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The Influence of Forward and Backward Associative Strength on False Recognition

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Abstract

An experiment examined the influence of two associative factors on false memory in the Deese-Roediger-McDermott paradigm (Deese, 1959; Roediger & McDermott, 1995): the strength of the association from studied items to unstudied lure items (backward associative strength, or BAS), and the strength of the association from unstudied lure items to studied items (forward associative strength, or FAS). In addition to manipulating BAS and FAS, participants were asked to respond rapidly at retrieval or were allowed to respond in a self-paced manner in order to examine the contributions of automatic and controlled memory processes to lure errors. The results of this study demonstrated that both BAS and FAS influenced lure errors under speeded retrieval conditions and under self-paced retrieval conditions, as well as that lure errors generally increased when retrieval time increased. These results favor the explanation of false memory offered by global-matching models over those of activation-monitoring theory and fuzzy-trace theory.

Keywords

false recognition; associations; models of recognition memory; controlled processes; automatic processes

Among the goals of human memory research is to understand the factors that promote both accurate and inaccurate remembering. Research examining memory's inaccuracies has proven important for a variety of applied reasons, such as understanding the limitations of eyewitness testimony in the legal system (Loftus, 1996), but can also be useful for understanding the theoretical mechanisms that underlie memory. The research described in this paper was designed with the latter purpose in mind, and therefore uses a basic memory paradigm (Deese, 1959; Roediger & McDermott, 1995) to investigate the characteristics of the representations that support memory errors. In this paradigm, a series of words are presented (e.g., *chirp*, *sparrow*, *bluejay*, *canary*, *feathers*, *nest*, *pigeon*, and *robin*) that are all associated with a single unstudied word (e.g., *bird*) known as the *lure item*. Thus, understanding the factors that influence the likelihood that people falsely believe lure items were studied potentially provides insight in to the representations that underlie memory errors.

One of the most commonly-cited factors that increases lure errors is the associative strength from study items to lure items, which is typically referred to as backward associative strength (BAS; Arndt & Gould, 2006; Deese, 1959; Gallo & Roediger, 2002; Roediger, Watson, McDermott, & Gallo, 2001). Although it makes intuitive sense that the strength of associations from study items to lure items increases lure errors, there are two potential

complications with attributing lure errors to BAS. First, associations in semantic memory tend to be bi-directional, such that pairs of concepts with a strong association from study items to lure items (i.e., high BAS) also tend to have strong connections from lure items to study items, a factor referred to as forward-association strength (FAS; Brainerd, Yang, Reyna, Howe, & Mills, 2008). Given this correlation between BAS and FAS, it is difficult to uniquely ascribe false memory effects to BAS, particularly considering virtually no studies have manipulated BAS while controlling FAS. Three extant studies provide relevant data regarding the unique influence that BAS has on false memory. McEvoy, Nelson, and Komatsu (1999) examined how BAS influenced false recall and false recognition in cases where FAS was controlled, and found that increases in BAS increased both false recall and false recognition. Although this study documents that BAS can influence false memory independent of FAS, it does not demonstrate that FAS has no influence on false memory. Roediger, et al. (2001) examined how differences in BAS and FAS across study lists influenced false recall and recognition, and found that while BAS differences predicted increases in false recall and recognition, increases in FAS did not. One potential problem with Roediger et al's conclusion that BAS was the primary determinant of false memory is that the range of FAS was substantially limited, varying between .01 and .06, which would in turn statistically limit its ability to be a reliable predictor of false memory (Brainerd & Wright, 2005). Indeed, when BAS and FAS were manipulated factorially across a wider range of values for each variable, both were found to increase lure errors (Brainerd & Wright, 2005).

A second complication with attributing lure errors to BAS is that such a claim implies acceptance of the representation structure inherent in spreading-activation theories of semantic memory (Collins & Loftus, 1975). Although spreading activation is at the heart of one prominent theory of false memory, activation-monitoring theory (Roediger, et al., 2001), other theories of false memory do not assume spreading activation supports lure errors (Arndt & Hirshman, 1998; Brainerd, Reyna, & Kneer, 1995). Critically, these theories explain false memory by using mechanisms that rely on the similarity between study items and lure items, which in turn leads them to suggest that both BAS and FAS should increase false memory. Thus, not all theories expect BAS alone to increase false memory, even though the research literature has largely focused on BAS as a cause of lure errors. Further, theories of false memory propose that false memory is produced by multiple interacting processes, and the characterization of these processes leads the theories to suggest that BAS and FAS play distinct roles in mediating false memory, which provides further impetus for separating their contributions to false memory. Next, we outline the general account of lure errors that is provided by three major theories of false memory, as well as the role that BAS and FAS play in producing and limiting false memories according to each theory.

Activation-monitoring theory (Roediger, et al., 2001) proposes that two processes work in opposition to one another to produce lure error rates: Spreading activation from study items' representations to lures' representations increases the likelihood that lure errors will occur, while monitoring processes are employed to examine whether lures' activation corresponds to an authentic memory, potentially reducing false memory. Thus, activation-monitoring theory proposes that increases in BAS should allow more activation to spread from study items to a lure's representation, increasing lure errors. In contrast, increases in FAS should not impact lure activation because FAS indexes the strength of the association between lure representations and studied items' representations, which provides a metric of how much experiencing a lure will activate its studied associates' representations in semantic memory. Indeed, if anything, activation-monitoring theory expects increases in FAS to lower lure error rates. Specifically, increases in FAS should improve monitoring by enabling retrieval of studied items when a lure is tested, which can serve as a basis for rejecting lures as unstudied (Gallo, 2004).

