On the Flexibility and the Fallibility of Associative Memory

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Abstract

The authors report the results of four experiments that explored the flexibility and fallibility of associative recognition memory. In each experiment, pairs were studied one or more times, and the task was to discriminate intact from rearranged pairs. The critical findings are that the pattern of false-alarm rates were dependent on the nature of the recognition procedure (e.g., ratings versus yes-no) and the situation in which the task was performed. The specific pattern of findings suggest that subjects adopt different recognition strategies in order to achieve a desired level of performance in the most efficient manner possible by varying the degree to which they base their decisions on familiarity versus recollected information. Implications for theories of recognition memory are discussed.

The limitations of memory are widely known. Laypersons usually condemn their "terrible memories". In doing so, they fail to appreciate the remarkable flexibility of human memory, which represents and retrieves varieties of information obtained from different perceptual modalities in the service of countless daily tasks each performed in countless situations. Flexibility and fallibility are hallmarks of human memory. The subject of the present investigation is what the fallibility of recognition memory can tell us about its flexibility.

Recognition tasks require the discrimination of studied items (or *targets*) from unstudied items (or *foils*). Recognition is successful when targets are endorsed (i.e., *hits*) and foils are rejected. Likewise recognition is unsuccessful when targets are rejected and foils are endorsed (i.e., *false-alarms*). Thus, recognition memory improves as the difference between hit rates and false-alarm rates increase.

Over the past dozen or so years, a dominant question in episodic memory has been how to characterize retrieval from recognition memory. One theory holds that recognition can be characterized by a single retrieval process (e.g., Donaldson, 1996; Dunn, 2004; Wixted & Stretch, 2004) and the other theory holds that at least two retrieval processes are required (e.g., Joordens & Hockley, 2001; Reder et al., 2000; Yonelinas, 2002 for a review). The former class of models is referred to as *single-process models* and the later is referred to as *dual-process models*. The debate is often framed such that only one model is needed to characterize all recognition tasks, and accordingly the same task is always performed in the same way.

These assumptions are parsimonious, but they might overlook the inherent flexibility of human memory. For instance, there are a wide variety of recognition tasks (including single-item recognition, associative recognition, source recognition, eye-witness identification, and memory scanning) and procedures (yes-no, ratings, forced-choice) and they are performed in countless situations. Thus, one might assume that these tasks at least have the potential to be performed in different ways. The present research explores the flexible nature of recognition memory in the context of the single versus the dual-process debate. One hypothesis is that different recognition tasks can be performed in different ways; perhaps even the same recognition task can be formed in different ways (e.g., Rotello, Macmillan, & VanTessel, 2000; Yonelinas, 1997).

Models of Associative Recognition

A major theoretical advance in human memory theory has been in its formalization, and here we describe three classes of models that have been recently applied to associative recognition. We will pay particular attention to the predictions that they make concerning the effect of pair repetitions on performance because this is one way that they can be distinguished (Cleary, Curran, & Greene, 2001; Kelley & Wixted, 2001; Xu & Malmberg, submitted).

Single-Process Recall-Only Models

According to recall-only models, associative recognition is performed in a manner very similar to cued recall (but see Anderson & Watts, 1971 and Postman & Stark, 1969). Memory is probed with a retrieval cue that represents one or both of the items comprising the test stimulus. As a result, episodic details may or may not be retrieved from memory: If details are retrieved, then they will either match the test pair or mismatch the test pair.

If they match, the test pair is positively endorsed. If they do not, the test pair is rejected. This is the simplest form of the *recall-to-reject* model, and it is usually assumed to belong to the threshold class of models because of the match versus mismatch basis for the recognition decision. While they differ in their details, the recall-only assumption is incorporated into several modern models including those described by Yonelinas (1997) and Diller, Nobel, & Shiffrin (2001).

A problem for the recall-only models are recent findings that show that increasing the number of target presentations has little or no effect on false-alarm rates (Cleary, et al., 2001; Kelley & Wixted, 2001; Xu & Malmberg, submitted). It is simplest to assume that increasing the number of times that pairs are studied should steadily improve the recall-to-reject process. If so, the single-process recall-only model predicts that false-alarms should steadily decrease with target presentations, and they apparently do not.

Single-Process Familiarity-Only Models

Single-process familiarity-based models assume that the basis for the recognition decision is a continuous random variable (e.g., Green & Swets, 1966), which is often referred to as familiarity. The simplest of these models is the *compound cue model* (e.g., Gronlund & Ratcliff, 1989), which assumes that the items that comprise a pair are stored jointly in a common memory trace. When memory is probed with a retrieval cue consisting of both test items, the output of memory is a level of familiarity, and the response is positive if it exceeds a subjective criterion. Since familiarity is assumed to be a nonlinear positive function of the similarity between the retrieval cue and the contents of memory, compound cue models predict that intact pairs will have a greater average familiarity than rearranged pairs. Strengthening targets increases the average familiarity of rearranged pairs, and thus the simplest version of the compound cue model predicts an increase in false-alarm rates with an increase in target repetitions, which is inconsistent with extant findings (Cleary et al., 2001; Kelley & Wixted, 2001; Xu & Malmberg, submitted).

A different type of familiarity-only model is the *independent cue model* (e.g., Dosher, 1984; Murdock, 1997). Like compound cue models, they assume that familiarity is the basis for recognition. Unlike compound cue models, independent cue models assume that the pair wise association of two items is represented separately from the items themselves or are otherwise stochastically independent. When a test pair is presented, the pair wise association is created anew and used to probe memory.

The strongest versions of the independent cue models assume that the probe only involves comparing the similarity of the independent cue to the contents of memory (Murdock, 1982). The items comprising a pair play no systematic role in the recognition decision. Since an intact pair is represented in memory but a rearranged pair is not (they match the contents of memory only randomly), intact pairs tend to be more familiar than rearranged pairs. In addition, strengthening target pairs should have no effect on the familiarity of rearranged pairs, and hence the independent-cue predictions are supported by a null effect of repetitions on false-alarm rates (Cleary et al., 2001; Kelley & Wixted, 2001; Xu & Malmberg, submitted).

A weaker version of the independent cue models assume that the probe of memory consists of both item and associative information (e.g., Criss & Shiffrin, in press; Hockley, 1992; Kelley & Wixted, 2001). Thus, the familiarity of a test pair is a function of the joint familiarity of the items and the association of the items. What these models predict when targets are repeated depends on whether repetitions increase, decrease, or have no effect on the familiarity of the rearranged pairs. Hockley (1992) suggested that item and associative information might be combined for intact pairs, but only item familiarity contributes to the recognition decision involving rearranged pairs. Accordingly, false-alarm rates should increase, and hence this version of the independent cue model is disconfirmed. In contrast, Kelley and Wixted (2001) assumed that increasing repetitions increases item familiarity but decreases the associative strength of rearranged pairs. When these two sources of evidence are of equal magnitude, the prediction is a null effect of repetitions on false-alarm rates.

