not low-unitization conditions while hippocampal and other recollection-related activity was found not to differ across these conditions.

The Current Experiments

Overall, unitization appears to reflect a critical learning mechanism by which familiarity is able to support new associative learning. However, the existing literature raises two critical questions about the process of unitization.

First, does unitization reflect a specialized form of learning or is it simply a form of semantic or elaborative encoding?

We have assumed that unitization is distinct from semantic elaboration or simple memory strengthening in the sense that it is expected to fuse items together to create new representations, and it is this new representation that supports familiarity for the association. In previous studies though, the high-unitization conditions may have involved more elaborative semantic processing than the low-unitization conditions (e.g., processing a new compound word may lead to deeper or more semantic processing than reading a sentence that includes those two words, or imagining an object in a color may be more meaningful than associating an object with a colored object). Although a number of prior studies have controlled for the overall effectiveness of encoding by balancing overall memory performance across conditions (e.g., Quamme et al., 2007; Diana et al., 2008), thus ruling against simple strength accounts of the results, differences in levels of semantic processing may still be responsible for the observed unitization effects.

In the current set of experiments we tested whether unitization was specialized in influencing associative familiarity by first looking to see if unitization led to a general increase in memory or whether it was restricted to associative recognition (Experiment 1). To the extent that unitization creates a new unit from a pair of items, rather than simply strengthening or elaborating those items, we expected unitization to preferentially increase associative recognition over item recognition. In contrast, if unitization reflects a general elaboration effect then it should benefit item and associative recognition in similar ways. In addition, ROC estimates of recollection and familiarity were examined in order to determine whether unitization preferentially increased familiarity in the associative test over the item test. We did not have strong predictions about the effects of unitization on recollection, however, based on previous studies we expected that recollection would not greatly benefit from unitization when compared to elaborative control conditions (e.g. Diana et al., 2008; Haskins et al., 2008).

To further test the specificity of the unitization effect to associative rather than item memory, we assessed implicit memory for associations and items (Experiment 2). If unitization fuses items together to create new representations, then we expect that it should preferentially improve implicit memory for associative rather than item information. Prior studies have indicated that familiarity is related to implicit memory (e.g., Wang et al., 2010), and thus we expected that associative priming should also benefit from unitization. Previous studies of associative implicit memory have shown significant associative priming on stem completion and free association measures when items are unitized by relation (e.g., highly related words like buttoned-shirt or idioms like small potatoes) or by processing strategies such as sentence generation and idiom definitions (Graf & Schacter, 1985; Schacter & McGlynn, 1989). However, whether the unitization manipulations that have been shown to affect associative familiarity also affect associative implicit memory is unknown. In addition, whether the unitization effects are selective to associative priming rather than item priming is also unknown. In the present study we used a lexical decision priming task for compound words that allowed us to examine both associative and item priming in the same task (e.g., Goshen-Gottstein, Moscovitch, & Melo, 2000). We expected that unitization would affect implicit memory in ways similar to familiarity: specifically, that unitization would increase associative priming but would not greatly affect item priming.

To test the claim that unitization was more than simply semantic processing we directly contrasted the effects of levels of semantic processing and levels of unitization on item and associative recognition (Experiment 3). Whereas levels of processing should affect both associative and item recognition, we expected unitization to affect associative rather than item recognition. Additionally, unitization should have its largest effects on associative familiarity rather than recollection, whereas semantic processing should affect both familiarity and recollection (see Yonelinas, 2002).

Second, are the beneficial effects of unitization on familiarity limited to creating new associations between items that are from the same stimulus domains?

We have argued that unitization can be determined by the way in which the subject processes the incoming stimuli (e.g., as a compound word or as two separate words). Thus, the unitization process is expected to be capable of operating at a fairly abstract level. As such, one would expect that it should be possible to unitize across different stimulus modalities or domains such as words and faces or visual and auditory stimuli. However, the stimuli might impose critical boundary conditions on the types of associations that can be supported by unitization. For example, it has been proposed that recollection is necessary for retrieving across-domain pairs, whereas familiarity supports associative memory primarily for items that are from similar processing domains (e.g., Mayes et al., 2007; also see Shimamura & Wickens, 2009; Staresina &Davachi, 2008). As such, a critical limitation of unitization may be that it is only effective at creating unitized representations of items that are from within single stimulus domains. For example, Mayes et al. (2007) argued that the hippocampus, which supports recollection, was critical for binding across stimulus domains such as faces and words, whereas the perirhinal cortex, which supports familiarity, was capable of supporting associative memory for within domain associations such as word-word or face-face associations.

Whether unitization is limited to within-domain associations has never been directly tested, and the indirect evidence that has been collected so far leads to somewhat mixed conclusions. On one hand, two studies of amnesics have indicated that patients with hippocampal lesions exhibit more of a deficit for face-word than face-face associative recognition (Mayes et al., 2004; Vargha-Kadhem et al., 1997). Although unitization was not directly manipulated in those studies, the relatively preserved associative performance for the face-face conditions may have arisen if the subjects unitized the face pairs and thus relied more on familiarity. However, in a similar study, Turriziani et al. (2004) found that hippocampal patients were similarly impaired on face-face and face-word associative recognition. Moreover, behavioral studies of healthy subjects have shown that familiarity as estimated using ROC and remember/know methods is higher for across-domain pairs (face-word) than within-domain pairs (face-face; e.g., Harlow et al., 2010; see also Park & Rugg, 2011), the opposite of what might be expected if familiarity were limited to within-domain associations. However, none of these studies have directly examined the effects of unitization on associative familiarity of these different types or materials, and thus we don't know whether the beneficial effects of unitization are restricted to within- or across-domain associations.

To test whether unitization effects on familiarity are limited to within-domain associations we examined the effects of unitization on face-face and face-word associations (Experiment 4), and on fractal-fractal and fractal-sound associations (Experiment 5). If unitization is limited to increasing associative familiarity of similar domain associations then the effects of unitization should be observed only for within-domain associations.

Experiment 1: Does unitization affect item and associative recognition in the same way?

The goal of Experiment 1 was to directly compare unitization effects on item and associative recognition tests. Although many studies have examined unitization effects on associative and source recognition, few have investigated item recognition and none have directly compared effects on the two kinds of tests. If unitization enhances familiarity specifically for associations—that is, it transforms associations into items—then it should benefit associative recognition tests more so than item recognition tests. We adopted the high- and low-unitization conditions from Quamme et al. (2007) which were designed specifically to encourage processing of the pair as two associated items (low unitization) or as a single unit (high unitization). The low unitization condition consisted of processing two words in the context of a sentence frame and judging the degree to which each word fit in that sentence, whereas in the high unitization condition the words were combined into a single concept by way of a novel definition of the pair. We expected that the high-unitization condition would increase associative recognition more so than item recognition, and that an examination of the parameter estimates would show that unitization increased familiarity in the associative test more than in the item test. Based on prior work we did not expect recollection to be greatly impacted by the unitization manipulation.

Method

Participants—Forty-four undergraduate students from the University of California at Davis participated for course credit (mean age 20.3 years, 26 women and 18 men) and were randomly assigned to the high- or low-LOU conditions.

Materials—Stimuli from Quamme, et al. (2007) were used for this experiment. They included a set of 500 nouns between 4–6 letters in length, with a mean frequency of 68.4 based on the Kucera and Francis (1967) norms. Quamme et al. randomly matched words to create unrelated cue – target pairs (e.g., *shame ribbon*); pairs that appeared related in any way were re-matched until all pairs were judged to be unrelated. We divided those pairs into 4 frequency-matched lists of 60 pairs (average frequency across lists for cue and target, respectively, 68.9 and 69.1); the remaining words were used as practice items and buffers in the study phase. For each subject, three lists were used in the study phase and target words from pairs in the remaining list were used as foils in the item recognition test. Two of the studied lists were used to create the associative recognition test; one list was used in its intact form and the other was used to create the rearranged items. The target (right-hand) words in the third studied list served as old items on the item recognition test. The lists were rotated such that each list occurred equally often in each test and study-status (old/new or intact/rearranged) conditions across participants. Order of test was also counterbalanced such that half the subjects took the item test first and half took the associative test first. Overall, subjects studied 180 target pairs, six buffers (three primacy, three recency), and were tested on 120 pairs in the associative test (60 intact, 60 rearranged) and 120 items in the item test (60 old, 60 new).

A fictional definition and a sentence frame were developed for each word pair by Quamme et al. (2007). The fictional definitions (for the high LOU condition) describe the meaning of the novel “word” formed by treating the word pair as a compound word. For example, the definition for *shame ribbon* is *An embarrassing ornament worn as punishment*. The sentence frames (for the low LOU condition) were constructed with two blank spaces such that the first word fit plausibly in the first space, and the second word fit plausibly in the second space; the sentence frame for *shame ribbon* was *Feeling full of ___, he untied the ____*.

Procedure—The experiment was conducted with groups of up to four participants at a time and programmed using E-Prime 1.0 (Psychology Software Tools, 2001). Subjects read instructions on their computer monitors before each task; experimenters reiterated the important points and checked for general understanding before subjects began each task. Study condition (high or low-LOU) was a between-subjects manipulation. The type of test (associative versus item recognition) was a within-subjects manipulation.

At encoding a definition (high LOU condition) or a sentence frame (low LOU condition) was presented at the top of the screen for 1500 ms in yellow font before the pair was presented below it in white font. The definition or sentence, the pair, and a four-point scale remained on the screen until the subject responded. In the high LOU condition, participants rated how well the definition made sense of the pair as a compound word on a 1 (Bad definition) to 4 (Good definition) scale. In the low LOU condition, subjects indicated how well each word fit into its corresponding blank in the sentence frame (1 for Bad fit and 4 for Good fit). In this condition the pair appeared with the to-be-judged item in blue font and the other word in white font; the left-hand word was always judged first and separately from the right-hand word. Participants were not warned that their memory for the words would be tested.

The recognition tests were administered two days after the study list was encoded. In the item recognition test, old items (the right-hand target word from study pairs, e.g., *ribbon*) and new items were presented one at a time in the middle of the computer screen. Participants rated how confidently they recognized each word on a scale from 1 (sure new) to 6 (sure old). In the associative recognition test, participants were presented with intact pairs and rearranged pairs from the study phase; participants again used a rating scale, from 1 (sure rearranged) to 6 (sure same) to indicate their memory for the pairs. For both tests, subjects were encouraged to try to use the entire response scale. Tests were self-paced.

Analyses—Hits and false alarms were calculated for each level of confidence for each participant and were used to create receiver operating characteristics (ROCs), and to obtain d_a as well as estimates of recollection and familiarity. d_a is a statistic that is analogous to *d*' (i.e., it measures the distance between the means of old and new item distributions) but it does not assume that the old and new (or intact and rearranged) distributions have equal variances, and it is equivalent to *d'* when the variances are equal (Macmillan & Creelman, 2005). The ROCs in this experiment were asymmetrical, indicating that d_a is a more appropriate measure of accuracy. To obtain estimates of recollection and familiarity, individual subjects' ROC data (hit and false alarm pairs per confidence bin) were fit with the Dual Process Signal Detection (DPSD)model (Yonelinas, 1994). Data were fit using maximum-likelihood estimation in Excel with the solver add-in. The DPSD model for item recognition included recollection and familiarity as memory parameters and the model for associative recognition included recollection (of intact items as intact), recollection-rejection (recollection-based rejections of rearranged items), and familiarity for the association. In the analyses below we focus on the recollection and familiarity estimates; recollection-rejection was unaffected by the manipulations in all but one case (noted below). Because the recollection estimate (and recollection-rejection estimate) is a probability, the model was constrained to produce values between 0 and 1. Familiarity, measured as d', was constrained at the lower end to be no smaller than 0. Although our primary focus is on the process estimates, ROCs were analyzed using standard signal detection measures including the intercept and slope from a linear fit of the z-transformed ROC as well as the quadratic estimate from the fit of a second-order polynomial. The raw confidence data are presented in the appendix.

The statistical analyses of overall recognition (d_a) and the process estimates (recollection and familiarity) were carried out using analysis of variance (ANOVA) followed by planned comparisons, with alpha set at .05. A measure of effect size, partial eta squared (η^2), is reported for significant main effects and interactions.

Results and Discussion

Each memory measure was submitted to a 2 (test) × 2 (LOU) mixed-design ANOVA with LOU as a between-subjects variable and test as a repeated measure. Overall recognition performance (d_a, see Figure 1) was subject to main effects of test and LOU that were qualified by an interaction between these factors (test $F(1, 62)$ =5.72, p =.02, η^2 =.085; LOU $F(1, 62)$ = 28.57, p< .001, η^2 = .315; interaction $F(1, 62)$ = 23.33, p< .001, η^2 = .273). Specifically, high unitization increased associative recognition compared to low unitization, but had no effect on item recognition (associative $t(62)$ = 6.28, p< .001; item $t(62)$ = .81, p = .42).

