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Familiarity for Associations? A Test of the Domain Dichotomy Theory

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Episodic recognition memory is mediated by functionally separable retrieval processes, notably familiarity (a general sense of prior exposure) and recollection (the retrieval of contextual details), whose relative engagement depends partly on the nature of the information being retrieved. Currently, the specific contribution of familiarity to associative recognition memory (where retrieval of the relationships between pairs of stimuli is required) is not clearly understood. In this study, we tested domain dichotomy theory, which predicts that familiarity should contribute more to associative memory when stimuli are similar (within-domain) than when they are distinct (between-domain). Participants studied stimulus pairs, and at test, discriminated intact from rearranged pairs. Stimuli were either within-domain (name–name or image–image pairs) or between-domain (name–image pairs). Across experiments we used 2 different behavioral measures of familiarity based on receiver operating characteristic curves and a modified remember–know procedure. Both experiments provided evidence that familiarity can contribute to associative recognition; however, familiarity was stronger for between-domain pairs, in direct contrast to the domain dichotomy prediction.

Keywords: episodic memory, associative recognition, familiarity, recollection, unitization

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Dual-process theory posits the existence of familiarity and recollection, two functionally and neurally separable processes underlying episodic memory retrieval (for a review, see Yonelinas, 2002). An item is familiar if it simply engenders a sense of having been encountered before, whereas recollection provides additional contextual details about a previous episode. The two processes have been repeatedly dissociated, using a wide range of encoding conditions (e.g., Jacoby, 1998), retrieval tasks (e.g., LeCompte, 1995), and stimuli (e.g., Ratcliff, McKoon, & Tindall, 1994), providing strong support for the dual-process distinction. Despite this, many substantive issues remain unresolved, including the relationship between the processes (Jacoby, 1991; Joordens & Merikle, 1993) and the ways in which they interact with other memory systems (Greve, van Rossum, & Donaldson, 2007; Yovel & Paller, 2004). Here, we focus on a related question: Under what circumstances can familiarity contribute to successful recognition?

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Familiarity is generally agreed to play an important role in standard item recognition memory tests, which assess memory for individual stimuli. Even when recollection is clearly impaired, for example, in amnesic patients (Holdstock et al., 2002; Mayes, Holdstock, Isaac, Hunkin, & Roberts, 2002), familiarity provides a strong basis for accurate performance. In contrast, in tests requiring memory for relationships between items, familiarity has traditionally been thought to play a less prominent role (Hockley & Consoli, 1999). Indeed, associative recognition tasks have been used to isolate recollection (e.g., Donaldson & Rugg, 1998), consistent with the belief that memory for such relationships should be supported exclusively by recollection (Yonelinas, 1997).

Does Familiarity Support Associative Recognition?

More recently, episodic memory theorists have begun to consider circumstances under which familiarity might contribute to associative recognition. In particular, a growing body of evidence suggests that when distinct stimuli are unitized (encoded and retrieved as a single unit), familiarity does contribute to associative recognition (Haskins, Yonelinas, Quamme, & Ranganath, 2008; Quamme, Yonelinas, & Norman, 2007; Rhodes & Donaldson, 2007). For example, behavioral and imaging data suggest that pairs of linguistically associated words, such as *traffic–jam*, evoke more familiarity at retrieval than semantically related word pairs, such as *cereal–bread* (Rhodes & Donaldson, 2008). Accordingly, some models of episodic memory propose that familiarity can support associative recognition but only when to-be-remembered pairs are unitized (Diana, Yonelinas, & Ranganath, 2007; Eichenbaum, Yonelinas, & Ranganath, 2007).

Whereas unitization has received substantial empirical support, the domain dichotomy theory (Mayes, Montaldi, & Migo, 2007) provides an alternative account of why familiarity might sometimes contribute to associative recognition. According to this view, familiarity can support successful associative recognition even when stimuli are not unitized; instead, the contribution of familiarity is driven primarily by overlapping component representations in the medial temporal lobes. It is important to note that whereas item familiarity can support associative recognition indirectly (e.g., by providing a cue for recollection), both the unitization and domain dichotomy accounts propose and refer to a separate global familiarity for the associated pair. Here, we provide a brief overview of domain dichotomy and its empirical predictions before presenting two experiments that directly test the domain dichotomy view.

The Domain Dichotomy Theory

Domain dichotomy is based on a neuroanatomical account of medial temporal lobe function. At the heart of the theory is the separation of within-domain and between-domain associations. Within-domain associations (e.g., between two images or two words) occur between pairs of items that share some characteristics (e.g., modality, semantic category, component features) and are therefore likely to be represented by activity in overlapping populations of neurons in the perirhinal cortex. Between-domain associations (e.g., between an image and a word) conversely share fewer characteristics, and therefore their representations are expected to be more distal and weakly connected.