A Dual-Process Model

Generally speaking, dual-process models assume that familiarity and recollective details may be used as evidence on which to base a recognition judgment (Atkinson & Juola, 1974). The dual-process model that we are considering is the one Xu and Malmberg (submitted) recently developed within the framework of the retrieving effectively from memory theory (REM, Malmberg, Holden, & Shiffrin, 2004; Malmberg & Shiffrin, 2005; Malmberg, Zeelenberg, & Shiffrin, 2004; Shiffrin & Steyvers, 1997). The formal details of that model are presented in the Appendix, but at least for the moment, we need only consider five basic assumptions:

1. There are two types of information on which to potentially base a recognition decision (Atkinson & Juola, 1974). A sense of familiarity is produced in response to a probe of memory by a global-matching process (e.g., Clark & Gronlund, 1996; Shiffrin &

Steyvers, 1997) and episodic details are produced by a sampling and recovering process (e.g., Malmberg & Shiffrin, 2005; Raaijmakers & Shiffrin, 1980).

2. The familiarity process provides information more quickly than the sampling and recovery process (e.g., Diller et al. 2001; Gronlund & Ratcliff, 1989).

3. Performance of explicit memory tasks involves the interaction of permanent structural processes and strategic control processes (Atkinson & Shiffrin, 1968).

4. Recognition should be performed in the most efficient manner and this involves a subjective weighting of the speed and accuracy with which recognition is performed. (Shiffrin & Steyvers, 1997; Xu & Malmberg, submitted).

5. The decision making steps of this model are shown in Figure 1. We assume that memory is probed with a compound cue, and the familiarity of the test pair is compared to a subjective criterion. If it does not exceed the criterion, the response is negative. If the familiarity of the test pair does exceed the criterion and the sampling and recovery processes are able to retrieve episodic details, those details are compared to the stimulus. If the details match the stimulus, the response is positive. If they do not match the stimulus, the response is negative. If the sampling and recovery processes fail, the subject guesses, with the far greater tendency to guess positively (Malmberg, Holden, & Shiffrin, 2004).

Insert Figures 1 and 2 here

In addition to considering how recognition *is* performed, one can consider how a recognition task *should be* performed within this framework. For instance, Malmberg, Zeelenberg, and Shiffrin (2004) concluded that when single-item recognition requires the discrimination of targets from randomly similar foils, a single-process continuous-state model suffices. Subjects adopt a single-process familiarity-based strategy when targets and foils are randomly similar because targets are generally more familiar than foils, and it is faster than the dual-process strategy because it does not require the outcome of the sampling and recovery process. On the other hand, Malmberg, Holden, and Shiffrin (2004) argued that a dual-process strategy is used when single-item recognition requires the discrimination of targets from similar foils because both seem relatively familiar: The episodic details provided by the sampling and recovery process are utilized to reject the otherwise familiar foils.

Xu and Malmberg (submitted) proposed that associative recognition is performed in a manner close to the way that single-item recognition performed when targets and foils are similar. Importantly, the tendency to rely on the recall-to-reject strategy is assumed to be under subjective control (perhaps by altering the initial criterion). This tendency is captured by the *a* parameter of the model. Figure 2 shows the predicted effect of repetitions on hit rates and false-alarm rates as a function of *a*. Regardless of the level of *a*, hit rates increase with increases in repetitions. In fact, the level of *a* has only a negligible effect on hit rates because subjects are biased to guess old to otherwise familiar items even when recollection fails. The level of *a* has a large effect on the pattern of false-alarm rates. When the recall-to-reject strategy is often used, false-alarm rates increase and then decrease. At intermediate levels of *a*, the false-alarm rate function is fairly steady after the initial increase. Hence, the dual-process model is not challenged by the null-effect of repetitions on false-alarm rates (Kelley & Wixted, 2001; Malmberg, Holden, & Shiffrin, 2004) because it is possible to pick two similar points on a nonlinear function. For instance, the one and twelve-presentation false-alarm rates are similar in Figure 2 when $a = 1.0$.

Thus, it is not possible to discriminate between independent cue models based on a null pattern of false-alarm rates. On the other hand, Xu and Malmberg (submitted) observed a variety of false-alarm rate functions. For unfamiliar items (e.g., pseudowords and Chinese characters), the false-alarm rate function *increased*. For familiar items (e.g., words and faces), the false-alarm rate function *decreased*. Dual-process models predict the variable false-alarm functions in an *a priori* manner (see Figure 2). Other models might be able to, but they need to adopt new assumptions in order to do so. Before doing so, however, it seems prudent further explore the effect or repetitions on associative recognition. In the following experiments, we explored the form of the false-alarm rate function for different recognition tasks and different situations. Because the methods used are very similar, we describe them in general terms first.

General Methods

Subjects. A total of 176 undergraduate students enrolled in introductory psychology courses at Iowa State University participated in exchange for course credit. All subjects were sampled from the Iowa State University subject pool, which consists of approximately equal numbers of males and females primarily between the ages of 18 and 21 years old. Experiments 1 and 2 were conducted between November 27 and December 8, 2004 and Experiments 3 and 4 were conducted between January 24 and February 18, 2005.

Design and Materials. These associative recognition experiments required the discrimination of intact pairs from rearranged pairs. In each experiment, 160 pairs of nouns were randomly created anew for each subject. These pairs were randomly assigned to one of four 40-pair study lists and to one of the five number-of-presentations conditions. The number of pair presentations was varied on 5 levels within subjects. Each pair was presented for 1.2 s of study 1, 2, 3, 6, or 12 times. There was at least one intervening pair between each presentation of a given pair. Following each study list, single digits were mentally added for 20 s. Four of the pairs in each condition were randomly determined to serve as intact pairs, and the remaining four pairs served as rearranged pairs. The rearranged pairs were formed by combining single items from same number-of-presentations condition.

Procedure. The methods used in the four experiments varied only in the task instructions given to the subjects. The tasks used in Experiments 1-4 were respectively confidence ratings, yes-no recognition, yes-no recognition with a 2 s. delay, and confidence ratings when the test list contained pairs constructed from unstudied items (i.e., XY pairs in addition to rearranged pairs). We refer to these as the *ratings*, *yes-no*, *yes-no delay*, and *XY* experiments respectively. In all experiments, pairs of words were presented one word above the other at both study and at test. Subjects were instructed that their task was to discriminate intact from rearranged pairs. Test pairs were presented until a response was made. We note the differences between the tasks in subsequent sections that describe each experiment.

Experiment 1: Ratings

As noted above, Kelley and Wixted (2001) found that FARs were not unaffected by increasing pair presentations. However, presentations were varied on only two levels (1 vs. 6 presentations) in those experiments, and hence it is unknown whether presentations have no effect on false-alarm rates or whether the function relating presentations to false-alarm rates is nonlinear. To obtain a better understanding of this function, we parametrically varied the number of pair presentations over a wider range and over five levels (1, 2, 3, 6, or 12). Once the form of the FAR function is established for the ratings task we will use it as a standard of comparison for the subsequent experiments.

