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The Effects of Unitization on Familiarity-Based Source Memory: Testing a Behavioral Prediction Derived From Neuroimaging Data

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Performance on tests of source memory is typically based on recollection of contextual information associated with an item. However, recent neuroimaging results have suggested that the perirhinal cortex, a region thought to support familiarity-based item recognition, may support source attributions if source information is encoded as a feature of the relevant item (i.e., "unitized"). The authors hypothesized that familiarity may contribute to source memory performance if item and source information are unitized during encoding, whereas performance may rely more heavily on recollection if source information is encoded as an arbitrary contextual association. Three source recognition experiments examining receiver operating characteristics and response deadline performance indicated that familiarity makes a greater contribution to source memory if source and item information are unitized during encoding. These findings suggest that familiarity can contribute to source recognition and that its contribution depends critically on the way item and source information are initially processed.

Keywords: source memory, familiarity, unitization, recollection, ROCs

Source memory provides information about the conditions under which an item was previously encountered. Thus, tests of source memory are generally thought to require recollection of contextual information associated with an item. If context identification is not needed, memory for an item can be based on assessments of its familiarity, even in the absence of recollection (see Diana, Reder, Arndt, & Park, 2006, and Yonelinas, 2002, for reviews). Within the brain, the medial temporal lobe (MTL) is critical for episodic memory in general (Eichenbaum, Otto, & Cohen, 1992; Scoville & Milner, 1957), but different MTL subregions may be differentially involved in recollection and familiarity processes. Neuroimaging studies examining the neural correlates of source recognition have generally shown that activity in the hippocampus and parahippocampal cortex is increased during encoding and retrieval of items for which the source is subsequently recollected, as compared with subsequently recognized items for which the source is not remembered (Davachi, Mitchell, & Wagner, 2003; Kensinger & Schacter, 2006; Ranganath et al., 2003). In contrast, activity in another MTL region, the perirhinal cortex, has been correlated with familiarity-based item recognition and not with successful source memory (Davachi et al., 2003; Kensinger & Schacter, 2006; Ranganath et al., 2003; Uncapher, Otten, & Rugg, 2006; Weis et al., 2004). These results are consistent with models that postulate that the hippocampus and parahippocampal cortex are critical for processing of episodic information that supports recollection-based discriminations, whereas the perirhinal cortex is critical for processing of item-based information that supports familiarity-based discriminations (Aggleton & Brown, 2005, 2006; Diana, Yonelinas, & Ranganath, 2007; Eichenbaum, Otto, & Cohen, 1994; Eichenbaum, Yonelinas, & Ranganath, 2007).

However, in contrast with this pattern of results, a recent study by Staresina and Davachi (2006) found that activation in the hippocampus and the perirhinal cortex was associated with successful source encoding. One possible account of the Staresina and Davachi results is that the perirhinal cortex encodes representations that support contextual recollection. Although this is possible, it does not explain why this pattern was not observed in the other studies. Another intriguing possibility is that familiarity information may have contributed to accurate source judgments in their task. To see how this could be the case, it is useful to consider the encoding procedures from the earlier studies that did not find perirhinal activation related to source recollection (e.g., Ranganath et al., 2003) and contrast them with the procedures of the Staresina and Davachi study.

In the study reported by Ranganath et al. (2003), participants were scanned while they encoded words that were shown in either red or green. If the word was green, participants were required to report whether the item would fit in a shoebox. If the word was red, participants were to report whether the item was alive. Source recognition was measured as the ability to remember the color associated with each word. Staresina and Davachi (2006) also examined source memory for color–word associations. In their experiment, participants were scanned while encoding words presented on one of four background colors: red, yellow, green, or blue. On each study trial, participants were asked to imagine the study item as though it were the same color as the background

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(e.g., the word *elephant* on a red background would indicate that the participant should imagine a red elephant). In addition, participants were asked to report whether this imagined object was plausible. As in the Ranganath et al. study, source recollection was measured as the ability to remember the color associated with each item.

These studies are different in several ways; however, the difference between the encoding tasks is the most salient. That is, the Ranganath encoding task (Ranganath et al., 2003) led participants to encode source information as an arbitrary contextual association (i.e., the item and the context color), whereas the Staresina encoding task (Staresina & Davachi, 2006) encouraged participants to encode source information as a feature of the item that was encoded (i.e., the color of the item that was imagined). These two encoding conditions differ in the degree to which they promoted "unitization" (e.g., Yonelinas, Kroll, Dobbins, & Soltani, 1999). Graf and Schacter (1989) proposed that unitization could occur by creating a new structure for materials processed concurrently, and that when a portion of the unitized item is viewed, the representation is then "reactivated as a whole" (p. 931). In the case of Staresina and Davachi's (2006) task, mental imagery was used to provide a structure for processing color as a feature of the item. Following this type of source unitization at encoding, presentation of the item might elicit reactivation of the unitized representation, which would produce a familiarity signal that could support accurate source memory. This is similar to Staresina and Davachi's (2006) conclusion that the results suggest "a role of the perirhinal cortex in supporting some forms of associative mnemonic processing (namely, intra-item)" (p. 9170). They argued that their source task required recovery of a feature of the item rather than a detail of the episode that is external to the item.

Although it is often assumed that memory for arbitrary associations such as those measured in source memory tests is only supported by recollection, several recent studies have indicated that familiarity can also support memory for certain types of associations when the items are unitized (Yonelinas et al., 1999). For example, in tests of associative recognition for word pairs, familiarity (measured using the remember/know procedure) is greater when the paired words form a compound word than when they do not (Giovanello, Keane, & Verfaellie, 2006). In addition, in a test of associative memory for the relationships between facial features, the contribution from familiarity (measured using analyses of recognition receiver operating characteristic [ROC] curves) is greater when faces are presented in their upright orientation than when they are presented upside down. Given that upright faces tend to be processed as single units whereas upside-down faces are processed as separate components (Searcy & Bartlett, 1996), the results suggest that familiarity can support associative recognition to some degree when the associations are processed as single units (Yonelinas et al., 1999). Convergent results have been obtained from event-related potential studies, demonstrating that the mid-frontal FN400 old–new effect, which is typically correlated with familiarity-based recognition,[1] is larger for associations that are rated as more unitized (Ecker & Zimmer, 2007; Jager, Mecklinger, & Kipp, 2006; Rhodes & Donaldson, 2007) or when the encoding conditions promote unitization (Opitz & Cornell, 2006).