This neuroanatomical account is itself derived in part from neural network models, which provide specific predictions about the role of familiarity. Computational models of familiarity typically invoke Hebbian-type learning rules, causing similar inputs to be stored as similar patterns of activation and strengthening the overlap of these representations through repeated activation (Norman & O'Reilly, 2003; but see Greve, Donaldson & van Rossum, 2010). This view implies that similar items should interact strongly, leading to better support from familiarity (Mayes et al., 2007). Consistent with this, some studies have shown patients with hippocampal lesions to be more strongly impaired at recognizing between-domain than within-domain pairs (Mayes et al., 2004; Vargha-Khadem et al., 1997). In the current study, we included a sample of healthy participants to test a prediction that domain dichotomy derives from lesion data, namely, that within-domain pairs should be better supported by familiarity than between-domain pairs.

Testing Domain Dichotomy

We assessed the predictions of domain dichotomy by examining associative recognition memory using two different measures of familiarity, safeguarding against the particular assumptions associated with each. First, we used confidence judgments made at test to form receiver operating characteristic (ROC) curves; this allows estimates of familiarity and recollection to be derived with mathematical memory models (see Yonelinas, 2002). Second, we used phenomenological data, asking participants directly about their memory experience. In the original remember–know procedure (Tulving, 1985), participants were required to identify whether they recollected some aspect of the original experience (remember), or whether they simply found the test stimulus familiar (know). Given recent criticism of this method, in particular by proponents of domain dichotomy (Mayes et al., 2007; Montaldi, Spencer, Roberts & Mayes, 2006), in this study, we used their modified procedure, making the terms *familiarity* and *recollection* explicit, training participants to distinguish recollection from high-confidence familiarity, and examining familiarity and recollection in separate tasks.

To examine memory, we used a standard associative recognition task, presenting pairs of stimuli at study and requiring participants to distinguish intact from rearranged pairs at test. If familiarity does contribute to successful associative recognition, both ROC analysis and the modified remember–know procedure should find evidence of it. Importantly, if the domain dichotomy view is correct, both methods should find greater estimates of familiarity for within-domain than for between-domain pairs. As we explain below, both experiments found evidence of familiarity, but in stark contrast to the predictions of domain dichotomy theory, familiarity contributed more when pairs were between-domain.

Experiment 1

We used names and abstract images as stimuli; because they differ both conceptually and perceptually, they should occupy different domains. In particular, each class of stimulus was chosen so that individual exemplars shared many features (e.g., size and shape), while still being individually distinguishable. Given these constraints, on average, a name–image pair should be more between-domain than either a name–name pair or an image–image pair. We also considered that one class of stimuli might be inherently more recognizable than another. To isolate relationship-driven memory differences, name–name and image–image pairs were collapsed to form a general within-domain condition; hence, the relationship between items differed across conditions (within-domain, between-domain), but the items did not.

It has also been suggested that two representations must be directly encoded for overlap to occur (Mayes et al., 2007). We encouraged direct encoding in two ways. First, the items comprising each pair were presented simultaneously at study. Second, participants were instructed to judge how well the two items went together, without linking them by additional self-generated cues.

Method

In Experiment 1, we examined memory with nine-point ROC curves, constructed separately for each participant. We estimated the contribution of familiarity and recollection with the dual-process signal detection (DPSD) model (Yonelinas, 1997), characterizing recollection as a probabilistic process and familiarity as a continuous signal.

Participants. Thirty right-handed participants completed the experiment; one data set was excluded as a result of noncompliance. The remaining 29 participants (11 female; mean age = 22.8 years, range = 18–31 years) all had normal or corrected-to-normal vision and no known neurological problems. Participants gave informed consent (approved by the University of Stirling Department of Psychology Ethics Committee) and either received course credits or were compensated for their time at a rate of £5 (approximately $7.50) per hour.