Recollection and familiarity estimates (see Figure 1) were low overall, but were affected by both test and LOU condition. Familiarity estimates were affected by LOU, but that effect was dependent on test type (LOU $F(1, 62)$ =14.82, p< .001, η^2 = .193; interaction $F(1, 62)$ = 15.93, p<.001, η^2 =.204). As with overall performance, high unitization increased familiarity for the associations compared to low unitization, but the manipulation had no effect on familiarity for items (associative $t(62)$ = 4.88, p< .001; item $t(62)$ = .04,p = . 967).Recollection estimates were influenced by test and LOU as well as by an interaction between the these factors (test $F(1, 62)$ = 11.26, p= .001, η^2 = .154; LOU $F(1, 62)$ = 14.48, p< .001, η2 =.189; interaction $F(1, 62)$ = 12.54, p= .001, η^2 = .168). High unitization increased recollection of associations compared to low unitization, but there was no significant effect of unitization on item recognition (associative $t(62)$ = 4.26, p< .001; item $t(62)$ = 1.01, p = .314).

In sum, Experiment 1 showed that unitization increased overall associative recognition, but did not affect item recognition, indicating that unitization selectively increases associative rather than item memory. Moreover, in line with several previous studies, an examination of parameter estimates indicated that unitization significantly increased familiarity estimates in the associative test (e.g., Diana et al., 2008; Haskins et al., 2008). In addition to the effects on familiarity, recollection also showed an increase with unitization in the associative test. Previous studies have not shown significant effects of unitization on recollection, but in some cases there have been numerical increases in recollection estimates (e.g., Haskins et al., 2008). In sum, the results of Experiment 1 demonstrate that unitization does not reflect a general memory strengthening effect, but rather that it has a selective beneficial effect on memory for the associations.

One potential concern with the current results is that overall performance was quite low. The conclusion that unitization affected associative recognition more than item recognition could not have been artifactually produced by floor effects though because floor effects should have made it more difficult to observe the significant interaction. However, the low parameter estimates of familiarity may be reason to question conclusions about the effects of unitization on familiarity. This issue is addressed in Experiment 3, where performance was increased by reducing the study-test delay from 2 days to 5 minutes, which eliminated the low familiarity estimates. Importantly, the same pattern of results was found indicating that the current familiarity results were not compromised by the low parameter estimates.

Experiment 2: How does unitization affect item and associative implicit memory?

Experiment 1 showed that unitization increased familiarity-based associative memory but not familiarity for individual items. To test the generalizability of these results we examined the effects of unitization on item and associative implicit memory. If unitization fuses items together to create new representations, then we expect that it should preferentially improve implicit memory for associative rather than item information. Prior research has shown unitization effects on implicit memory for new associations on word completion tasks (e.g., Graf & Schacter, 1985) and free association (Schacter & McGlynn, 1989) using different unitization manipulations (e.g., sentence generation and pre-experimentally unitized items, respectively). However, one criticism of these implicit tasks is the potential for contamination from explicit memory; findings of unitization effects on such tasks would be bolstered by using different methods that reduce the chances of explicit contamination, such as speeding responses. Additionally, it is unknown whether the unitization manipulations that influence familiarity in recognition tasks will have similar effects on implicit memory tasks. Thus, to test the generality of these effects we used a speeded lexical decision priming task for compound words that allowed us to examine both associative and item priming (e.g., Goshen-Gottstein, et al., 2000) with the same unitization manipulation as used in Experiment 1. We expected that unitization would increase associative priming but would not affect item priming. To test this hypothesis, participants processed word pairs in either the high- or low-unitization conditions used in Experiment 1 (novel definitions and sentence frames, respectively). Afterward, they made lexical decisions about compound words. The word list contained a mixture of real compound words (e.g., hillside) and nonwords (e.g. fork colony) neither of which had been in the earlier study list. Most critically, the list also contained intact and rearranged word pairs that had been studied in either the high or low unitized encoding conditions. We expected that unitization would manifest in a cost to performance in this task, such that participants would be more likely to mistake high-unitize pairs for real words than they would low-unitized pairs, due to increased fluency of processing. Such effects should occur if the processes underlying priming and familiarity are shared, as has been suggested in the past (e.g., Mandler, 1980; Jacoby, 1991; Jacoby & Dallas, 1981; Parks, 2013; Wang & Yonelinas, 2010; 2012). Priming was measured as the absolute difference between incorrect ‘word’ responses to studied (intact and rearranged) and new items. We expected that priming would be greater for intact than rearranged pairs in the high- but not the low-unitization condition, revealing an effect of unitization on associative priming. We expected no effect of unitization on item priming (rearranged – new ‘word’ responses).

Method

Participants—Forty eight undergraduate students (average age 19.4, 33 women and 15 men) enrolled in a psychology course at UC Davis participated in this experiment in return for class credit.

Materials—Stimuli in the study phase consisted of word pairs (e.g., shame ribbon) and either a novel definition or a sentence frame that was used to guide processing of the pair.

Word pairs and their associated definitions (high-LOU condition) and sentences (low-LOU condition) were the same as those used in Experiments 1 (adapted from Quamme et al., 2007), but arranged differently. Six word-pair lists with 25 pairs each were balanced for frequency of the cue and the target, with cue frequencies ranging from 55 to 58 and target frequencies ranging from 45 to 49 (Kucera & Francis, 1967). These lists were rotated through counterbalance conditions; word pairs appeared equally often as intact, rearranged, and new pairs on the lexical decision test across subjects. They also appeared equally often in the high- and low-LOU conditions. Order of these study tasks was counterbalanced such that half the participants completed the high-LOU condition first and half completed the low-LOU condition first. Overall, subjects encoded 100 pairs (half in the high- and half in the low-unitization condition).

The lexical decision task included 50 intact pairs, 50 rearranged pairs, 50 new pairs, and 100 real compound words. Real compound words were included to make the task realistic. Because few compound words are listed in the Kucera and Francis (1967) compendium, they were culled from various sources (ranging from academic articles to the internet) and frequency information is missing for most of them. However, most of the compound words appeared to be relatively rare words and could be expected to have low frequencies (e.g., doughnut, purebred, pinstripe, hillside, strawberry). Compound words were chosen such that the components of the compound (e.g., hill and side for hillside) were not words that made up the pairs adapted from Quamme et al. All stimuli were presented with a dash between the two words that made up the compound, regardless of whether it was a real or fake compound word (e.g., *dough-nut*, *shame-ribbon*).

Real and fake compound words were also used in a series of 65 titration trials before the lexical decision task. Fake compound words in these trials were created by mixing parts of real compound words (e.g., hill-berry). None of these words overlapped with words from other tasks.

Overall, subjects encoded 100 word pairs (50 high-LOU and 50 low-LOU) and made 250 lexical decisions about 100 real compound words, 100 studied pairs (25 high-LOU intact pairs, 25 high-LOU rearranged pairs, 25 low-LOU intact pairs, 25 low-LOU rearranged pairs) and 50 new pairs (fake compounds).

Procedure—The experiment was conducted with groups of up to four participants at a time and programmed using E-Prime 1.0 (Psychology Software Tools, 2001). Subjects read instructions on their computer monitors before each task; experimenters reiterated the important points and checked for general understanding before subjects began each task.

The study phase was the same as that from the unitization condition of Experiment 1 except that it was manipulated within-subjects rather than between. Following the encoding condition, the subjects read instructions for the lexical decision task and went through a series of titration trials. On each trial of the lexical decision task a stimulus (e.g., hill-side) was presented in the center of the screen with a prompt in blue font beneath it that asked “real word?” and the response options (no or yes) presented at the bottom of the screen on the left and right respectively. Subjects used the ‘z’ key on the keyboard to make a no response and the '/' key to make a yes response. Finally, subjects were instructed to respond within the response window, which was to be determined by the titration trials. Overall, it was emphasized to subjects that they would need to respond quickly and that if they did not respond within the given time frame, the item would disappear from the screen and the next trial would initiate (with a 500 ms ISI between trials).

After 5 practice trials, participants were given three blocks of 20 trials each with different response deadlines in a titration phase (first block 1100 ms, second block 900 ms, last block 800 ms). The goal of the titration phase was to identify a speed at which participants could respond both quickly enough to avoid ceiling performance, but also accurately enough to avoid floor performance. Experimenters selected the response deadline based on the titration trials and subtracted 50 ms for the actual deadline used in the test(if 900 was identified as the participants optimal time, the deadline at test was actually 850ms). However, all subjects needed the fastest deadline to keep scores off ceiling and thus all subjects were tested with a 750 ms response deadline in the test.

Results and Discussion

The proportions of items in each condition that elicited a "word" response are presented in Table 1. Priming scores for the lexical decisions were created by subtracting the incorrect "word" responses to fake compound words (i.e., new pairs) from the incorrect "word" responses to old (fake) pairs for each of the intact/rearranged by encoding conditions. Therefore, "priming" here refers to a greater tendency to call a studied stimulus a "word" compared to non studied stimuli. The likelihood of accepting legal and new illegal compounds was .50 and .25, respectively. As is evident in Figure 2, the priming scores were greater than zero in all conditions (ps<.01), indicating subjects were more likely to respond 'word' to stimuli that were previously studied. Most importantly, for the pairs that had been studied in the high unitization condition subjects were more likely to respond 'word' to intact than rearranged pairs ($t(47) = 3.08$, $p = .003$), indicating that there was significant associative priming for the high unitization pairs. In contrast, in the low unitization condition there was no significant difference between the intact and rearranged pairs ($t(47) = .28$, $p = .78$), indicating that there was no associative priming in the low unitization conditions. To directly compare the associative priming effects priming was submitted to a 2 (LOU) × 2 (item type [intact/rearranged]) repeated measures ANOVA, which revealed a significant effect of item type ($F(1, 47) = 4.59$, $p = .04$, $\eta^2 = .089$) and a marginally significant interaction between LOU and item type ($F(1, 47) = 4.02$, $p = .051$). Thus, the data are in the expected direction but the critical interaction fell just short of significance. To determine whether unitization had similar effects on item priming as it did on associative priming we specifically compared the priming scores for rearranged items between high and low unitization conditions. This test revealed no effect of unitization ($t(47) = .07$, $p = .94$).

In sum, these results demonstrate implicit memory for associations, but only when those associations have been processed as a single coherent unit. Thus, the data replicate associative priming and unitization effects reported in prior implicit memory studies(e.g., Graf & Schacter, 1985; Kan et al., 2011; Schacter & McGllynn, 1989), but additionally show that it is only the associative information that is being primed rather than item information. In addition, the current results show that the same unitization manipulation that increases familiarity in an associative recognition test but not an item test, also increases priming for associative but not item information.

Experiment 3: Is unitization dissociable from levels of processing?

The unitization effects observed so far appear to be more than semantic LOP effects, in the sense that the unitization effects were limited to associative memory, whereas LOP generally affects item recognition (for a review see Craik, 2002). Importantly, however, LOU and LOP effects have never been directly contrasted in the same experiment. Prior studies (e.g., Quamme et al., 2007) were careful to match overall performance levels between conditions, but may still not have controlled elaborate processing between conditions. Moreover, as far as we know no previous study has examined the effects of LOP on recollection and familiarity in associative recognition. So we currently don't know how unitization and levels of processing effects are related.

The goal of Experiment 3 was to directly compare the effects of a LOU manipulation to those of a LOP manipulation on both item and associative recognition tests. The difference between the two types of encoding conditions was in the way that they guided processing of the pair. The unitization conditions were the same as those used in Experiments 1 and 2, and were designed specifically to encourage processing of the pair as two associated items or as a single unit. In contrast, the LOP conditions were designed to focus subjects on processing the items deeply (i.e., rating the pleasantness of each of the two words) or shallowly (i.e., counting the number of vowels in each of the two words). If high-unitization conditions are simply engaging more elaborative processing than low-unitization conditions then we should find that these two manipulations have similar effects on item and associative recognition. However, we predicted that the two manipulations would have very different effects on item and associative recognition. That is, deeper semantic processing of the word pairs should strengthen both item and associative memory. In contrast, unitizing the two items should benefit associative recognition to a greater extent than item recognition, as found in Experiment 1.

Experiment 3 differed from Experiment 1 in that memory was tested on the same day as the study list was presented rather than waiting for a 2 day delay. As mentioned previously, one potential concern with Experiment 1 was that performance was quite low and this resulted in very low estimates of familiarity for some subjects. We expected that with the shorter delay we would avoid possible confounds related to low performance that may have compromised the analysis of the parameter estimates in Experiment 1. Thus our expectation was that as in Experiment 1 unitization would lead to a significant increase in familiarity in the associative test, but should have less of an effect on familiarity in the item test.