Ratings Procedure. Sixty-eight subjects were instructed to judge on a 4-point Likert scale how confident they were that the pair of items was studied together (1 = high confidence studied, 2 = moderate confidence studied, 3 = moderate confidence not studied, 4 = high confidence not studied). Subjects were free to distribute their responses over the ratings as they saw fit. To make their response, participants were to enter the appropriate number into the computer using the keyboard.

Insert Figure 3 and Table 1 here

Results and Discussion

All contrasts that are reported are from repeated measures ANOVAs. *t*-tests are two tailed, and the standard of reliability is .05 for planned comparisons. The hit rates and false-alarm rates for all experiments are plotted as a function of the number of pair presentations in Figure 3. Table 1 reports these in a numerical fashion and the results of a regression analysis of the relationship between the number of target presentations and false-alarm rates.

Figure 3A shows that hit rates increased [$F(1, 67) = 502.28$, $p < .0005$] and false-alarm rates remained fairly steady as the number of target presentations increased [Linear: $F(1, 67) = .03$, $p = .87$; Quadratic: $F(1, 67) = 2.76$, $p = .10$]. These results replicate the findings of Kelley and Wixted (2001); there was not reliable difference between the false-alarm rates in the 1- versus the 6-presentation condition [$t(67) = 1.55$, $p = .13$]. Because the ANOVA contrasts assume equal intervals between the levels of the number of presentations, Table 1 also reports the results of a regression analysis of the relationship between false-alarm rates and the number of presentations. Neither the linear nor the quadratic relationships accounted for much of the variance in the false-alarm rates, although more was accounted for by the quadratic trend[1].

Experiment 2: Yes-No Recognition

The goal of the present experiment was to generalize the findings from the ratings task, where we found a flat, almost linear false-alarm rate function, to the yes-no task. Many single-process models of associative recognition assume that the ratings and yes-no tasks utilize the same information in order to make a decision, and hence they predict equivalent levels of performance and the same patterns of hit and false-alarm rates for each task. Likewise, Xu and Malmberg's (submitted) dual-process model predicts that the form of the functions relating false-alarm rates to repetitions will be same for the

[1] As in Xu and Malmberg (submitted) the tendency to use the high confidence old rating increased with increases in the number of target presentations when a false alarm was made [$F(1,48) = 10.64$, $p < .003$].

ratings and yes-no task if subjects wait to make their recognition decision until all available evidence is obtained from memory.

The yes-no task is, however, a simpler task than the ratings task. According to many single-process familiarity-based models, ratings are based on a comparison of a familiarity value to a set of criteria, whereas yes-no recognition is based on a comparison to a single criterion (Green & Swets, 1966), and additional comparisons should slow the performance of the ratings task relative to the yes-no task. Alternatively, Baranski and Petrusic (1998) speculated that confidence is determined after an initial yes-no decision has been made, especially when subjects emphasize speed over accuracy. In several visual discrimination experiments, they observed that initial discrimination decisions are often reversed when a subsequent confidence rating is given. More recently, similar observations were made using a recognition memory task. Van Zandt and Moldonado-Molina (2004) had subjects perform a speeded yes-no task followed by an unspeeded rating task. Again, subjects often reversed their initial yes-no decision.

To explain these findings, Baranski and Petrusic (1998) proposed and Van Zandt and Molodonado-Molina (2004) formally described a single-item recognition model that assumes for a two-choice task evidence accumulates in two counters in response to a stimulus. As soon as one counter reaches threshold, a yes-no decision is made. Importantly, evidence continues to accumulate after the initial yes-no decision has been made, and this additional evidence can influence the subsequent rating decision. Sometimes, the additional information leads to a decision reversal, particularly when the initial yes-no decision is incorrect.

Van Zandt and Molodonado-Molina's (2004) findings also suggest, within the dual-process framework, that familiarity and recollective details might accumulate at different rates during retrieval. The time course of retrieval during item and associative recognition was compared by Gronlund and Ratcliff (1989) using a signal-to-respond method. In these experiments, pairs were studied and single-item targets, single-item foils, intact pairs, and rearranged pairs were tested. Subjects were instructed to respond positively to single-item targets and intact pairs and negatively to single-item foils and rearranged pairs when a signal was presented. The main finding was that the rate with which performance increased was much greater for single-item than for associative recognition, primarily because of a non-monotonic relationship between response lag and the FARs for rearranged pairs: FARs initially increase and then decrease after about 700 ms, asymptoting at about 1400 ms subsequent to the probe.

Gronlund and Ratcliff (1989) concluded that item familiarity accumulated more quickly than associative familiarity, within the framework of the compound cue model. However, there is a different interpretation of these findings within the frameword of a dual-process model. Specifically, it might be the case the recollected information becomes available later than familiarity.

According to the dual-process model, responding before the sampled and recovered evidence has been obtained will primarily diminish the tendency to effectively use a recall-to-reject strategy. If so, Figure 2 shows that effect will be observed almost entirely in the pattern of false-alarm rates. Hit rates should be little affected because subjects tend to guess old to targets regardless of whether the recollection is successful or not. Responding before the recollection process is complete, however, should result in a strictly positive relationship between repetitions and false-alarm rates. If subjects overemphasize speed and underemphasize accuracy for the yes-no task, then lower hit rates and greater false-alarm rates are predicted by the single-process models as the result of having incomplete evidence on which to make a decision.

Yes-No Procedure. The design of this experiment is exactly like the design of Experiment 1 except, 36 subjects were instructed to respond either "yes" or "no" to indicate whether the items comprising a pair were studied together. To respond "yes" and "no", subjects pressed the "1" and "2" keys, respectively.

Results and Discussion.

Figure 3B and Table 1 show that repetitions increased hit rates [$F(1, 35) = 337.41$, $p < .0005$] and false-alarm rates (see Table 1). The linear trend in false-alarm rates was reliable [$F(1, 35) = 25.78$, $p < .0005$], and there was a smaller quadratic trend [$F(1, 35) = 3.93$; $p = .06$]. Again, however, the ANOVA contrast assumes equal intervals, and hence the nature of the trend is better informed by an additional regression analysis which shows that the quadratic trend accounts for more of the variance than the linear trend.

This suggests that the pattern of false-alarm rates is different from what was obtained in Experiment 1, in which a ratings task was used. A between-subject analysis comparing the patterns of hit rates and false-alarm rates for yes-no versus the ratings (Exp 1) tasks indicates that the task did not affect them [both $F < 1.0$], nor was there an interaction between presentations and tasks on hit rates [$F(1, 102) = 1.35$]. There was, however, a reliable interaction between the task and presentations on false-alarm rates [$F(1, 102) = 16.77$, $p < .0005$].