Stimuli. Each stimulus consisted of a pair of items presented above and below central fixation, as illustrated in Figure 1. We

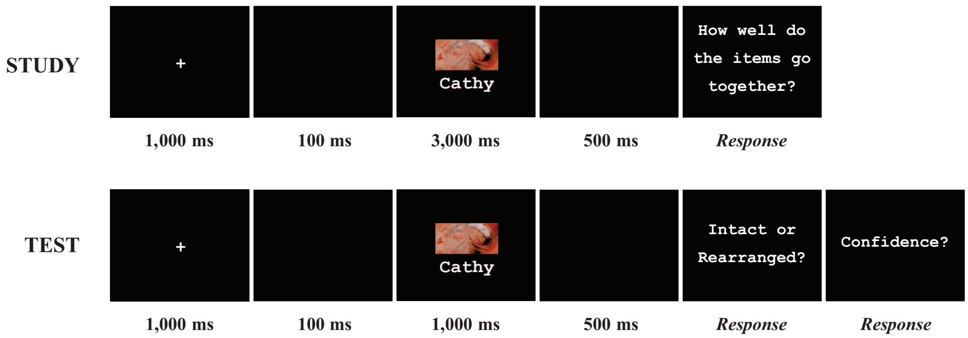

Figure 1. Procedure for Experiment 1. At study, participants were presented with a pair of items and given a direct encoding task. At test, participants were presented with two items from the study phase and asked to judge whether they were originally presented together (intact) or in different pairs (rearranged), then indicate how confident they were of their answer on a 5-point scale. Participants performed the task separately for pairs of names, pairs of images, and mixed pairs.

included three stimulus conditions. Within-domain conditions comprised pairs of either Christian names (within-domain names) or abstract images (within-domain images); a between-domain condition consisted of equal proportions of image–name and name–image pairs. Names were screened for length (four to seven letters) and frequency in the adult population (derived from names in the top 1,000 U.S. male or female names between 1950 and 1990; see www.ssa.gov). Common shortenings of the same name were used if they were easily distinguishable from each other (e.g., Tony/Anthony). A separate group of participants ($N = 9$) rated 575 images for abstractness (nameable; slightly nameable; abstract), and the most abstract were selected for use in this study. The selected images were rated "abstract" 93% of the time. In total, 324 names and 324 images were used.

Procedure. The experiment was implemented with E-Prime (www.pstnet.com), and responses were collected with a five-button Psychology Software Tools serial response box. Instructions and lexical stimuli were presented in boldface white 18-point Courier New typeface against a black background. At a viewing distance of approximately 1 m, the items in each stimulus pair together subtended a maximum visual angle of 3.7° vertically and 3.4° horizontally.

The experiment was divided into 12 blocks, four for each stimulus condition, ordered randomly. Each block was further divided into a 27-trial study phase and an 18-trial test phase. At test, nine pairs of items were intact (appeared together in the preceding study phase) and nine were rearranged (appeared in separate study trials). For example, given three pairs A–B, C–D and E–F at study, an intact test pair would be A–B, and a rearranged test pair would be C–F (discarding items D and E). Thus, every item shown at test had been encountered exactly once at study, and successful performance required participants to remember the relationships between items.

Figure 1 shows the procedure for Experiment 1. Each study trial began with a blank screen for 500 ms, followed by a central fixation cross for 1,000 ms and a second blank screen for 100 ms. The to-be-remembered pair was then presented for 3,000 ms. Following a 500-ms blank screen, participants were required to indicate on a scale ranging from 1 to 5 how well the two items went together; this response initiated the beginning of the next trial.

Test trials were identical to study trials except that each pair was presented for 1,000 ms, and the response screen asked participants to judge whether the items were intact or rearranged. Following the "intact/rearranged" response participants indicated how confident they were that they were correct, again using a scale of 1–5. This confidence response initiated the beginning of the next trial.

At both study and test, the mapping of left and right buttons to "intact/rearranged" and 1–5 responses was fully counterbalanced across blocks of four participants; the stimulus condition (within-domain/within-domain/between-domain) and test condition (intact/rearranged/not shown) of each item was fully counterbalanced across blocks of nine. On average, the procedure took 1.5 hr to complete, including a practice block and debriefing.

Results

Mean ROC curves for each condition are presented in Figure 2; each exhibits clear curvilinearity, consistent with a contribution of familiarity to performance. Below we report on an explicit assessment of whether the contribution of familiarity varies across conditions, as predicted by the domain dichotomy theory.

As a more informative measure of performance than accuracy, discrimination d_a was calculated directly from participant confidence judgments. Where μ_i and μ_r denote the mean confidence rating to intact and rearranged pairs respectively, and σ_i and σ_r denote their standard deviations, d_a is calculated by the following:

$$d_a = \frac{\mu_i - \mu_r}{\sqrt{(\sigma_i^2 + \sigma_r^2)/2}}$$

We also fit individual participants' ROC curves to the associative DPSD model, which yielded three parameters: recall to accept (rate of recollection to intact pairs), recall to reject (rate of recollection to rearranged pairs), and familiarity. All estimates were computed separately for each participant and condition.