Method

Participants—Participants were 96 students (19.9 years old, 64 women and 32 men) at the University of California, Davis enrolled in a psychology class. Sixty-four of the subjects were randomly assigned to the LOU conditions (unitize or sentence) and 32 were randomly assigned to the LOP conditions (deep or shallow). The difference in numbers of participants in each condition arose because of a miscommunication with a research assistant. Note that in a secondary analysis we randomly removed participants in the LOU condition to equate for number of participants in each condition, and this led to the same conclusions as the main analysis. Participants received extra credit to apply toward a psychology class for their participation.

Materials and Procedure—Experiment 3 used the same materials as Experiments 1 and 2. Experiment 3 compared LOU to LOP processing at study and thus included the previous LOU conditions (high and low-unitization) as well as deep and shallow processing conditions. In the LOP study conditions, word pairs were presented centrally in white font on a black background with the orienting task prompt and associated response options below the pair in blue font. The shallow processing condition was a vowel counting task; subjects counted the vowels in each word and chose one of the three response options to indicate which word had more (response options: left word, same number, right word). The deep processing condition was a pleasantness judgment task; subjects indicated whether the left-side or right-side word was the more pleasant of the two. Stimuli in the LOP conditions also remained on screen until a response was made. The LOP manipulations were selected such that the deep condition required semantic processing of the items whereas the shallow condition required only perceptual processing of the words. In addition, because the LOU manipulation required subjects to relate the two words to one another, we also required subjects in the LOP conditions to make relational judgments (which word has more syllables or which was more pleasant).

The recognition tests were the same as those used in Experiment 1 (item and associative recognition tests) and were administered after the study list was finished.

Results and Discussion

The average d_a(overall recognition) values for all conditions are shown inFigure 3 (see Appendix for confidence ratings). The patterns of performance suggest that deep processing improved performance regardless of test type but that high LOU encoding relative to low-LOU encoding was especially helpful on the associative test and slightly hurt performance on the item test. The data were submitted to a 2 (study task) × 2 (level) × 2 (test) mixed-design ANOVA with study task and level as between-subjects factors and test as a within-subjects factor; we report only the highest level effects of interest for complex interactions.

Importantly, the three-way interaction was significant ($F(1, 92) = 9.10$, $p = .003$, $\eta^2 = .09$) indicating that the LOP and LOU manipulations affected item and associative tests differently. This interaction was broken down into two-way interactions between Test and Level for each encoding condition separately; the Test × Level interaction was significant for the LOU condition (Test × Level, $F(1, 62) = 15.75$, $p < .001$, $\eta^2 = .20$;). Thus, in the LOU conditions, the type of test dictated whether unitization mattered or not; high unitization increased performance on the associative test($t(62) = 2.58$, $p =.012$) but had little effect in the item condition ($t(62)= 1.36$, $p =.180$).In contrast, the main effects of Test and Level were significant for the LOP condition, but the interaction was not (Test, $F(1, 30) = 11.74$, $p = .002$, $\eta^2 = .28$; Level, $F(1, 30) = 55.63$, $p < .001$, $\eta^2 = .65$, interaction,$F(1, 30) = .$

20, p = .360). Follow up tests showed that deep processing produced higher *d* a scores than shallow processing in both tests (item t(30) = 6.25, p < .001; associative t(30) = 4.75, p < .001). These effects show that in the LOP condition, performance was better on item than associative tests, but the effects of deep versus shallow processing were the same for the two tests.

Overall recognition performance was decomposed into recollection and familiarity process estimates by fitting the DPSD model to the ROCs and obtaining parameter estimates for each participant (see Figure 3). Familiarity estimates were submitted to a 2 (study task) × 2 (level) × 2 (test) ANOVA, which revealed a significant three way interaction between the factors ($F(1, 92) = 10.00$, $p = .002$, $\eta^2 = .098$). The three way interaction was broken down to examine test and level in the LOP and LOU conditions separately. In the LOU condition, a significant test by level interaction ($F(1, 62) = 12.88$, $p = .001$, $\eta^2 = .172$) showed that the effects of high versus low unitization depended on test type. Specifically, familiarity estimates were greater for high than low unitization in the associative test but there was no difference on the item test (associative $t(62) = 2.52$, $p = .014$; item $t(62) = -1.45$, $p = .153$). In contrast, only the main effects of test and level were significant in the LOP condition, showing that familiarity was higher in the item test than the associative test and greater for deep than shallow processing (test, $F(1, 30) = 13.60$, $p = .001$, $\eta^2 = .312$; level, $F(1, 30) = 22.62$, $p < .001$, $\eta^2 = .430$). Follow up tests confirmed that deep processing led to higher familiarity in both item and associative test conditions (item $t(30) = 4.07$, p < .001; associative $t(30) = 3.26$, $p = .003$). Thus, LOP and LOU had very different patterns of effects on familiarity estimates. Familiarity was greater after deep processing, compared to shallow processing, and higher on the item than on the associative test. In contrast, high unitization resulted in much higher familiarity estimates than low unitization on the associative test; however the two LOU conditions produced equivalent familiarity estimates in the item test. Thus, high-unitization was found to specifically benefit familiarity in an associative recognition task.

Recollection estimates were submitted to the same ANOVA (test × level × study task) which revealed a marginally significant three-way interaction ($F(1, 92) = 3.28$, $p = .073$) which was broken down into two-way interactions between test and level for the LOP and the LOU conditions separately. For the LOU conditions, the effect of test was significant ($F(1, 62) = 19.65$, $p < .001$, $\eta^2 = .241$) and the interaction between test and level was marginally significant ($F(1, 62) = 3.71$, $p = .059$): high unitization led to greater recollection on the associative test than on the item test ($t(31) = -4.38$, $p < .001$), but low unitization produced approximately equivalent levels of recollection on the two tests. In the LOP condition, the test by level ANOVA revealed only a significant effect of level, with deep processing resulting in higher recollection than shallow processing ($F(1, 30) = 19.40$, $p < .001$, $\eta^2 = .393$). Overall, LOP and LOU had different effects on recollection: deep processing improved recollection regardless of the type of test whereas high compared to low unitization produced better recollection on the associative test but not on the item test.

In summary, the results showed that the effects of increasing LOU are functionally distinct from those of increasing LOP. Deep compared to shallow levels of processing increased recognition on both item and associative recognition tests, whereas high compared to low levels of unitization led to better performance on associative recognition but slightly worse performance on item recognition. These results show that unitizing cannot simply be described as elaborate processing. In addition, the process estimates showed that deep compared to shallow processing improved both recollection and familiarity in both item and associative recognition, whereas high compared to low levels of unitization increased familiarity in the associative test but did not affect familiarity in the item test. Moreover, deep versus shallow processing increased recollection regardless of the type of test, whereas high unitization increased recollection only on the associative test. The results thus indicate that unitization effects do not simply reflect deeper levels of processing and they are consistent with our expectations that unitization is effective at forming new units that can support familiarity-based associative memory.

Finally, one of the concerns with Experiment 1 was that low levels of overall performance may have affected the process estimates. The shorter delay used in Experiment 3 let to much higher levels of performance (see Figures 1 and 3). Importantly, the results of Experiment 3 replicate those of Experiment 1 in showing that LOU increased associative but not item familiarity. The convergent results observed in these two experiments verify that the results from Experiment 1 were not greatly affected by the low overall levels of performance observed there.

Experiment 4: Does unitization increase familiarity for face-word pairs?

Prior experiments have demonstrated that high-unitization conditions can increase the degree to which associative recognition can rely on familiarity, but in a majority of these studies the items that have been paired together have been from very similar processing domains (e.g. word pairs, face parts). Thus, it is not clear whether unitization is limited to forming new associations between similar types of items or whether it reflects more general associative ability that is useful in creating associations across stimulus domains. The levels of unitization framework assumes that unitization can occur at a fairly abstract level so we expect that it should be useful in forming associations across domains as well as within domains. However, others have suggested that only recollection can support memory for across-domain associations such as face-name pairs and that familiarity may only be useful in supporting within-domain associations such as face-face pairs (Mayes et al., 2004).

We contrasted these two hypotheses in Experiment 4 by pairing either two faces together (within-domain stimuli) or a word and a face together (across-domain stimuli) and crossed this domain manipulation with a manipulation of LOU. In the high-unitization within-domain condition, participants were presented with a male and female face which were encoded as a “married couple”, whereas in the low-unitization within-domain condition, the two faces were encoded as two unrelated individuals. For the across-domain conditions we paired a face with a word or phrase representing a hobby, such that in high-unitization conditions the hobby defined the person and in the low-unitization condition the person was simply linked to the hobby in some way (e.g., a person was a skier or they simply had interacted with a skier, respectively).

If unitization is useful in linking across-domain associations then familiarity should be greater in the high- compared to the low-unitize condition for the face-word pairings. Alternatively, unitization may not be an effective encoding strategy for across domain materials and so it may not increase familiarity estimates for the face-word associations.

Method

Participants—Participants were 144 undergraduate students (average age 19.8, 102 women and 42 men) at UC Davis who participated in the experiment in return for extra credit in a psychology course. Subjects were randomly assigned to one of the four experimental conditions.

Materials—Materials used in this experiment are illustrated in Figure 4 for each experimental condition. Stimuli differed according to the experimental conditions (high within, high across, low within, low across) and consisted of face-face pairs (the within conditions) or face-hobby pairs (the across conditions). Face-face pairs always consisted of one male and one female face. Half the hobby-face pairs included a male face and the other half included a female face. The face stimuli were developed and first used by Althoff and Cohen (1999). The images are Caucasian faces presented on black backgrounds.

In addition to the face-face or hobby-face pairs, subjects were also presented with sentences that were developed to guide processing of the stimulus pairs (either low or high LOU) and to introduce the hobby in all conditions. In the high LOU conditions, sentences treated the pairs as single objects; in the high- within (face-face) condition, sentences referred to the face pairs as married couples who enjoyed a particular hobby or activity, and in the high-across (hobby-face) condition the sentences identified the face in terms of the hobby (see Figure 4 for an example). In the low LOU conditions, the sentences referred to each item in the stimulus pair, but did not treat the two items as a single conceptual unit. Rather, they indicated an arbitrary link between the two people in the pair through the hobby. In the low-across condition, the sentences referred to an arbitrary link between the person and the hobby (see Figure 4).

To create face-face pairs, male and female faces from Althoff and Cohen (1999) were randomly paired together and inspected for plausibility as a married couple; pairs that appeared to have very large age differences were rearranged until individuals in each couple appeared to be within approximately 10 to 20 years of age. These face-face pairs were then randomly assigned to hobbies. Sentences were written for all four experimental conditions for each hobby (see Figure 4). The experimental conditions dictated which type of pair (face-face or hobby-face) and type of processing sentence would be presented. A total of 160 pairs were used as target items during the study and test phases. An additional 16 were used as primacy and recency buffers and an additional three were used as practice items. Two counterbalance orders were constructed so that items that were tested as intact in one counterbalance condition were rearranged in the second counterbalance condition. Two more counterbalance conditions were created so as to have two sets of pairs (e.g., face 1 paired with face 2 in one condition and face 1 paired with face 3 in the other).

In order to avoid floor effects (a pilot study indicated that memory for face-face pairs were often much worse than for face-word pairs) subjects completed eight study-test blocks (with 20 target pairs per block) in the within-domain conditions, whereas subjects completed one study-test block (studying all 160 pairs at once prior to the test) in the across-domain conditions. Overall, subjects in all conditions studied 160 target pairs and were presented with 80 intact and 80 rearranged pairs at test.

Procedure—Subjects were tested individually and the experiment was controlled by Eprime 1.0 (Psychology Software Tools, 2001). Exact instructions for the study phase differed across experimental conditions and are detailed below for each condition. On each study trial a sentence was first presented at the top of the computer screen. Subjects were given six seconds to read the sentence; they were instructed to read the sentence out loud and to press the spacebar when finished reading. If they pressed the spacebar too fast (within 1500 ms of the sentence onset) they received a "Slow Down!" warning; if they took longer than six seconds to press the spacebar they received a "Move on" prompt. Pressing the spacebar erased the sentence and presented the to-be-remembered pair along with a rating scale appropriate for the experimental condition (see below). Subjects were asked to think out loud in order to make their judgment and were recorded (recordings were made to encourage participants to take the task seriously but were not analyzed further). The importance of creating vivid visual images was stressed across all study conditions. Subjects entered a numerical rating on a four-point scale to indicate their judgment; if this rating took less than two seconds or more than eight seconds after the pair appeared on screen, subjects received a "slow down" or "move on" warning, respectively. Finally, each trial was followed by a blank (black screen) 500 ms inter-stimulus interval. The experimenter talked through an example in the instructions with the participant in order to ensure they understood the instructions. The experimenter was present for three practice trials of the think-aloud study phase to ensure understanding; once it was certain that the subject understood the task, the participant was left alone to complete the study block. On test trials, participants were presented with one pair (either intact or rearranged) at a time and they responded on a 6-point confidence scale with 1 as "Sure Rearranged" and 6 as "Sure Intact". Test trials were self-paced and subjects were encouraged to spread their responses across the scale.

