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On the Relationship Between Memory and Perception: Sequential Dependencies in Recognition Memory Testing

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Many models of recognition are derived from models originally applied to perception tasks, which assume that decisions from trial to trial are independent. While the independence assumption is violated for many perception tasks, we present the results of several experiments intended to relate memory and perception by exploring sequential dependencies in recognition. The findings from these experiments disconfirm the independence assumption for recognition memory. In addition, the pattern of sequential dependencies observed in recognition differs from that observed for many perception tasks. This suggests that sequential dependencies arise from mnemonic or perceptual processes and not from decision processes that should be common to memory and perception tasks.

Keywords: recognition, assimilation, sequential dependencies, judgments of frequency, absolute identification

Historically, research on perceptual processes preceded research on memory processes. Fechner, Weber, and Helmholtz established sophisticated research programs years before the initial report from Ebbinghaus. Not surprisingly, memory research has been strongly influenced by the methodology and theories developed for perception research (e.g., Donders, 1969; Green & Swets, 1966). The extension of signal detection theory (SDT) from perception tasks, like detection and identification, to memory tasks, like recognition, is common (Banks, 1970; Bernbach, 1967; Egan, 1958; Kintsch, 1967; Lockhart & Murdock, 1970).

In its application to perception, SDT assumes an internal representation of the current environment in the form of a signal embedded in noise (Green & Swets, 1966). The signal, *S*, and the noise, *N*, are continuous random variables, and the representation, *E*, is a positive function of both. When the stimulus is presented, *E* takes a greater value on average than when the stimulus is absent. The decision concerning the presence of the signal is based on a comparison of *E* to a criterion, *C*. If $E \geq C$, then the response affirms the presence of the signal. The tendency to respond positively is related to the value of *C*, which reflects the prior probability of *S* and the costs and rewards associated with different outcomes.

SDT is an elegant model, but this simple presentation of it is nevertheless needlessly complicated. It is essentially a model of binary decisions, where *E* is the evidence on which a decision is based. We need not assume that the source of *S* is a representation of the external environment. When the assumptions about *S* are simplified, SDT becomes potentially applicable to any binary decision (cf. Thurstone, 1927). For instance, recognition is the discrimination of events that occurred from those that did not occur, and an appropriate extension of SDT only requires that a representation of the past rather than the very near present is the origin of *S*. This assumption does not alter the utility or predictions of SDT, and it is a basic assumption of many models of recognition (Malmberg, 2008, for a review).

In this article, we investigate a fundamental assumption of SDT: Individual decisions are based solely on the evidence associated with the current stimulus. Accordingly, the response on test trial $n - j$, where $j > 0$ and *j* is referred to as *lag*, is independent of the response made on trial *n*. This is the *independence assumption*, and a correlation between responses on trial *n* and $n - j$ is a *sequential dependency* (cf. Treisman & Williams, 1984). Sequential dependencies may be positive or negative correlations between prior responses and/or stimuli and subsequent responses, which are referred to as *assimilation* and *contrast*, respectively.

Sequential dependencies in recognition are not typically reported, but this does not necessarily indicate that they are nonexistent. Rather, memory researchers treat sequential dependencies as random noise by almost always reporting the central tendencies of their observations. In contrast, sequential dependencies are often reported in research using perception tasks such as absolute identification (Holland & Lockhead, 1968; Ward & Lockhead, 1971), perceptual categorization (Jones, Love, & Maddox, 2006; Jones & Sieck, 2003; Stewart, Brown, & Chater, 2002), and detection (Howarth & Bulmer, 1956). Our evidence indicates that sequential dependencies do occur in recognition memory. Moreover, many models of perception are not generalizable to recognition. We suggest that fundamental differences in the nature of the systems supporting memory and perception are likely to be the causes of the differences in the patterns of sequential dependencies observed and not differences in the manner in which decisions are made. We therefore begin with a short discussion of what is documented about sequential dependencies in the perception liter-

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ature, followed by a review of several findings from the recognition literature that suggest sequential dependencies occur there too. These discussions are followed by investigations using both standard recognition procedure and one that is more closely aligned with the procedures in the perception literature, namely, a judgment of frequency (JOF) task.

Absolute Identification

Perception is examined with a number of procedures, all of which impart sequential dependencies. *Detection* requires one to ascertain the presence versus the absence of a stimulus on a series of trials. When the intensity of the stimulus produces an intermediate level of accuracy, an error is made on a fair number of trials, and those errors are systematically related to the responses made on prior trials (Collier & Verplanck, 1958; Howarth & Bulmer, 1956). Likewise, *perceptual classification* (a.k.a. identification) is a decision regarding to which one of two learned categories a stimulus belongs. For instance, in an auditory perception experiment, one category might consist of *LOUD* stimuli, and the other might consist of *SOFT* stimuli. Assimilation is observed when *LOUD* responses are more likely following *LOUD* responses than following *SOFT* responses (Tanner, Haller, & Atkinson, 1967).

Although sequential dependencies are observed in several perception procedures, recent research has been particularly active in accounting for those generated by the absolute identification task (Brown, Marley, Donkin, & Heathcote, 2008; Petrov & Anderson, 2005; Stewart, Brown, & Chater, 2005). Absolute identification is the classification of stimuli belonging to n mutually exclusive categories that differ in their magnitude along a continuous dimension such as the length of a line, the brightness of a visual stimulus, or the frequency of an auditory stimulus and so forth. Category membership is usually expressed by an ordered mapping of the stimuli to numerals, with the most extreme categories labeled 1 and n. After training, subjects are quite good at discriminating among the various stimuli when presented in pairs. However, as the number of categories approaches Miller's magical number 7 $\pm$ 2, performance decreases precipitously, especially for those stimuli falling in the middle of the range (Miller, 1956). Prior results indicate that the response on trial $n - 1$ may be positively correlated with the response on trial n, and/or the response on trial $n -$ 2, 3, . . . may be negatively related to the response on trial n. For instance, Holland and Lockhead (1968) varied the intensity of acoustic stimuli at 10 levels and found assimilation among adjacent responses, contrast at greater lags, and performance to be least accurate for mid-range stimuli.

One reason to focus modeling efforts on absolute identification is that the sequential dependencies are robust. Stewart et al. (2005) wrote, "We know of no absolute identification experiment in which strong sequence effects . . . were not found" (p. 883). Another reason to focus on absolute identification is the challenge the findings present for theory. "Unidimensional absolute identification has captured the imagination of various investigators not only because the empirical results are so startling and counterintuitive but because the results provide perplexing problems for classic psychophysical models" (Shiffrin & Nosofsky, 1994, p. 358). Thus, sequential dependencies pose a limit to our understanding of fundamental aspects of the mind and brain, and to the extent that models of recognition have been derived from classical psychophysical models, sequential dependencies may also pose similar problems for them.

Whereas detection and classification are analogous to the tasks commonly used to investigate recognition memory, absolute identification shares little with the typically used binary recognition procedure. We nevertheless find it is useful to consider models of absolute identification for several reasons. First, there is an historical relationship between absolute identification and the understanding of memory going back to Miller's article on information transmission and memory capacity (Miller, 1956). Indeed, memory theory plays a critical role in some models of absolute identification (Brown et al., 2008; Petrov & Anderson, 2005). Second, sequential dependencies do occur for binary-classification perception tasks like those commonly used to investigate recognition memory (Howarth & Bulmer, 1956; Jones et al., 2006; Stewart & Brown, 2004). This is demonstrated in a series of the earliest articles by Collier and Verplanck (Collier, 1954a, 1954b; Collier & Verplanck, 1958; Verplanck, Collier, & Cotton, 1952). Moreover, the JOF recognition memory procedure is closely related to absolute identification, although it is not commonly used. Thus, the procedural disparities between perception and recognition research may be more apparent than they are real. Third, the issues addressed by the models may guide the specific questions asked in the present investigations of recognition. For instance, models of absolute identification suggest that researchers should be concerned with assimilation and contrast, and the role feedback plays (Lockhead, 1984; Mori & Ward, 1995). Last, models of absolute identification may help to explain recognition findings to the extent that they are consistent with those obtained in perception experiments. To the extent that they are not, such models may help to identify where the similarities between memory and perception breakdown.

Bias Versus Interference Models of Sequential Dependencies

Treisman and Williams (1984; Treisman, 1985) made the first attempt at a formal account of sequential dependencies by extending the SDT model of binary decisions to detection and absolute identification. According to SDT, fluctuations in response bias are systematically related to the test context (Green & Swets, 1966). For instance, positive responses are more likely to occur when the prior probability of target trials (i.e., signals) is greater than the prior probability of foil trials (i.e., no signals). The Treisman and Williams model is a straightforward extension of this framework. It assumes that stimuli recently encountered are those likely to be encountered again in the near future, but over the long haul the frequency of a stimulus conforms to the long-term priors. Assimilation is the result of the criterion on trial n tracking the response on trial $n - 1$, and contrast results from the stabilization of the criterion to the preferred location over longer sequences. For present purposes, the key observation is that Treisman and Williams assumed that biased decision making is the source of sequential dependencies.

While Treisman and Williams proposed that sequential dependencies are the result of the manner in which decisions are made, Lockhead (2004) questioned the fundamental assumption that the perceiver's goal is to detect the intensity of a stimulus. He stated that the goal of perception is to detect changes in the environment, and thus psychophysical judgments are made in reference to a relationship between the magnitude of the current stimulus and broader stimulus conditions or context. Indeed, a spate of new models that all assume that assimilation is the result of information used to make a response on one trial carrying over to interfere with the response on subsequent trials currently competes with the Treisman and William's model (Brown et al., 2008; Petrov & Anderson, 2005; Stewart et al., 2005). The details of these models will be discussed in the General Discussion. For now, it is important to note that Treisman's and Lockhead's views illuminate a critical distinction between sequential dependencies arising from systematic fluctuations in response bias and systematic interference from the information used to categorize stimuli.