Overall task performance is summarized in Figure 3A. Paired t tests revealed significantly lower discrimination in the within-domain image condition (0.86) than either the between-domain (1.91), $t(28) = 6.62$, $p = .001$, or within-domain name (1.86), $t(28) = 6.19$, $p = .001$, condition. No difference in discrimination was found between the between-domain and within-domain name conditions ($p = .766$).

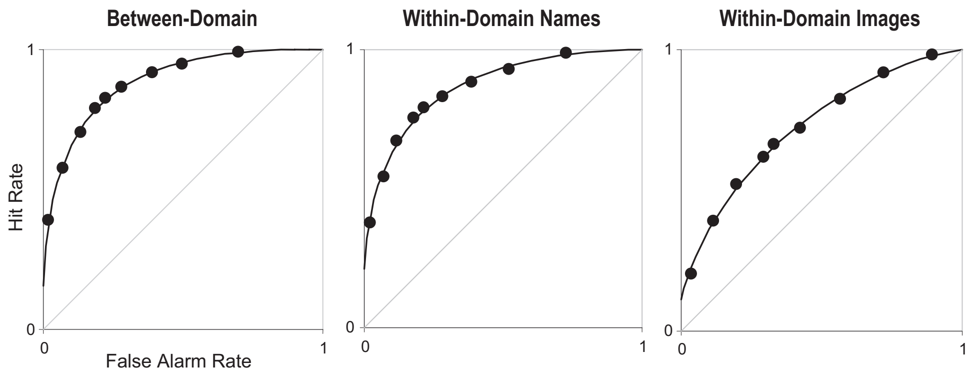

Figure 2. Group receiver operating characteristic curves for each condition from Experiment 1. Data points show mean hits and false alarms for each decision criterion; curves are from the best fitting dual-process signal detection model in each case. Note that reported parameter estimates were obtained by fitting the dual-process signal detection model to individual participant data; these group receiver operating characteristic curves provide a visual comparison between conditions. All three show clear curvilinearity.

Mean familiarity estimates for each condition are presented in Figure 3B. Paired *t* tests showed significantly lower familiarity estimates for the within-domain image condition (0.44) than either the between-domain (1.15), $t(28) = 4.00$, $p = .001$, or the within-domain name (1.08), $t(28) = 3.69$, $p = .001$, condition; within-domain name and between-domain conditions did not reliably differ ($p = .658$). Crucially, and inconsistent with domain dichotomy, neither within-domain condition had higher familiarity than the between-domain condition.

Recollection rates were analyzed with an analysis of variance (ANOVA), with variables of type (recall to accept, recall to reject) and condition (between-domain, within-domain name, within-domain image). A main effect of condition, $F(2, 56) = 4.50$, $p = .015$, reflected lower recollection for within-domain image (0.15) than between-domain (0.24), $t(28) = 2.24$, $p = .033$, or within-domain name (0.26), $t(28) = 2.70$, $p = .012$, conditions, but within-domain name and between-domain conditions did not differ ($p = .517$). A main effect of type, $F(1, 28) = 12.08$, $p = .002$, reflected higher rates of recall to accept (0.27) than recall to reject (0.17); this did not interact with condition ($p = .661$). Overall recollection rates are illustrated in Figure 3C, collapsed across type.

We assessed relationship-driven effects in two ways. First, items were matched across conditions by collapsing within-domain pairs together for each participant. Paired *t* tests revealed stronger discrimination for between-domain than within-domain pairs (1.91 vs 1.22), $t(28) = 4.83$, $p = .001$; Cohen's $d = 1.096$; driven by greater familiarity (1.15 vs 0.75); $t(28) = 2.46$, $p = .021$; Cohen's $d = 0.711$, but not recollection (0.24 vs 0.21, $p = .337$). Second, we controlled for item effects by regressing discrimination, familiarity, and recollection separately against variables of item (two, one, zero names) and relationship (within-domain, between-domain); full details are given in the online supplemental material. Item type was significant for all three dependent variables: Names