Finally, recent studies of amnesic patients have also investigated the effects of unitization on associative recognition. These studies have indicated that patients with hippocampal damage who have deficits in recollection but exhibit preserved familiarity are severely impaired at associative recognition for random word pairs. However these patients' performance is relatively preserved if the word pairs form existing compound words (Giovanello et al., 2006) or if random word pairs have been encoded as if they were compound words (Quamme, Yonelinas, & Norman, 2007). Interestingly, amnesic patients with damage to both the hippocampus and the perirhinal cortex were impaired at recognition of both unitized and nonunitized associations (Quamme et al., 2007). This finding suggests that the perirhinal cortex may be able to support familiarity-based recognition of unitized associations but not nonunitized stimuli, whereas the hippocampus can support associative recognition for nonunitized and unitized associations.

The evidence that we have reviewed so far suggests that (a) the perirhinal cortex supports familiarity-based recognition, and (b) unitization of item–item associations can increase the contribution of familiarity to associative recognition. However, what remains unclear is whether unitization of item and source information can increase the contribution of familiarity to source memory tests, as the results of Staresina and Davachi (2006) may have suggested. Although it is possible that the items were unitized with the source color in that study, there are various reasons to expect that this might not have occurred. For example, the association between each item and its background colors was arbitrary (e.g., the word *elephant* and the color red). Thus, it might not have been possible to unitize color and item information. In addition, in associative recognition, each item is typically paired with only one other item, so the effects of unitization between the items would be fairly distinctive. In contrast, source memory tests typically pair a small number of sources (e.g., two or four colors) with a large number of different items. Thus, any beneficial effects of item–source unitization might have been overcome by interference.

We conducted three experiments aimed at addressing the question of whether it is possible to unitize item information and source information and whether this unitization leads to increased familiarity-based memory. Because any particular method for measuring the contribution of recollection and familiarity relies on assumptions that can be violated, our approach is to seek convergence across two different methods—analyses of ROCs of recognition confidence ratings and analyses of source recognition under speeded and nonspeeded conditions.

In Experiment 1, we examined source recognition in conditions that were designed to be similar to those used in the Ranganath et al. (2003) and Staresina and Davachi (2006) studies. Participants encoded items and background colors in a condition that encouraged unitization (i.e., by rating the plausibility of the item in the source color) or did not encourage unitization (i.e., by making pleasantness or size judgments depending on the source color). Participants then rated the confidence of their source recognition responses. The confidence ratings were then used to generate ROC curves by plotting the hit and false alarm rates at different response criterion levels.

[1] Some researchers have argued that these event-related potential effects may actually reflect neural correlates of conceptual priming (e.g., Paller, Voss, & Boehm, 2007). However, it is presently unclear whether familiarity and conceptual priming are driven by similar or different forms of neural plasticity.

The contribution of recollection and familiarity to source decisions was estimated by examining the shape of the ROC curves. We predicted that increasing the contribution of familiarity to source memory would lead to ROCs that were more curvilinear. The degree of curvilinearity can be assessed by using linearity analyses and fitting a dual-process signal detection model (Yonelinas, 1994, 1999) to the source memory ROC curves. This model has been found to provide excellent fits for observed ROCs in a wide variety of recognition paradigms including tests of source memory (for a review, see Parks & Yonelinas, 2007; but see also Wixted, 2007). The model assumes that recollection is a threshold process (i.e., some proportion of items are recollected, others are not) that supports relatively high confidence responses, whereas familiarity reflects a signal detection process that contributes to a wider range of confidence responses. Thus, if source memory decisions relied primarily on recollection, the model predicts primarily linear source ROCs in probability space (Yonelinas et al., 1999). However, because familiarity is expected to reflect a signal detection process, the model predicts that as the contribution of familiarity increases, the ROCs should become more curvilinear due to the Gaussian nature of the familiarity strength distributions (Parks & Yonelinas, 2007; Yonelinas, 1994). On the basis of prior findings indicating that increases in familiarity lead ROCs to move upward and become more curved in probability space (e.g., Yonelinas, 1999), we expected that the ROCs in the unitized condition would be higher and more curved than those in the nonunitized condition. We did not have any a priori predictions about the effects of unitization on recollection, but based on previous studies (Giovanello et al., 2006), we expected recollection to be less affected by this manipulation.

Experiment 2 was identical to Experiment 1, except that the unitized and nonunitized encoding tasks were modified to control for overall differences in performance and for differences in the visual imagery elicited by the study instructions. That is, we wished to determine whether unitization would increase the curvilinearity of source memory ROCs, even when overall performance was matched between the unitized and nonunitized conditions. In addition, Experiment 2 attempted to determine whether the effects of unitization could be observed when visual imagery was required in both the unitized and nonunitized encoding conditions.

Experiment 3 was identical to Experiment 2 except that only "yes/no" responses were collected, and recognition was tested under either unspeeded conditions or speeded conditions that were expected to effectively eliminate the contribution of recollection. Previous studies have indicated that when participants are required to respond prior to a deadline of 750 ms, source memory can be reduced to chance, whereas item recognition remains well above chance (Hintzman & Caulton, 1997; Hintzman, Caulton, & Curran, 1994; McElree, Dolan, & Jacoby, 1999). These results have been interpreted as indicating that source recollection is a slower process than familiarity (which is significantly more accurate than chance even at 300-ms deadlines). On the basis of these results, our expectation was that under speeded conditions, associative recognition should be greater for the unitized than the nonunitized conditions, because familiarity is more useful after unitized than after nonunitized encoding conditions.

Finally, it should be noted that our account of the discrepancy between the Ranganath et al. (2003) and Staresina and Davachi (2006) studies is entirely post hoc. Although those studies were not designed to test our unitization account, we propose that unitization can explain the results and therefore also provide a priori predictions for the current experiments. That is, if the unitization account of the imaging results is correct, then we can expect the source ROCs in these two conditions to be quite different, and most important, the parameter estimates of familiarity to be greater in the conditions used by Staresina and Davachi (2006) than in those used by Ranganath et al. (2003). We are not aware of any other memory theory that would predict a priori that these different encoding conditions would lead to differences in ROC shape or in estimates of familiarity.