These analyses confirm what is apparent in Figure 3B: The pattern of false-alarm rates but not the pattern of hit rates depends on the nature of recognition task. For ratings, false-alarm rates are little affected by the number of target presentations. For yes-no recognition the false-alarm rates increase with presentations. This disconfirms models that must predict a null effect of presentations on false-alarm rates, most notably independent cue models that assume that item and associative information are statistically independent and only associative information is used to probe memory (Murdock, 1997). Within the framework of these models, the present results suggest that both item and associative information contribute to yes-no associative recognition, although it is unclear why, within the present independent cue frameworks, that the nature of the retrieval cue depends on the distinction between ratings and yes-no recognition.

The combined results of experiments 1 and 2 also disconfirm independent cue models that assume that the ratings and yes-no tasks differ only in the number of criteria used to make decisions (e.g., Kelley & Wixted, 2001), as these models predict equivalent levels of performance regardless of whether a yes-no rating procedure is used. We note that the median latencies of correct responses were approximately twice as fast for the yes-no task than for the ratings task (1.8 s vs. 3.4 s, $p < .0005$). Thus, it is possible that the slower rating decisions are due to the additional decisions that are required.

It is possible that different subjects use different recognition strategies. If so, we might expect that those who rely more heavily on a recall-to-reject strategy would respond more slowly than those who rely more heavily on the familiarity based strategy. On the other hand, the yes-no task might have encouraged all (or most) of the subjects to rely on the familiarity based strategy. If so, there should be little or no relationship between response latencies and false-alarms. To investigate these possibilities, we analyzed the correlation between false-alarm rates and mean latencies across subjects, and we divided the subjects evenly by assigning subjects to groups based on the mean false-alarm latencies in order to see if false-alarm rates were affected by whether subjects were assigned to the fast versus the slow group. The results of both analyses found no reliable relationship between false-alarms and response latencies, which suggests that subjects were adopting similar recognition strategies.

Experiment 3: Yes-No Delay

The variable patterns of false-alarms found in Experiments 1 and 2 disconfirm the simplest forms of all the single-process models that we considered. However, the independent cue models can be salvaged if associative information is available later than item information and if subjects adapt different strategies in response to task demands and situational factors. It makes sense within some independent cue frameworks (Criss & Shiffrin, in press; Kelley and Wixted, 2001; Murdock, 1997) that associative information becomes available later than item information because the test items need to be processed prior to creating a compound retrieval cue. If subjects adopt a strategy that emphasizes speed over accuracy, then at least some of the response might be based on item familiarity and not on associative familiarity.

These results are also consistent with the hypothesis that the ratings task requires two different decisions (Baranski & Petrusic, 1998; Van Zandt & Moldonado-Molina, 2004). Within the framework of the dual-process model, one might suppose that initially a familiarity value is compared to a criterion followed by a recall-to-reject strategy if the criterion is exceeded (as shown in Figure 1). If subjects in Experiment 2 emphasized speed to the detriment of accuracy, "yes" responses might have sometimes been based on familiarity when the use of recollected information would have led to a "no" decision.

The ratings task used in Experiment 1 is necessarily more time consuming than the yes-no task because there are two decisions. The first is a yes-no judgment performed based on familiarity. The second is a confidence judgment, which might be based on a combination of familiarity and recollected evidence. The additional confidence decision might have allowed time for the recollected information to become available without a time cost to the subject. That is, on some test trials an initial "yes" decision based on the pair's familiarity (see above) might be overridden by the occurrence of recollected information while the confidence judgment is being made, and this ultimately results in a "no" decision.

If subjects emphasized speed over accuracy in Experiment 2, then imposing a delay before the yes-no decision can be made would allow subjects to utilize recollected without a time cost (cf. Van Zandt & Moldonado, 2004). The predictions of the dual-process model are shown in Figure 2. An increase in the *a* parameter corresponds to an increase in the tendency to utilize information that has been sampled and recovered. Because both familiarity and recollected information indicate that a target pair was studied, increasing *a* does not substantially affect hit rates. However, increasing *a* increases the tendency to reject otherwise familiar rearranged pairs based on sampled and recovered information, and thus false alarm rates are generally lower and the function relating repetitions to false alarm rates is flat or inverted-U shaped.

Yes-No Delay Procedure. The yes-no delay condition, was the same as the yes-no condition except each test pair was presented on the computer monitor for 2 s before subjects were prompted for their yes-no decision. Thirty-eight subjects participated in this experiment.

Results and Discussion.

Figure 3C shows that repetitions increased hit rates [$F(1, 37) = 211.69$, $p < .0005$]. Visual inspection of Figure 3C indicates that function relating presentations to false-alarm rates has a decidedly inverted-U shaped nonlinearity. Table 1 shows that the linear trend in the false-alarm rates was not reliable ($F(1, 37) = 1.61$, $p = .21$), but the quadratic trend was reliable ($F(1, 37) = 7.22$, $p = .011$). The regression analysis leads to a similar conclusion, as the variance accounted for by the quadratic trend is much greater than variance accounted for by the linear trend.

A planned between-subject analysis of the data from Experiments 2 and 3 indicates no main effect of task (yes-no vs. yes-no delay) on hit or false-alarm rates [both $F(1, 72) < 1.0$]. There was also no interaction between task and presentations on hit rates [$F(1, 72) = 1.45$, $p = .23$]. However, there was a significant interaction between task and presentations on false-alarm rates [$F(1, 72) = 10.01$, $p < .002$). When subjects responded freely, false-alarm rates increased steadily. The delay imposed on making a yes-no response produced in an initial increase followed by a decrease in false-alarm rates. Moreover, the delay imposed on the recognition decision had no effect on hit rates.

These results are consistent with the hypothesis that when subjects perform a yes-no recognition task, they sometimes tend to overemphasize speed over accuracy. The result is an overemphasis on the familiarity component of retrieval and a neglect of a slower but more accurate recollective component. When a delay in responding is imposed and the outcome of the recollective component of retrieval is made available at no time cost, they will use this information to reject rearranged pairs because there is no time cost in doing so.

Experiment 4: XY Pairs

The present assumption is that recognition tasks can be performed in a variety of ways and the strategy adopted seeks to balance speed versus accuracy to meet a subjective goal of efficient performance. For the yes-no task in Experiment 2, subjects appeared to sacrifice accuracy in favor of quicker responses, and false-alarm rates rose steadily. When in Experiment 3, there was no time cost associated with slower responses, false-alarm rates did not rise steadily and in fact decreased a small amount after 6 pair presentations.

We note that subjects also apparently adopted different associative recognition strategies in experiments conducted by Postman and Stark (1969) and Anderson and Watts (1971). Postman and Stark (1969) had subjects study one or two lists of pairs. The group that studied one list served as the control group (*A-B*), a second group studied two lists that shared no common items (*A-B*, *C-D*), and the last group studied two lists that did share cues (*A-B*, *A-D*). Memory was tested for the pairs only on the first list either by cued recall or associative recognition. Importantly, the rearranged foils used in the associative recognition condition were from pairs that only came from the most recent list. Postman and Stark (1969) observed interference in the *A-B A-D* group for cued recall but not for associative recognition. In contrast, Anderson and Watts (1971) used foils that were constructed from items from both lists, and interference was observed. These findings demonstrate a certain amount of flexibility in associative recognition. The same task, namely associative recognition, can be performed in different ways depending on the testing conditions.