The source of the sequential dependencies may have important consequences for the generalizability of sequential dependencies from perception to memory tasks. For example, tracking and stabilization in the Triesman and Williams model should generalize to different tasks that share the same decision structures, just as shifts in bias due to changes in prior probabilities and cost–reward structures of the environment are found for many different tasks including recognition (Green & Swets, 1966; Ratcliff, Sheu, & Gronlund, 1992). That is, if the bias to respond affirmatively increases as the result of tracking in a perceptual detection task, then similar sequential dependencies should be observed for recognition memory. Likewise, if one decreases a bias to respond affirmatively as the result of stabilization of the criterion location over a series of perceptual detection trials, then similar patterns of contrast should be observed for recognition. On the other hand, if the information used to make decisions produces sequential dependencies, one may not necessarily expect that the same patterns of effects would be observed across tasks that depend on different sources of information, as memory and perception do.

Sequential Dependencies in Recognition Memory

A broad goal of the present experiments is to empirically relate memory and perception. The logic underlying our approach is a traditional one (Estes, 1992; Green & Swets, 1966; Nosofsky, 1986). Whether the task is perceptual or mnemonic in nature, there are two systems that support it: a cognitive system and a decision system. For memory tasks, the cognitive system supports the acquisition, representation, and retrieval of memories. For perception tasks, the cognitive system represents the environment. In both literatures, there is a debate concerning which system produces sequential dependencies (see previous discussion). Traditionally, tasks that share the same decision structures are assumed to share the same decision processes (e.g., Green & Swets, 1966; Macmillan & Creelman, 1991). This is the basis for the application of SDT to memory and perception tasks, for instance. If two tasks that share the same decision structure produce different patterns of sequential dependencies, then the interactions observed are almost certainly generated by differences between the perceptual and mnemonic systems and not by differences in the decision processes. If one can assign causality to the differences in the cognitive systems, one can then relate them theoretically.

From the analysis of the absolute identification literature, we identified several issues to investigate. How are sequential dependencies related to lag? Are sequential dependencies contingent on prior stimuli or prior responses? What impact does feedback have on sequential dependencies? Before discussing our findings, it is important to place the present research in context. Although memory research has borrowed heavily from perception research, current memory theory is quite different from the models that we have just discussed. This is true even for recognition, where the findings concerning sequential dependencies are sparse. Hence, the manner in which sequential dependencies have been interpreted in the memory literature is very different.

To explain the relation between recognition and perception, one must describe the procedures used to test them. Recognition is often explored using a study–test procedure. A list of to-be-remembered items is studied, and memory is tested after a retention interval with a series of studied and unstudied items. The subject's task is to endorse only the studied items. Therefore, there are two types of sequential dependencies that may affect recognition performance. Whereas in the perception literature, every trial is a test trial and therefore sequential dependencies may only be attributable to them, sequential dependencies in recognition may be due to the order in which items were studied or the order in which they are tested.

Study–order sequential dependencies have been reported; hit rates are increased, response latencies are decreased, and confidence levels are enhanced when there is a complementary mapping of the serial relationships between study and test orders (Ratcliff & McKoon, 1978; Schwartz, Howard, Jing, & Kahana, 2005). For example, when items *A* and *B* are studied in nearby serial positions and *B* and *C* are studied in more distant serial positions, *B* is often better recognized when tested immediately following *A* compared with *C*. This is known as *recognition priming*. Ratcliff and McKoon proposed that when sentences are studied and individual words are tested, for instance, testing an item "primes" a trace consisting of the individual words that comprise a proposition stored during study, and this explains why the response to the second item tested from that proposition is faster than when the prior test item was stored as part of a different proposition. This is one example of a memory model that assumes sequential dependencies are the result of *enhanced memory access*.

Schwartz et al. (2005) had subjects study a long list of landscape photos and tested memory using a confidence rating procedure. They found that the highest confidence "old" rating was about 4% more likely to be used on trial $n + 1$ if it was used on trial n, and this tendency decreased as lag between presentations of *A* and *B* during study decreased. Perhaps because it was not immediately apparent how a long series of landscape photos could be represented by a set of propositions (cf. Ratcliff & McKoon, 1978), Schwartz et al. proposed within a dual-process framework that testing an item brings to mind the items that were studied at nearby serial positions (cf. Atkinson & Juola, 1974; Mandler, 1980). Because the next test item has already been recollected, subjects respond positively and with high confidence to it.

Sequential dependencies have also been observed between test trials. Ratcliff and Starnes (2009) using a confidence ratings procedure observed the slope of the *z*ROC (receiver operating characteristic) was greater when responses followed an "old" response than when responses followed a "new" response. They argued that (a) this finding was difficult to explain on the basis of changes in the state of memory and (b) shifts in decision criteria could explain the changes in slope, although they did not specify how. Düzel and Heinze (2002) also concluded that a shift in the decision criterion produced greater false-alarm rates following old responses than following new responses. However, they did not observe a corresponding change in hit rates, and therefore, the criterion shift explanation is inadequate. Thus, the criterion shift accounts of test–order sequential dependencies in the recognition literature are either incomplete or incoherent explanations of the phenomena that they seek to explain.

Experiment 1: Sequential Dependencies Between Studied and Unstudied Items

The concern over whether a shift in response bias versus a change in the state of memory is the source of sequential dependencies is somewhat reminiscent of the well-established debate in the perception literature. Compared with the perception literature, however, the research on sequential dependencies in recognition memory is very slight and unorganized. When these dependencies are acknowledged, different enhanced memory accounts have been proposed to explain that an “old” response to the second item is faster and more likely when items tested consecutively were also studied in temporally related positions (Ratcliff & McKoon, 1980; Schwartz et al., 2005). However, the correlation between the responses made to consecutively tested targets may not be due solely to enhanced memory access; recognition priming may be part of a greater pattern of assimilation. That is, it is important to distinguish between changes in recognition performance that result from enhanced memory access versus changes in recognition performance that result from an assimilation of the current response and prior responses. For instance, the greater tendency to make a second hit after a hit was made to a prior stimulus may be derived inappropriately from the information used to make the initial judgment and not necessarily an enhanced ability to access the memory trace corresponding to second stimulus. Thus, according to the *assimilation hypothesis*, recognition priming is due in fact to interference arising from prior tests and not due to enhanced memory access.

In this experiment, we investigated the assimilation hypothesis by measuring the effect of the response on trial $n - 1$ on the response made on trial n. Because we were interested in the study-order sequential dependencies, subjects studied pairs of items in order to maximize the manipulation of temporal proximity. In the near-pairs condition, items from the same study pair were occasionally tested consecutively, and in the distant-pairs condition, consecutively tested items were always studied at least eight items apart. According to enhanced memory models, positive sequential dependencies should only be observed in the near-pairs condition. According to the assimilation hypothesis, positive sequential dependencies should be observed even when consecutively tested targets have not been studied in near-temporal proximity, and perhaps even more compelling is the prediction that there are correlations between adjacent responses to unstudied items.

In this experiment, we used a confidence rating procedure. We noted that some models attribute assimilation to the carryover of information from trial $n - 1$ to trial n (e.g., Brown et al., 2008; Petrov & Anderson, 2005; Stewart et al., 2005). According to many models of recognition, confidence reflects the amount of evidence used to make a decision (Green & Swets, 1966). High-confidence old responses require the most amount of evidence that an item was studied, and high-confidence new responses require the least amount of evidence used to make a decision. If information carries over from one trial to the next, then there should be a greater tendency to produce a hit on trial n when a high-confidence hit occurred on trial $n - 1$ than when a low-confidence hit occurred on trial $n - 1$, and there should be a greater tendency to produce a hit on trial n when a low-confidence hit occurred than when a miss occurred on trial $n - 1$. That is, $P(\text{hit}_n|\text{high}_{n-1}) > P(\text{hit}_n|\text{low}_{n-1}) > P(\text{hit}_n|\text{miss}_{n-1})$.

Method

Subjects. Ninety undergraduate psychology students at the University of South Florida took part in exchange for course credit.

Design, materials, and procedure. There were two study–distractor–test cycles. The stimuli were nouns drawn randomly from Kucera and Francis (1983) norms, with normative frequencies between 20 and 50 occurrences per million and assigned randomly to pairs, conditions, and lists anew for each subject. The study lists consisted of 40 pairs of words. The words were presented side by side on a computer monitor, and each pair was displayed for 2 s with a .1-s interstimulus interval (ISI). Subjects were instructed to relate the members of each pair by mentally creating sentences using the words of a pair during study.

After each study list, subjects performed a 30-s math task in which they mentally added single digits and entered the sums into the computer. Following the math task, memory was tested via single-item recognition. Subjects were randomly assigned to the *near-pairs* condition or the *distant-pairs* condition. In the *distant-pairs* condition, 80 targets were tested. Following the test of one member of a studied pair, at least seven items were tested prior to testing the other member of a studied pair. In the near-pairs condition, 40 target trials involved consecutively testing items from the same studied pair. The order in which items from a given pair was tested was determined randomly. The remaining 40 target trials along with 80 foil trials were randomly assigned to the remaining positions on the test list with the constraint that these targets from the same pair were tested with at least seven intervening trials. We tested recognition using a self-paced confidence rating task. The ratings task used a 4-point scale, where pressing *1* on the computer keyboard indicated a high-confidence old response, *2* indicated a low-confidence old response, *3* indicated a low-confidence new response, and *4* indicated a high-confidence new response. Feedback was not provided.

Results and Discussion

Linear contrasts are reported for the analyses of variance (ANOVAs), and *t* tests are two-tailed unless otherwise stated, with a level of significance of .05.

Hit rate contingencies. In these analyses, we asked whether a hit was more or less likely on trial n following a hit versus following a miss on trial $n - 1$? We also investigated the correlations between consecutive responses when two items were studied as part of the same pair (i.e., near pair) versus when consecutively tested items came from different pairs (i.e., distant pairs). A mixed ANOVA with the prior response as a within-subject factor and the pair type as a between-subjects factor revealed a main effect of the prior response on the probability of a hit, $F(1, 88) = 73.00$, mean square error (MSE) = 0.015, $\eta^2 = .43$, $p < .0005$. The main effect of pair type was not reliable. However, the mixed-factor interaction was reliable, $F(1, 88) = 7.24$, $MSE = .108$, $\eta^2 = .04$, $p < .01$. Planned comparisons separately analyzed the contingencies in the near-pairs and the distant-pairs conditions. Figure 1 shows that the probability of a hit was greater following a hit than following a miss in the near-pairs and the distant-pairs conditions, $t(42) = 6.41$, $d = 2.04$, $p < .001$, and $t(46) = 4.28$, $d = 2.12$, $p < .001$, respectively, with a more robust sequential dependency observed in the near-pairs condition.