High-LOU, Within-Domain (*high-within*) Study Condition: In the high-within (face-face) condition, subjects' task was to judge the relationship satisfaction of married couples. To make that judgment, they were instructed to create detailed and vivid images of the couple based on the information given about their hobby (e.g., see the upper left panel of Figure 4). Subjects were instructed to imagine the couple engaged in this activity and to think of it as an activity that defined the two people as a married couple, and further, to use the activity or hobby as a context in which they could imagine the couple interacting in a specific way. Because time on each trial was limited, subjects were told that they should use the couple's appearance (and whatever stereotypes it might evoke) to help them create their image and develop their judgment. Finally, subjects were told to base their judgment of relationship satisfaction on what they imagined about the couple and their hobby.

High-LOU Across-Domain (*high-across*) Study Condition: In the high-across (hobby-face) condition subjects were instructed that their task was to judge the ease of imagining the hobby as a fundamentally defining feature of the person (see Figure 4). Subjects were instructed to create a visual image of the person engaged in the hobby or activity and to think of that hobby as something that defined that person. Subjects were further instructed to take the person's appearance into consideration (along with stereotypes it might evoke) when creating the imagery and making their judgment. Subjects rated the ease of imagining the person as defined by the hobby listed.

Low-LOU Within-Domain (*low-within*) Study Condition: In the low-within (face-face) condition, subjects judged how easy or hard it was to imagine the two people in the situation that was described by the sentence (see Figure 4). Subjects were instructed to create a very vivid image of the two people in the situation described, using their appearances (and associated stereotypes) to help construct the image. Subjects were instructed to elaborate on the information provided by thinking about these people in this situation and how they might act, react, etc. Subjects then judged how easy or hard it was to create this image.

Low-LOU Across-Domain (*low-across*) Study Condition: Subjects in the low-across (hobby-face) condition judged how easy or hard it was to imagine the person in the situation described by the sentence (see Figure 4). Subjects were instructed to imagine the person in the specific situation described in the sentence as vividly as possible and to use the person's appearance (and associated stereotypes) to help them construct that image. Subjects were encouraged to elaborate on the information given in order to construct a more vivid image. Subjects then based their judgment on the ease of creating this image.

Results and Discussion

The recognition (d_a) means are presented in Figure 5 (see Appendix for confidence ratings). A 2 (LOU) × 2 (domain) ANOVA indicated that there were main effects of LOU and domain but that they were qualified by an interaction between the variables (LOU $F(1, 140) = 5.66$, $p=.019$, $\eta2 = .039$; domain $F(1, 140) = 32.46$, $p< .001$, $\eta2 = .188$; interaction $F(1, 140) = 4.97$, $p =.027$, $\eta2 =.034$). Planned contrasts indicated that recognition was improved by high-unitization for the across-domain stimuli (which were easier to recognize in general) but had little effect on within-domain stimuli (across $t(70) = 2.97$, $p=.004$; within $t(70) = .12$, $p= .91$)

Recollection and familiarity estimates (see Figure 5) were each submitted to the same 2 (LOU) × 2 (domain) ANOVA described above. Estimates of familiarity were greater for high- than low-unitization conditions ($F(1, 140) = 6.14$, $p=.014$, $\eta^2 = .042$) and greater for across- than within-domain stimuli ($F(1, 140) = 14.74$, $p< .001$, $\eta^2 = .095$). The interaction did not quite reach significance ($F(1, 140) = 3.63$, $p = .059$).Planned contrasts showed that high compared to low unitization increased familiarity for the across-domain (hobby-face) associations, but had no effect on the within-domain (face-face) stimuli (across $t(70) = 2.66$, $p =.010$; within $t(70) = .51$, $p =.613$). Additionally, specific comparison of estimates in the low-unitization condition showed a trend for greater familiarity for across- than within-domain associations ($t(70) = -1.77$, $p = .082$). Recollection estimates were higher for across-domain stimuli than within-domain stimuli, but no other effects reached significance (F(1, 140) = 33.77, p< .001, η^2 =.194).

The results of this experiment showed that unitization led to a significant increase in familiarity for the across-domain associations (face-word), demonstrating that unitization effects are not limited to within-domain associations. In fact, the unitization effect was significant for the across-domain condition but not for the within-domain condition. Although the interaction was not quite significant the results suggest that unitization may be even more effective for the across-domain than the within-domain associations. Why the unitization effect was not significant in the within-domain conditions in the current experiment is not clear. Previous studies have shown that unitization increases associative familiarity for face-parts and word-pairs. One possibility is that it may be particularly difficult to unitize two separate people or faces, whereas it is easier to unitize a person with a hobby. Whether other unitization manipulations can effectively impact familiarity for face-face pairs should be assessed in future studies. However, the important finding in the current study is that unitization did increase familiarity for across-domain pairs which contrasts with earlier claims that familiarity is only able to support associations for within-domain pairings(Mayes et al., 2007).

Experiment 5: Does unitization increase familiarity for fractal-sound pairs?

Experiment 4 showed that unitization enhanced familiarity for face-word pairs. Experiment 5 was designed to test the generalizability of these cross-domain effects by examining memory for fractal-sound pairs (see Figure 6). LOU has been shown to be a successful manipulation when the stimuli are inherently meaningful, but it is unclear the extent to which the background familiarity for words and faces matters for creating new units. In addition, rather than instructing subjects to treat the items as a single unit or as two separate units as was done in the previous studies, we presented materials either sequentially, to ensure the two items were processed as separate units, or simultaneously, to promote the encoding of the two items as a single unit. If unitization supports the creation of across-domain associations then familiarity should be greater in the simultaneous than sequential condition for the fractal-sound pairs. In contrast, if unitization is not effective at forming across-domain associations then the unitization manipulation should not affect performance on the fractal-sound pairs.

Method

Participants—Participants were 144 students (mean age 19.4 years, 112 women and 32 men) at the University of California, Davis enrolled in psychology classes. Participants were randomly assigned to one of the four experimental conditions and received extra credit to apply toward a psychology class for their participation.

Materials—Stimuli consisted of fractal images (see Figure 6) and abstract sounds that were randomly matched to create fractal-fractal pairs for the within-domain conditions and fractal-sound pairs for the across-domain conditions. Fractals were generated using a free fractal generation program obtained online (Tiera-zon; Ferguson, 1998). Fractals were 320 × 240 pixels and in color. Abstract sounds were collected from various online sources for free sound effects. All sounds were edited to be 2 s in length. Some sounds were used "as is" if they were not easily-named sounds. Other, nameable sounds (e.g., a door creak or breaking glass) were edited so as to create non-nameable sounds. In general, both the fractals and sounds were created and/or chosen to make verbal labeling of the items as difficult as possible.

Fractals and sounds were randomly paired to create two study lists of fractal-fractal pairs (within conditions) and fractal-sound pairs (across conditions). Half the subjects received the first list and half received the second. In addition, the intact or rearranged status was also counterbalanced such that pairs were presented equally often as intact or rearranged at test.

Pairs (regardless of type) were presented in eight study-test blocks. Each of the eight study blocks consisted of 20 target pairs and 1 buffer at each end of the list. Each of the tests consisted of 10 intact and 10 rearranged items from the preceding study list. Thus, participants studied 160 items (plus 16 buffers) and were tested on 80 intact and 80 rearranged pairs.

Procedure—In all conditions, subjects were presented with pairs (fractals, or fractals and sounds) to be remembered for a later test. Encoding was intentional but no orienting instructions were given. Fractals were presented on a computer monitor and sounds were presented through head phones. Participants were asked to read instructions on the computer screen and then the experimenter followed up by reiterating important points. Participants completed three practice study trials before starting the experiment proper.

In the *simultaneous within* condition, subjects viewed pairs of fractals centered on a black screen for four seconds each during each study block. In the *simultaneous across* condition, subjects were presented with a fractal centered on the screen for two seconds while an abstract two-second sound was played; this fractal-sound pairing was repeated after a 150 ms delay in order to equate overall encoding time with the within-domain conditions. In the *sequential within* condition, subjects were presented with a pair of fractals separated in time; the first fractal was presented on the left side of the screen (in the same position it would be in if it were in the simultaneous condition) for two seconds, followed by a checkerboard mask presented in the same location for 300 ms; the mask was removed and the second fractal in the pair was presented on the right side of the screen for two seconds (in the same place it would appear if it had been in the simultaneous within condition). In the *sequential across* condition, subjects viewed the fractal (presented centrally) for two seconds, which was masked with the checkerboard for 300ms before the screen cleared and the two-second abstract sound was played.

Test instructions were given after the first study phase and before the first test. At test, subjects were presented with intact and rearranged pairs and were to discriminate between them using a six-point confidence scale anchored at 1 with "Sure Rearranged" and at 6 with "Sure Intact". All items remained in their original spatial locations (e.g., right hand items remained on the right even in rearranged pairs). In the within conditions (fractal-fractal pairs), pairs were displayed on screen until subjects made a recognition response. In the across condition, fractals and sounds were presented simultaneously; after the initial playing of the sound, subjects were given the option of pressing the spacebar to hear the sound again before making a recognition decision. The recognition test was self-paced and subjects were encouraged to spread their responses across the confidence scale.

Results and Discussion

Overall recognition was measured using d_a(see Figure 7) and was submitted to a 2 (domain) × 2 (temporal contiguity) between-subjects ANOVA. A main effect of temporal contiguity ($F(1, 140) = 13.14$, $p< .001$, $\eta^2 = .09$)was qualified by an interaction between contiguity and domain ($F(1, 140) = 10.39$, $p= .002$, $\eta^2 = .07$).Simultaneous presentation compared to sequential presentation led to an increase in associative recognition for the across-domain (fractal sound) pairs ($t(70) = 5.12$, $p< .001$), but had no effect on within domain (fractal-fractal) pairs ($t(70) = .27$, $p= .788$).

The same 2 (domain) × 2 (temporal contiguity) between-subjects ANOVA was conducted with familiarity estimates and revealed a main effect of temporal contiguity ($F(1, 140) = 10.44$, $p=.002$, $\eta^2 = .069$) that was qualified by a significant interaction between domain and contiguity ($F(1, 140) = 20.00$, $p< .001$, $\eta^2 = .125$). Specifically, simultaneous presentation increased familiarity estimates compared to sequential presentation ($t(70) = 5.56$, $p<.001$) for across-domain stimuli, but did not affect on familiarity for within-domain associations ($t(70) = -.893$, $p=.375$). The same analysis was conducted with recollection estimates and only a significant effect of domain was observed ($F(1, 140) = 12.37$, $p= .001$, $\eta^2 = .081$) indicating that it was easier to recollect across-domain pairs than it was within-domain pairs.

Overall, simultaneous compared to sequential presentation increased associative recognition memory and familiarity for the across-domain pairs (fractal-sounds), indicating that unitization does facilitate familiarity for across-domain associations. Moreover, the unitization effects were much larger for the across-domain materials, and there was little evidence that unitization improved performance on the within-domain pairs. The results from Experiment 5 converge with those from Experiment 4 indicating that the unitization effects on familiarity generalize at least across these different sets of materials.

Model Fits

Before discussing the results further it is important to consider how well the DPSD model fit the current ROCs. Although many previous studies have found that the model provides an acceptable account of recognition ROCs, if the current ROCs are fit poorly then this would undermine the interpretation of the parameter estimates of recollection and familiarity. As a comparison we also report on the fits of another common ROC model, the unequal variance signal detection model (UVSD). To address this issue we examined whether the DPSD model and the UVSD model (e.g., Wixted, 2007) significantly deviated from the data (using the G^2 statistic) for each participant and tallied the percent of participants for whom the models fit the data (i.e., did not significantly deviate from the data). These percentages are presented in Table 2 for each experiment in which recollection and familiarity estimates were derived (Experiments 1, 3, 4, and 5). Overall the two models provided similar and adequate fits to the data with the DPSD model fitting an average of 86.3% of participants' data and the UVSD model fitting an average of 87.2% of the participants' data. Thus, the recollection and familiarity estimates derived in these experiments provide a good description of the data. An additional set of analyses were conducted only with data that the DPSD model fit adequately for Experiments 1, 3, 4 and 5. All main effects and interactions reported for the full data set remained significant[2]. Therefore it is highly unlikely that the effects on familiarity reported above were due to artifacts of model fitting. However, the DPSD model is clearly not the only model that can potentially explain the data, as the UVSD model fit the data well too. It is also likely that other models, such as the mixture model (e.g., DeCarlo, 2003), may provide similarly good accounts of the data. Note, however, that UVSD and the mixture models do not make a-priori predictions about the effects of unitization on recollection and familiarity or implicit memory whereas dual process theory underlying the DPSD model does. As noted below in the General Discussion, it is also unclear how a single process model like UVSD could explain the dissociative effects of unitization on item and associative recognition.