Experiment 1

In our first experiment, we compared source memory ROCs that resulted from encoding tasks like those used by Staresina and Davachi (2006) and Ranganath et al. (2003). We predicted that source ROCs would be more curvilinear for items encoded in the task used by Staresina and Davachi (the unitized condition) than for items encoded in the task used by Ranganath et al. (the nonunitized condition), on the basis of the idea that the unitized condition would increase the contribution of familiarity to source memory.

Method

Participants. Sixty-nine students from the University of California, Davis, participated in the experiment for partial course credit. Thirty-four participants were randomly assigned to the unitized source condition, and 35 participants were randomly assigned to the nonunitized source condition.

Materials. The words shown to each participant were randomly selected from a pool of 360 nouns with an average Kučera-Francis (Kučera & Francis, 1967) frequency of 30, an average concreteness of 590, and an average imageability of 580. Word length ranged from three to eight letters, and frequency ranged from 3 to 198 on the Kučera-Francis scale. Words were examined to determine the difficulty of imagining the item in a particular color, and only words that were relatively easily imagined were retained.

Procedure. The instructions were manipulated between subjects such that participants in the unitized source condition were given instructions that encouraged them to unitize the item and source information, whereas participants in the nonunitized source condition were given typical source task instructions. We chose a between-subjects design in order to minimize the possibility of contamination of the encoding tasks from one condition to another. In each condition, participants were presented with words that were presented on either a red or yellow background and were told to remember the word and colors for a later memory test. In the unitized source condition, participants were told to form a mental image of the item in the same color as the background color on the screen (i.e., red or yellow) and to make a key press indicating whether or not the item was plausible in the background color (for example, to form a picture of a red elephant and to respond that this was not a plausible image).[2] In the nonunitized source condition, participants were told to make an animacy judgment (i.e., "Is this item alive?") if the item was presented on a red background and to make a size judgment (i.e., "Would this item fit in a shoebox?") if the item was presented on a yellow background. During the study list portion of the experiment, each item was presented for 4,500 ms followed by a 500-ms fixation. Participants were required to respond during the time the stimulus was on the screen. Each stimulus consisted of a single word from the noun pool, either a red or yellow square (approximately 2 in. × 2 in.) behind the word, and the relevant study question at the bottom of the screen. The study list was 250 words long.

Following the presentation of the study list, participants were reminded of the test instructions (all instructions for the experiment were given first at the beginning of the session). They were asked to give old/new responses on a confidence scale from 1 to 6, with 6 representing *the most confident old responses* and 1 representing *the most confident new responses*. Following each old/new response, participants were asked to indicate the background color on which the word was presented using a scale from 1 to 6. For the color (source) judgments, 6 represented *the most confident "red" response*, and 1 represented *the most confident "yellow" response*. The test list consisted of all 250 old words and an additional 83 new words.

Results and Discussion

A preliminary analysis was conducted to examine overall performance by collapsing across confidence (i.e., for red items, Confidence Responses 4 through 6 were treated as old responses, and 1 through 3 were treated as new responses). Table 1 presents the memory scores for item recognition and source recognition. Item recognition accuracy, as measured using d', was numerically greater for unitized than nonunitized conditions, but the difference was not significant ($p > .10$). There was no significant difference in false alarms ($p > .10$), but the hit rate in the unitized condition was significantly greater than the hit rate in the nonunitized condition, $t(67) = 2.34$, $p < .05$. Source recognition accuracy was measured as the proportion of correct source judgments because it was a forced-choice test. Source accuracy was found to be significantly greater in the unitized than in the nonunitized condition, $t(67) = 3.36$, $p < .01$. These analyses indicate that the unitization manipulation increased source accuracy and had a similar but smaller effect on item recognition. Because the current hypotheses focused only on source recognition, the item recognition data will not be discussed further.

Figure 1 shows the average source recognition ROCs for the unitized and nonunitized conditions plotted in probability space

Table 1
Old/New Hits and False Alarms (FAs) and Source Proportion Correct for Experiment 1

	Old/new			
Condition	Hits	FAs	d'	Source correct
Unitized source	0.85	0.21	2.0	0.70
Nonunitized source	0.79	0.23	1.7	0.62

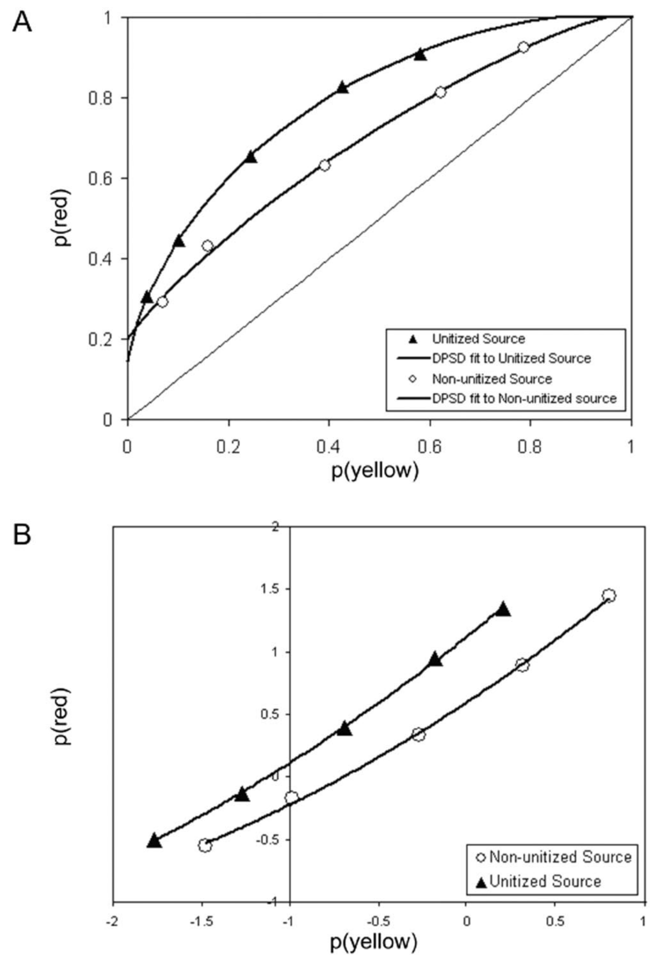

Figure 1. A: Source receiver operating characteristics (ROCs) based on average unitized source and nonunitized source data collapsed across subjects in Experiment 1. Solid lines represent dual process signal detection model fits to the data. B: Source *z*-ROCs based on average unitized source and nonunitized source data collapsed across subjects in Experiment 1. Solid lines represent polynomial trend lines fit to the data.