The same analyses were carried out on the latencies of the targets. The prior response had a significant effect on the latency of a subsequent hit, $F(1, 88) = 6.83$, $MSE = 0.508$, $\eta^2 = .07$, $p = .011$. The main effect of pair type was also reliable, $F(1, 88) = 5.70$, $MSE = 1.44$, $\eta^2 = .06$, $p = .019$. While hits were faster following a hit than following a miss in the near-pairs condition, $t(42) = 2.06$, $d = 3.80$, $p < .05$, the trend in the distant-pair condition did not reach significance, $t(46) = 1.37$, $p = .18$. The mixed factor interaction between pair type and the prior response was not reliable.

Thus, hits were more likely and generally faster following a hit than following a miss. This occurred both when consecutively tested targets were studied as part of the same pair and when consecutively tested targets were members of pairs that were studied in relatively distant temporal proximity. The finding of sequential dependencies among targets tested in the distant-pairs

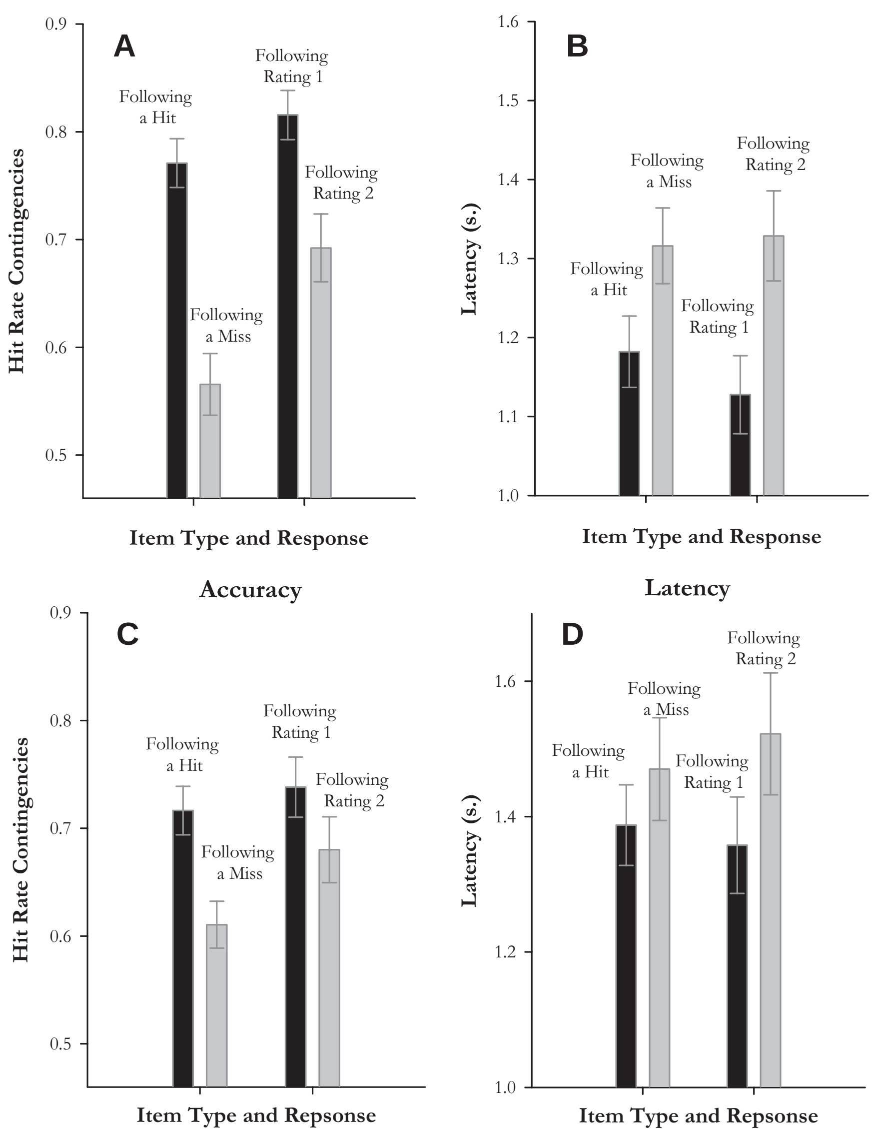

Figure 1. The hit rates and response latencies observed in Experiment 1. Note: The panels A and B show the hit-rate contingency and latency data (in seconds) for the near-pairs condition. The panels C and D show data for the distant-pairs condition in which items tested on trial n and $n + 1$ were always studied at least eight items apart. Error bars are standard errors.

condition is difficult for the enhanced memory hypothesis to explain.

False-alarm rate contingencies. An even stronger test of the enhanced memory hypothesis involves testing for sequential dependencies between trials in which unstudied items are tested. In these analyses, we therefore investigated whether a false alarm to a foil on trial *n* was dependent on the response made on trial $n - 1$. A mixed ANOVA involving the prior response (hit vs. miss) and pair type (near vs. distant) showed a main effect of the prior response, $F(1, 88) = 58.74$, $MSE = 0.092$, $\eta^2 = .34$, $p < .0005$. The main effect of pair type was not reliable, but the mixed interaction was reliable, $F(1, 88) = 4.05$, $MSE = 0.064$, $\eta^2 = .03$, $p = .047$. Figure 2 shows that the probability of a false alarm was greater after a hit than after a miss in both the near-pairs and distant-pairs conditions, $t(42) = 3.61$, $d = 1.11$, $p < .001$, and $t(46) = 4.02$, $d = 1.19$, $p < .001$, respectively. This suggests that the sequential dependency involving foils tested after targets was more pervasive in the distant-pairs condition.

We further tested the enhanced memory hypothesis by investigating whether a false alarm to a foil was dependent on the prior response made to a different foil. A mixed ANOVA involving the prior response (false alarm vs. correction rejection) and pair type (near vs. distant) found a main effect of the prior response on the probability of a false alarm on trial *n*, $F(1, 88) = 14.76$, $MSE = 0.02$, $\eta^2 = .14$, $p < .001$. Neither the main effect of pair type nor the interaction was reliable. A subsequent analysis found the probability of a false alarm was greater following a false alarm than following a correct rejection in both the near-pairs and distant-pairs conditions, $t(42) = 3.03$, $d = 0.94$, $p < .05$, and $t(46) = 2.60$, $d = 0.77$, $p < .05$, respectively.

There was also a main effect of the prior response on the latency of false alarms when the prior test item was hit versus a miss, $F(1, 88) = 4.85$, $MSE = 0.29$, $\eta^2 = .05$, $p < .05$. When the prior item was a foil, the effect was attenuated and unreliable, $F(1, 88) = 3.04$, $MSE = 0.09$, $p = .085$. False alarms were significantly faster following a hit, $t(42) = 2.44$, $d = 0.75$, $p < .05$, and following a false alarm, $t(46) = 2.08$, $d = 0.61$, $p < .05$, than following a miss or a correct rejection, respectively, but only in the near-pairs condition and not in the distant-pairs condition. While the later results indicate that sequential dependencies were less robust in the distant-pairs condition, the accuracy data indicate the opposite. Moreover, the fact that sequential dependencies exist at all for unstudied items is impossible to explain by current enhanced memory accounts of recognition priming.

Ratings contingencies. Figure 1 shows the probabilities of a hit following high- and low-confidence hits and the corresponding latencies. A mixed ANOVA with the prior old rating (high vs. low) as a within-subject factor and the pair type as a between-subjects factor found a main effect of the prior rating, $F(1, 88) = 14.71$, $MSE = .420$, $\eta^2 = .14$, $p < .0005$. Neither the main effect of the pair type nor the interaction was reliable. In the near-pairs condition, the probability of a hit on trial *n* was greater following a high-confidence hit than a low-confidence hit on trial $n - 1$, $t(42) = 3.58$, $d = 1.11$, $p < .001$. In addition, the probabilities of a hit following a high-confidence response and low-confidence response were significantly greater than following a miss, $t(42) = 8.63$, $d = 2.66$, $p < .001$, and $t(42) = 3.46$, $d = 1.07$, $p < .001$, respectively. In the distant-pairs condition, the probability of a hit following a high-confidence response was significantly greater than following a miss, $t(46) = 4.86$, $d = 1.43$, $p < .001$. However,

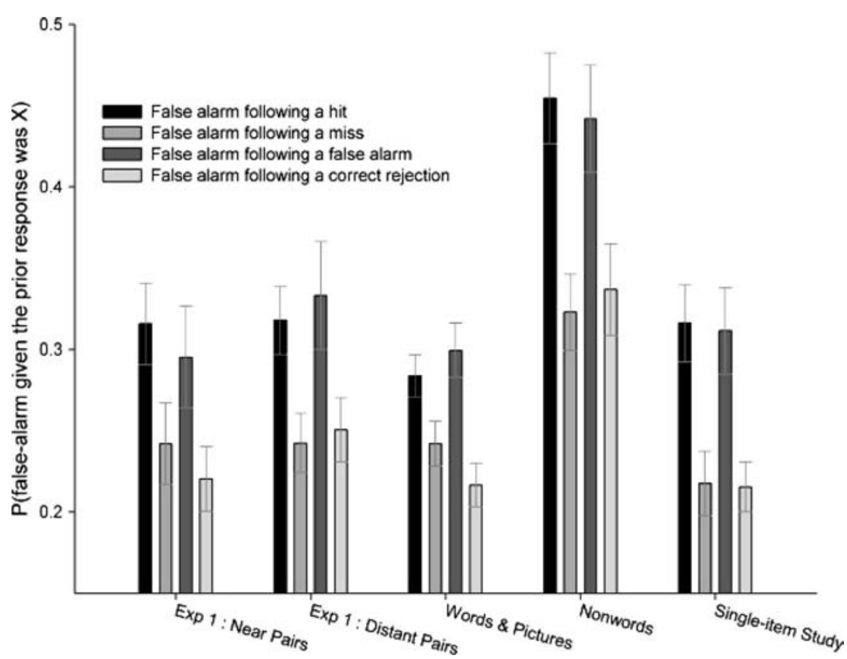

Figure 2. False-alarm contingencies for Experiment 1 (and three others). Note: The data labeled "Exp 1" are from the near-pairs and the distant-pairs conditions of Experiment 1. The data labeled "Words & Pictures" and "Nonwords" are from experiments identical to the near-pairs condition of Experiment 1, other than the nature of the stimuli. The data labeled "Single-Item Study" are from an experiment in which words were studied one at a time, instead of in pairs. Error bars are standard errors.

the probability of a hit was only slightly greater following a low-confidence hit than a miss, $t(46) = 1.91$, $p = .062$, and the probability of hit was only marginally greater following a high-confidence hit than a low-confidence hit, $t(46) = 1.91$, $d = 0.56$, $p < .062$.