General Discussion

The goal of this research has been to examine the effects of unitization, the process by which separate items are transformed into a single coherent unit. Unitization is a concept with a long history and a broad reach across many different areas of cognition and perception, but we have focused specifically on its effects on associative memory. The LOU framework proposes that there is a continuum of unitization such that any given pair of items may be processed more or less as two independent things or as a single thing. At the low end lie encoding strategies that encourage attention to each item in the pair such that the two are treated as totally independent units to be (arbitrarily) associated. In such situations (e.g., classic associative memory or paired associate tasks), successful memory relies heavily on the associative links between the elements (as well as the individual items themselves). At the high end of the LOU continuum lies complete unitization, wherein attention to the independent elements of the pair is minimal compared to attention to the new object created by the pairing of the elements. Thus, the ability to remember associations under conditions of low unitization relies on memory for the association between the individual elements whereas memory of the pair at the high can be based on object recognition. This basic processing continuum, in combination with the theoretical tenets of the dual process theory, suggests a range over which familiarity and other automatic forms of memory are likely to support memory of the association. At the low end, where memory is based on the binding of the elements, familiarity is not expected to be very useful for discriminating associations. As encoding moves away from that extreme low-unitization case, it is expected that the degree to which familiarity can support associative memory will increase. At the high end, because the elements have been fused into a single item, familiarity is expected to be able to support recognition, no longer of a true association but of the item created by unitization.

We tested these ideas in five experiments focusing on two broad questions: *Is LOU different than LOP?* and *Is unitization limited by stimulus domain?* The results demonstrate that LOU

[2]With the smaller data set, some planned comparisons were no longer significant in this analysis however all trends remained in the same direction as reported for the full dataset.

is different than LOP, and it works even for pairs made up of different types of stimuli. We address these points and some of their implications below.

Is LOU just LOP? No

Experiments 1 through 3 examined the issues of whether unitization affects item and associative memory different and of whether unitization effects are simply levels of processing effects; that is, is high unitization just very deep processing? All three experiments compared high- versus low-unitization conditions on item and relational tests. Experiment 1 examined associative and item recognition, Experiment 2 examined associative and item priming, and Experiment 3 compared LOU and LOP conditions on associative and item recognition tests. In all three cases, despite different testing conditions, unitization affected associative memory but had little effect on item memory. If the unitization manipulation were the same as a LOP manipulation one would have expected performance to be enhanced in the high-unitization condition on both the item and the associative tests. However, Experiment 1 showed that high-unitization specifically benefits performance on an associative recognition test rather than the item test, and it affected familiarity on the associative test rather than the item test. A similar pattern was found for implicit memory on a lexical decision test in Experiment 2: high-unitization increased associative priming relative to low-unitization, whereas there were no unitization effects on item priming. Experiment 3 directly compared LOU to LOP and showed that whereas deep LOP conditions increased performance on both item and associative tests, high-unitization specifically led to better performance on the associative test, and these effects were found predominantly in the familiarity estimates. Thus, these experiments provide converging evidence that levels of unitization effects are functionally dissociable from semantic levels of processing effects.

The current results are in agreement with previous studies in showing that unitization effects on associative recognition increase performance primarily by increasing familiarity (e.g., Diana et al., 2008; 2010; 2011; Haskins et al., 2008; Quamme et al., 2007). However, we did observe some evidence that recollection might also benefit from unitization at least under some conditions. That is, although the unitization effects on recollection were not significant in most of the current experiments, in Experiment 1, recollection in the associative test was significantly larger in the high than low unitization condition. Moreover, in Experiment 3, unitization led to a numerical increase in recollection estimates in the associative test, and a numerical decrease in recollection estimates in the item test. Future work will be needed to determine if consistent unitization effects can be observed on recollection, and what the factors are that lead recollection to benefit from this type of encoding. On the basis of the current results though it is quite clear that the effects of unitization on recollection are quite subtle compared to the effects seen on familiarity, and compared to the levels of processing effects seen on recollection.

Why is it important to know that LOU is distinct from LOP? Characterizing the encoding conditions that optimize later memory ability is an important goal of memory research. To the extent that that we now know that unitization is distinct from levels of processing, the current results represent an advance in understanding the processes that are involved in the initial formation of memory. Moreover, to the extent that unitization was found to affect associative but not item memory, the results add to previous work pointing to the separability of item and associative information (e.g. Gronlund & Ratcliff, 1989; Hockley & Cristi, 1996), as well as recollection and familiarity (e.g., Yonelinas, 2002). In both of these prior literatures there have been several experimental manipulations that have been found to affect recollection and associative recognition more so than item recognition or familiarity (e.g., dividing attention, generation, speeding responses, etc.), and far fewer manipulations showing the opposite. The current unitization manipulations provide just such evidence, and this is important in showing that familiarity and item recognition are not simply less sensitive to experimental manipulations than is recollection.

In addition, the unitization manipulations explored here could have useful practical applications that are different from those of LOP. For example, in educational contexts, the ability to learn arbitrary associations is critical, and promoting encoding strategies in addition to semantic processing should be particularly useful in promoting associative learning. Determining which unitization strategies will be useful in various learning contexts will be an important question for future research. In addition, patients with hippocampal lesions as well as healthy individuals with age-related reductions in hippocampal volume can exhibit severe deficits in recollection (e.g., Eichenbaum et al., 2007; Yonelinas, et al., 2007), and so can suffer from quite profound and debilitating associative memory deficits, including difficulties remembering to take medications, forgetting names and dates, etc. However, in many cases, the brain regions supporting familiarity such as the perirhinal cortex are relatively preserved and so familiarity and implicit memory abilities are relatively or completely intact. If, as the current results suggest, unitization encoding strategies are effective at promoting familiarity-based associative memory, this opens up the possibility that their memory impairments might be mitigated by promoting unitization encoding strategies. As mentioned earlier, unitization encoding strategies have been found to reduce the associative memory impairment observed in amnesic patients (Quamme et al., 2007), and a recent study has shown that the associative memory deficits seen in healthy aging also appear to be reduced with unitization strategies (Bastin, et al., 2013).

Can we unitize across domains? Yes

A second major aim of the current study was to investigate whether unitization was effective at forming associations across stimulus domains or whether it was limited to within-domain associations. Experiments 4 and 5 showed not only that unitization was effective for across-domain stimuli, but that it was more effective for across- than within-domain stimuli. For example, in Experiment 4 high unitization improved memory, and specifically familiarity, for word-face pairs more so than for face-face pairs. In Experiment 5, high unitization increased familiarity for fractal-sound pairs much more so than for fractal-fractal pairs. Thus, the current data indicate that across-domain associations can benefit from unitization.

These results are consistent with Harlow et al. (2010) who reported that across-domain stimuli produced greater familiarity than within-domain stimuli. Although they didn't examine unitization effects, they did compare estimates of recollection and familiarity for name-name, name-image, and image-image stimuli. They found that name-name and name-image pairs produced equivalent familiarity estimates, both of which were significantly greater than familiarity for image-image pairs. Those authors concluded that the results were inconsistent with the domain dichotomy view that familiarity (and perirhinal cortex) can only support within-domain associations and recollection (and the hippocampus) is necessary for across-domain associations (Mayes et al., 2007).

Our finding that unitization fostered greater familiarity for across-domain than within-domain stimuli also conflicts with the domain dichotomy view, but one might argue that the within-domain stimuli were already unitized by virtue of being within-domain (Mayes et al., 2007) and that the unitization strategy could not enhance that unitization further (e.g., Rhodes & Donaldson, 2008). If true though, it is not clear why some within-domain stimuli, such as words, benefited from unitizing strategies while others, such as faces and fractals, did not. We suspect that the complexity of the stimuli might be an important factor. Complex stimuli may be more difficult to unitize because they impose greater attentional processing demands and/or because their combination doesn't result in a coherent object. For instance, while it is easy to unitize two unrelated words, unitizing two unrelated sentences would be difficult and the result of such an attempt may not make much sense and thus not gel into a single coherent concept. Similar problems seem likely when the stimuli are two fractals or two faces; the attempt to combine them into a single object may simply not work because the resulting concept (or percept) doesn't easily form a coherent object. Additionally, even if possible to form a coherent concept/percept out of two complex stimuli, it may be that the attentional demands of doing so overwhelm the system and undermine the potential benefits of unitization. In general then, it may be the case that relatively simple stimuli like words are easy to unitize within-domain whereas relatively complex stimuli such as fractals are difficult to unitize within-domain.

Another difference between the domain dichotomy view and the LOU framework concerns the importance of seemingly small details in the presentation of to-be-paired stimuli. Montaldi and Mayes (2010) argued that subtleties of presentation such as spatial position or a viewer's perspective of objects are unlikely to promote different levels of unitization. However, based on the evidence found here, we would argue precisely the opposite: that attention to the to-be-associated items determines how they are encoded and that there are a host of variables such as spatial position, perspective, and timing that are highly likely to influence whether two (or more) items are unitized or not. As a very simple example, the Gestalt principle of grouping relies primarily on subtle differences in spatial proximity. Indeed, attention research has shown that two items are more likely to be perceived as a single item as the spatial distance between them decreases (e.g., Triesman, Khanemen, & Burkwell, 1983) and recent research has shown that such subtle differences have downstream effects on memory as well (e.g., Kan, Keane, Martin, Parks-Stamm, Lewis, Verfaellie, 2011). The current results add to the evidence that these differences in processing engaged at encoding can have fairly dramatic effects on the retrieval processes (or representations) engaged at test. For example, it is striking that in Experiment 5 increasing familiarity for across-domain pairs was merely a matter of presenting them simultaneously. Similarly, Kan et al. (2011) manipulated unitization by presenting pictures of touching objects or physically separated objects and found greater associative priming in the spatially contiguous (unitized) condition. Thus, simple and seemingly innocuous variables, like spatial position and timing, can affect the degree of unitization. Moreover, the fact that these manipulations worked suggests that unitization of across-domain stimuli may often occur without explicit instruction or specific encoding strategies, a finding that also presents a challenge to the domain dichotomy view (Montaldi & Mayes, 2010).

Overall, the current results show that across-domain stimuli can benefit from unitization strategies, and so indicate that unitization is useful in promoting familiarity-based associative memory across a broad range of conditions and type of materials. Had we found it was limited only to within-domain associations it would have pointed to a serious limitation to the usefulness of unitization. Nonetheless, although the results indicated that unitization was not limited to within-domain associations, they did reveal that the types of materials that are being associated do impact how effective unitization strategies might be. Specifically, certain within-domain associations such as fractal-fractal pairs or face-face pairs appeared to benefit very little from overt unitization manipulations. Whether these limitations of unitization are related to stimulus complexity and whether they generalize to other materials types will be important questions to address in future studies.

Challenges to Unitization

There are three potentially important limitations to the conclusions we have drawn about unitization. First, could the complexity of the stimuli account for the unitization and domain effects? Prior work has shown that highly complex stimuli can lead to increases in familiarity estimates in ROC studies that are likely to rely heavily on recollection (Parks, Murray, Elfman, & Yonelinas, 2011). Thus, it could be argued that familiarity estimates in the current studies were inflated by this effect. However, it is unlikely that complexity played a role in the experiments that relied solely on words (Experiments 1 – 3) given that the stimuli were controlled across unitization conditions to be as similar as possible and the words themselves are quite simple. Perhaps more relevant would be the stimuli in Experiments 4 (words and faces) and 5 (fractals and abstract sounds), but complexity still fails to explain the unitization effects, the domain effects, or their interaction. That is, the stimuli were controlled across unitization conditions such that the only differences were processing differences. In addition, a complexity explanation would predict greater familiarity for more complex stimuli, and in Experiment 4 it was arguably the simpler stimuli (words and faces) that were easier to unitize and fostered greater familiarity. In Experiment 5 it seems likely that the complexity of the stimuli was fairly well controlled (fractal-fractal and fractal-sound pairs) but if the fractal-fractal pairs were more complex, then they should have resulted in greater familiarity. Instead, the degree of familiarity for the pair depended critically on the interaction between processing (simultaneous or sequential presentation) and the type of stimulus (across or within-domain). Overall we expect that should complexity be a factor in unitization effects, unitization strategies may actually be more difficult to use successfully for more complex stimuli (e.g., unitizing two distinct scenes may be more difficult than unitizing two distinct words).

A second potential challenge to the current results comes from debates about the nature of recollection and familiarity (e.g., Parks & Yonelinas, 2007; Wixted, 2007; Yonelinas & Parks, 2007). As noted above, DPSD and other dual-process theories hold that recollection is a threshold process, one that is subject to failure. Single-process models such as the unequal variance signal detection (UVSD) model and dual-process interpretations of UVSD (e.g., Wixted, 2007) argue instead that recollection is a continuous memory signal just like familiarity[3]. Thus, it could be argued that the ROC estimates were biased because of the specific model that was used to derive parameter estimates. However, a great deal of evidence has been obtained showing that the estimates derived on the basis for ROCs converge with results from other methods that do not rely on ROCs such as the process dissociation, remember/know, structural equation and second-choice paradigms (for reviews see Yonelinas & Parks, 2007; Yonelinas, 2002; Yonelinas et al, 2010; but also see Wixted, 2007; and Parks &Yonelinas, 2007). Additionally, the finding that unitization affected associative recognition and associative priming but not item recognition or item priming is not dependent on the application of the DPSD model.