The difference between the Postman and Stark (1969) and Anderson and Watts (1971) experiments was the compositions of the test lists. In the Postman and Stark experiment, the foils were always rearranged pairs formed from items studied on the last study list, whereas some of the foils were formed from pairs from the first study list in the Anderson and Watts experiment. In Postman and Stark (1969), the foils consisted of a target item paired with an item from the most recent list. Thus, the subject only needed to determine whether the foil item was from the most recent list. If so, the pair could be rejected. In the Anderson and Watts (1971) experiment, some of the foils were drawn from pairs from the first list. Thus, subjects could not rely on a strategy by which items could be rejected based solely on list membership and had to determine whether the two items were studied together on the first list.

Here we adopt a similar but different method to explore whether subjects will adapt to task conditions by presenting at test some pairs consisting of items that were not studied (i.e., *XY* pairs)[2]. The *XY* pairs are only randomly similar to the studied pairs, and hence they will on average be far less familiar than intact pairs. We hypothesize that under these conditions, subjects will be less inclined to use a recall-to-reject strategy

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[2] Our *XY* pairs are different from Anderson and Watts' (1971) extra-list foils in two respects. Both members of their extra-list foils were studied and they consisted of one item appearing on each list.

because on the majority of the test trials they can respond as accurately but more quickly if they use a strategy that emphasizes familiarity (cf. Xu & Malmberg, submitted). If so, we expect to see relatively high false-alarm rates compared to those obtained in Experiment 1, where only intact and rearranged pairs were tested. In addition, our model predicts that hit rates should not be substantially affected by the change in the strategy.

XY Procedure. Thirty-four subjects performed the confidence ratings task as in Experiment 1, but they were also told that some of the test pairs were comprised of items that were not studied, and they were instructed to respond negatively to these pairs. Here, 4 of the pairs from each condition were randomly selected to be intact pairs, and 2 of the pairs were selected to be rearranged pairs. In addition, each test list contained 10 *XY* pairs, which were randomly constructed from words that were not studied. Thus, each test list contained equivalent numbers of targets (20) and foils (20).

Results and Discussion

Figure 3D shows that repetitions increased hit rates [$F(1, 33) = 187.20$, $p < .0005$]. Table 1 reports an ANOVA conducted on the false-alarm rates for the rearranged pairs (i.e., the XY-pair FARs were not included). The linear trend in false-alarm rates was not reliable [$F(1, 33) = 2.31$], but the quadratic trend was [$F(1, 33) = 17.02$, $p < .0005$], suggesting that form of the function relating false-alarm rates to presentation is nonlinear. The false-alarm rates appear to initially increase and then decrease as the number of target presentations increase. This conclusion is supported by the regression analysis which shows that the quadratic coefficient is much greater than the linear coefficient.

A planned comparison of the performance of the subjects in the ratings experiment (i.e., Exp 1) to the performance of the present subjects shows that task did not affect hit rates [$F(1, 100) < 1$], but the task did affect false-alarm rates [$F(1, 100) = 12.58$, $p < .001$]. Inspection of Figure 3D and Table 1 indicates that the false-alarm rates were substantially greater when *XY* pairs were included on the test list. In addition, there was a task by presentation interaction on false-alarm rates [$F(1, 100) = 13.07$, $p < .0005$], suggesting that the form of functions relating false-alarm rates to presentations vary depending on whether *XY* pairs are included in the test list. When this is so, the function is much more nonlinear than when only intact and rearranged pairs are tested.[3]

Model Fitting

The different pattern of false-alarm rates suggests within the current framework that the contribution of recollection to associative recognition depends on the nature of the task. Specifically, the contribution of recollection to performance appears greater in Experiments 1 (ratings) and 3 (yes-no delay) than in Experiment 2 (yes-no) and 4 (XY pairs).

To verify this conclusion, we conducted a simulation to determine whether the *a* parameter varies in a manner consistent with it. In this Monte Carlo simulation, all parameter values were held fixed with the exception of *a*, which was varied from .30 to 1.0 in increments of .025. The remaining parameter values are listed in the Appendix. For each value of *a* for each experiment, 1500 subjects were simulated. The "best

[3] The average RT in Exp 4 was 2.3, which falls in between the latencies of Exp 1 (3.4) and Exp 2 (1.8). This is what would be expected given that half of the foils in Exp 4 could be discriminated from the targets based only on familiarity, unlike in Exp 1. In addition, one would not expect the RTs in Exp 4 to be as fast as in Exp 2 because the rating task is more complicated than the yes-no task.

fitting” value of *a* was that which minimized the mean squared difference between the model and the data. As expected, the contribution of recollection to associative recognition was greater for the ratings (.975) and the YN-Delay (.775) tasks and lesser for the yes-no and XY-pairs (.700 and .500) tasks.

Given that there was only one free parameter to account for 10 data points in each simulation, the model fits are reasonable. The best fit occurred for Yes-No task (Exp 2), with a mean squared difference of .0008, which indicates that the average deviation of the model form the data was less than .03. The worst fit occurred for the XY-Pairs task, which had a mean squared difference of .0031, which indicates that average deviation of the model from the data was about .055.

To further explore the fits of the model to the data, we plot in Figure 4 the deviations of the model from the data and 95% confidence intervals of the data. In most cases, the best fits fall with those confidence intervals. However, Figure 4 shows that for all experiments, the predicted rate of increase in hit rates is more rapid than what was observed. The other significant departure of the model from the data is for the false-alarm rates for the XY-Pairs task. The model tends to underestimate those false-alarm rates by about .06. The problem for the model is the FAR in 12 presentation condition. When minimizing the squared deviation, the model attempts to capture this point by lowering all the other FARs. Thus, the model is underestimating the remaining FARs. To model the performance for XY pairs we assumed that recollection always failed because one cannot recall what was not studied (i.e., u^* for XY pairs is zero). An underestimate of the FAR for XY pairs occurred, which was .05 versus .10 observed in the data.

The departure of the model from the hit rates is potentially the more serious of the two shortcomings for two reasons. First, it occurs in all experiments. Second, according to the model, the contribution of recollection to performance, q, is limited by how well items are encoded: $\hat{q} = ac\,(1 - (1 - u^*)^{rt_j})$, where a is the effectiveness of the sampling and recovery processes and u^* and c determine how many features are encoded and how accurately they are encoded given that a pair was studied r times and each time t attempts at storage was made. The assumption is that one cannot recall what has not been encoded. If, however, encoding (i.e., u^*) occurs at too rapid of a rate with respect to repetitions, then the contribution of recollection to performance (i.e., q) is also increasing at too rapid. Perhaps the simplest way to amend the model is to assume that the amount of encoding decreases with each subsequent target presentation. That is, u^* is negatively related to repetitions. The challenge, which we defer, is to incorporate this assumption both during encoding and during retrieval.