Overall, a similar pattern was found in the latency data when computed as a function of the confidence rating. A 2 (pair type: between) $\times$ 2 (prior rating: within) mixed-factorial ANOVA revealed a main effect of pair type on mean reaction times, $F(1, 88) = 7.47$, $MSE = 0.27$, $\eta^2 = .08$, $p < .01$. There was also a main effect of the prior rating on mean reaction times, $F(1, 88) = 8.80$, $MSE = 0.170$, $\eta^2 = .09$, $p < .01$, but there was no pair type by prior rating interaction, $F < 1$. In the near-pairs condition, a hit following a high-confidence response was significantly faster than following a miss, $t(42) = 3.45$, $d = 1.06$, $p < .001$. In addition, hits following a high-confidence hit were faster than those following a low-confidence hit, $t(42) = 3.31$, $d = 1.02$, $p < .05$. The difference in latencies of the hits following low-confidence hits versus misses was not reliable, $t(42) = 0.19$, $p = .85$. In the distant-pairs condition, a similar pattern was observed, but none of the planned comparisons were significant.

Replications and extensions of these results. While the sequential dependencies in the perception literature foreshadowed the present ones, we nevertheless explored their reliability by conducting several other experiments using the exact same design and procedure as we used in the near-pairs condition of this experiment. The only difference between the near-pairs condition of this experiment and several additional experiments that we conducted was the nature of the stimulus materials and a lack of orienting task, as specified in Experiment 1. For instance, in one experiment, instead of only using words we also used landscape photos, like those used by Schwartz et al. (2005). In another experiment, the stimuli were nonwords. These materials were chosen on the speculation that landscape photos and nonwords are less likely than words to be combined and formed into a propositional representation as proposed by Ratcliff and McKoon (1978). Figure 2 shows the false-alarm rate contingencies from these experiments. The false-alarm contingencies are unambiguous: The tendency to respond "old" to a foil on trial n is always greater following an old response than following a new response on trial $n - 1$, and this tendency toward assimilating responses holds for a variety of different stimuli. (The results of the hit-rate and rating contingencies were the same as those observed in Experiment 1.) Again, this pattern of false-alarm contingencies is inconsistent with the enhanced memory hypothesis.

We also noted, however, that the design used in the experiments reported thus far, in which pairs were studied, was different from the standard recognition design in which single items are studied. Moreover, a typical recognition experiment randomly assigns items to study and test positions. We therefore conducted a straightforward single-item study–test experiment in order to establish the generalizability of the results across study procedures. In this sense, the testing conditions of this experiment were very similar to the distant-pairs condition of Experiment 1. The data labeled "Single-Item Study" in Figure 2 show the tendency to respond "old" on trial n is greater following an old response than following a new response on trial $n - 1$. Therefore, with greater confidence that the assimilation that we observed was not a fluke or generated by peculiarities in experimental design, in the remainder of the experiments, a single-item study–test design was used.

In summary, sequential dependencies were observed in both the near-pairs condition and the distant-pairs condition even when one or both of the items in question were not studied. These findings are likely to be impossible to explain with the enhanced memory access model. The results also indicate that hits are more likely and fastest following high-confidence old responses, followed next by hits that follow low-confidence old responses, and last by hits that follow new responses. Thus, the response on trial n is predicted by the confidence associated with the prior response. Both high- and low-confidence old responses on trial $n - 1$ predict an enhanced probability of an old response on trial n compared with a miss. This further challenges enhanced-access models of recognition that assume that high-confidence responses are uniquely associated with recollection and that recollection is the basis for enhanced memory access (e.g., Diana, Reder, Arndt, & Park, 2006; Schwartz et al., 2005). In the following experiments, we attempted to generalize these initial findings and to explore several variables whose effects characterize sequential dependencies in perceptual testing.

Experiment 2: The Time Course of Sequential Dependencies

In the perception literature, assimilation is short lived, and its magnitude depends on the feedback provided. After a lag of 1, a positive sequential dependency often reverses, producing a negative sequential dependency or contrast effect when feedback is provided (Holland & Lockhead, 1968). When feedback is not provided, assimilation is magnified and extends to lags of 2 or 3 (Lockhead, 1984; Mori & Ward, 1995). Since feedback is almost never provided in recognition experiments unless the researcher is interested in manipulating response bias (cf. Maddox & Estes, 1997), we might expect to observe an assimilation pattern that diminishes from a lag of 1 to a lag of 3 in a typical recognition experiment, indicating that recognition under typical testing conditions is susceptible to assimilation of responses but not contrast.

We addressed the time course of assimilation in recognition testing in two ways under conditions in which feedback was not provided. First, we recorded prior responses going back to a lag of three test trials. Second, we varied the ISI between test trials to determine the extent to which assimilation is reduced by the passage of time versus the number of interpolated test trials. These findings are important insofar as some models of perception assume that assimilation decays over time rather than as a function of lag (Brown et al., 2008; e.g., Darwin, Turvey, & Crowder, 1972; Sperling, 1960), and the decay hypothesis is supported by recent results showing a reduction in assimilation and an increase in contrast with increases in ISI (Matthews & Stewart, 2009). In contrast, no models of recognition implicate the passage of time as a source of noise or forgetting. Instead, all models assume that memories of recent or similar events interfere in one way or another with retrieval (Malmberg, 2008, for a review). On this assumption, we hypothesized that lag, as measured by the number of intervening trials or events, would be negatively related to assimilation and not the passage of time per se.

Method

Subjects. Thirty-six undergraduate students at the University of South Florida participated in exchange for course credit.

Design, materials, and procedure. The experiment consisted of two study–distractor–test cycles. The design, materials, and procedure were exactly the same as Experiment 1 with the following exceptions. Each study list consisted of 80 words presented one at a time in the center of a computer monitor for 1.5 s with a .1-s ISI. The subjects were simply instructed that they would be presented a list of words, and their memory for the list would later be tested. At test, 160 self-paced recognition trials were recorded using the 4-point rating procedure. The ISI between test trials was varied within lists such that on half of the test trials, there was a 2-s interval between the response on trial $n - 1$ and the presentation of the stimulus on trial n. For the remaining half of the test trials, a 4-s ISI was used.

Results and Discussion

Figure 3 shows the probabilities of old responses occurring after old and new responses as a function lag and ISI. Two $2 \times 3 \times 2$ linear ANOVAs were conducted with the prior response (yes or no), lag (1, 2, or 3), and ISI (1 or 4 s) as within-subject factors. The first analysis compared the hit rates following hits versus misses. The main effect of the prior response was reliable, $F(1, 34) = 22.28$, $MSE = .009$, $\eta^2 = .23$, $p < .0005$. The next analysis compared the false-alarm rates following false alarms versus correct rejections, where there was also a main effect of the prior response, $F(1, 34) = 27.88$, $MSE = .26$, $\eta^2 = .29$, $p < .0005$. This is a pattern of positive sequential dependencies that is consistent with the assimilation of responses across trials. A reliable interaction between the prior response and lag indicates that the sequential dependency decreased with increases in lag for targets, $F(1, 34) = 8.03$, $MSE = .006$, $\eta^2 = .06$, $p = .008$, and for foils, $F(1, 34) = 7.45$, $MSE = .006$, $\eta^2 = .05$, $p = .01$. However, the left panel of Figure 3 shows that these are not crossover interactions, which indicates a lack of contrast in the sequential dependencies. The right panel of Figure 3 shows that there was no reliable effect of ISI, and ISI did not reliably interact with the prior response for either targets or foils (both $F < 1$).

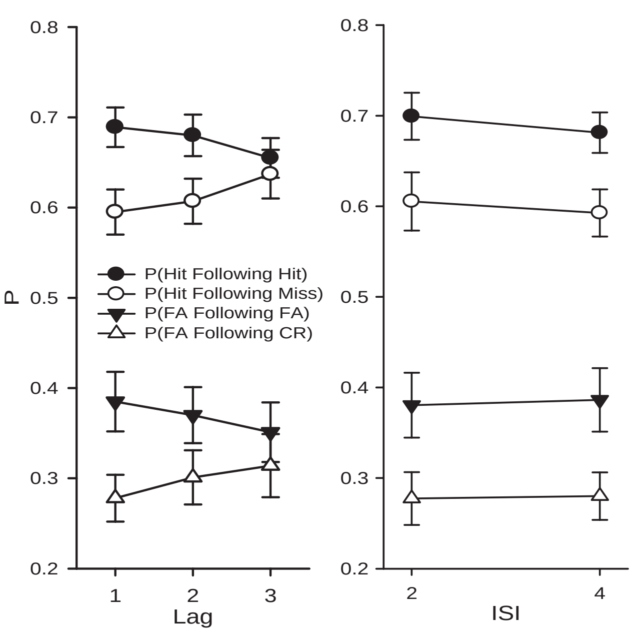

Figure 3. Sequential dependencies from Experiment 2. Sequential dependencies are plotted as a function lag, where X represents the response made on trial $n - 1$. Error bars are standard errors. P = probability; dd = xxxx; FA = false alarms; CR = correct rejections; ISI = interstimulus interval.