Fuzzy-trace theory (Brainerd, et al, 1995) argues that memory traces are stored on a verbatim to gist continuum. Verbatim traces contain the perceptual details of an experience, which allows people to differentiate memories from one another, while gist traces represent the commonalities among events. Fuzzy-trace theory argues that the more an unstudied test item matches a gist trace, the more likely people are to falsely endorse that item as studied. Lure items show particularly high error rates because they possess substantial semantic overlap with studied items, and thus are likely to strongly match gist traces that were formed when study items related to lures were encoded. Given that semantic overlap is the basis for lure errors in fuzzy-trace theory, increases in both BAS and FAS should increase how well lures match gist traces, because both variables can be interpreted as metrics of the semantic similarity between lures and their studied associates. Thus, increases in both BAS and FAS should increase lure errors. In addition to gist-based inflation of lure errors, fuzzy-trace theory proposes that false memory can be reduced when people retrieve verbatim traces of studied items related to lures. Specifically, retrieval of study items' verbatim traces can serve as a basis for people to decide that a lure does not represent an authentic memory, but instead is an item that feels familiar due to its similarity to a gist memory trace, enabling rejection of the lure item (Brainerd, et al., 1995). Importantly, fuzzy-trace theory proposes that factors which influence the semantic similarity between lure items and studied items, such as FAS and BAS, will also influence the extent to which people utilize gist retrieval compared to verbatim retrieval (Brainerd & Wright, 2005). In particular, greater semantic similarity within a study list leads people to rely to a greater extent on gist memory retrieval, and to a lesser extent on verbatim memory retrieval. Thus, fuzzy-trace theory expects that increases in both BAS and FAS will increase the likelihood that people rely on gist traces and will decrease the likelihood people utilize verbatim trace retrieval when making memory judgments. As a consequence, while verbatim retrieval should reduce lure errors, it should do so less often when BAS and FAS are high compared to when they are low.

Finally, global-matching models (Arndt & Hirshman, 1998; Hintzman, 1988) argue that lure errors occur because lure items share similarity with the memory traces of their studied associates. Specifically, global matching models propose that during encoding, each event that is experienced produces a memory trace. During later memory retrieval, test items are compared to all of the traces in memory, producing an activation value based upon the similarity of each trace to the tested item. Those similarity values are then summed, producing an overall value for how much memory as a whole is activated by the test item. As applied to lure errors, global-matching models claim that lures are moderately similar to the memory traces of their studied associates. Although lure items may not strongly resemble any individual trace in memory, they can accrue substantial evidence they were studied based upon the fact that they will activate a number of memory traces to a moderate degree, because the summation of multiple moderate similarity values will produce relatively high levels of activation of memory as a whole. Consequently, global-matching models claim that lure errors result from shared similarity between lure items and the memory traces of their studied associates. Given this characterization, global-matching models view BAS and FAS as metrics of the similarity between a lure item and its studied associates rather than indexes of the strength of a directional association between two concepts. The view that both BAS and FAS are measures of how similar a lure item is to the memory traces of its studied associates leads global-matching models to predict that increases in both variables should increase how well lure items match the memory traces of their associates in memory, which will in turn increase lure errors.

The present study

In the present study, we sought to test these theories by orthogonally manipulating BAS and FAS. Manipulating BAS and FAS in the same study will disentangle their respective roles in

producing and/or limiting false memory, which will in turn test each theory's account of false memory. Importantly, because BAS and FAS are typically confounded (Brainerd, et al, 2008), and most prior work has manipulated BAS without also manipulating FAS (Arndt & Gould, 2006; Gallo & Roediger, 2002), separating their contributions to false memory will help clarify if the effect of BAS found in prior studies was primarily driven by BAS, was a combined influence of BAS and FAS, or was primarily driven by FAS.

Additionally, a retrieval time manipulation was used to separate the role of relatively automatic and relatively controlled processes in producing lure errors (Arndt & Gould, 2006; Benjamin, 2001). Specifically, participants were required to respond early in retrieval (the *speeded retrieval condition*) or were allowed to respond at their own pace (the *self-paced retrieval condition*). Thus, when theories propose that false memory is increased by factors influencing constructs such as activation (Roediger, et al, 2001), gist trace strength (Brainerd, et al, 1995), or familiarity (Arndt & Hirshman, 1998), those effects should be evident when the retrieval task requires speeded judgments, because each construct represents a rapidly-retrieved source of memorial information. In comparison, when theories propose that false memory is influenced by factors such as monitoring (Roediger, et al, 2001) or verbatim trace retrieval (Brainerd, et al, 1995), the influence of those processes should only be evident later in retrieval, because each represents a process that requires deliberation, memory search and/or conscious effort on the part of participants. Thus, because relatively automatic processes influence performance in both the speeded and self-paced retrieval conditions, while only monitoring influences performance in the self-paced retrieval condition, the *change* in lure errors between the speeded and self-paced retrieval conditions provides an index of how processes such as monitoring or verbatim retrieval influence the production of false memory.