General Discussion

We sought to observe the flexibility of associative memory using an associative recognition task. The results of Experiment 1 replicate those of Kelley and Wixted (2001) insofar as the number of target presentations had little or no effect on false-alarm rates using the ratings method. In contrast, the yes-no procedure used in Experiment 2 produced steadily increasing false-alarm rates, suggesting that the evidence used to perform the ratings and the yes-no tasks are not always the same. We assumed that recollective evidence becomes available later during retrieval than familiarity, and subjects performing the yes-no task at least sometimes responded before the contribution of recollective evidence was available. We tested this hypothesis in Experiment 3 by imposing a 2 s delay on the yes-no responses. The finding of a concave down non-linear function relating repetitions to false-alarm rates supported this hypothesis, suggesting that the evidence used to perform a given task can be influenced by situational factors. In this case, the 2 s delay imposed on the subjects allowed them to utilize the slower but more accurate recollective evidence without a time cost.

Given this apparent flexibility in associative memory, we took a page from the verbal learning literature and further speculated that when the familiarity process usually provides accurate information that they would rely less on the slower, more effortful recollective information. Thus, we introduced a significant number of randomly similar *XY* pairs to the test list in Experiment 4 on the assumption that when targets and foils are randomly similar that familiarity is a relatively efficient means for discriminating targets from foils. We observed a substantial increase in false-alarm rates for the rearranged pairs and the function relating repetitions to false-alarms was more nonlinear relative to what was observed in Experiment 1. This provides additional support for the hypothesis that subjects adapt their recognition strategy to the task situation and suggests that familiarity was more likely to be the basis of the recognition task when *XY* pairs were tested than when they were not tested.

On the Strategic Use of Recognition Memory

We hypothesized that subjects attempt to use an efficient recognition strategy, and an interesting question concerns *how* subjects adapt their strategy to the task and situation at hand. One possibility is that they attempt to achieve a specific level of accuracy from situation to situation. If so, we would expect to see similar overall hit rates and false-alarm rates from situation to situation, even though the patterns of false-alarm rates might vary, and our results are consistent with this expectation.

The pattern and magnitudes of the hit rates were virtually indistinguishable in all four experiments. For false-alarm rates, we compared yes-no performance (Exp 2) to ratings performance (Exp 1), and there was no main effect of task, even though the pattern of false-alarm rates varied between the tasks. The same was true when we compared yes-no performance in the delay versus the no-delay conditions.

The comparison between the ratings (Exp 1) and the *XY* experiments is particularly interesting (Xu & Malmberg, submitted). The false-alarm rates for rearranged pairs are substantially higher when *XY* pairs are tested than when they are not. However, the rearranged false-alarms only represent half of the foils tested. The remaining half comes from the *XY* pairs, which have substantially lower false-alarm rates. When a weighted average is obtained the overall false-alarm rate when *XY* pairs are tested is .18 versus .23 when they were not tested (Exp 1). The difference in overall false-alarm rates is reliable [$t(102) = 2.04$, $p = .044$]. However, since this difference is rather small and given the results from the ratings versus yes-no and the yes-no versus delay comparisons, it is perhaps safest to conclude that subjects attempt to achieve similar levels of recognition performance across different tasks or situations.

The question of how subjects adjust performance need not imply that subjects are able to monitor accuracy on a trial-by-trial basis. Presumably, everyone knows that accuracy decreases as the amount of time spent on a task decreases. For example, students allocate a subset of a finite amount of time to each question on an exam. Thus, subjects might estimate based on "metamemorial knowledge" how long it would take to achieve a given level of performance and allocate their time accordingly (Nelson & Narens, 1990).

Conclusions

The present set of experiments demonstrates the flexible nature human recognition memory. Our conclusion is not that the availability of recollective information versus familiarity information varies from situation to situation. Rather, we conclude that the basis for the associative recognition decision varies from situation to situation, and that subjects adopt an associative recognition strategy that seeks to attain a given level of accuracy in the most efficient way possible.

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Appendix: Xu and Malmberg REM Dual-Process Model

In REM, generic knowledge is stored in lexical/semantic memory traces and events are stored in episodic traces. When words are studied, their lexical/semantic traces are retrieved into a short-term memory buffer. New episodic traces are created by copying the values from the lexical/semantic traces residing in the short-term memory buffer to new incomplete and error prone episodic vectors.

Specifically, lexical/semantic traces are assumed to be vectors of w features whose values, V, are geometrically distributed integers. (g is the geometric distribution parameter.) u^* is the probability of storing a feature in an episodic trace, and c is the probability of copying that feature correctly from a lexical/semantic trace. If an error in encoding is made, a feature value is drawn randomly from the geometric distribution. A zero value represents no feature is stored.

The number of features stored increases with study time, but the amount of extra storage diminishes over time: $t_j = t_{j-1}(1 + e^{-b_j})$, where t_j is the number of attempts at storing a feature for an item residing continuously in the short-term buffer for j seconds, and b is a rate parameter (Malmberg & Shiffrin, 2005). When an item is repeated, an additional t_j attempts at storing features occurs. The additional features are usually accumulated in an existing trace rather than creating a new trace (Malmberg & Shiffrin, 2005; Shiffrin & Steyvers, 1997, 1998) in order to account for the effects of a variety of strengthening operations. Here, we simply assume that this probability is 1.0. Thus, the probability of storing a feature, m, given the item it comprises was studied r times and each time t attempts were made to store the feature is:

$$P(m) = 1 - (1 - u^*)^{rt} \tag{1}$$

When a pair of items is studied, a concatenation of two episodic traces is stored.

We assume that the concatenation of the two lexical/semantic or temporary short-term vectors corresponding to stimulus pair serves as a retrieval cue (cf. Gronlund & Ratcliff, 1989). The compound cue is matched to all of the concatenated traces stored during study. For each trace j, a likelihood ratio, λ_j, is calculated as

$$\lambda_j = (1-c)^{n_{jq}} \prod_{i=1}^{\infty} \left[\frac{c + (1-c)g(1-g)^{i-1}}{g(1-g)^{i-1}} \right]^{n_{ijm}}, \tag{2}$$

where n_{jq} is the number of mismatching features in the jth concatenated trace and n_{ijm} is the number of features in the j^{th} concatenated trace that match the features in the compound retrieval cue. λ_j represents the degree of match or "activation" of the concatenated trace j in response to probe with the retrieval cue. The more similar the compound cue is to the concatenated trace j, the greater λ_j will be. The recognition decision is based on $\Phi = \frac{1}{n}\sum_{j=1}^{n}\lambda_j$. If the Φ exceeds a subjective criterion the response is positive.

We assume recall conforms to the standard set of assumptions in SAM (Raaijmakers & Shiffrin, 1980) and REM (Malmberg & Shiffrin, 2005). After the probe of memory, a trace is sampled with replacement. The greater the similarity between trace i and the cue, the more likely trace i will be sampled. The greater the similarity between trace k and the cue, the less likely trace i will be sampled. Once a trace is sampled, an attempt is made to recover its contents. If recovery is successful and the contents match the stimulus the response is "old". If recovery is successful and the contents do not match the stimulus the response is "new". Otherwise the subject guesses yes with probability γ.