In summary, the results of this experiment are similar to those in the perception literature that show assimilation but no contrast in the absence of feedback (Holland & Lockhead, 1968). Moreover, the present experiment is typical of those reported in the recognition literature, and therefore, these results also indicate that assimilation is likely to be a factor in all single-item study/single-item test experiments. On the other hand, assimilation was not attenuated by increases in ISI, as was reported to be the case for absolute identification (Matthews & Stewart, 2009). This constitutes a difference between the sequential dependencies observed in recognition and perception.

Experiment 3: Relating Recognition to Absolute Identification

The differential effect of ISI on the sequential dependencies in recognition memory and perception, where assimilation is first reduced and then reversed by the passage of time (Matthews & Stewart, 2009), suggests that these dependencies may be produced by quite different processes. The reduction in assimilation with increases in lag, but not in time, is for instance inconsistent with some models of sequential dependencies (e.g., Brown et al., 2008). Perhaps it is more provocative to note, however, that models attributing sequential dependencies to decision processes, as in the Treisman and Williams' (1984) model, do not generalize to recognition tasks with similar decision structures as perceptual detection tasks. It is quite possible, therefore, that differences in sequential dependencies may reflect differences in the mnemonic and perception processes.

To develop this reasoning, it is critical to compare the performance of tasks that place similar demands on the subject. Extant models of sequential dependencies in perception have been applied primarily to absolute identification (Brown et al., 2008; Petrov & Anderson, 2005; Stewart et al., 2005), and it has a different decision structure than the recognition tasks used in Experiments 1 and 2. Absolute identification requires the categorization of a set of n stimuli using n mutually exclusive responses. A set size, n, of three or greater is used, and it is not uncommon for the set size to be as large as 10. Assimilation is observed when the response used on trial n is positively correlated with those on prior test trials. For instance, assume that positive sequential dependencies exist and that the stimulus on trial $n - 1$ was judged to belong to category m. If the nominal category of the stimulus on trial n is j, such that $m > j$, then the category assigned to the current stimulus will tend to be overestimated to the extent that the difference $m - j$ is large. If $m < j$, then the current stimulus will tend to be underestimated. These data are visualized by plotting the mean error $(j - m)$ for the stimuli on trial n as a function of the stimulus or response on trial $n - 1$. Assimilation is observed when the error becomes more positive as the magnitude of the prior stimulus or response increases.

In this experiment, we utilize a judgment of frequency procedure to further compare the relationship between memory and perception on tasks involving the classification of stimuli into more than two categories. Like absolute identification, the JOF procedure used to study recognition memory maps *n* stimuli onto *n* mutually exclusive responses (Hintzman, 1988; Hintzman & Curran, 1994, 1995; Hintzman, Curran, & Oppy, 1992; Malmberg, Holden, & Shiffrin, 2004). In a JOF experiment, the number of times that items are studied is varied, and the subjects' task is to judge the frequencies of the prior occurrences of the test items. In principle, the number of different stimulus categories in a JOF experiment is only limited by the vigilance and motivation of the subject. Therefore, we may be able to observe sequential dependencies between adjacent responses and analyze them in a manner analogous to those in perception research. When a category of unstudied items is included at test (i.e., frequency equal to zero), moreover, old–new recognition data are also obtained because the probabilities of JOFs greater than zero to targets and foils correspond to hit rates and false-alarm rates, respectively. Hence, we used an absolute-judgment JOF task in the present experiment in order to better relate the present findings to those from perception research.

Method

Subjects. Forty-one undergraduate students at the University of South Florida participated in exchange for course credit.

Design and materials. The stimuli were nouns drawn randomly from Kucera and Francis' (1983) norms with normative frequencies between 20 and 50 occurrences per million. Four study lists were constructed from these words via random assignment. Each list consisted of 120 stimulus presentations. A 30-word study list consisted of 10 words randomly assigned to be presented two, four, or six times in a pseudorandom order. At least one intervening word was presented between each presentation of a given word. Each stimulus presentation lasted 1 s, with a 100-ms ISI. The self-paced test list consisted of these 30 targets and 30 foils presented in random order that was determined anew for each subject.

Procedure. Subjects were instructed that they would be presented four lists of words presented two, four, or six times and that a math task would be performed after each list. The math task consisted of adding digits mentally for 30 s. Upon completion of the math task, each word from the study list was presented one at a time, and the subjects' task was to indicate how many times the word was studied. The responses were limited to 0, 2, 4, or 6. Responses were made by typing the appropriate number into the computer using the computer keyboard. Subjects were instructed that some of the items were not studied and to respond by typing 0 in order to indicate so.

Results

Accuracy. The left panel of Figure 4 shows and a one-way repeated-measures ANOVA revealed a main effect of repetitions on hit rate, $F(1, 40) = 108.915$, $MSE = 0.01$, $\eta^2 = .73$, $p < .001$. The mean false alarm rate was .22 ($SD = .19$). The right panel of Figure 4 shows that the mean JOF increased as the number of times an item was presented increased. This function is plotted against the calibration line.

Old-new sequential dependencies. Figure 5 shows the sequential dependencies in the old–new recognition judgments. Linear contrasts obtained from 2 (prior response: old or new) × 3 (lag: 1, 2, or 3) ANOVAs indicate that for targets, there was a main effect of the prior response, $F(1, 40) = 7.69$, $MSE = 0.02$, $\eta^2 = .10$, $p = .008$, but there was no main effect of lag ($F < 1$). For foils, neither the main effect of the prior response, $F(1, 38) = 3.96$, $MSE = 0.02$, $\eta^2 = .02$, $p = .054$, nor the main effect of lag was reliable, $F(1, 38) = 3.94$, $MSE = 0.02$, $\eta^2 = .02$, $p = .055$. Old responses on trial *n* were more likely to occur after "old" than "new" responses on trial $n - 1$ and as in Experiment 2, but there is no hint of contrast. The unreliable interactions between the prior response and lag from this experiment indicate that assimilation was more persistent for both targets, $F(1, 40) = 1.89$, $p = .18$, and foils ($F < 1$) than in Experiment 2.

JOF sequential dependencies. In generalizing the findings from the perception literature on absolute identification to recognition memory, the primary questions concern the nature of the sequential dependencies in the JOFs. The left panel of Figure 6 plots the mean error in JOFs as a function of the number of times the item on trial *n* was studied and the response made on trial $n - 1$. For an initial analysis, linear contrasts from a 4 (prior response: 0, 2, 4, or 6) × 4 (current stimulus: 0, 2, 4, or 6) ANOVA revealed a main effect of the current stimulus, $F(1, 34) = 247.62$, $MSE = 2.52$, $\eta^2 = .81$, $p < .0005$. The judgment on trial *n* increased as the magnitude of the stimulus increased, reflecting the deviation from the calibration line shown in right panel of Figure 4. More important, there was a main effect of the prior response on the error in the JOFs, $F(1, 34) = 23.23$, $MSE = 0.86$, $\eta^2 = .03$, $p < .0005$. The interaction of the stimulus and the prior responses was not significant, $F < 1$. Therefore, as the JOF on trial $n - 1$ increased, subjects increasingly overestimated the number of times the item on trial *n* was studied. This positive sequential dependency is consistent with assimilation observed in similar perception tasks, such as absolute identification.

The right panel of Figure 6 plots the mean error in JOF on trial *n* as a function of lag and the JOF made at that lag. Contrast is observed in absolute identification, such that negative sequential dependencies are observed at lags greater than 1. In the present data, the magnitude of the sequential dependencies appears to decrease with lag, but the change in magnitude of the sequential dependencies does not result in a reversal (i.e., contrast). Linear contrasts obtained from a 3 (lag: 1, 2, or 3) × 4 (prior response: 0, 2, 4, or 6) ANOVA found that there was no reliable main effect of the prior response, $F(1, 40) = 3.59$, $MSE = .32$, $\eta^2 = .06$, $p = .065$, there was no significant main effect of lag, $F < 1$, and no reliable interaction between the prior response and lag, $F(1, 40) = 3.91$, $MSE = .10$, $\eta^2 = .02$, $p = .055$. The slightly less than reliable interaction, however, somewhat suggests that the error in current JOF becomes less affected by the JOF with increases in lag, but that the positive relationship between the judgments at Lag 1 did not reverse at greater lags.

A potential problem with these initial analyses is that the previous stimulus is correlated with the previous response. To disentangle the effect of previous stimulus and the previous response, it is desirable to hold one factor constant. Given the design of the experiment, we reduced the variability associated with the prior

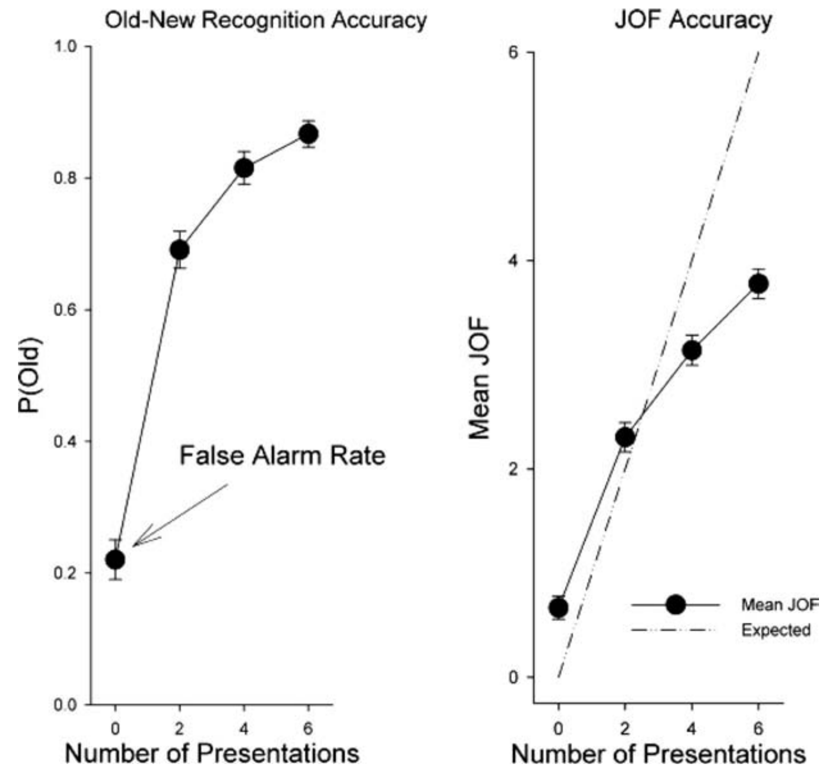

Figure 4. Recognition and judgment of frequency (JOF) accuracy data from Experiment 3. The probability of an old response, p(old), is the false-alarm rate when the number of presentations of the stimulus is 0. Otherwise, it corresponds to the hit rate. Error bars are standard errors.

response by collapsing over two levels of it. At one level, we collapsed over the Responses 0 and 2, and the other level we collapsed over the Responses 4 and 6. In addition, we carried out a similar control for the number of presentations on the trial $n - 1$ (i.e., the prior stimulus) and the current stimulus.