Performance when retrieval is speeded should distinguish between theories that propose lure errors are driven by spreading activation from study items' representations to lures' representations and theories that propose lure errors are driven by similarity-based familiarity processes. Specifically, activation-monitoring theory argues that lure errors occur because activation spreads from study item representations to lure representations, the associative direction indexed by BAS (Roediger, et al., 2001). Thus, it predicts that BAS, but not FAS, should increase false memory when retrieval is speeded, because lure representation activation should be available immediately after a test item is perceived. In contrast, global-matching models and fuzzy-trace theory suggest that both BAS and FAS should influence lure errors under speeded retrieval conditions. This prediction results from the claim that how well lure items match gist traces (Brainerd, et al., 1995) and lure item familiarity (Arndt & Hirshman, 1998) are 1) determined by how similar lure items are to studied items, and 2) relatively automatic influences on memory performance, making them available early in retrieval.

As a consequence of their claims about slower-acting memory processes, the three theories make largely distinct predictions regarding how BAS and FAS should influence changes in lure errors between the speeded and self-paced conditions. Activation-monitoring theory suggests two opposing influences can contribute to changes in performance between the speeded and self-paced retrieval conditions. First, people may retrieve evidence that lure items were associated with encoding context, which can occur to the extent that lure representations become highly active during encoding (Roediger, et al, 2001). Thus, because BAS, but not FAS, indexes the the extent to which activation from study item representations spreads to lure item representations during encoding, increases in BAS can increase the likelihood lure representations become associated with encoding context, producing increased lure errors when people have time to retrieve contextual information from memory. Second, people may employ monitoring processes, in which they attempt to

verify whether lure items were authentically experienced. One way in which monitoring processes may work is that people are able to recall some or all of the items related to a lure that were studied, which allows them to decide that the lure was not studied (Gallo, 2004). Thus, monitoring may improve with increased FAS, because it indexes the likelihood that studied items will be brought to mind when people are provided with a lure as a retrieval cue. To the extent that FAS improves monitoring, lure errors should decline more between the speeded and self-paced retrieval conditions when FAS is high relative to when FAS is low. In summary, activation-monitoring theory can explain increases in lure errors between the speeded and self-paced retrieval conditions if they are mediated solely by BAS, and decreases in lure errors between the speeded and self-paced retrieval conditions if they are mediated solely by FAS.

Fuzzy-trace theory suggests that self-paced retrieval enables people to retrieve verbatim memory traces of lures' studied associates, producing a decline in lure errors compared to when retrieval is speeded. As noted above, increases in BAS and FAS should reduce the extent to which people utilize verbatim retrieval, because increases in BAS and FAS both increase the similarity of lure items to gist traces, leading people to rely more on semantic similarity in making their memory judgments. Thus, fuzzy-trace theory expects the decline in lure errors between the speeded and self-paced retrieval conditions to be smaller when BAS and FAS are high than when they are low. Importantly, fuzzy-trace theory expects lure errors to decline between the speeded and self-paced retrieval conditions as long as verbatim trace retrieval is utilized. As a result, while the theory can explain differences in how much lure errors decline between the speeded and self-paced retrieval conditions as a function of FAS and BAS, it expects lure errors to decline between the speeded and self-paced retrieval conditions as long as verbatim retrieval occurs. Finally, if one assumes that verbatim retrieval fails entirely in some experimental conditions, fuzzy-trace theory can explain cases where lure errors fail to decrease with increased retrieval time. In summary, fuzzy-trace theory expects lure errors to decrease less in the high BAS and FAS conditions when retrieval time increases, and can explain cases where lure errors fail to decline between the speeded and self-paced retrieval conditions, assuming verbatim trace retrieval does not occur in some experimental conditions (e.g., high BAS/high FAS study lists, where participants judgments may be heavily driven by the semantic similarity between lure items and gist traces).

Finally, global-matching models propose that both BAS and FAS influence how well lure items match traces in memory, which in turn determines the amount of memory activation that supports lure errors. Global-matching models generally claim that memory activation is available relatively early in retrieval, leading them to expect that the effects of BAS and FAS on lure errors should occur under speeded retrieval conditions. However, global-matching models also have been shown to explain results that suggest memorial information accrues with increased retrieval time (Brockdorff & Lamberts, 2000), and can explain results suggesting that lure items inspire retrieval of source information (Hicks & Starns, 2006a). Given that source retrieval is typically viewed as requiring deliberate retrieval effort, and deliberate retrieval processes require time to execute, global-matching models have the ability to explain a general increase in lure errors with increased retrieval time. However, because the accrual of information from memory over time and retrieval of source information from memory is based upon the same basic retrieval mechanisms and representations as familiarity, global-matching models must predict that both BAS and FAS will influence lure errors when retrieval is self-paced, the same result the models expect to occur when retrieval is speeded.

Method

Participants

One hundred and four Middlebury College students participated as part of a research appreciation requirement or in exchange for \$10 payment.