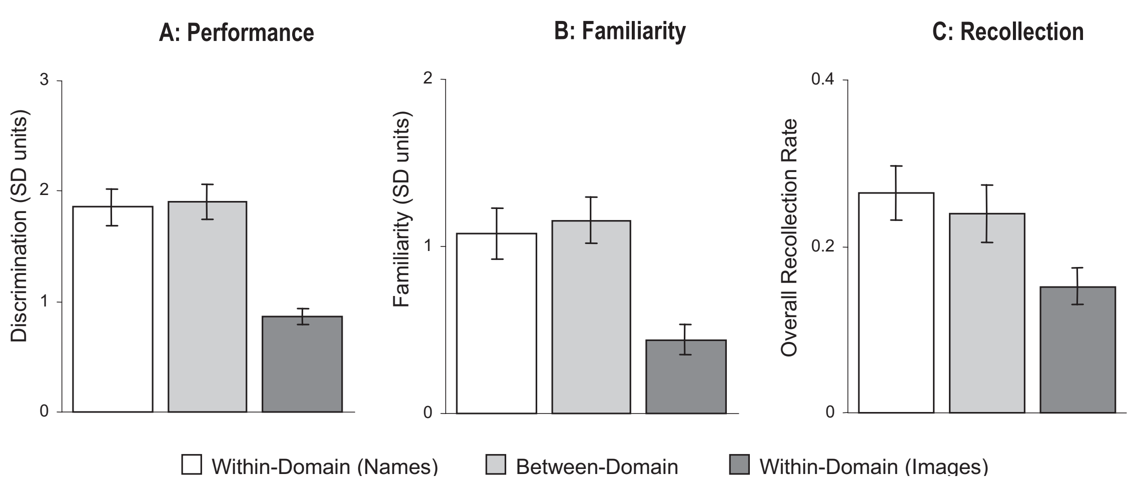

Figure 3. Mean (A) discrimination, (B) familiarity and (C) recollection rate from Experiment 1 for each condition, measured by fitting individual participant data to a dual-process signal detection model of associative recognition. Contrary to the domain dichotomy prediction, the between-domain condition exhibits just as much familiarity as the performance-matched within-domain name condition.

led to better discrimination ($B = 0.991$, $p = .001$), familiarity ($B = 0.636$, $p = .001$), and recollection ($B = 0.112$, $p = .010$) than images. Relationship had a significant effect (between-domain > within-domain) on discrimination ($B = 0.547$, $p = .002$) and familiarity ($B = 0.392$, $p = .016$) but not on recollection ($p = .391$). All reported effect sizes are unstandardized. Importantly, both methods revealed greater familiarity for between-domain than within-domain pairs, independent of item effects, the opposite pattern to that predicted by domain dichotomy.

Discussion

Familiarity estimates from a DPSD model were significantly greater than zero for all pair types, consistent with a contribution of familiarity to associative recognition. Contrary to the prediction of domain dichotomy, however, we observed greater familiarity for between-domain than within-domain pairs. Most importantly, this difference was present when controlling for stimulus class: Analysis revealed independent effects of item type (stimulus class) and relationship (within-domain/between-domain) and, critically, when directly compared between-domain pairs were more familiar than within-domain pairs of the same items.

In examining the effect of relationship type, we have used the familiarity estimate from the DPSD model. This provides a stronger test of the domain dichotomy prediction than familiarity as a proportion of overall recognition, which is as likely to reflect differences in recollection as familiarity. Nonetheless, others have argued that a greater ratio of familiarity to accuracy for within-domain pairs may constitute evidence for domain dichotomy (Bastin, Van der Linden, Schnakers, Montaldi, & Mayes, 2009). We therefore also compared proportional familiarity across conditions; this did not provide an alternative basis for supporting the domain dichotomy view (full details available online). Finally, we also re-examined the data using an alternative unequal-variance signal detection (UVSD) model (Wixted, 2007) to reinforce the conclusion that discrimination was greater for between-domain than within-domain pairs (1.83 vs 1.31), $t(28) = 3.83$; $p = .001$. In short, regardless of the approach taken to estimate memory processes, the ROC data are inconsistent with domain dichotomy theory.

Experiment 2

The DPSD model used to obtain process estimates in Experiment 1 is well suited to this purpose for two reasons: It generally gives a close fit to the ROC data, and it explicitly distinguishes between recollection and familiarity. Nonetheless, the model relies on a number of assumptions; consequently, parameter estimates should be interpreted with caution and preferably corroborated with other measures. In particular, the DPSD model assumes that familiarity and recollection are functionally independent. However if the processes are correlated, as in a redundancy view (Joordens & Merikle, 1993; see also Greve et al., 2010), both the DPSD model and the traditional remember–know paradigm would underestimate the true strength of familiarity for conditions eliciting high recollection.