(ROCs) and *z*-space (*z*-ROCs). The probability ROCs exhibited an inverted U shape, and the *z*-ROCs exhibited a U shape, as is typical in tests of source recognition (e.g., Parks & Yonelinas, 2007). An examination of Figure 1 shows that the ROC in the unitized condition was higher than that in the nonunitized condition, which is consistent with the preliminary analysis that indicated that unitization increased overall source recognition accuracy. On closer examination, it is apparent that there was little difference in performance between the unitized and nonunitized conditions at the highest level of source confidence (i.e., the left-most point of each ROC); however, the unitized condition exhibited an accuracy advantage over the nonunitized condition at more liberal response criteria. This pattern is consistent with the claim that familiarity

[2] This encoding task differed from the Staresina and Davachi (2006) encoding task in that two background colors were used rather than the four used in the original task.

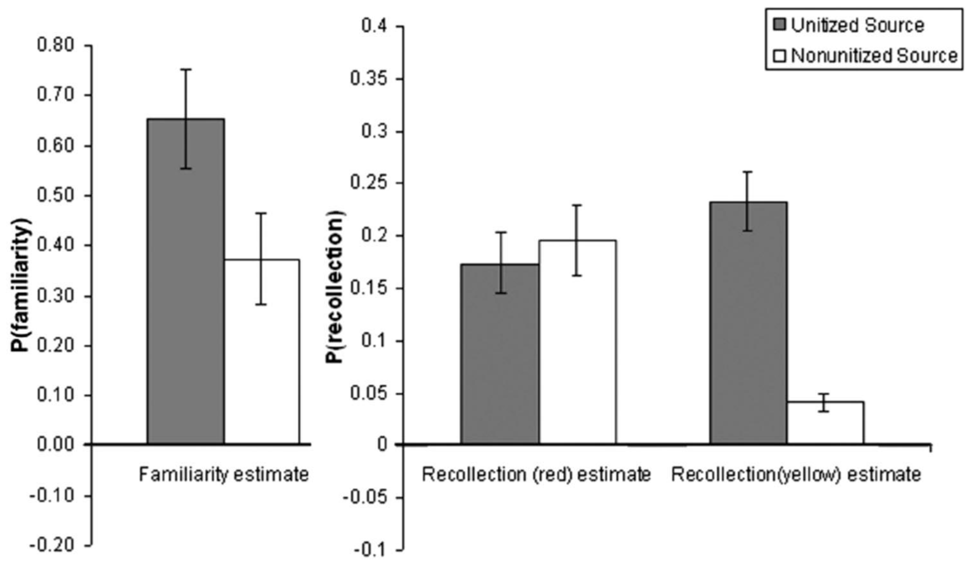

Figure 2. Parameter estimates from the individual source receiver operating characteristics in the unitized source and nonunitized source conditions for Experiment 1. Recollection (yellow) indicates the recollection estimate for items studied on a yellow background, and recollection (red) indicates the recollection estimate for items studied on a red background. Error bars indicate the standard error.

contributes more to the unitized condition than the nonunitized condition. That is, because familiarity is expected to contribute to intermediate levels of response confidence, the benefit in accuracy for the unitized over the nonunitized conditions should become most apparent as the response criterion becomes more lax. In addition, the ROC in the unitized condition appears more curvilinear than in the nonunitized condition, as would be expected on the basis of the dual process model, if familiarity were to contribute more after unitization encoding.

In order to assess the curvilinearity of the ROCs, we conducted a linearity analysis on the ROCs of each participant. That is, we first fit each ROC with a linear function, then we introduced a quadratic term and assessed whether this led to a significant improvement in fit.[3] The linearity analysis of the probability space ROCs indicated that the average quadratic for the unitized and nonunitized ROCs was –1.59 and −0.43, respectively (a negative quadratic indicating an inverted U-shaped function). The quadratic for the unitized condition was significantly more negative than the quadratic for the nonunitized condition, $t(63) = -4.49$, $p < .001$. These analyses indicate that the unitized condition led to a more curvilinear ROC than did the nonunitized condition, as predicted. An additional linearity analysis was conducted on the *z*-ROCs and indicated that the average quadratic for the unitized and nonunitized *z*-ROCs was .15 and .18, respectively (a positive quadratic indicating a U-shaped function). The quadratics in the two conditions did not differ significantly, $t(58) = 1.28$, $p = .20$.

Further analyses of the probability space ROCs were conducted by fitting the dual process signal detection model (Yonelinas, 1994, 1999) to the ROCs. The model was fit to each participant's ROCs using a regression method in which estimates were derived for familiarity (measured in d') and recollection (measured as probabilities) for items studied in yellow and those studied in red. Figure 2 shows the average estimates of recollection and familiarity for the unitized and nonunitized conditions. Most important, an analysis of the familiarity estimates indicated that familiarity was significantly greater in the unitized source condition than in the nonunitized source condition, $t(67) = 2.08$, $p < .05$. This confirms our finding that the probability space ROCs were more curvilinear in the unitized condition than in the nonunitized condition. The dual process signal detection model predicts a more curvilinear inverted U-shaped ROC as the contribution from familiarity increases.

Estimates of recollection indicated that approximately 20% of the items were recollected in each condition, with the exception of the red items in the nonunitized encoding condition, which were associated with noticeably lower recollection estimates. For the red items, the recollection estimate did not differ significantly between the unitized source and the nonunitized source conditions, $t(67) = -0.49$, $p = .63$, whereas for the yellow items, the recollection estimate was greater for the unitized source condition than for the nonunitized source condition, $t(67) = 6.59$, $p < .001$. This suggests that the size judgment (always associated with a yellow background) was less effective than either the animacy judgment or the unitizing encoding task.

The results from Experiment 1 support our hypothesis regarding the contribution of familiarity in the unitized source and nonunitized source conditions. Source memory ROCs were more curvi-

[3] Linearity analyses suffer from sensitivity to outliers; therefore, any quadratic terms greater than two standard deviations above the mean or below the mean were excluded from the analysis. For the ROCs, there were two outliers in each condition, and for the *z*-ROCs, there were three outliers in each condition.

linear in the unitized source condition than in the nonunitized source condition. In addition, model-based fits of the ROCs indicated that the unitized in comparison with the nonunitized encoding condition led to a significant increase in the contribution of familiarity to source recognition performance. This suggests that if source information is encoded as a feature of the item, subsequent source attributions are more effectively supported by familiarity than if the source information is not unitized. Our results support the proposal that Staresina and Davachi's (2006) source encoding task produced more familiarity-based discrimination because it induced unitization to a greater degree than previous source encoding tasks.