Stimuli and Study/Test List Construction

One hundred forty-four sets of four words (themes) were chosen from Nelson, McEvoy, and Schreiber (1998) such that all associates within a given theme produced the same word (the lure) with a nonzero probability (BAS), and such that the lure produced each associate with a nonzero probability (FAS). Thirty-six themes were constructed for each of the four conditions formed by crossing BAS (high vs. low) and FAS (high vs. low). High BAS/High FAS themes contained four associates that on average both *produced* the lure item in free association (BAS) and *were produced by* the lure item with a relatively high probability (FAS). High BAS/Low FAS themes contained four associates that on average produced lure items in free association with a relatively high probability, but were produced by the lure item in free association with a relatively low probability. Low BAS/High FAS themes contained four associates that on average produced lure items in free association with a relatively low probability, but were produced by the lure item in free association with a relatively high probability. Finally, Low BAS/Low FAS themes contained four associates that on average produced the lure item in free association with a relatively low probability and were produced by the lure item in free association with a relatively low probability. Stimulus sets for each BAS and FAS condition were constructed such that the average high and low levels of each variable were equated across conditions manipulating the other variable.

In order to construct stimulus sets that manipulated both BAS and FAS while equating the average high and low levels of each variable across conditions manipulating the other variable, it was necessary to allow a slight degree of overlap between the *lowest* mean FAS for a theme in the High BAS/High FAS condition (lowest mean theme FAS = 0.053) and the *highest* mean FAS in the two Low FAS conditions (highest mean theme FAS = 0.056 in both the High BAS/Low FAS and the Low BAS/Low FAS conditions). Although allowing this overlap in stimulus characteristics between one of the high FAS and the low FAS conditions was not desirable for the purposes of maximizing the size of the FAS manipulation, this slight overlap would have the effect of limiting the effects of FAS on false memory. Thus, this characteristic of the FAS manipulation in this study would only be a concern if FAS does not influence false memory. Mean BAS and FAS for each condition, as well as the range of mean BAS and FAS for themes in each condition is presented in Table 1.¹

Half of the stimuli (18 themes) from each of the four BAS/FAS conditions were presented during encoding, while the other half of the stimuli were used as unstudied items on the recognition memory test. There were two study-test cycles, such that nine themes from each of the four BAS/FAS conditions were presented on each study list, producing a study list length of 144 words. For each test list, two studied items from each theme, the lure item from each theme, and comparable items from unstudied themes (two associates and their related lure from nine themes in each of the four BAS/FAS conditions) were presented, producing a test list length of 216 words.

¹Stimuli are available from Jason Arndt.

Procedure

Participants were instructed that they would see a series of words and that their task was to do their best to remember them for a later memory test. Study items were presented serially in the center of a computer screen for 2000 msec. Study items were presented blocked by theme, with the order of items within a theme and the order of themes within a study list randomized separately for each participant. Upon completion of the first study list, participants were given a recognition memory test. Participants were instructed to judge each word for whether it was or was not studied on the immediately-preceding study list. One test was assigned to the speeded retrieval condition, and the other test was assigned to the self-paced retrieval condition. For the self-paced retrieval test, participants were instructed to simply press the “O” key for an old response or the “N” key for a new response once they had determined the studied status of each test item. For the speeded retrieval test, participants were instructed to respond to each test item within 750 msec of when it was presented (Benjamin, 2001). Further, participants were given feedback regarding their response time for each item, and a warning in red font to respond more quickly when their response time exceeded 750 msec for any given response. Test items were presented in a unique random order for each participant. Finally, once participants completed the first recognition memory test, they were given a second study list, which was followed by a second recognition memory test, with the recognition memory test being assigned to the retrieval time condition (speeded vs. self-paced) that they had yet to complete. Participants were instructed the second study and test would not contain any items that were shown during the first study and test that they had just completed, so their memory for those words was no longer being investigated. Assignment of themes to be studied or unstudied, as well as to the retrieval time factor (speeded vs. self-paced) and the order of the speeded vs. self-paced retrieval test (first vs. second study-test cycle) was counterbalanced across participants.

Results

Preliminary analyses of false alarm rates for new items and lures that were related to unstudied items (referred to as *new lures* hereafter) demonstrated that baseline false alarm rates declined with increased retrieval time (both $p < .001$). Thus, in order to evaluate performance changes accurately across the retrieval time conditions, we computed d' (Green & Swets, 1966) for both studied items and lure items. Although computing d' for lure items is not typically done, when baseline error rates change across levels of an independent variable such as retrieval time, d' provides a measure of how the memorial evidence supporting lure errors is affected by experimental conditions that is not contaminated by baseline false alarm rate differences (Arndt, 2006). Thus, because theories of false memory propose increases or decreases in the *memorial evidence* supporting lure errors when additional retrieval time is provided, d' is the most appropriate measure to evaluate their predictions. For completeness, studied item hits, false alarms to new items, false alarms to lure items, and false alarms to new lures are presented in Table 2 as a function of Retrieval Time, BAS, and FAS.