The left panel of Figure 7 plots the error on trial n as a function of the prior response and prior stimulus for each stimulus value. An initial omnibus 2 (prior response: within) × 2 (prior stimulus: within) × 2 (current stimulus: within) ANOVA was conducted. Linear contrasts reveal that there was a main effect of the current stimulus, $F(1, 40) = 221.82$, $MSE = 1.62$, $\eta^2 = .71$, $p < .0005$. This indicates that the manipulation of the number of presentations was effective. There was also a main effect of the prior response, $F(1, 40) = 46.58$, $MSE = 0.36$, $\eta^2 = .03$, $p < .0005$. When the prior response was 0 or 2, the JOF tended to underestimate the current stimulus to a greater degree than when the prior response was 4 or 6. This is a positive sequential dependency characteristic of assimilation of the prior response and the current response. Last, there was a main effect of the prior stimulus, $F(1, 40) = 13.26$, $MSE = 0.18$, $\eta^2 < .005$, $p < .01$. When the prior stimulus was 0 or 2, the JOF overestimated the current stimulus to a greater degree on average than when the prior stimulus was 4 or 6. This is a negative sequential dependency characteristic of contrast between the prior stimulus and the current response. However, there was also a significant prior stimulus by current stimulus interaction, $F(1, 40) = 5.74$, $MSE = 0.17$, $\eta^2 = .03$, $p < .05$. When the current stimulus was 0 or 2, the effect of the previous stimulus was unreliable, $t(40) = 0.98$, $p = .33$. In contrast, the current stimulus was overestimated to a greater degree when the current stimulus was 4 or 6 and the prior stimulus was 0 or 2 than when the prior stimulus was 4 or 6, $t(40) = 4.01$, $d = 0.32$, $p < .0005$. Thus, the negative sequential dependency held for only the current stimuli that were relatively greater in magnitude, and it was in the opposite direction from the sequential dependency associated with the prior response. There were no other significant interactions.

To investigate contrast over longer lags, we conducted similar analyses that included lag as a factor. The right panel of Figure 7 plots the error on trial n as function of the response made at lag k for each collapsed stimulus value. A 2 (prior response) × 2 (prior stimulus) × 3 (lag) ANOVA was computed. Linear contrasts revealed that there was a main effect of the prior response, $F(1, 40) = 5.30$, $MSE = 0.30$, $\eta^2 = .02$, $p < .05$, but no main effect of lag, $F < 1$, or the prior stimulus, $F(1, 40) = 3.86$, $p = .057$. However, both the prior stimulus and the prior response interacted with lag, $F(1, 40) = 5.48$, $MSE = 0.15$, $\eta^2 = .02$, $p < .01$, and $F(1, 40) = 6.69$, $MSE = 0.145$, $\eta^2 = .03$, $p < .01$, respectively. A key question in relating memory and perception is whether these are crossover interactions, such that a positive sequential dependency is observed at Lag 1 and a negative sequential dependency is observed at a later lag.

To investigate these interactions with lag, we conducted simple effects analyses. At a lag of 1, the magnitude of the error in the JOF was greater when the prior response was 0 or 2 than when the prior response was 4 or 6, $t(40) = 4.34$, $d = -0.42$, $p < .0005$.

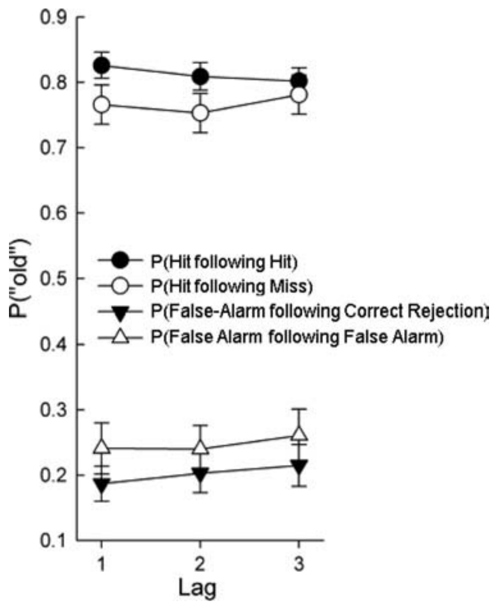

Figure 5. Old–new sequential dependencies from Experiment 3. Hits were more likely following hits than misses, and false alarms were more likely following false alarms than following correct rejections. Error bars are standard errors. p(old) = probability of an old response.

Inspection of Figure 7 indicates that this is a positive sequential dependency. That is, the JOF on trial *n* was biased toward the prior response. At lags of greater than 1, however, there was no simple effect of the prior response, both $t < 1$. Thus, assimilation toward the prior response was observed at Lag 1, but significant levels of contrast were not observed at longer lags. Another set of simple effect analyses on the interaction between the prior stimulus and lag revealed that at a lag of 1, the current stimulus tended be underestimated to a lesser degree when the prior stimulus was 0 or 2 than when the prior stimulus was 4 or 6, $t(40) = 4.02$, $d = 0.36$, $p < .0005$. Again, this suggests that there is a degree of contrast at Lag 1. At lags of greater than 1, however, there was no simple effect of the prior stimulus, both $t < 1$. Thus, there is no hint of contrast at lags greater than 1, and the effect of the prior stimulus at Lag 1 appears to be in the opposite direction of the prior response.

Last, we note that the previous response interacted with previous stimulus, $F(1, 40) = 6.00$, $MSE = 0.19$, $\eta^2 = .02$, $p < .05$. There was no simple effect of the prior stimulus when the prior response was 4 or 6. However, when the prior response was 0 or 2, the current JOF underestimated the stimulus to a greater degree when the prior stimulus was 0 or 2 than when the prior stimulus was 4 or 6, $t(40) = 3.65$, $d = 0.26$, $p < .0005$. This further indicates that the sequential dependencies over Lags 1–3 are dependent on both prior response and the prior stimulus.

In summary, these results extend to the JOF procedure the prior findings that show old–new assimilation in recognition memory testing. In addition, assimilation of the current JOF and the prior JOF responses was observed in the JOFs at Lag 1. There was also contrast between the current response and the prior stimulus, especially at Lag 1. Note the contrast in the JOFs is different from that which has been reported in the perception literature, where contrast between the prior stimulus and the current response is most notable at lags greater than 1. We therefore explored the relation between lag and sequential dependences further in Experiments 4 and 5. There was also a slight asymmetry observed in the calibration curve shown in Figure 4. While the hits rates increase with increases in presentations, the accuracy of the mean JOF decreases. In Experiment 4, we explored the possibility that this high degree of error associated with JOFs made to items with high frequencies is due to the assimilation of the responses to a high proportion of foils.

Experiment 4: The Effect of Feedback

To gain a better understanding of the relation between the sequential dependencies observed in the perception literature and those observed in recognition memory, it would be useful to observe the effects of variables on recognition known to influence sequential dependencies in perception. Typically, feedback enhances assimilation in absolute identification at Lag 1 and reduces contrast at greater lags (Lockhead, 1984). In addition to reducing assimilation in absolute identification, feedback also decreases the effect of the prior response and increases the effect of the prior stimulus (Mori & Ward, 1995). Some have speculated that feedback serves as a proxy for the stimulus, whereas in the absence of feedback, assimilation is thought to be attributable to the response on trial $n - 1$ (Stewart et al., 2005). Thus, we expected to observe

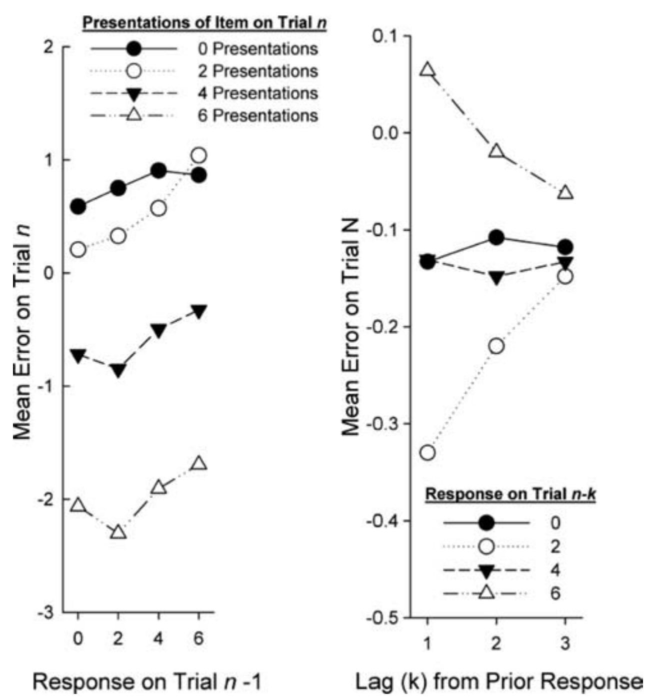

Figure 6. Sequential dependencies in judgments of frequency (JOFs) observed in Experiment 3. The left panel plots the sequential dependencies at Lag 1. Each function corresponds to a different level of the current stimulus. The increase in the error of the JOF on trial *n* with increases in the magnitude of the response on trial $n - 1$ is referred to as *assimilation*. The right panel plots the error in the JOF as a function of lag for each level of the prior response. The assimilation observed at Lag 1 diminishes with respect to increases in lag.