Experiment 2

The results from Experiment 1 supported the unitization hypothesis, but one critical issue is that overall accuracy was better for participants in the unitized source condition than for participants in the nonunitized source condition. This is not surprising, given that the unitized encoding task used by Staresina and Davachi (2006) required participants to use visual imagery, whereas the nonunitized encoding task used by Ranganath et al. (2003) required very little imagery. In Experiment 2, we used two new encoding tasks that promoted visual imagery and that were designed to lead to comparable levels of overall performance. In the unitized condition, participants were told to visualize the item as though it were the same color as the background and then to generate an explanation for why the item was in that particular color. This encouraged participants to process color information as a feature of the item to be encoded. In contrast, in the nonunitized condition, participants were told to visualize the item in a situation with a green dollar bill if the background was green or with a red stop sign if the background was red; then the participants were told to generate an explanation for why the item was associated with that associated item. This encouraged participants to encode the background color as a separate piece of information that was associated with the item representation. As in Experiment 1, we expected more curvilinear ROCs and higher familiarity estimates for the unitized encoding condition than for the nonunitized condition.

Method

Participants. Twenty-eight students at the University of California, Davis, participated for partial credit in their psychology courses. Thirteen participants were randomly assigned to the nonunitized condition, and 15 participants were randomly assigned to the unitized source condition.

Materials. The materials used in Experiment 2 were the same as those used in Experiment 1.

Procedure. The procedures were identical to those used in Experiment 1 except that the encoding instructions were changed, and the source colors were red and green rather than red and yellow. In the unitized condition, participants were told to imagine the word as though it were the same color as the background and then to form an explanation for why the item was that color. Participants were then required to make a keyboard response indicating whether it was hard or easy to come up with the explanation. In the nonunitized condition, participants were told, if the item was presented on a red background, to imagine the item associated with a red stop sign and then generate an explanation for this association. If the item was presented on a green background, they were instructed to imagine the item associated with a green dollar bill and to generate an explanation for this association. Participants were then to make a response indicating whether the explanation was easy or difficult to generate.

Results and Discussion

Old/new and source responses were analyzed for accuracy by collapsing across confidence (i.e., for green items, Confidence Responses 4 through 6 were treated as old responses, and 1 through 3 were treated as new responses). Table 2 shows the average of these accuracy measures. Item recognition using these collapsed measures revealed no significant differences between hits, false alarms, or d' in the unitized and nonunitized source conditions (all $ps > .50$). There was also no effect of source condition on the proportion of correct source judgments ($p = .49$). Thus, the encoding conditions elicited comparable overall levels of source memory in the unitized and nonunitized conditions.

An examination of Figure 3 shows that the ROCs in the unitized and nonunitized conditions were overlapping with approximately equal area under the curve, which is consistent with the preliminary analysis indicating that source recognition accuracy was equal in the two conditions. A further examination of the ROCs indicated that performance in the nonunitized condition was slightly higher than in the unitized condition for the left-most point, but this pattern was reversed as lower confidence responses were included. This pattern is consistent with the claim that familiarity contributed more to performance in the unitized condition than in the nonunitized condition. The unitized ROC also appears to be more curvilinear, as would be expected if familiarity were to contribute more to that condition.

A linearity analysis of the subject ROCs indicated that the average quadratic for the unitized and nonunitized ROCs was –1.58 and –0.65, respectively (a negative quadratic indicating an inverted U-shaped function). The difference between the quadratics in the two conditions was borderline significant, $t(24) = -2.02$, $p = .05$. The numerical difference between the quadratics for the probability space ROCs was similar in magnitude to the results of Experiment 1. In addition, an examination of the z-ROCs indicated that the average quadratic for the unitized and nonunitized z-ROCs was 0.15 and 0.18, respectively (a positive quadratic

Table 2
Old/New Hits and False Alarms (FAs) and Source Proportion Correct for Experiment 2

Condition	Old/new Hits	Old/new FAs	Old/new d'	Source correct
Unitized source	0.82	0.30	1.6	0.68
Nonunitized source	0.80	0.33	1.4	0.64

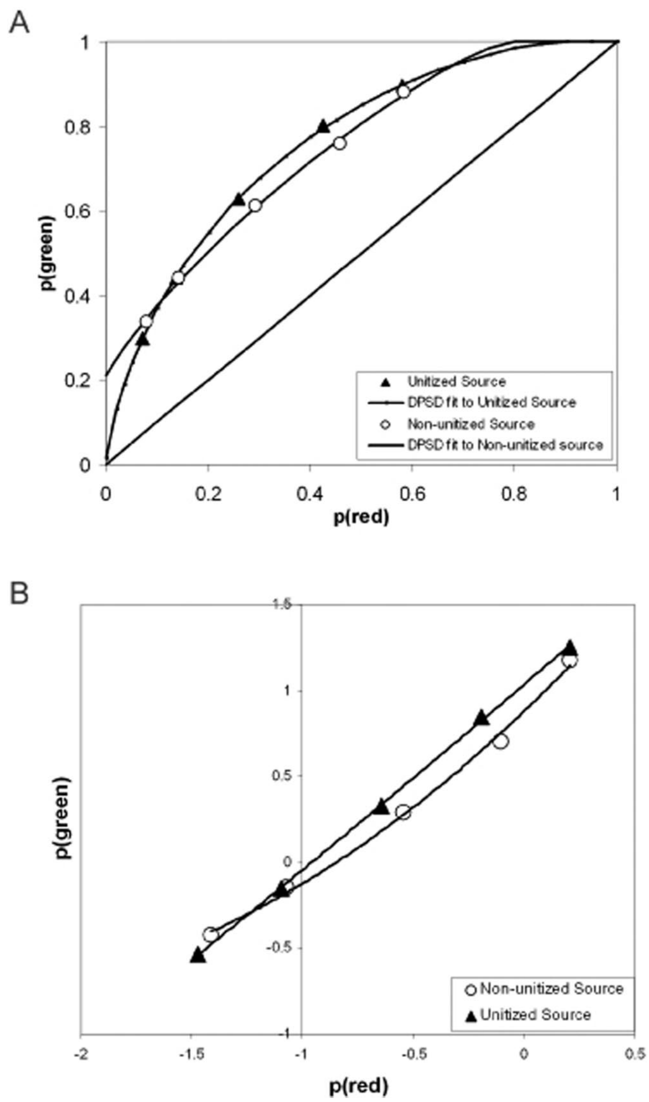

Figure 3. A: Source receiver operating characteristics (ROCs) based on average unitized source and nonunitized source data collapsed across subjects in Experiment 2. Solid lines represent dual process signal detection model fits to the data. B: Source *z*-ROCs based on average unitized source and nonunitized source data collapsed across subjects in Experiment 2. Solid lines represent polynomial trend lines fit to the data.

indicating a U-shaped function).[4] The quadratics for the *z*-ROCs in the two conditions did not differ significantly, $t(24) = -0.43$, $p = .67$.