Figure 1 presents d' for studied items as a function of Retrieval Time, BAS, and FAS. A 2 (Retrieval Time) $\times$ 2 (BAS) $\times$ 2 (FAS) within-subjects ANOVA on d' for studied items produced only one reliable effect, that of Retrieval Time, $F(1,103) = 152.99$, $MSE = .741$, $p < .001$, such that discriminability increased with retrieval time ($p > .10$ for all other main effects and interactions). Figure 2 presents d' for lure items as a function of Retrieval Time, BAS, and FAS. A 2 (Retrieval Time) $\times$ 2 (BAS) $\times$ 2 (FAS) within-subjects ANOVA on d' for lure items produced three reliable results. First, there was a main effect of BAS, $F(1,103) = 15.22$, $MSE = .423$, $p < .001$, indicating that lure d' was greater when high BAS associates were studied compared to when low BAS associates were studied. Second, there was a main

effect of FAS, $F(1,103) = 15.13$, $MSE = .316$, $p < .001$, indicating that lure d' was greater when high FAS associates were studied compared to when low FAS associates were studied. Third, there was a main effect of Retrieval Time, $F(1,103) = 20.90$, $MSE = .450$, $p < .001$, indicating that lure d' increased with increased retrieval time (Arndt, 2006). None of the interactions were significant (all $p > .10$).

Although there were no interactions of BAS or FAS with retrieval time, we conducted separate $2 \text{ (BAS)} \times 2 \text{ (FAS)}$ within-subjects ANOVAs on the speeded and self-paced retrieval conditions in order to ensure the effects of BAS and FAS were evident when retrieval was speeded and when retrieval was self-paced. The analysis of the speeded retrieval condition produced main effects of BAS, $F(1,103) = 5.01$, $MSE = .282$, $p = .027$, and FAS, $F(1,103) = 6.76$, $MSE = .407$, $p = .011$, with both main effects demonstrating that lure d' was greater when BAS and FAS were high compared to when they were low. Further, this analysis did not produce an interaction between BAS and FAS ($F < 1$). Similarly, the analysis of the self-paced retrieval condition produced main effects of BAS, $F(1,103) = 14.01$, $MSE = .411$, $p < .001$, and FAS, $F(1,103) = 7.99$, $MSE = .258$, $p = .006$, with both main effects demonstrating that lure d' was greater when BAS and FAS were high compared to when they were low. Further, this analysis did not produce an interaction between BAS and FAS, although the interaction approached significance ($F(1,103) = 3.44$, $MSE = .399$, $p = .066$). This trend toward an interaction suggests that the effects of FAS on lure d' tended to be greater when BAS was high than when BAS was low. Most important, however, is that the results of both the overall analysis and those examining the speeded and self-paced retrieval conditions separately demonstrated that 1) both BAS and FAS increased lure d' , 2) lure d' increased when people were given increased retrieval time, and 3) both BAS and FAS increased lure d' when retrieval was speeded as well as when retrieval was self-paced.

Discussion

The results of this study suggest two basic conclusions. First, relatively automatic memory processes that underlie lure errors are influenced by both BAS and FAS, as documented by the fact that both variables influenced lure d' when retrieval was speeded. This outcome is consistent with the predictions of theories that claim lure errors are underlain by either similarity-based familiarity, as claimed by global-matching models, or retrieval of gist memory traces, as claimed by fuzzy-trace theory. Importantly, this outcome is inconsistent with the claim that spreading activation underlies lure errors, as suggested by activation-monitoring theory. Second, relatively controlled or time-consuming memory processes that underlie memory errors are also influenced by both BAS and FAS, and have the effect of increasing lure errors. Evidence for this conclusion comes from the finding that lure d' increased with retrieval time, that retrieval time did not interact with BAS or FAS, and that lure d' showed main effects of both BAS and FAS when retrieval was self-paced, the same result that occurred when retrieval was speeded.

Theoretical Implications

Overall, the results of this study are best explained by global-matching models. Specifically, global-matching models can explain the observed increase in lure errors with retrieval time, as increases in retrieval time enable increased accrual of information from memory (Brockdorff & Lamberts, 2000), and allows people to retrieve contextual details from memory when tested with lure items (Hicks & Starns, 2006a). Further, global-matching models generally suggest that this increase in lure errors should be influenced by factors that affect how much lures match the representations of studied items in memory. Thus, variables that influence lure errors when retrieval is speeded (e.g., BAS, FAS) should also influence lure errors when retrieval is self-paced, which was the outcome observed in this study.

In contrast, activation-monitoring theory and fuzzy-trace theory both encounter difficulty explaining key results of this study. While activation-monitoring theory is able to explain why speeded judgments were influenced by BAS, it is not capable of explaining why FAS also influenced speeded judgments, because FAS indexes activation spread from lure item representations to studied item representations. Consequently, changes in FAS should not be able to influence lure representation activation levels. Further, activation-monitoring theory is unable to explain why the increase in lure d' with additional retrieval time was not mediated solely by BAS, given its claim that only BAS should impact lure activation during encoding, such that only BAS should have increased the likelihood that lure items became associated with encoding context. Finally, activation-monitoring theory encounters difficulty explaining why lure d' increased, rather than decreased, with additional retrieval time when FAS increased – if anything, increased FAS should have enabled better retrieval of lures' studied associates when people were given time to employ monitoring processes during retrieval, which should have diminished, rather than increased, peoples' tendency to endorse lures as studied.