The contribution of recollection to recognition performance is partly determined by how well traces are encoded and by control processes that implement different retrieval strategies. We further assume that the recall-to-reject strategy requires a degree of cognitive effort or control beyond that which familiarity-based retrieval imposes. Hence, strategic, situational, and subjective factors can affect the tendency to rely on recollection as a source of evidence on which to make the recognition decision.

The relatively complex control and retrieval assumptions are expressed by a simple function (Malmberg, Holden, & Shiffrin, 2004): The probability that recollection is the basis for the old-new decision is:

$$\hat{q} = ac\,(1 - (1 - u^*)^{rt}\;) \,. \qquad (3)$$

a varies between 0 and 1. It scales the contribution of recollection to performance independently of how well items are encoded.

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Table 1. *The Effects of the Number of Target Presentations on False-Alarm Rates in Experiments 1-4.*

	Number of Target Presentations						
Task	0	1	2	3	6	12	Regression Coefficients
Exp 1:	---	.21	.26	.22	.24	.22	Linear: $R^2 = .01$
Ratings		(.16)	(.18)	(.17)	(.18)	(.20)	Quadratic: $R^2 = .19$
Exp 2:	---	.15	.23	.26	.29	.32	Linear: $R^2 = .75$
Yes-No		(.13)	(.20)	(.20)	(.23)	(.27)	Quadratic: $R^2 = .92$
Exp 3:	---	.24	.27	.30	.30	.27	Linear: $R^2 = .05$
Yes-No		(.16)	(.16)	(.20)	(.20)	(.21)	Quadratic: $R^2 = .82$
Delay							
Exp 4:	.10	.23	.41	.35	.42	.33	Linear: $R^2 = .03$
XY Pairs	(.14)	(.25)	(.21)	(.25)	(.26)	(.26)	Quadratic: $R^2 = .58$

Figure Captions

Figure 1. Flowchart for the REM Dual-Process Model.

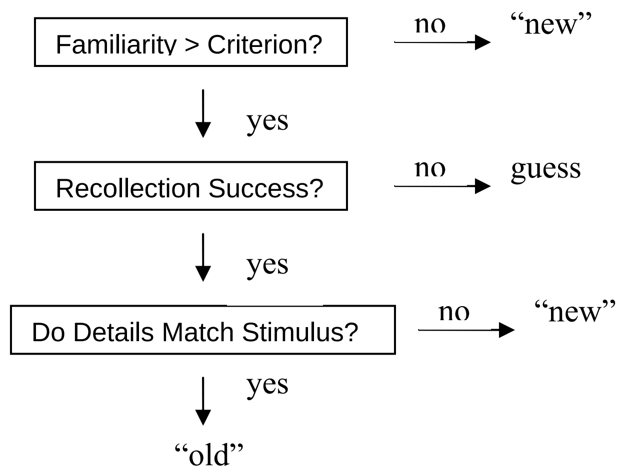
Figure 2. The Effect of Varying the Use of a Recall-to-Reject Strategy (*a*) on Associative Recognition

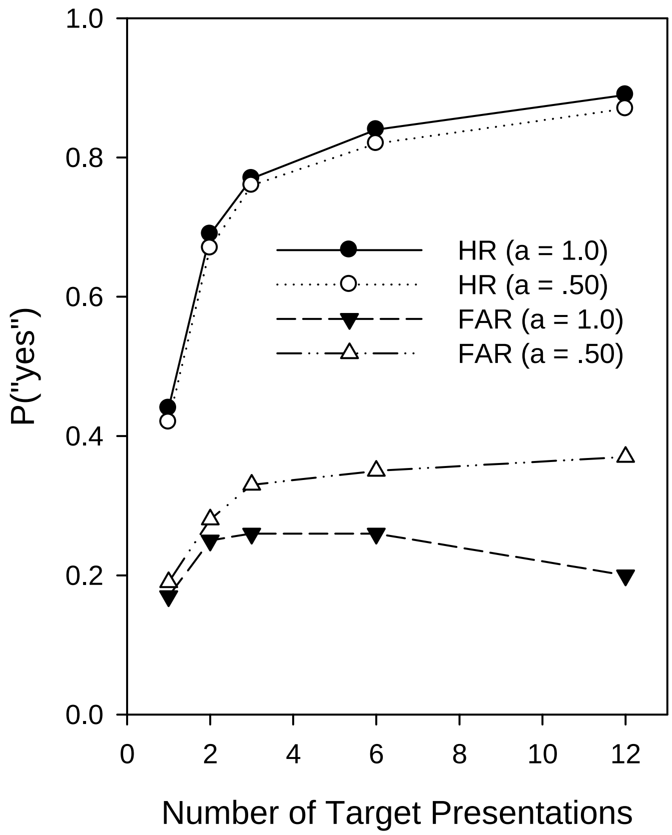
Note. In this simulation, the contribution of recollection (*a*) is varied from .2 to 1.0. The parameters used in these simulations are: $w = 20$, $t_1 = 4$, $c = 0.7$, $g = 0.4$, old-new criterion = 2.2, $\gamma = 0.8$.