Finally, a potential limitation of the unitization framework is that unitization has no single operational definition and so there is no litmus test that can be applied to a condition to determine if unitization did or did not occur (e.g., Mayes et al., 2007; Montaldi & Mayes, 2010). As we have used the term unitization, it is a relative construct rather than an absolute one. The relative nature of unitization is highlighted by the fact that two very similar conditions have served as both the high and low unitization conditions in different studies. In the current study, including words in a sentence frame was treated as a low unitization condition because it was compared to a condition in which the words were encoded as new compound words, whereas Graf and Schacter (1985) treated words in generated sentences as a high unitization condition because they compared that to the case where two words were presented in isolation with a vowel counting task.

Given the relative nature of unitization we don't expect that there will be any single defining feature of unitization. Although in some sense this can be a limitation, it is an advantage in the sense that it can be applied across a wide range of materials and processing contexts. Importantly, in all of the experiments we report, we contrasted two encoding conditions that clearly differed in the degree to which the two items were treated as separate items or as a single item. This is true across the unitization literature as well. Unitization has been manipulated in many different ways with many different types of materials (Rhodes & Donaldson, 2008; Graf & Schacter, 1985; Diana et al., 2010; Rhodes & Donaldson, 2008; Pilgrim et al., 2011; Schacter & McGlynn, 1989; Kounios et al., 2001; Kan et al., 2011; Yonelinas, 1999; Jager et al., 2006), and in all of these experiments, there was a comparison between conditions that differed unambiguously in terms of the degree to which the pairs were treated as single units. So although the construct is a relative one, it is by no means ambiguous or circular. Nonetheless, as with any construct, it can be difficult to rule out all alternative accounts of an observed unitization effect in a single experiment, thus it is important to look for convergence across various manipulations of unitization as we did in the current set of experiments.

[3]Importantly, there is growing evidence that recollection is both subject to a threshold and is continuous past that threshold, e.g., Kelley & Wixted, 2001; Onyper, Zhang, & Howard, 2010; Parks, Murray, Elfman, & Yonelinas, 2011.

Can single process models explain LOU effects? No

Single process models assume that recognition memory can be accounted for by a single underlying memory strength signal (e.g., Donaldson, 1996; Dunn, 2004). Such models are challenged by the various dissociations revealed in the current experiments. For example, whereas LOP led to similar increases in item and associative recognition, LOU lead to increases in associative, but not item recognition. These results join a growing body of research showing the functional and neural separability of item and associative recognition (Hockley & Cristi, 1996). These findings fall naturally from dual process models and are not easily explained as arising from a single process model (see Yonelinas, 2002 for a review). There are more complex models that have attempted to account for both kinds of memory, such as those using multiple dimensions of memory strength (e.g., multidimensional source models Glanzer, Hilford, & Kim, 2004), but it's unclear how such models could predict unitization effects without relying on two memory constructs that behave differently. Additionally models such as the UVSD model currently have no mechanism by which to predict unitization effects whereas dual process and dual system models have a long history of theorizing about the role that unitization plays a role in relational memory (e.g., Mandler, 1980; Graf & Schacter, 1985; Schacter & McGlynn, 1989; Yonelinas, 1997).

Future directions

Determining whether there are other encoding manipulations that facilitate familiarity-based associative recognition will be an important question for future studies. One way may be through extensive repetition. For example, there are some associations in the language that appear to be associated through multiple repetitions, such as *peanut butter and jelly*. However whether this is different from unitization or is just another means of unitizing is unclear, and the relevant experimental evidence is currently mixed. For instance, Schacter and McGlynn (1989) presented novel British idioms (e.g., curtain lecture) to American participants up to eight times under four different orienting task conditions designed to vary the elaborative nature of the processing. They predicted that if unitization occurred automatically with repetition then the type of processing wouldn't matter. However, they found that repetition in the context of deep processing tasks led to successful unitization while repetition in the context of shallow processing tasks did not. They therefore concluded that repetition alone, without semantic processing, may not lead to unitized representations. However, many studies have examined effects of repetition on associative memory (e.g., Kelley & Wixted, 2001; Kilb & Naveh-Benjamin, 2011; Light, Patterson, Chung, & Healy, 2004) and those that have examined process estimates have found that familiarity is increased by repetition (e.g., Kilb & Naveh-Benjamin, 2011). What remains to be seen is whether such increased familiarity for associations after repetition is due to unitization or to some other mechanism.

In the current experiments we have focused on unitization manipulations at the time of encoding, however future studies will be needed to determine whether similar effects may be observed at the time of test. That is, we expect that the manner in which the test pairs are processed during the test phase may also affect familiarity based-associative recognition. If at time of test participants are required to process the two words as two separate items they may show less familiarity-based associative memory than if they process the test pairs as a single compound word. In addition, familiarity may only be useful for the memory decision when the pair is processed as a single item at both study and test. Thus, unitizing at study may not always confer a familiarity (or implicit memory) benefit; it may depend on processing the stimuli at test as single items as well.

Another important question for future research will be to determine the brain regions that support unitization. As described earlier, lesion and neuroimaging studies have indicated that the perirhinal cortex, which is a region that is critical for familiarity, is also critical for unitization (Quamme, et al., 2007; Haskins, et al., 2008; Diana, et al. 2010). Whether this region plays a role in all forms of unitization is not yet clear, and which other brain regions are involved is largely unknown. Most of the existing studies have used unitization manipulations like the word-pair manipulations used in Experiments 1–3, so relatively little is known about more perceptual stimuli like fractals and sounds. Two recent studies have reported that the perirhinal cortex is involved in unitization of both real world objects (Staresina & Davachi, 2010) and novel objects (Rubin, Chesney, Cohen, & Gonsalves, 2013), but in addition have also implicated the fusiform gyrus which is a region earlier in the ventral processing stream. The results suggest that although the perirhinal cortex is critical for unitization, with more perceptual forms of unitization, regions earlier in the visual stream might also be involved in supporting unitized representations.

Conclusion

An overarching theme in this paper is that the combination of processes that support memory depends critically on the stimulus, the way the stimulus was encoded, and the task demands of the test. The evidence presented here, along with previous findings, argue in favor of the concept of LOU and the fact that unitization is a critical way of processing stimuli that can shift what processes can later contribute to memory decisions at test. The current results indicate that unitization reflects a specialized learning mechanism by which familiarity is able to support new learning. Unitization is functionally distinct from elaborative encoding in the sense that it is restricted primarily to associative memory and has the largest effect on familiarity. In addition, it is not limited to forming links between materials within processing domains but rather it was found to be particularly effective at associating materials across different processing domains. The results indicate the importance of unitization as an encoding process, one that is particularly important in supporting novel familiarity-based associative memory.

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Appendix

Appendix Table 1

Confidence ratings for old/intact and new/rearranged items in Experiments 1 and 3.

	Confidence Ratings											
	Old / Intact						New / Rearranged					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Experiment 1												
High-Unitize												
Item	253	327	294	318	332	396	361	393	363	343	278	182
Associative	208	245	250	252	298	667	397	445	390	261	226	201
Low-Unitize												
Item	212	283	320	393	371	341	299	362	354	374	333	198
Associative	184	298	364	418	324	332	213	334	399	437	310	227
Experiment 3												
LOP												
Deep Processing												
Item	68	81	71	103	166	531	265	228	202	132	84	109
Associative	96	122	118	132	160	332	243	199	165	151	99	103
Shallow Processing												
Item	100	118	183	205	202	152	131	188	215	195	159	72
Associative	81	183	198	208	180	110	108	170	245	230	140	67
LOU												
High Unitization												
Item	165	235	236	225	346	713	400	470	372	273	233	172
Associative	152	173	161	135	253	1046	660	471	328	174	127	160
Low Unitization												
Item	165	214	196	209	285	851	489	429	363	250	181	208
Associative	184	212	258	187	238	841	499	411	423	243	169	175

Note. There were 32 subjects per condition with the exception of the LOP conditions in which there were 16 subjects per condition.

Appendix Table 2

Confidence ratings for intact and rearranged items in Experiments 4 and 5.

	Confidence Ratings											
	Intact						Rearranged					
	1	2	3	4	5	6	1	2	3	4	5	6
Experiment 4												
Within Domain												
High Unitization	248	402	484	416	524	806	651	552	556	427	409	285
Low Unitization	316	424	488	355	453	844	760	607	499	356	368	290
Across Domain												
High Unitization	244	252	330	339	401	1314	1026	549	494	354	219	238
Low Unitization	249	340	493	392	391	1015	742	576	688	402	285	187
Experiment 5												
Within Domain												
High Unitization	290	364	379	424	537	886	966	487	369	355	342	361
Low Unitization	198	316	441	598	566	761	800	497	400	508	358	317
Across Domain												
High Unitization	257	310	335	339	489	1150	1096	559	383	317	297	228
Low Unitization	294	425	497	507	418	739	761	498	548	467	377	229

Note. There were 36 subjects per condition.

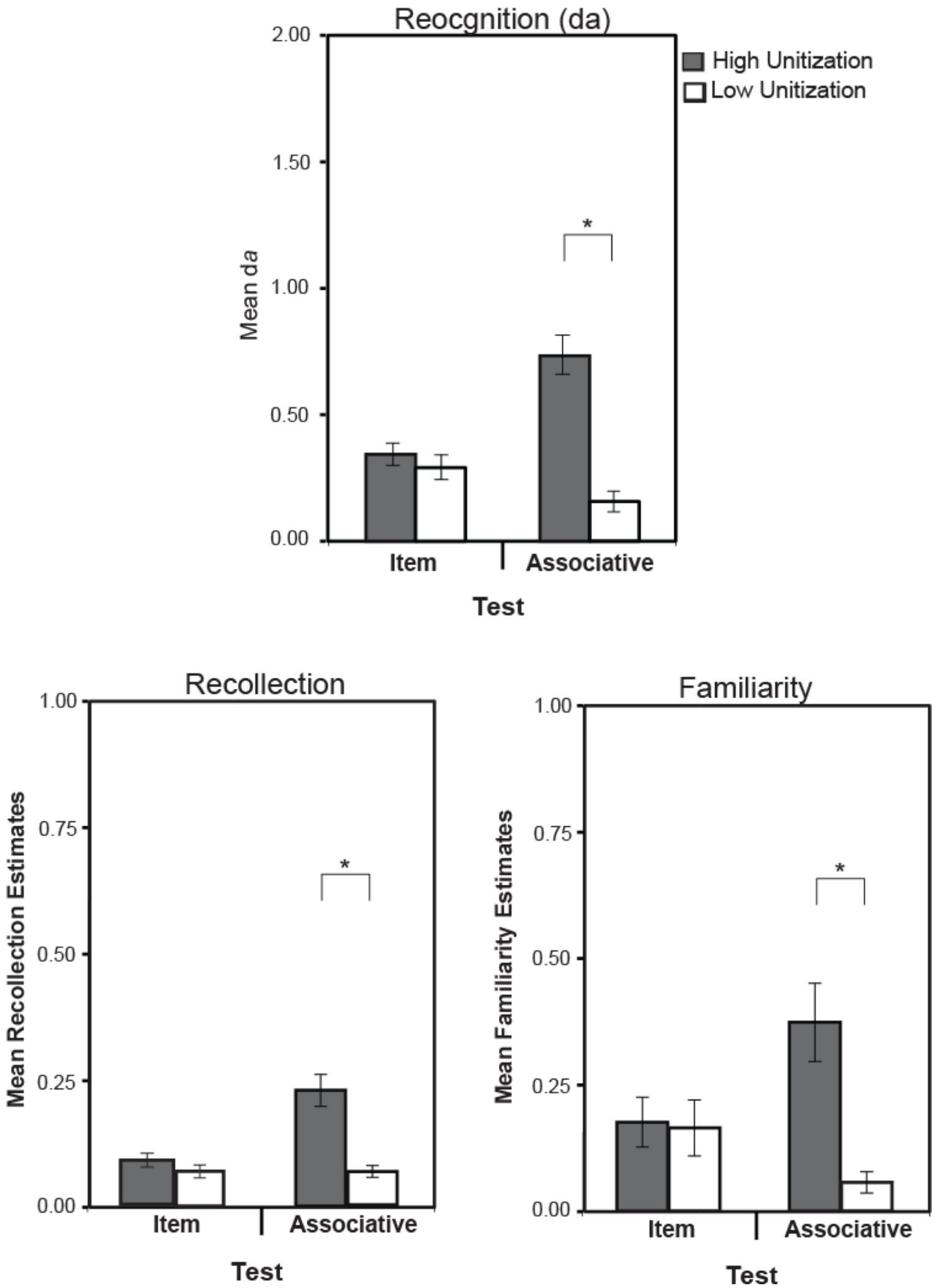

Figure 1.