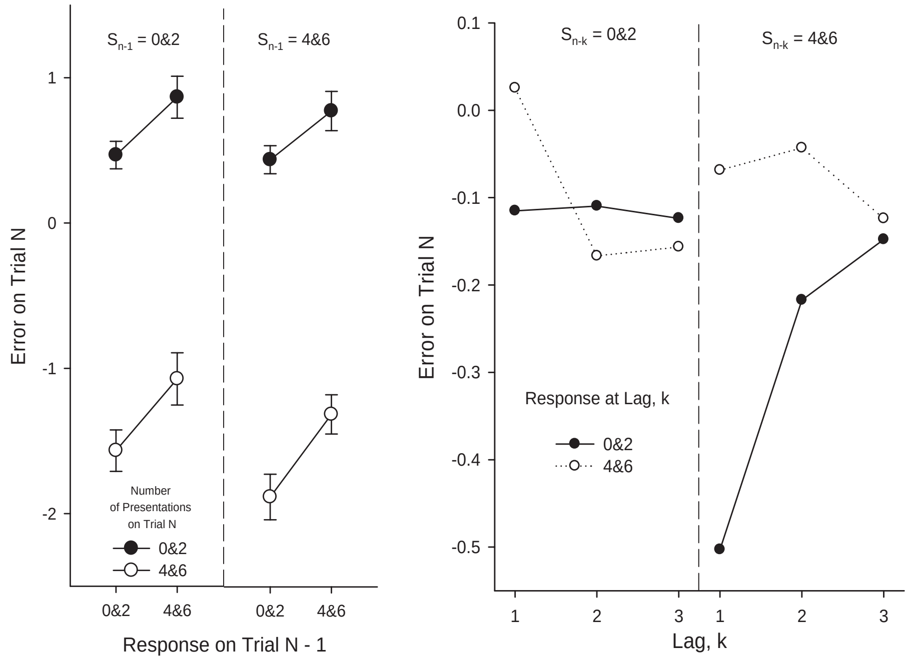

Figure 7. Sequential dependencies for different levels of the prior stimulus and the prior response for Experiment 3. The left panel plots the sequential dependencies at lag 1. Each function corresponds to a different level of the current stimulus. The right panel plots the error in the JOF as a function of lag for each level of the prior response. S_{n-1} = value of the stimulus held constant on trial $n - 1$; variables j & k represent the stimuli presented j or k times or the prior response j or k.

smaller amounts of assimilation and less of an effect of the prior stimulus in the no-feedback condition of this experiment.

Another common finding in perception is that accuracy is least accurate for those stimuli that lie in the middle of the continuum. (Lacouture & Marley, 1995; Murdock, 1960; Siegel, 1972). The *bow effect* is often symmetric with respect to the midpoint of the continuum (Stewart et al., 2005). However, asymmetrical functions have also been reported (Petrov & Anderson, 2005), and the calibration data from Experiment 3 indicate that JOFs are less accurate for the most frequently presented items than for the most infrequently presented items (see Figure 4). We speculated that the asymmetry was due to the relatively large number of foil trials in Experiment 3, and we therefore eliminated the foil trials in this experiment. It is also possible that the shape of the accuracy curve was influenced by the methods used to create it; the accuracy at ends of the range is more restricted than the accuracy in the middle of the range. Therefore, we increased the range of repetitions to obtain more data points and better assess the bow effect utilizing a signal detection analysis described by Luce, Nosofsky, Green, and Smith (1982).

Method

Subjects. Ninety-eight undergraduate students at the University of South Florida participated in exchange for course credit.

Design and materials. With the following exceptions, this experiment is a replication of Experiment 3. Repetitions were manipulated within subject and within lists, and feedback was manipulated between subjects. Four lists of 60 words each were studied. The words were drawn randomly and anew for each subject from the pool described earlier. Within each list, 10 words were randomly assigned to be presented for 1 s, either once, twice, three, four, five, or six times, with at least one intervening word between each repetition. Each test list consisted of the 60 words presented at study. Of the 98 subjects, 57 received feedback indicating the correct response after each JOF test trial, and 41 received no feedback.

Procedure. Subjects studied four lists and performed a math task after each. Upon completion of the math task, each word from the study list was presented one at a time, and the subjects' task was to indicate how many times the word was studied by typing the appropriate number into the computer using the numerical keys 1–6. After each test trial, for the group that received feedback, the word "correct" or the word "wrong" was presented one line above the sentence "That word was studied *x* times," where *x* was the true number of times the word had been studied. The test trials were self-paced; all feedback was veridical and was presented for 3 s prior to the next test trial.

Results

JOF accuracy. The right panel of Figure 8 shows a significant main effect of the number of presentations on mean JOFs, $F(1, 96) = 279.83$, $MSE = 0.43$, $\eta^2 = .74$, $p < .001$. The left panel plots the probability of a correct JOF as a function of the stimulus and the presence of feedback. A mixed ANOVA was conducted with feedback as a between-subjects factor and the stimulus (1, 2, 3, 4, 5, 6 presentations) as a within-subject factor. A linear contrast

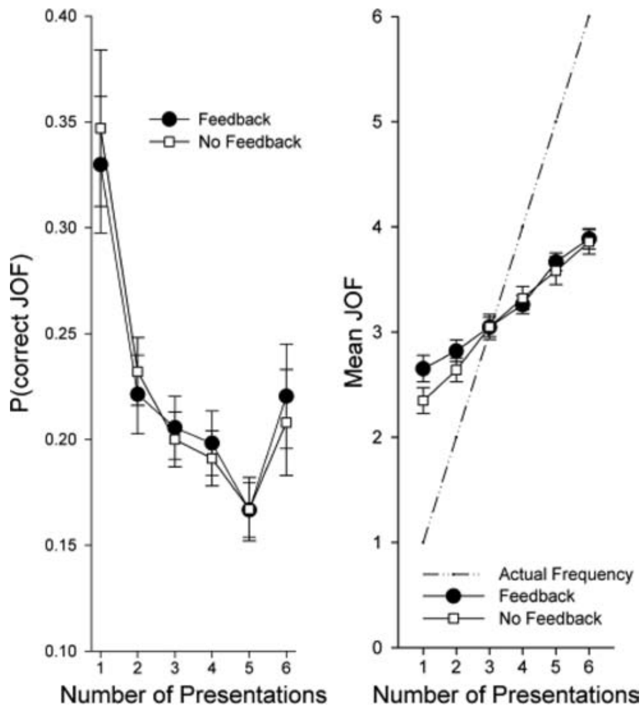

Figure 8. Accuracy of judgments of frequency (JOFs) from Experiment 4. Note: The left panel plots the probability of a correct JOF as a function of the number of times the stimulus was presented. The right panel plots the mean JOF as a function of the number of times the stimulus was presented. Error bars are standard errors.

produced a main effect of the stimulus, $F(1, 96) = 24.35$, $MSE = 0.03$, $\eta^2 = .20$, $p < .001$. There was not a reliable main effect of feedback or a feedback by stimulus interaction, both $F < 1$. Visual inspection indicates that accuracy is greatest for items presented one time and decreases until a lesser upswing in accuracy for the items presented six times.

The elimination of foil trials in the present experiment did not produce a clearly symmetrical accuracy function. However, it is possible that the form of the accuracy function may be influenced by response bias, especially a bias to respond "1." To better assess the shape of the accuracy function, we used the method developed by Luce et al. (1982) to separately measure accuracy and bias in experiments involving tasks in which more than two categories of stimuli must be discriminated. Accordingly, we computed $d'_{\mathrm{i,\ i+1}}$ for each repetition condition, which provides a measure of discriminability that is not subject to range restrictions and controls for response bias. Figure 9 shows that there is little advantage for stimuli presented one time when accuracy is measured in this fashion. A one-way ANOVA indicated that here was not a significant main effect of repetitions i, on $d'_{\mathrm{i,\ i+1}}$, $F(1, 40) = 1.16$, $MSE = 0.12$, $\eta^2 = .03$, $p = .288$. However, the quadratic component of the ANOVA suggests caution is warranted insofar that a nonlinearity may be obscured by noise in the data, $F(1, 40) = 2.17$, $MSE = .28$, $p = .149$.

Feedback and sequential dependencies in JOFs. Figures 10A and 10B plot the error in the current JOF as a function of feedback, the prior response (1, 2, 3, 4, 5, or 6 presentations), and the current stimulus (1, 2, 3, 4, 5, or 6). Linear contrasts were obtained from a mixed 2 × 6 × 6 ANOVA with feedback as a between-subjects factor and the current stimulus and prior response as within-subject factors. There was a main effect of the prior response on the error in the JOF, $F(1, 54) = 108.03$, $MSE = 1.67$, $\eta^2 = .05$, $p < .001$, and a main effect of the current stimulus, $F(1, 53) = 1019.05$, $MSE = 2.93$, $\eta^2 = .86$, $p < .001$. There was no main effect of feedback nor did feedback interact with the prior response, Fs < 1. Thus, feedback did not significantly affect the positive sequential dependency between prior response and current response.

In the perception literature, however, feedback given during the absolute identification task has been found to play a more important role in the sequential dependencies between the prior stimulus and the current response (Mori & Ward, 1995). To investigate whether a similar pattern is observed in JOFs, we replaced the prior response factor with the prior stimulus factor in an ANOVA similar to the one described previously (Figures 10C and 10D). There was a main effect of the current stimulus, $F(1, 79) = 1596.07$, $MSE = 2.87$, $\eta^2 = .90$, $p < .001$, and a main effect of the prior stimulus, $F(1, 79) = 94.05$, $MSE = 1.15$, $\eta^2 = .02$, $p < .001$. While there was no main effect of feedback, $F < 1$, feedback did interact with the prior stimulus, $F(1, 79) = 35.22$, $MSE = .43$, $\eta^2 = .01$, $p < .0005$. In contrast to analysis of the effect of the prior response, feedback did affect the positive sequential dependency between prior stimulus and current response.