Fuzzy-trace theory can explain the finding that lure errors increased with increases in both BAS and FAS based upon its claim that BAS and FAS increase how similar lure items are to gist traces formed during the encoding of the lures' associates. However, the theory encounters difficulty explaining the fact that lure d' increased with retrieval time, because it proposes that self-paced retrieval should enable people to retrieve verbatim memory traces, which should have reduced, rather than increased, lure errors between the speeded and self-paced retrieval conditions. Although the basic mechanisms proposed by fuzzy-trace theory do not explain the finding that lure errors increase with retrieval time, prior research conducted using the theory's basic framework may provide an account. Specifically, Brainerd and Wright (2005) used the conjoint recognition methodology (Brainerd, Reyna, & Mojardin, 1999; Brainerd, Wright, Reyna, & Mojardin, 2001) to examine the effect that FAS and BAS had on three processes' contributions to false recognition: *similarity responding*, *phantom recollection* and *recollection rejection*. Similarity responding results from test items matching gist traces and gives rise to a feeling of familiarity with a test item, which in turn increases the probability people will endorse the test item as studied. Phantom recollection results from test items that very closely match gist memory traces, which gives rise to a strong feeling of familiarity that is confused with the psychological experience of recollecting the test item as having been studied. Thus, although phantom recollection results in a different phenomenological state than similarity responding, both responses are based upon test items matching gist memory traces. Finally, recollection rejection occurs when a verbatim memory trace is retrieved that provides evidence that a test item was not actually studied, but instead that a different item was studied. Thus, recollection rejection is based upon retrieval of verbatim representations of the details of encoding an item, and has the effect of leading people to reject a similar test item for which they are unable to retrieve a verbatim representation (e.g., a lure item in the DRM paradigm).

The results of conjoint recognition analyses of lure errors from Brainerd and Wright's (2005) study produced three outcomes of note. First, increasing FAS increased similarity responding for lures. Second, increasing BAS increased phantom recollection for lures. Third, increasing BAS and FAS *decreased* the extent to which recollection rejection was used to reduce lure errors. The first two results are consistent with the notion that increasing BAS and FAS both increase how well a lure item matches gist memory traces, because both similarity responding and phantom recollection are based upon how well lure items match gist traces. Further, these two results are consistent with the present results documenting that both BAS and FAS increased lure errors when retrieval was speeded, which ensured that rapidly-retrieved sources of information (such as test items matching gist traces) predominantly influenced performance. The third result suggests that both BAS and FAS

should influence the extent to which lure errors change when additional retrieval time is provided. Specifically, lure errors should be higher when BAS and FAS were high than when they were low because high BAS and FAS impaired recollection rejection more than low BAS and FAS. Importantly, although increasing both BAS and FAS impaired recollection rejection, the conjoint recognition model estimates of recollection rejection were positive in all conditions, suggesting that recollection rejection should have had the effect of *reducing* lure errors, rather than *increasing* lure errors, when additional retrieval time was provided. Thus, although the interpretation of the conjoint recognition analysis parameters can explain why lure errors were impacted by both BAS and FAS when retrieval is speeded, as well as when retrieval is self-paced, there does not appear to be a mechanism that allows fuzzy-trace theory to explain why lure errors increased, rather than decreased, when people were provided with additional retrieval time in the present study.

In summary, the present data favor the explanation of the effects of BAS and FAS on false memory advanced by global-matching models over those advanced by activation-monitoring theory and fuzzy-trace theory. Although the present data favor global-matching models' explanation, it is important to note that this conclusion does not suggest that monitoring or verbatim retrieval are never used to limit false memory (see Brainerd, Reyna, Wright, & Mojon, 2003 for a review of memory editing). Rather, the present data suggest that there are empirical circumstances where those processes do not operate to decrease memory errors. Indeed, the present data, where lure errors generally increased between speeded and self-paced retrieval conditions, suggest that activation-monitoring theory and fuzzy-trace theory may require modification in order to explain why slowly-retrieved information increases false memory in some circumstances.

The Effect of Retrieval Time on False Alarms

One concern readers may have regarding the present data is that lure errors increased between the speeded and self-paced retrieval conditions, while it is often found that false alarms to lures that are similar to studied items increase in the early stages of recognition memory retrieval, and decrease with increased retrieval time thereafter (e.g., Doshier, 1984; Gronlund & Ratcliff, 1989; Hintzman & Curran, 1994). Although it is difficult to be certain about why a different pattern arose in the present study, one possibility is that lure item errors in the DRM paradigm are underlain by different processes than other types of lure errors, such as plurality-reversed lures (Hintzman & Curran, 1994), rearranged lures in an associative recognition task (Gronlund & Ratcliff, 1989), and semantic associates of single study items (Doshier, 1984). Specifically, items that produce errors which increase early in retrieval but decline with additional retrieval time are likely produced by familiarity. Thus, early in retrieval, when familiarity dominates performance, errors can increase, while later in performance, when recollection of the exact form of a studied item is increasingly available, familiarity-based errors will tend to decrease (Brainerd, et al., 2003; Diana, Reder, Arndt, & Park, 2006; Rotello & Heit, 2000). In contrast, studying multiple associates of a lure item in the DRM paradigm seems to produce not only enhanced familiarity for lure items, but also enables lure items to retrieve encoding context when they are tested (Arndt, 2010). This difference in the memorial information underlying lure errors would also lead the two classes of errors to show different trajectories as a function of retrieval time. In particular, familiarity-based lure errors will only produce an increase in errors early in retrieval when familiarity is unopposed by recollection of studied items. Thus, once there has been sufficient time for recollective information to be retrieved, such familiarity-based lure errors will be reduced by recollection of related items that were actually studied. In contrast, lure errors in the DRM paradigm would be expected to increase between the early and late stages of retrieval processing, because recollection of encoding context would provide further evidence that lures were studied (Arndt, 2006).