Further analyses of the probability space ROCs were conducted by fitting the dual process signal detection model (Yonelinas, 1994, 1999) to the ROCs, as in Experiment 1. Figure 4 shows the average estimates of recollection and familiarity for the unitized and nonunitized conditions. As predicted, the familiarity estimate was greater in the unitized source condition than in the nonunitized source condition, $t(26) = 2.11$, $p < .05$, indicating that unitization increased the extent to which familiarity contributed to performance.

Given that performance was equal in the unitized and nonunitized conditions for Experiment 2, but the unitized condition produced a larger familiarity estimate from the dual process model, we might expect that there was a larger contribution of recollection in the nonunitized condition. Estimates of recollection indicated that approximately .22 of the items were recollected in each condition, with the exception of the green items in the unitized encoding condition, which were associated with noticeably lower recollection estimates (.10). For the red items, the recollection estimate did not differ significantly between the unitized source and the nonunitized source conditions, $t(26) = 0.22$, $p = .83$, whereas for the green items, the recollection estimate was greater for the nonunitized source condition than for the unitized source condition, $t(26) = -2.19$, $p < .05$. This suggests that participants were less able to use recollection when unitizing an item with the color green. This did not occur in the nonunitized condition, indicating that there was no difference in participants' ability to use recollection when associating an item to a stop sign or a dollar bill. It may be that participants' stories for why an item was red were more distinctive than they were for why an item was green, leading to an increased contribution from recollection for the red items. Although we did not predict this difference in recollection estimates, it does not conflict with our hypotheses.

Experiment 2 showed that unitization increases the curvilinearity of the probability space ROCs. Based on the dual process signal detection model, this suggests that there is an increase in the degree to which familiarity can support accurate source recognition, even when overall performance is comparable, in the unitized condition. In addition, unlike in Experiment 1, the encoding instructions in both conditions promoted visual imagery, suggesting that the differences across conditions were not likely due to differences in visual imagery.

Experiment 3

In Experiment 3, we used a response deadline procedure to gain converging evidence regarding the effects of unitization on source familiarity. We used the same encoding tasks used in Experiment 2 but investigated source recognition under nonspeeded and speeded conditions. In the nonspeeded condition, we tried to isolate the effects of unitization on recollection by telling the participants to respond only when they could remember specific details about the study event. Thus, unlike the previous experiments (in which the least confident responses still required a guess as to the background color), the nonspeeded condition allowed participants to respond "unknown" when they did not feel they recollected the study source. In the speeded conditions, we used a response deadline of 750 ms because previous studies showed that recollection-based memory tends to be near chance at this deadline, whereas familiarity-based memory is above chance (Hintzman & Caulton, 1997; Hintzman et al., 1994; McElree et al., 1999). Thus, if unitization led to an increase in familiarity-based source recognition, then under the speeded conditions, performance should be greater in the unitized than the nonunitized condition.

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[4] As in Experiment 1, we removed any outliers greater than two standard deviations above the mean or below the mean. For the ROCs, there were two outliers in the nonunitized condition, and for the probability ROCs, there was one outlier in the nonunitized condition. There were no outliers for the *z*-ROCs.

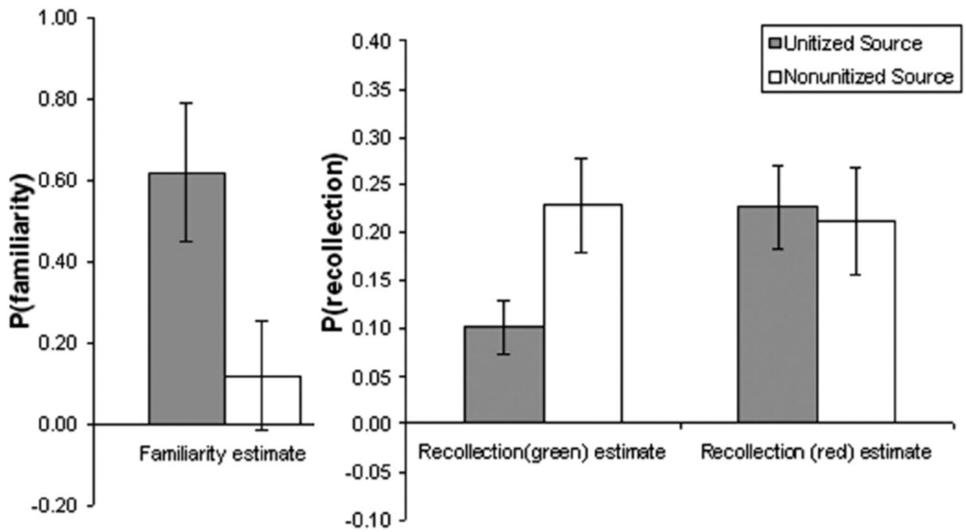

Figure 4. Parameter estimates from the individual source receiver operating characteristics (ROCs) and *z*-ROCs in the unitized source and nonunitized source conditions for Experiment 2. Recollection (green) indicates the recollection estimate for items studied on a green background and recollection (red) indicates the recollection estimate for items studied on a red background. Error bars indicate the standard error.

Method

Participants. Thirty-four students at the University of California, Davis, participated in the experiment for partial credit in their psychology courses. Seventeen participants were randomly assigned to the unitized source condition, and 17 participants were randomly assigned to the nonunitized source condition.

Materials. The materials used in this experiment were the same as those used in Experiment 2.

Procedure. The same instructions were given in as in Experiment 2 for the unitized source and nonunitized source encoding conditions. Each participant studied two lists of 100 words. During the study list portion of the experiment, each item was presented for 4,500 ms, followed by a 500-ms fixation. Each stimulus consisted of a single word from the noun pool, either a red or green square behind the word, and the relevant study question at the bottom of the screen.