To minimize the impact of this (unknown) statistical relationship on parameter estimates, Mayes et al. (2007) suggested a modified remember–know procedure, whereby familiarity and recollection measures are obtained separately. Participants are trained to distinguish between familiarity and recollection (rather than the potentially misleading terms *knowing* and *remembering*). In a familiarity-only procedure, participants are asked not to actively recollect but to report recollection when it occurs. This measure of familiarity ought to be more reliable because the recollection rate is low, and therefore the relationship between the two processes should have a small effect. In a recollection-only procedure, recall of some specific aspect of an original presentation is required for an old–new judgment, regardless of confidence. Making the distinction between strongly familiar and recollected trials explicit should result in more reliable estimates of recollection. Thus, Experiment 2 replicates Experiment 1, replacing ROC curves with the modified remember–know procedure.

Method

Participants. An additional 18 (10 female) participants (mean age = 19.1 years, range = 17–25 years) completed a modified remember–know procedure. The exclusion criteria, consent, ethics, and payment rates were identical to those in Experiment 1.

Procedure. Each participant performed the familiarity-only task of the modified remember–know procedure for six consecutive blocks (two of each condition) and the recollection-only task for another six blocks; task order was counterbalanced across participants. In the familiarity-only task, the "intact/rearranged" and confidence judgments at test were replaced with a single "familiar-intact/unfamiliar-rearranged/recollected" judgment. Participants responded intact or rearranged on the basis of familiarity only; when involuntary recollection occurred (of any aspect of an original study episode), they were required to respond "recollected."

In the recollection-only task participants made a single "recollected–intact/recollected–rearranged/no recollection" judgment. Here, participants responded "intact" only if they recalled some aspect of the original study presentation and "rearranged" if they recalled one of the items being paired with another at study. In the absence of explicit recollection, they were required to respond "no recollection," regardless of confidence. With the exception of these procedural differences, Experiment 2 was identical to Experiment 1.

Results

Nonrecollected trials (of unknown accuracy) in the recollection-only experiment were assigned the (known) accuracy for nonrecollected trials in the familiarity-only procedure, giving an overall accuracy for each participant and condition. Mean accuracy for each condition (between-domain $M = 0.81$; within-domain name $M = 0.81$; within-domain image $M = 0.66$) did not reliably differ across Experiments 1 and 2 (between-domain $p = .423$; within-domain name $p = .441$; within-domain image $p = .338$), suggesting that the change in retrieval task did not significantly alter performance. Familiarity was assessed by examining discrimination (false alarm corrected hits) in the familiarity-only procedure after discarding recollected trials.[1] Paired t tests revealed lower familiarity for the within-domain image (0.24) than for the between-domain condition (0.38), $t(17) = 2.83$, $p = .011$), but the within-domain name condition (0.33) did not reliably differ from either the within-domain image ($p = .385$) or the between-domain ($p = .516$) condition. Figure 4A shows familiarity-driven discrimination for each condition.

We similarly examined discrimination in the recollection-only procedure, after discarding nonrecollected trials. Paired t tests revealed poorer recollection for within-domain image (0.42) than for between-domain (0.70), $t(17) = 4.52$, $p = .001$, or within-domain name (0.71), $t(17) = 5.84$, $p = .001$, conditions, but between-domain and within-domain name pairs showed no difference ($p = .875$). Figure 4B shows recollection-driven discrimination for each condition.

As for Experiment 1, familiarity, recollection and accuracy were regressed against item and relationship type. All trends were in the same direction as Experiment 1 and were significant for accuracy (items: $B = 0.125$, $p = .001$, and relationship, $B = 0.064$, $p = .031$) and recollection (items: $B = 0.293$, $p = .001$, and, marginally, relationship, $B = 0.136$, $p = .059$). Whereas the familiarity regression lacked sufficient power (items: $B = 0.088$, $p = .314$, and relationship, $B = 0.101$, $p = .183$), when compared directly, between-domain pairs did exhibit greater familiarity (0.38 vs 0.28), $t(17) = 2.13$, $p = .048$ (Cohen's $d = 0.549$) as well as accuracy (0.81 vs 0.75), $t(17) = 3.30$, $p = .004$ (Cohen's $d = 0.679$) and recollection (0.70 vs 0.57), $t(17) = 2.17$, $p = .044$ (Cohen's $d = 0.516$) than within-domain pairs of the same items.

Discussion

The results from Experiment 2 closely match those from Experiment 1: Familiarity appears to support performance in all three conditions, but in contrast to a domain dichotomy view, the contribution was greater for between-domain than within-domain pairs. Of particular importance was the demonstration of phenomenological evidence for familiarity, given that familiarity estimates from the DPSD model rely upon an assumption that recollection is thresholded. If recollection is graded (Wixted, 2007), the curvilinearity that is interpreted as reflecting familiarity could be accounted for by weaker recollection. While possible, this explanation is inconsistent with above-chance performance in the familiarity-only procedure. In addition, participants all reported themselves well able to distinguish between familiar and recollected trials, both during the practice phase and at the end of the study. Thus, together, our results suggest that performance is being supported by a process that both looks (Experiment 1), and feels (Experiment 2), like familiarity.