Mean recognition scores (d*a*) for Experiment 1 are in the top panel, mean recollection estimates are in the bottom left panel and mean familiarity estimates are in the bottom right panel. Asterisks indicate significant differences.

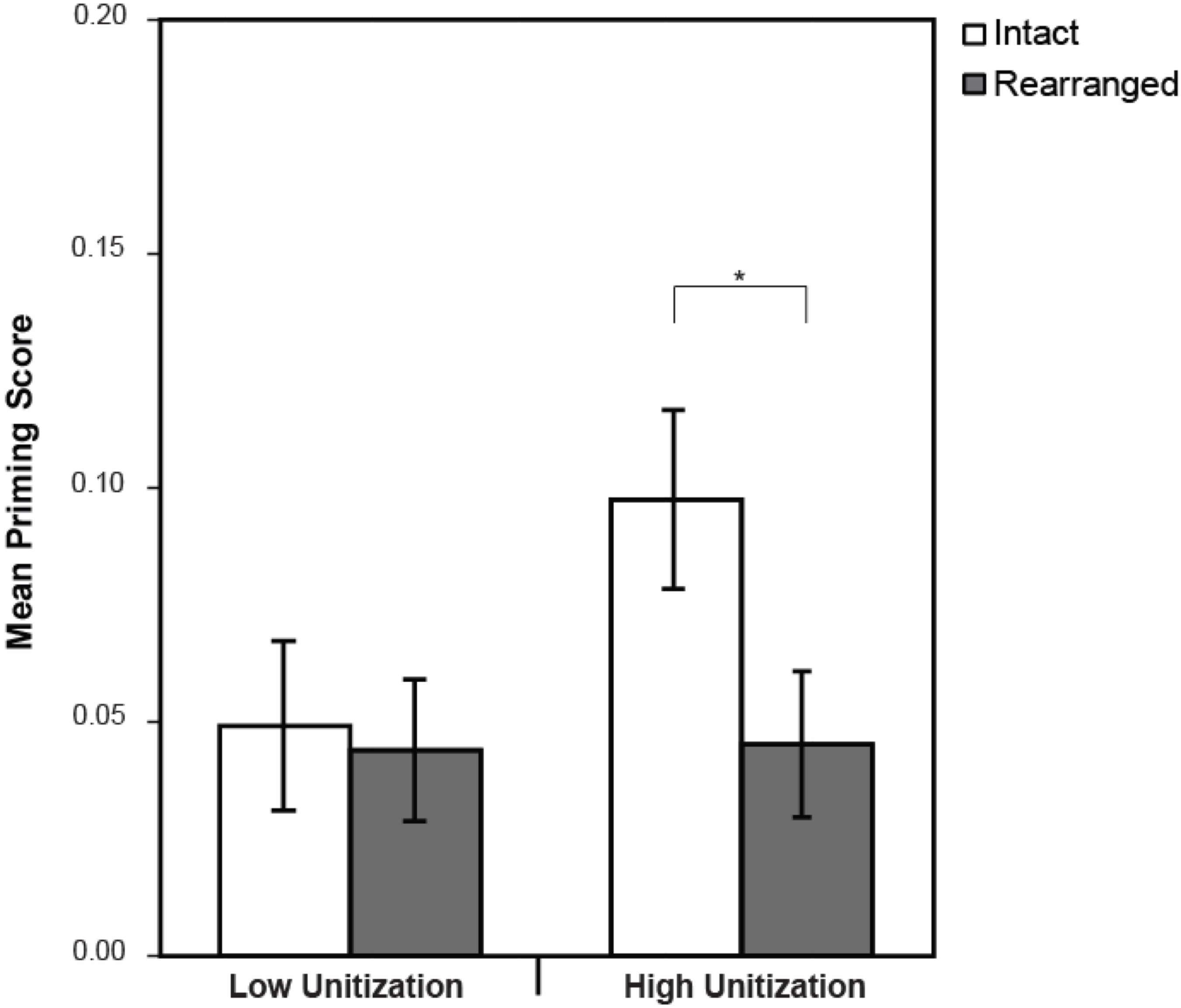

Figure 2.
Mean priming scores for low unitization (sentence frame) and high unitization (novel definition) conditions on the speeded lexical decision task in Experiment 2. Significant differences are indicated by asterisks.

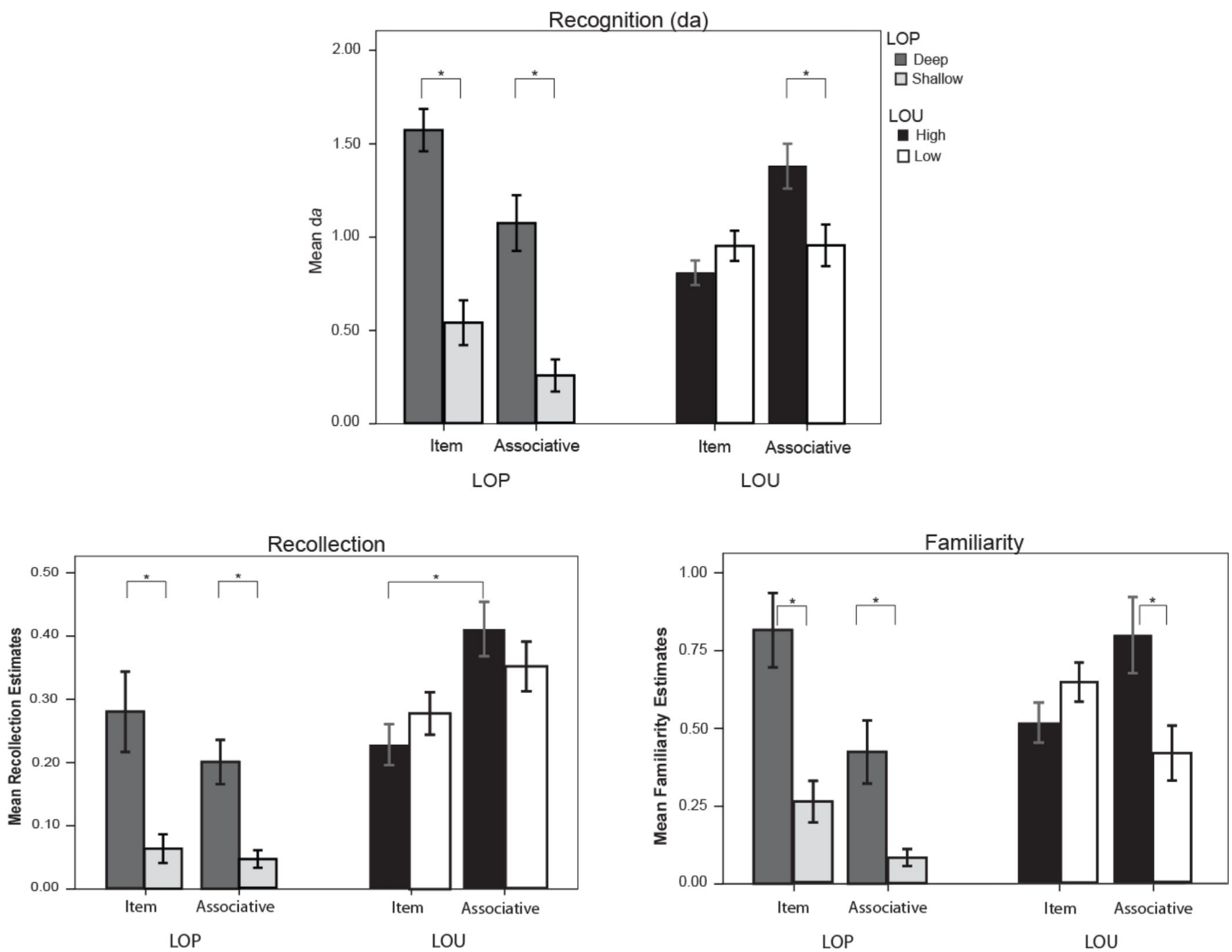

Figure 3.

Mean recognition scores (da) for Experiment 3 are presented in the top panel with mean recollection estimates on the bottom left and mean familiarity estimates on the bottom right. Asterisks indicate significant differences. LOP, levels of processing; LOU, levels of unitization.

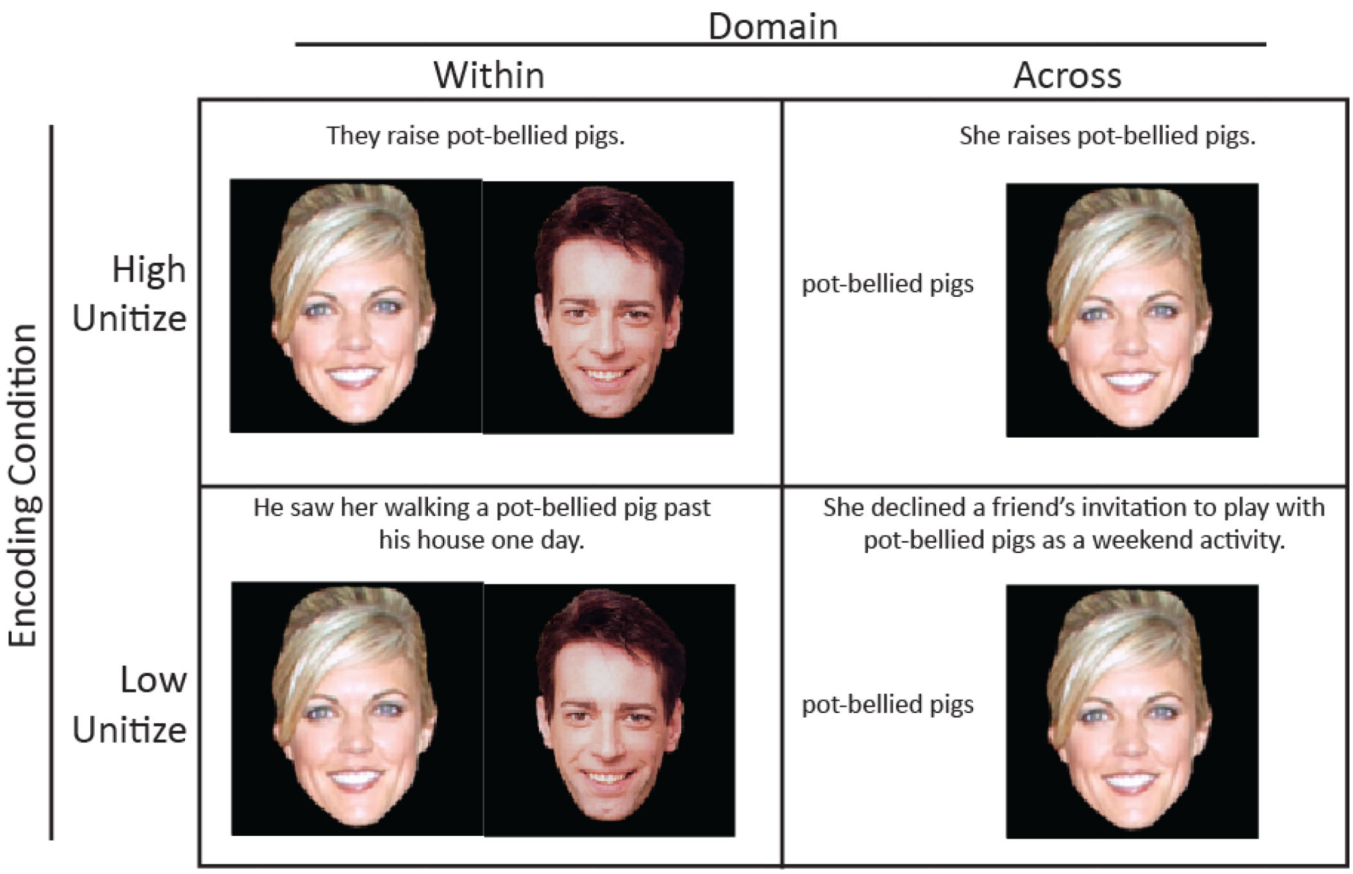

Figure 4.
Example of stimuli used in Experiment 4.