Immediately after being presented with each study list, the participants were given a source recognition test in either the 750-ms speeded condition or the nonspeeded condition. The order of the testing procedures was counterbalanced across subjects. In both test lists, participants were shown the 100 study words and asked to respond with the background color of the word (red or green). In the speeded condition, participants were required to respond in less than 750 ms from the time the test word was presented. If the response did not occur before the deadline, the participant heard a buzzer and saw the message "Please respond more quickly." The participant then pressed the space bar to begin the next trial. In the nonspeeded condition, participants were given unlimited time to respond with the background color of each word. Also, in the nonspeeded condition, participants were instructed to respond only if they recollected the source information. That is, they were given the option to respond with an "unknown" key in the nonspeeded condition and told to respond "unknown" unless they could retrieve specific details about the study trial.

Results and Discussion

Source accuracy was first analyzed separately for the nonspeeded and speeded conditions. Average performance in the unitized source and nonunitized source conditions for these two procedures is presented in Table 3. The number of missed trials, because of "unknown" button presses in the nonspeeded condition and missed deadlines in the speeded condition, are also reported in this table. A two-way analysis of variance revealed significant main effects of response deadline condition, $F(32) = 228.7$, $p < .001$, and encoding condition (unitized source vs. nonunitized source), $F(32) = 13.6$, $p < .01$, such that performance was more accurate in the nonspeeded condition and the unitized source encoding condition. The interaction between encoding condition and response deadline was not significant, $F(32) = 1.85$, $p = .18$, such that the unitized source and nonunitized source conditions were significantly different in both the nonspeeded condition, $t(32) = 3.48$, $p < .01$, and the speeded condition, $t(34) = 2.05$, $p < .05$.

The speeded condition was also analyzed to determine whether the unitized source and nonunitized source conditions were signif-

Table 3
Proportion Correct Source Judgments in the Nonspeeded and Speeded (750-ms Deadline) Conditions for Experiment 3 (With Standard Errors in Parentheses)

	Nonspeeded		Speeded	
Source hits	Correct	Missed	Correct	Missed
Unitized source	0.90 (0.02)	29.8	0.58 (0.02)	25.6
Nonunitized source	0.79 (0.03)	29.3	0.52 (0.02)	14.2

Note. Average number of missed source judgments out of 100 total trials ("Unknown" in nonspeeded condition and missed deadline in speeded condition) are also shown.

icantly greater than chance (50%). Individual *t* tests revealed that, although the unitized source condition produced accuracy greater than chance, $t(16) = 3.74$, $p < .01$, accuracy in the nonunitized source condition was not significantly above chance, $t(16) = 1.38$, $p = .19$. As seen in Table 3, the unitized condition produced significantly more trials on which the 750-ms deadline was missed than did the nonunitized condition, $t(32) = 3.65$, $p < .01$. This difference in the number of missed trials could artificially increase the accuracy of the unitized trials because participants may have been more likely to miss an item for which their memory was weak. Therefore, we conducted a secondary analysis of the accuracy in the deadline condition in which we yoked the participants in the unitized condition to those in the nonunitized condition and only included participants whose number of missed trials was less than or equal to the greatest number of missed trials in the nonunitized condition (26 missed trials). We then analyzed the number of missed trials in the remaining 8 participants in the unitized condition and all 17 participants in the nonunitized condition and confirmed that the mean number of missed trials (15.75 vs. 14.24) was not significantly different, $t(23) = 0.58$, $p = .57$. When the accuracy data were analyzed for the remaining participants in the unitized condition, they were found to be slightly higher than in the original analysis (59%) and significantly greater than chance, $t(7) = 2.83$, $p < .05$. Thus the results of our initial analyses were supported, suggesting that the difference in the number of missed trials in the original analysis cannot explain the accuracy differences in the deadline condition.

The results of this experiment show that when item and source information were unitized, participants performed significantly above chance even at a 750-ms deadline designed to minimize the influence of recollection at retrieval. In contrast, when the encoding task discouraged unitization, performance at the 750-ms deadline was not significantly different from chance, suggesting that participants were less able to use familiarity in this condition.

It was somewhat surprising that there was a performance advantage in the nonspeeded condition for the unitized condition in comparison with the nonunitized condition. In Experiment 2, using the same encoding tasks, we did not see an effect of unitization on recollection. Because the nonspeeded condition was designed to maximize the influence of recollection, we did not expect to see an advantage for unitized over nonunitized items in this condition. It is possible that, in this study, unitization increased recollection as well as familiarity. Another possibility is that participants in Experiment 3 found it difficult to complete the recollection-only instructions and were inclined to respond with the background color even when that judgment was based purely on familiarity. In either case, these findings do not relate to our primary hypotheses, which concern the influence of familiarity on source attributions.

General Discussion

The goal of the current experiments was to determine whether unitization of item and source information would increase the contribution of familiarity to source recognition. These experiments were initially motivated by a discrepancy in the neuroimaging literature on source memory. Many functional magnetic resonance imaging studies have indicated that hippocampal activity is associated with successful source memory performance, whereas perirhinal activation is related to item recognition even when source recognition is not accurate. However, Staresina and Davachi's (2006) recent study reported hippocampal and perirhinal cortex activation related to accurate source recognition. As the authors pointed out in their article, their encoding task was unusual in that it encouraged participants to view source information as a feature of the item being encoded, which is in contrast to most previous source tasks that have used encoding tasks that were arbitrary with respect to the source information. Based on recent findings (e.g., Quamme et al., 2007), we hypothesized that the contribution of familiarity to source recognition would be increased under conditions in which source and item information were unitized during encoding. Analyses of source ROCs and response deadline results in the current study were consistent with this hypothesis. Encoding manipulations that led participants to process the item and source as a single unit resulted in more curvilinear source ROCs. This increase in curvilinearity in the unitized condition produced an increase in familiarity estimates from the dual process signal detection model. These effects were observed using encoding tasks designed to mimic those used in the neuroimaging studies that motivated the current study and under more carefully controlled conditions in which visualization was promoted and overall performance was matched across both encoding conditions. Furthermore, using response speed conditions designed to reduce the contribution of recollection, source memory remained above chance in the unitized condition but not in the nonunitized condition.