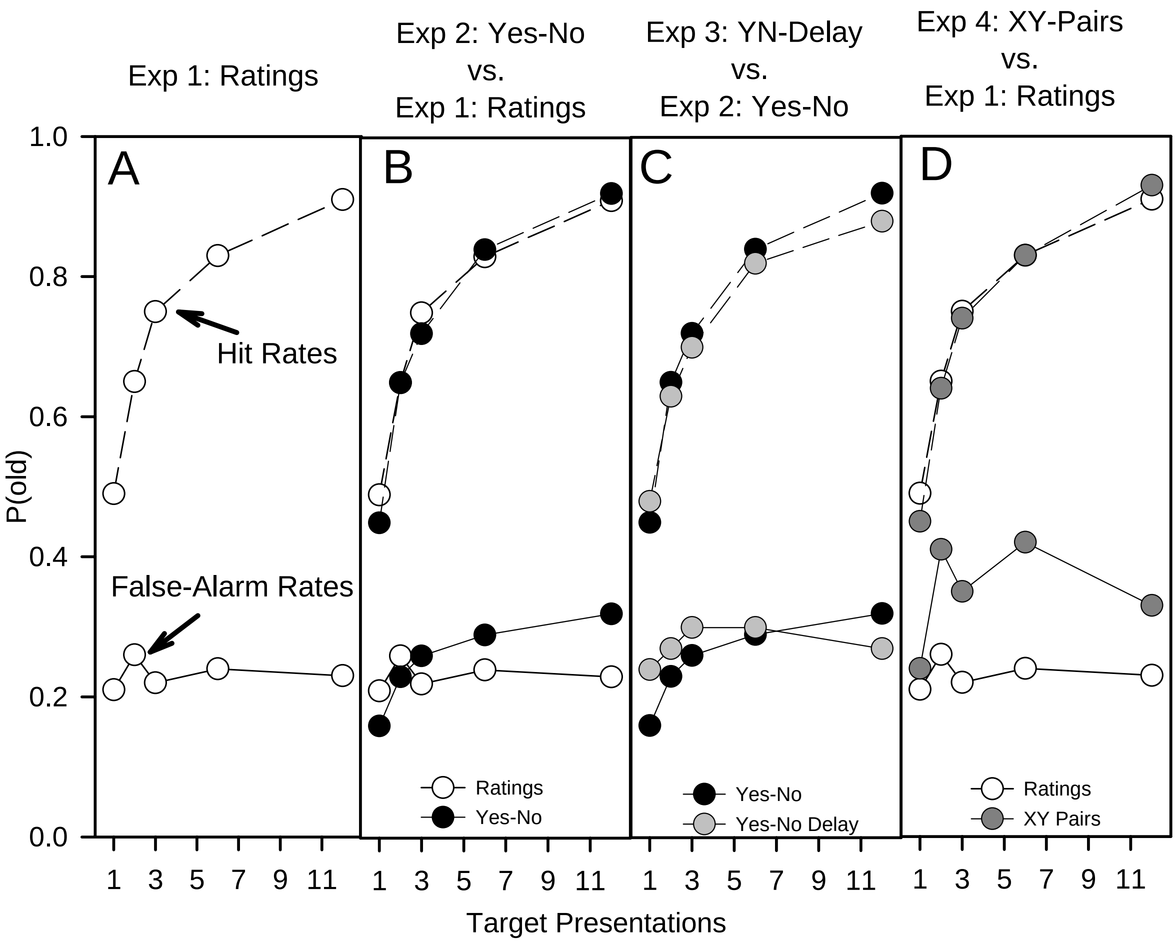
Figure 3. Results of Experiment 1-4.

Figure 4. Dual-Process Model Fit to Experiments 1-4.

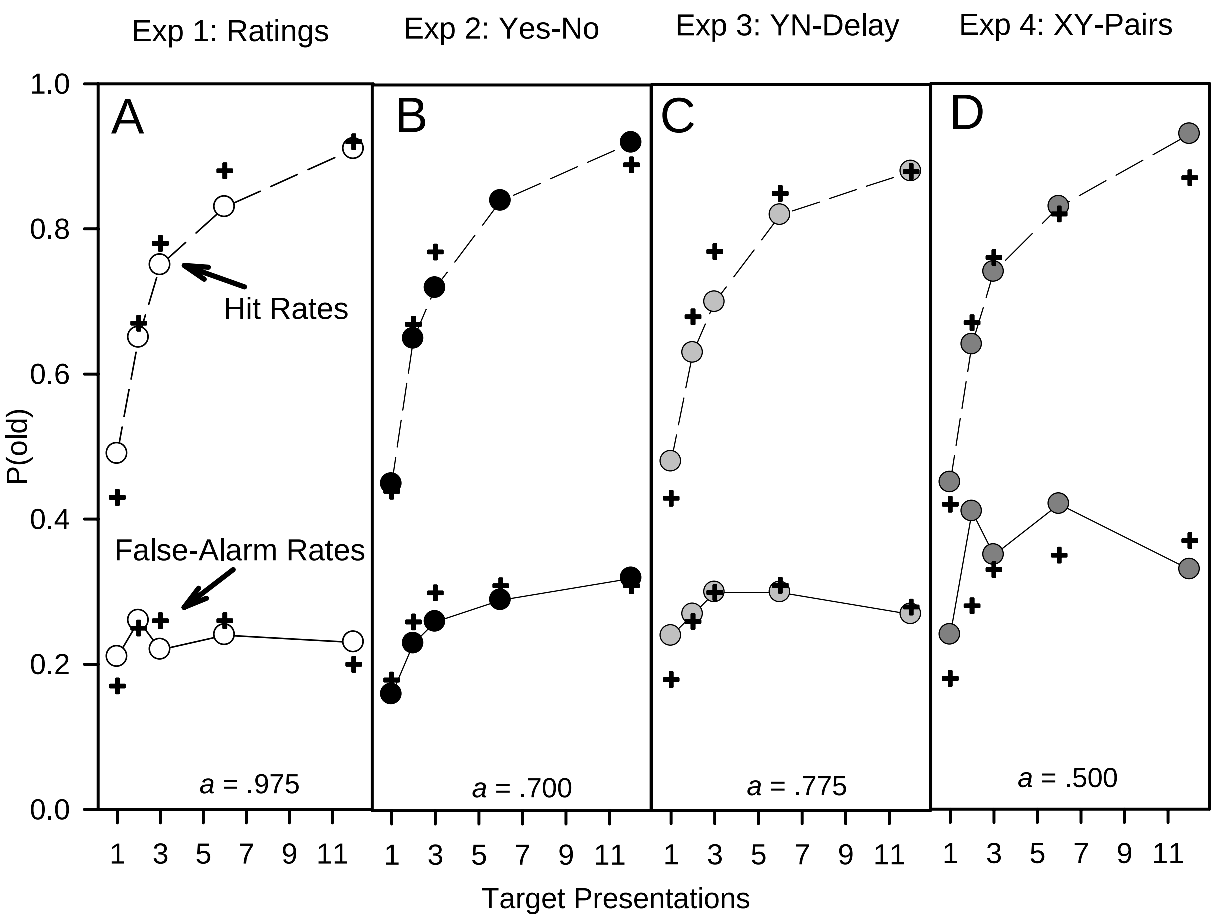
Note. The plus signs represent the best fit of the model to the data when only the degree to which a recall-to-reject strategy is utilized (*a*) varies between fits. The other parameters used in these simulations are: $w = 20$, $t_1 = 4$, $c = 0.7$, $g = 0.4$, old-new criterion = 2.2, $\gamma = 0.8$.


Familiarity > Criterion?
no
“new”
yes
Recollection Success?
no
guess
yes
Do Details Match Stimulus?
no
“new”
yes
“old”


1.0
0.8
0.6
0.4
0.2
0.0
P("yes")
0
2
4
6
8
10
12
Number of Target Presentations
HR (a = 1.0)
HR (a = .50)
FAR (a = 1.0)
FAR (a = .50)



Exp 1: Ratings
Exp 2: Yes-No vs. Exp 1: Ratings
Exp 3: YN-Delay vs. Exp 2: Yes-No
Exp 4: XY-Pairs vs. Exp 1: Ratings
A
B
C
D
Hit Rates
False-Alarm Rates
P(old)
1.0
0.8
0.6
0.4
0.2
0.0
1 3 5 7 9 11
Target Presentations
Ratings
Yes-No
Yes-No
Yes-No Delay
Ratings
XY Pairs



Exp 1: Ratings
Exp 2: Yes-No
Exp 3: YN-Delay
Exp 4: XY-Pairs
A
B
C
D
Hit Rates
False-Alarm Rates
a = .975
a = .700
a = .775
a = .500
P(old)
Target Presentations