Importantly, the results of several prior studies document that DRM lure errors commonly increase with increases in retrieval time. One prior study measured lure errors in the DRM paradigm with d' and found an increase between speeded and self-paced retrieval conditions (Arndt, 2006; Experiment 3). Further, a re-analysis of the results from other studies that manipulated retrieval time and measured lure errors with false alarm rates (Arndt & Gould, 2006; Benjamin, 2001; Heit, Brockdorff, & Lamberts, 2004) also suggest that lure d' often increases or fails to decrease between speeded and slower retrieval conditions.² For these re-analyses, lure d' was computed for individual subjects as a function of each experimental condition using the lure error rate as a hit rate and the false alarm rate for unstudied weak associates of lure items (Arndt & Gould, 2006, Experiment 1; Benjamin, 2001) or entirely unrelated test items (Arndt & Gould, 2006, Experiment 2; Heit, et al., 2004) as the false alarm rate. When hit rates or false alarm rates were 1.0 or 0.0, standard corrections were used in order to allow computation of d' (Snodgrass & Corwin, 1988).

Arndt and Gould (2006) examined how a number of variables (BAS, study time, number of associates studied, study repetition) influenced lure errors in speeded and self-paced retrieval conditions. In their studies, there were five conditions that were comparable to those in the present study (4 associates studied, study items presented once during encoding). Four of those conditions showed a qualitative increase in lure d' between speeded and self-paced retrieval conditions, although only one showed a reliable increase in lure d' (the 500 msec study time condition for high BAS items in Experiment 2; $t(31) = 2.38, p = .024$). Similarly, Benjamin (2001; Experiment 2) used both speeded and self-paced retrieval conditions to examine the influence of study item repetition (once vs. thrice) on lure errors. When study items were shown once (i.e., the condition most similar to the present study), lure d' increased between the speeded ($M = 0.974$) and self-paced ($M = 1.489$) retrieval conditions ($t(29) = 3.29, p = .003$). When study items were shown thrice, lure d' qualitatively increased between the speeded ($M = 1.233$) and self-paced ($M = 1.336$) retrieval conditions, albeit not significantly ($t(29) = 0.57$). Thus, while not all conditions show *reliable* increases in lure d' between speeded and self-paced retrieval conditions, a *qualitative* increase in lure d' is typically observed when speeded and self-paced retrieval conditions are compared, provided people are presented with four or more associates of a lure item during encoding. These results are consistent with the observed increase in lure d' with increased retrieval time found in the present study, and suggest that DRM lure errors typically do not respond to increased retrieval time in the same way as other types of memory errors.

Finally, Heit et al (2004) examined lure errors using response signals at 200, 400, 600, and 1100 msec post-stimulus (Reed, 1976). Further, they either tested participants in standard retrieval conditions similar to those used in the present study or under conditions where participants were warned to avoid making lure errors. As shown in Figure 3, lure d' generally increased from the first response signal (~550 msec post-stimulus) to the later response signals.³ Formal analyses of lure d' as a function of the four response signal durations documented a difference among the response signals for each of the four conditions shown in Figure 3 (smallest $F(3,57) = 2.967, MSE = 0.447, p = .039$ for the Experiment 1 warning condition). Further, this overall difference among the response signals was generally due to an increase in lure d' following the fastest response signal – all paired t -tests comparing the 200 msec response signal with later response signals were significant other than the comparison between the 200 msec and 400 msec deadlines in Experiment 1's warning condition ($t(19) = 1.47, p = .159$), and the comparison between the 200 msec and 600 msec response deadlines in Experiment 2's standard condition ($t(19) =$

²I thank Aaron Benjamin and Evan Heit for graciously providing their data.

³Total retrieval times for each condition depicted in Figure 3 were estimated by adding the maximum response time on any given trial allowed by Heit, et al. (2004), 350 msec, to the response signal durations.

1.83, $p = .083$). Underscoring that the overall difference among response signals was due to a difference between the first and later retrieval conditions, lure d' did not reliably differ among the slowest three response signals for any of the four conditions depicted in Figure 3 (largest $F(2,38) = 1.588$, $MSE = 0.389$ $p = .218$ for the Experiment 2 standard condition).