General Discussion

The results presented here provide evidence that familiarity can contribute to the retrieval of novel associations. Our data suggest that familiarity supported performance in an associative recognition task, regardless of pair type (names, images, mixed pairs) or how performance was assessed (ROC analysis, modified remember–know procedure). As illustrated in Figure 5, however, familiarity was consistently greater for between-domain pairs. These results therefore present a fundamental challenge to domain dichotomy theory, raising questions about how familiarity should best be characterized and what role it plays in associative recognition.

The results of any study evidently rely, to some extent, on the stimuli used, and at present there is no precise definition of a domain to guide this choice. Perhaps, therefore, our particular stimuli simply do not give rise to overlapping representations as predicted. Data from neuroimaging may be important in this regard: Future studies should demonstrate whether individual classes of stimuli are indeed represented in separate domains and whether item representations converge spatially (with functional magnetic resonance imaging) and temporally (using electroencephalography). More broadly, in functional terms, perhaps familiarity is not well characterized by the kinds of tuning mechanisms and overlapping representations that are proposed by the models that motivate domain dichotomy theory (for further discussion, see Greve et al., 2010).

Although our findings are clear, they stand in contrast to a study that claims support for domain dichotomy (Bastin et al., 2009), in which face–face pairs were shown to elicit more proportional familiarity than face–name pairs. These data are strikingly consistent with the lesion data reported by Mayes et al. (2004), and the use of forced-choice procedures may account for some differences with our study. However, we have reservations about the strength of evidence the results of Bastin et al. provide for domain dichotomy: Face–name pairs actually gave rise to better associative recognition during pilot testing (familiarity was not reported), and face–face pairs were therefore presented for longer at study to equate performance. Given this manipulation, it is possible that familiarity, like overall recognition, may have originally been matched or greater for face–name pairs; unfortunately the design of the experiment makes this impossible to determine. Even more importantly, between-domain pairs were not compared with within-domain pairs from the two domains, making it mathematically impossible to disentangle (or characterize their result in terms of) item and relationship effects.

In our findings, the relationship effect is demonstrably independent of item effects. Proponents of domain dichotomy might argue that the predicted effect is still present, masked by a larger effect in the opposite direction, a possibility that is, of course, impossible to rule out. Thus, here we focus on the key finding that between-domain pairs were recognized more easily than within-domain pairs: Why might this be? In both experiments, between-domain pairs elicited greater estimates of familiarity. This raises the possibility that they might be more robustly unitized than within-domain pairs, given that unitization has been implicated in familiarity for associations (Rhodes & Donaldson, 2007, 2008; Quamme et al., 2007). It is, however, circular to categorize stimuli as unitized (or not) on the basis of differences in familiarity alone, emphasizing the need for independent means of assessing unitiza-

[1] This estimate of familiarity is accurate under an assumption of stochastic independence (recollected trials are, on average, no more or less familiar than nonrecollected trials). We also assessed familiarity under the alternative statistical assumptions of redundancy (recollected trials are more familiar) and exclusion (recollected trials are less familiar). The results are qualitatively similar, and are included as supplementary material online.

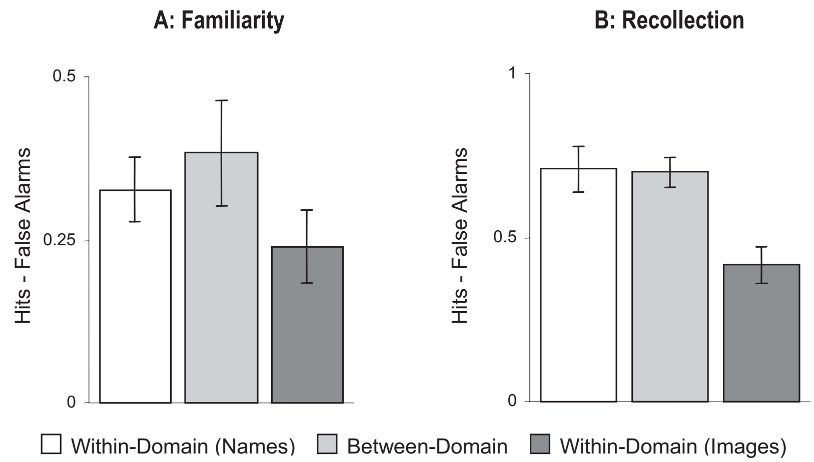

Figure 4. Mean (A) familiarity-driven and (B) recollection-driven discrimination for each condition in Experiment 2. The between-domain and within-domain name conditions did not differ for either process, matching the pattern observed in Experiment 1.

tion. Memory for unitized pairs might be more strongly impaired by manipulations that introduce perceptual differences between study and test (e.g., switching the positions of items, or presenting them separately), or, as suggested by Mayes et al. (2007), recognition or perception of the individual components might be reduced following unitization.