An alternative explanation for the results of Experiment 3 is that unitization may increase the speed of the recollection process. Thus, rather than increasing the contribution of familiarity, unitization may simply make recollection more likely to occur under the 750-ms deadline. However, given the results of the ROC analyses in Experiment 2 suggesting an increased contribution from familiarity, it seems more likely that the results of this experiment reflect the same increased contribution from familiarity rather than increased speed. The data using the ROC and response deadline methods converged to suggest that familiarity contributed to accurate source decisions to a greater degree if item and source information were unitized.

The current results join a growing body of research indicating that the contribution of familiarity to memory for arbitrary associations is increased if the information is encoded as an integrated unit (Giovanello et al., 2006; Yonelinas et al., 1999). The current results extend those previous results by showing that arbitrary source information, such as background color, can be unitized with item information. These results attest to the utility of familiarity in supporting memory for arbitrary associations of various different types of episodic information.

The current findings may explain apparently discrepant results from neuroimaging studies regarding the contribution of the perirhinal cortex to source recognition. As noted earlier, various models of recognition have proposed that the perirhinal cortex supports familiarity, whereas the hippocampus and parahippocampal cortex are critical for recollection of associated contextual information (Aggleton & Brown, 2005, 2006; Diana et al., 2007; Eichenbaum et al., 1994, 2007). Consistent with these models, several functional magnetic resonance imaging studies of source memory have reported that activation in the hippocampus and perirhinal cortex is related to recollection and familiarity, respectively. Although the results from Staresina and Davachi (2006) seemingly conflicted with these findings, the present results reconcile the discrepancy by suggesting that source recognition in their study could have been largely supported by familiarity. That is, because the Staresina and Davachi task led participants to encode color information as a feature of the item, source memory for color information could be based on familiarity, which in turn may reflect the strength of item representations formed in the perirhinal cortex.

The present results suggest a clear hypothesis that can be tested in future imaging studies. Perirhinal cortex activity should be correlated with source memory accuracy when item and source information are unitized. In contrast, when source is treated as associated contextual information, we would expect that hippocampal and parahippocampal activation should be correlated with successful source memory accuracy.

In addition to providing an interpretation of previous imaging findings, our results have several implications for behavioral investigations of source memory. First, the results show that tasks such as source recognition are not process-pure measures of recollection such that even memory for arbitrary (e.g., word–color) associations does not necessarily rely solely on recollection. Second, the current results suggest predictions as to whether source ROCs will be curvilinear or linear, providing insight into the factors that influence the shape of ROCs in source memory tests (e.g., Glanzer, Hilford, & Kim, 2004; Qin, Raye, Johnson, & Mitchell, 2001; Slotnick & Dodson, 2005; Wixted, 2007).

In addition to dual process models, many single process models have been proposed that also provide fits to ROC curves. In general, these models assume that recognition is based on a familiarity process alone (McClelland & Chappell, 1998; Shiffrin & Steyvers, 1997). Although the current experiments were not designed to differentiate between single and dual process models of recognition, we expect that these single process models would provide a better fit to the ROCs from the unitized condition than the nonunitized condition because we found an increased contribution from familiarity in the unitized condition. However, it is not clear that these models would predict a priori that the source ROCs should become more curved under the unitization encoding conditions.

Curvilinear source ROCs have sometimes been cited as evidence against a dual process theory of recognition memory on the basis of the argument that recollection would be the only process used in source recognition. However, dual process theories do not require that source recognition tests provide a process-pure measure of recollection. In fact, as we have shown, unitization can explain curvilinear source ROCs at least in some cases. We expect that unitization may occur to some degree even in source tasks that do not specifically encourage unitization. This would lead to small amounts of familiarity-based processing, even in typical source tasks. It should be noted, however, that curved source ROCs are not necessarily indicative of unitization—there are other factors that have been shown to contribute to curved source ROCs, such as differences in familiarity between sources (Yonelinas et al., 1999), high feature overlap (Elfman, Parks, & Yonelinas, 2007), and the use of complex stimuli (Qin et al., 2001). Thus, it is not the case that unitization can account for all of the studies in which source ROCs are curved. Future studies are needed to further delineate the causes of curvilinear source ROCs and the conditions in which they occur.

Unless unitization is directly manipulated, it is difficult to assess the extent to which unitization can explain curvilinear ROC findings. For this reason, previous studies of unitization (Giovanello et al., 2006; Quamme et al., 2007; Yonelinas et al., 1999), including the current investigation, have used direct manipulations that clearly distinguish between unitized and nonunitized items or encoding conditions (e.g., existing compound words; newly created compound words; upright and upside-down faces; and item and color vs. item and a second colored item). Because each of these experiments used a clear conceptual definition of unitization that was delineated a priori, they do not suffer from circular reasoning. It would be helpful to have an independent method for assessing the extent to which unitization has occurred. Such a method would be useful in determining whether the slight curve seen in ROCs in the nonunitized conditions in the current experiments was due to some residual unitization or to some other factor.

It has previously been suggested that unitized associations may be relatively inflexible in terms of the way information can be retrieved (Cohen, Poldrack, & Eichenbaum, 1997; Mayes, Montaldi, & Migo, 2007). For example, when novel word associations have been unitized (e.g., *motor–bear* is encoded as "a motorized stuffed animal"), associative recognition is disrupted by reversing the order of the word pair at test (e.g., *bear–motor*); this is not the case, however, for associations that are encoded in a nonunitized fashion (Haskins, Yonelinas, Quamme, & Ranganath, 2007). In a similar vein, it may be possible to use retrieval characteristics as a method to assess the degree to which source information is encoded as a feature of the item or encoded as a contextual association. For example, in Experiment 3, the nonunitized source information (a stop sign) is more similar across trials than the unitized source information (applying the feature "red" to each of the items). This is because the unitized source information is represented in a new structure as a feature of the item, whereas representation of the nonunitized source information is unchanged by its association with the item. This difference in representation may influence the amount of interference from other items that have been studied with the same source and affect ability to retrieve item information on the basis of source information cues.

The results from the experiments presented here illustrate the utility of bridging the behavioral and neuroimaging literatures on source recognition. The possibility that familiarity could support source recognition responses was suggested by recent findings in the neuroimaging literature that examined the neural substrates of source recognition. The finding that familiarity supports source judgments to a greater degree if item and source information is unitized during encoding fits well with other behavioral and patient studies of associative recognition and extends our understanding of the types of memory discriminations that can be supported by familiarity.

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