The results of re-analyzing Heit, et al's (2004) data are best viewed as failing to disconfirm the regularity that DRM lure errors can increase with retrieval time, rather than directly supporting the regularity, for two reasons. First, lure errors in Experiment 2 showed a qualitative tendency to decrease, rather than increase, after approximately 750 msec of retrieval time, although this trend may have occurred because very few DRM themes, four, were studied prior to each memory test. In comparison, other studies examining the influence of retrieval time on DRM lure errors have used many more than four DRM themes in a study list (16 themes in Benjamin, 2001; 20 and 48 themes in Arndt & Gould, 2006; 36 themes in the present study). Second, the majority of the increase in lure d' was observed after approximately 550 msec of retrieval time, such that lure d' did not show reliable increases after approximately 750 msec of retrieval time. While the lack of a reliable decrease in lure d' as retrieval time increased above 750 msec is consistent with the claim that DRM lures have a different underlying basis than familiarity-based errors, retrieval of encoding context is likely to occur later in retrieval than 750 msec. Thus, our re-analysis of Heit et al's (2004) data do not provide strong confirmation of the hypothesis that DRM lure errors increase with retrieval time because they are partially underlain by retrieval of encoding context. Importantly, however, Heit et al's (2004) data do not suggest that lure errors are underlain by the same memorial information as familiarity-based errors, because increased retrieval time did not reduce lure d' , even under conditions that were optimal for recollective information to produce rejection of DRM lure errors (short study lists, participants warned to avoid lure errors in Experiment 2). In summary, most studies examining the influence of retrieval time on DRM lure errors have found that lure d' increases with increased retrieval time, whether qualitatively or statistically (Arndt & Gould, 2006; Benjamin, 2001). These results document that the present results, which showed an increase in lure d' with increased retrieval time, are typical of studies of DRM lure errors, and support the notion that lure errors have a different underlying basis than memory errors that are attributable solely to familiarity (e.g., Hintzman & Curran, 1994).

In conclusion, the present results support the points raised by Brainerd and colleagues (2008; Brainerd & Wright, 2005) about the importance of examining multiple variables in order to understand the bases of false memories, particularly when one is seeking to understand the associative/semantic variables that underlie false memory. Indeed, the present results underscore the conclusions of Brainerd et al (2008) in illustrating that DRM lure errors are best characterized as occurring due to shared similarity between lures and studied items rather than due to spreading activation from study items' representations to lure items' representations (Collins & Loftus, 1975; Roediger, et al., 2001). Further, the current results replicated those of Brainerd and Wright (2005) demonstrating that both BAS and FAS influenced lure false memory. Thus, researchers seeking to understand the memorial bases of false memory would benefit from following the lead of Brainerd, et al (2008) by examining the role that numerous word association variables beyond BAS plays in producing and limiting false memories (e.g., Brainerd & Wright, 2005; McEvoy, Nelson, & Komatsu, 1999). While the present study only examined two such variables, backward and forward association strength, this investigation proved profitable in advancing both theoretical and empirical understanding of the bases of lure errors. Critically, the fact that the present results document that both BAS and FAS influence memory errors suggests that separating their effects on false memory is important for future investigations of false memories. For example, it will be important to understand whether BAS, FAS, or both influence the conviction with which participants believe they can recollect lures' occurrence

on a study list (Roediger & McDermott, 1995), as well as the bases of lure item source judgments (Hicks & Hancock, 2002; Hicks & Starns, 2006b). Regardless of the outcome of such future investigations, the present results suggest the importance of separating the effects of these two variables that have been confounded in most previous work documenting the effects of BAS on false memory (e.g., Arndt, 2006; Arndt & Gould, 2006; Arndt & Hirshman, 1998; Hicks & Hancock, 2002).

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Note: error bars represent the standard error of the mean.

Figure 1.

Old-new d' as a function of Retrieval Time, Backward Associative Strength (BAS) and Forward Associative Strength (FAS).

Note: error bars represent the standard error of the mean.

Figure 2.

Lure d' as a function of Retrieval Time, Backward Associative Strength (BAS) and Forward Associative Strength (FAS).

Figure 3.

Lure d' from Heit, Brockdorff, and Lamberts (2004) as a function of Retrieval Time, Experiment, and Warning Condition.

Table 1

Mean backward (BAS) and forward (FAS) associative strengths for stimulus sets formed by crossing low vs. high backward associative strength and low vs. high forward associative strength.

FAS Condition	BAS Condition			
	Low		High	
	Mean FAS	Mean BAS	Mean FAS	Mean BAS
Low	.034 (0.016; 0.056)	.037 (0.021; 0.057)	.034 (0.015; 0.056)	.305 (0.177; 0.419)
High	.125 (0.058; 0.198)	.037 (0.019; 0.057)	.131 (0.053; 0.205)	.306 (0.092; 0.610)

Note: the range of mean BAS and FAS for themes in each condition is reported in parenthesis.

Table 2

Mean proportion “old” responses to studied items, new items, lure items, and new lure items as a function of Retrieval Time, Backward-Association Strength (BAS) and Forward-Association Strength (FAS).

	BAS Condition			
	Low		High	
	Low FAS	High FAS	Low FAS	High FAS
<i>Studied Items</i>				
Speeded Retrieval	.49 (.02)	.50 (.02)	.47 (.02)	.51 (.02)
Self-Paced Retrieval	.66 (.02)	.65 (.02)	.67 (.02)	.67 (.02)
<i>New Items</i>				
Speeded Retrieval	.23 (.02)	.25 (.02)	.21 (.02)	.24 (.02)
Self-Paced Retrieval	.16 (.01)	.17 (.02)	.15 (.01)	.19 (.02)
<i>Lure Items</i>				
Speeded Retrieval	.31 (.02)	.35 (.02)	.40 (.02)	.44 (.02)
Self-Paced Retrieval	.33 (.02)	.32 (.02)	.40 (.02)	.45 (.02)
<i>New Lures</i>				
Speeded Retrieval	.24 (.02)	.22 (.02)	.27 (.02)	.27 (.02)
Self-Paced Retrieval	.18 (.02)	.17 (.02)	.21 (.02)	.18 (.01)