One aspect of the current findings is not predicted by unitization: In Experiment 2, between-domain pairs elicited higher levels of recollection compared with within-domain pairings of the same items. Given that unitization is primarily an account of familiarity, it is compatible with this change in recollection but does not readily explain it. Instead, better memory for individual items might assist recollection and thereby support stronger associative recognition. For example, items might be more distinctive when presented as part of a between-domain pair and, therefore, better recognized (Curran, Tanaka, & Weiskopf, 2002). Results from Criss and Shiffrin (2004) also suggested that increasing the number of similar items in a list impairs memory, predicting poorer item recognition for within-domain conditions. Intriguingly however, the same study suggested that associative recognition performance was dependent on the similarity of pairs rather than items, posing a challenge for a purely item-level explanation.

Finally, our data demonstrate that the nature of the stimuli is important for remembering: Names were generally better remembered than images. The relationship-driven difference we report here is, however, statistically independent of this item-type effect. Interestingly, a previous study with faces and words (Criss & Shiffrin, 2004: Experiment 1, Group A) finds a similar effect of

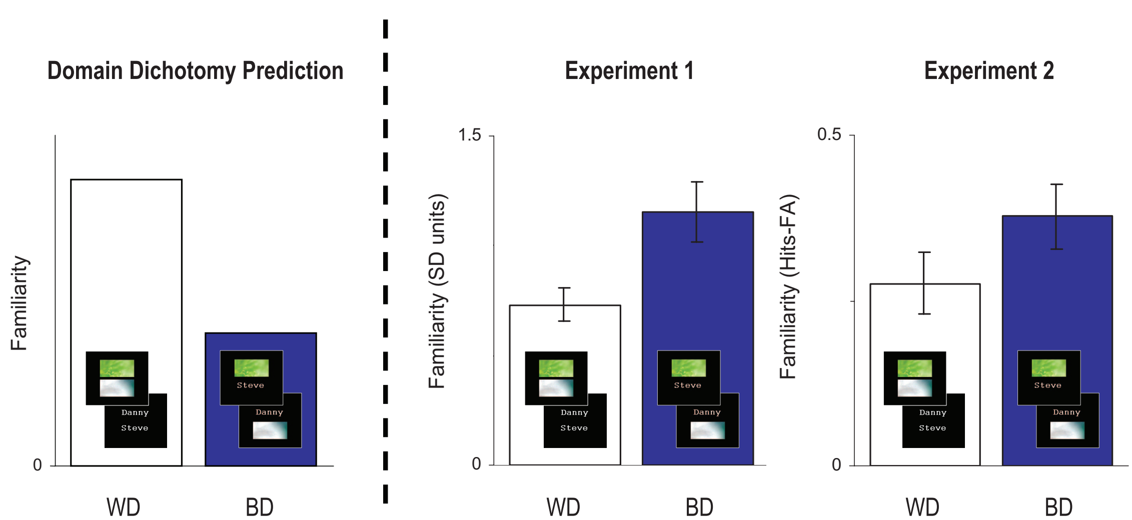

Figure 5. Familiarity for within-domain (WD) and between-domain (BD) pairs of the same items as predicted by the domain dichotomy view and as observed in Experiments 1 and 2. Between-domain pairs elicited greater estimates of familiarity in both experiments, clearly contradicting the predictions of domain dichotomy theory. FA = false alarms.

relationship, also independent of stimulus type effects. An important aim for future research will be to establish whether, in broader terms, relationship effects are influenced by the nature of stimuli (e.g., Rhodes & Donaldson, 2007) or exist generally for certain types of association (e.g., within- or between-domain).

We began this study in search of evidence for domain dichotomy in one area where it has been notably lacking: psychological studies of normal subjects. Whereas our results do not support domain dichotomy, they are consistent with a role for familiarity alongside recollection in associative recognition. Interestingly, they also suggest that the way items are combined might change the contribution of each process to retrieval. Characterizing these relationship effects remains an important goal for future research.

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