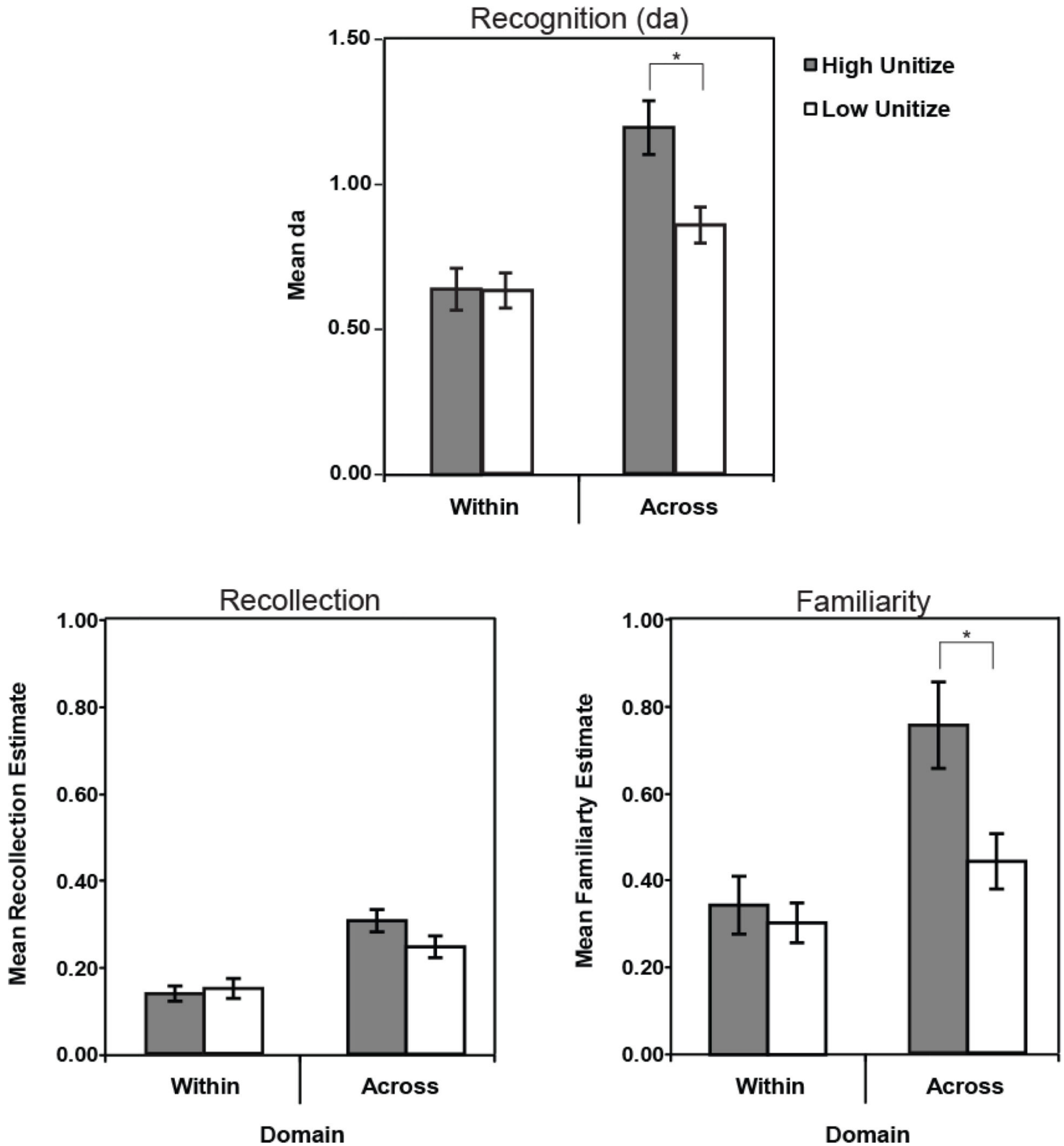

Figure 5.

Mean recognition (d*a*), recollection, and familiarity estimates for Experiment 4. Asterisks indicate significant differences.

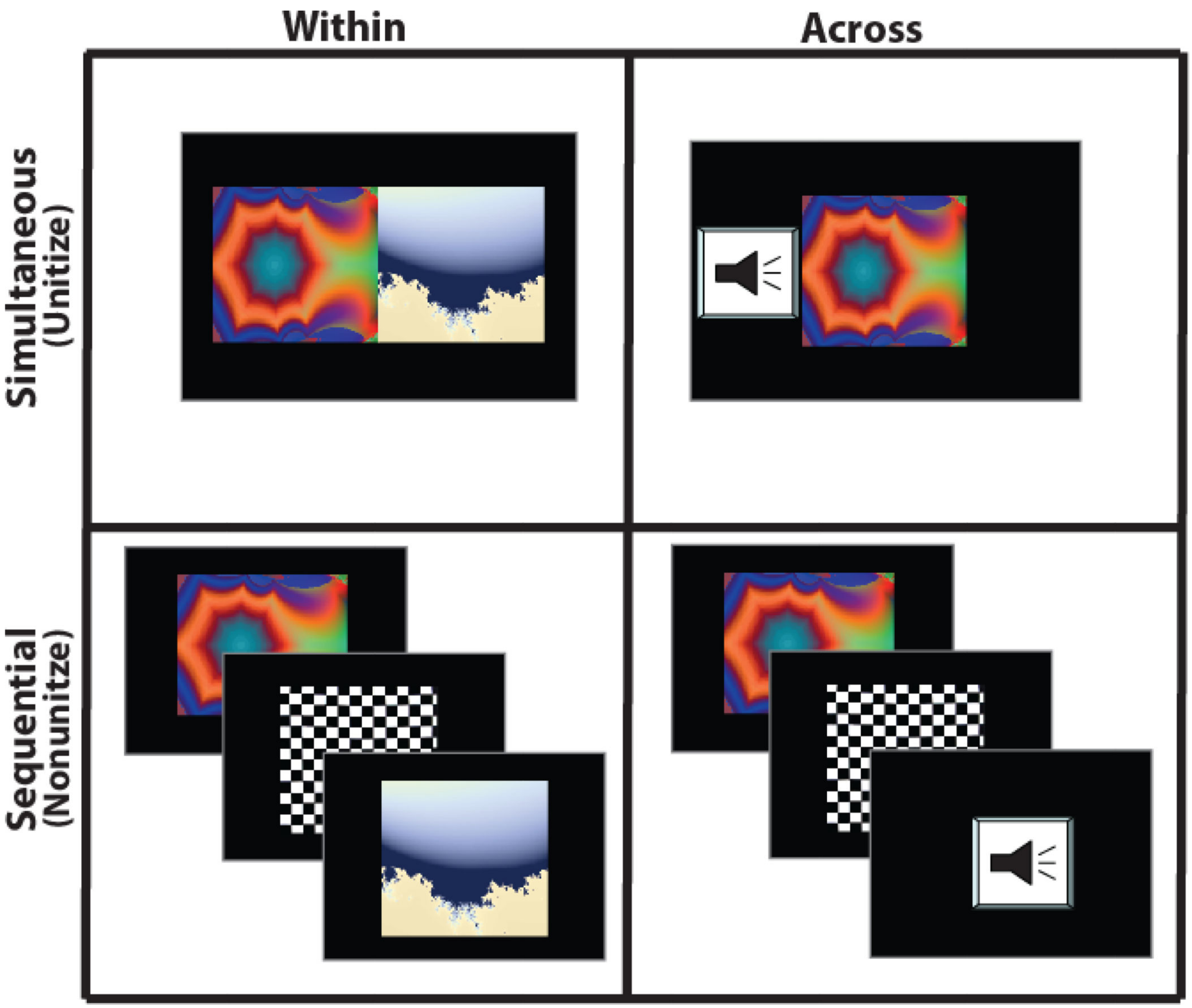

Figure 6.
Example of stimuli in Experiment 5.

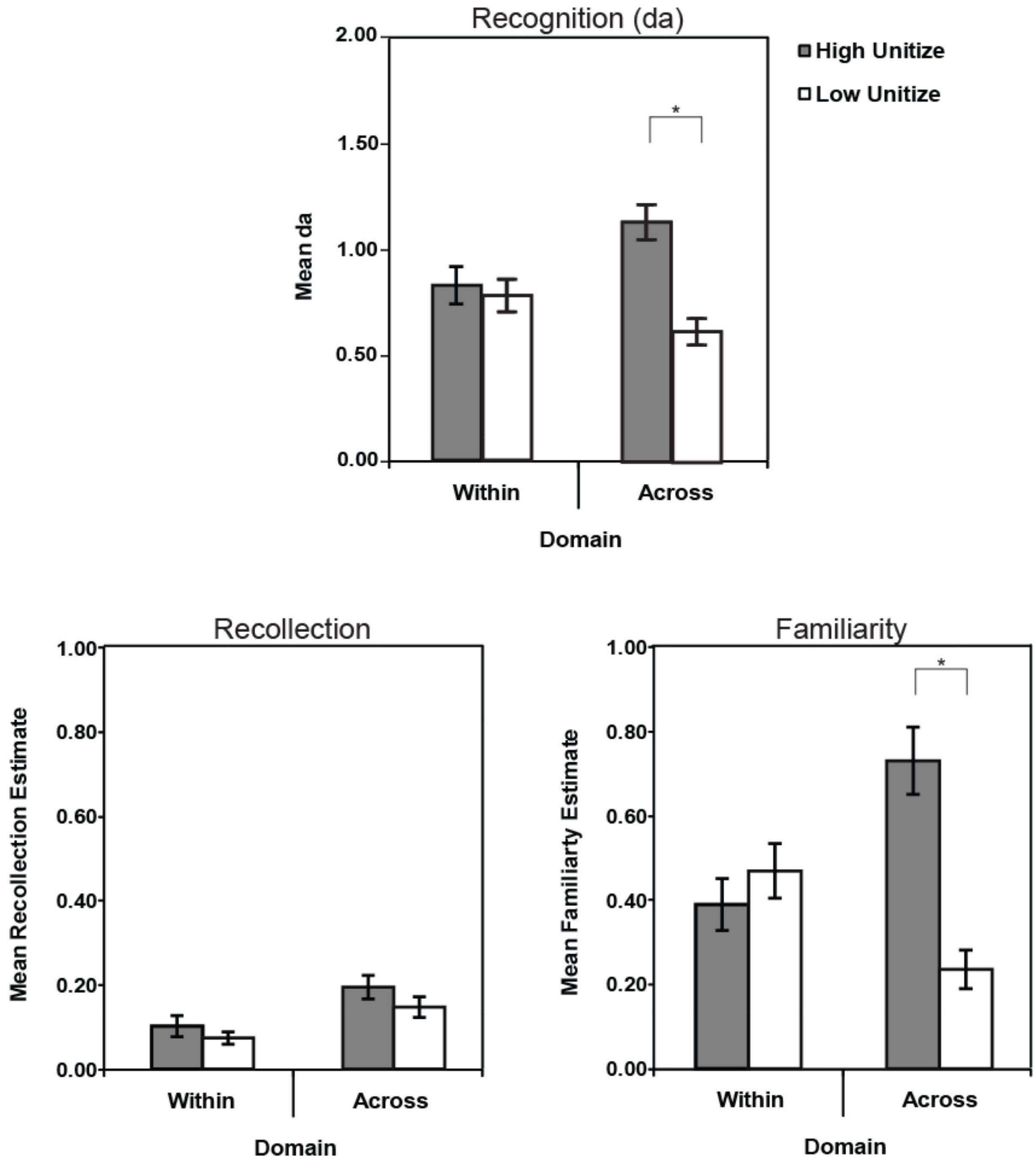

Figure 7.

Mean recognition (da), recollection and familiarity estimates for Experiment 5. Asterisks indicate significant interactions or significant differences (main effects are not depicted).

Table 1

Mean accuracy scores for lexical decisions in Experiment 2.

	LOU	
	Sentence (Low)	**Definition (High)**
Intact	0.71 (.21)	0.66 (.19)
Rearranged	0.72 (.19)	0.72 (.20)
	New Items	
Real Compounds	.50 (.17)	
Illegal Compounds	.76 (.20)	

Note. Standard deviations presented in parentheses. LOU = levels of unitization. All stimulus types were illegal words except Real Compounds.

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Table 2

Fit of DPSD and UVSD models to data.

	DPSD	UVSD
Experiment 1		
Item Low	0.94	0.91
Item High	0.91	0.88
Associative Low	0.66	0.88
Associative High	0.75	0.84
Experiment 3		
LOP		
Item Shallow	0.88	0.81
Item Deep	0.81	0.81
Associative Shallow	0.81	0.81
Associative Deep	0.88	0.94
LOU		
Item Low	0.97	0.97
Item High	0.84	0.94
Associative Low	0.75	0.84
Associative High	0.81	0.97
Experiment 4		
Within Low	0.89	0.81
Within High	0.94	0.92
Across Low	0.89	0.86
Across High	0.86	0.86
Experiment 5		
Within Low	0.92	0.86
Within High	0.94	0.86
Across Low	0.92	0.81
Across High	0.89	0.86

Note: Values reflect the proportion of participants for whom the DSPD (dual process signal detection) and the UVSD (unequal variance signal detection) models fit the data adequately (i.e., did not significantly deviate from the data using the G statistic). LOP = Levels of processing. LOU = Levels of unitization.