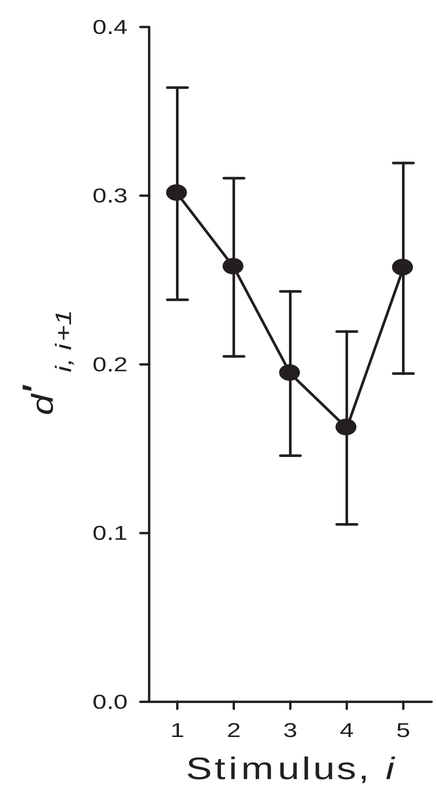

Figure 9. Sensitivity as a function of the number of times an item was presented for Experiment 4. Note: $d'_{i,\ i+1}$ measures the ability to discriminate a stimulus of magnitude i from a stimulus of magnitude $i + 1$. Error bars are standard errors.

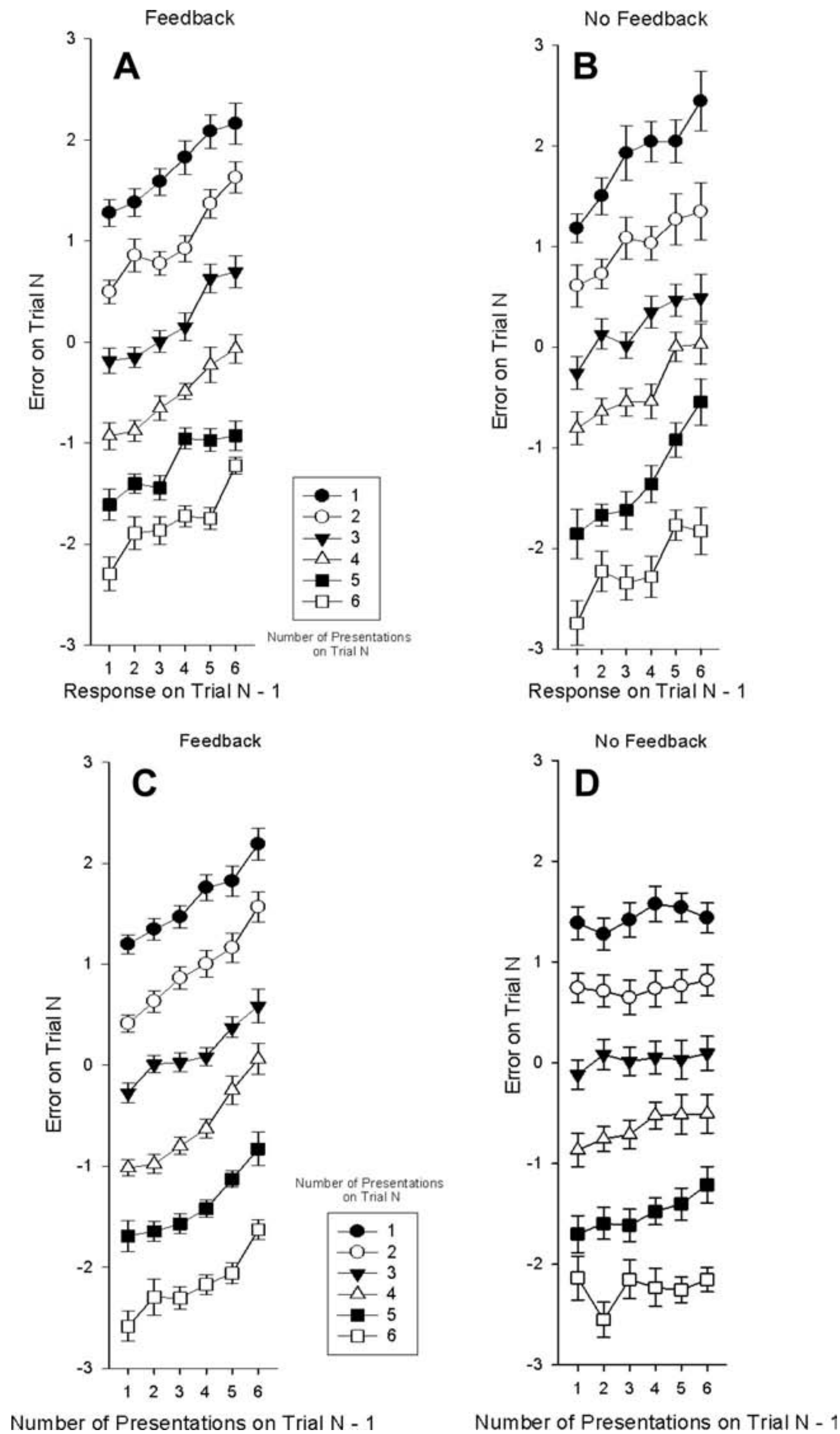

Figure 10. Sequential dependencies at Lag 1 for Experiment 4. Panels A and B plot the error in the judgments of frequency (JOFs) as a function of the prior response, and Panels C and D plot the error in JOFs as a function of the prior stimulus. The feedback and no-feedback conditions are presented in the left and right panels, respectively. Assimilation to the prior response is observed in both feedback conditions, whereas assimilation to the prior stimulus is attenuated in the absence of feedback. Error bars are standard errors.

Figures 10C and 10D clearly show that the correlation between the prior stimulus and current response is much greater when feedback was provided. Thus, the present results are consistent with the findings of Mori and Ward (1995); under no-feedback conditions, the prior stimulus has little relation with the response made on trial *n*, whereas the prior response does. In contrast, when feedback is provided, the prior stimulus is related to the JOF given on the next trial. Researchers in the perception literature have speculated that under these conditions, feedback serves as a proxy for the prior stimulus, and this is the source of the assimilation between responses given on adjacent test trials that is typically observed (e.g., Stewart et al., 2005).

Lag, feedback, and sequential dependencies in JOFs. Contrast is a negative sequential dependency between responses that is typically observed at lags greater than 1 when feedback is provided in perception testing (Stewart et al., 2005; Treisman & Williams, 1984). To assess the interaction of lag, feedback, and the prior response on the error in the current JOF, we obtained a set of linear contrasts from a 2 (feedback) × 3 (lag) × 6 (prior response) mixed ANOVA. The left and right panels of Figure 11 plot sequential dependencies as a function of lag in the feedback and no-feedback conditions, respectively. There was not a reliable main effect of lag, $F(1, 96) = 1.59$, $MSE = 0.042$, $\eta^2 < .01$, $p = .22$, or feedback, $F < 1$. There was a main effect of the prior response, $F(1, 96) = 52.16$, $MSE = 0.605$, $\eta^2 = .26$, $p < .0005$, and there was an interaction between lag and the prior response, $F(1, 95) = 59.97$, $MSE = 0.18$, $\eta^2 < .09$, $p < .001$. The interactions between lag and feedback and the prior response and feedback were not reliable, both Fs < 1. Thus, the pattern of sequential dependencies in the feedback and no-feedback conditions were similar. Visual inspection supports the conclusion that the lag by prior response interaction is not a crossover interaction; the error in JOFs is simply attenuated with increases in lag. Prior analyses of the Lag 1 sequential dependencies (see previous) indicated a positive correlation exists between the prior response and error immediately following the trial. Note in Figure 11 that the ordinal relationship is almost uniformly maintained from Lag 1 to Lag 3 between mean error in JOFs and the prior responses.

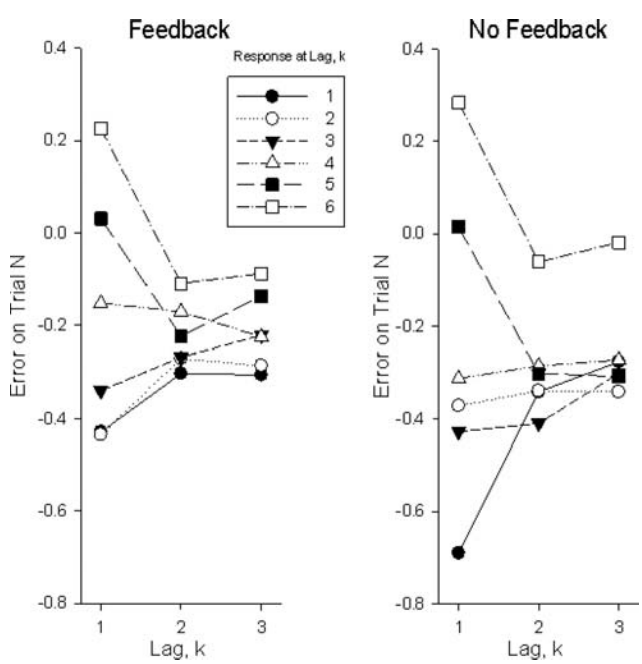

Figure 11. Sequential dependencies as a function of lag for Experiment 4. The left and right panels plot the error in the judgments of frequency (JOFs) as a function of lag and the prior response in the feedback and no-feedback conditions, respectively. Assimilation at Lag 1 diminishes with increases in lag.

Assessing the relationship between the effects of the prior response and the prior stimulus. We conducted several additional analyses under conditions meant to better control for the correlation between the prior response and the prior stimulus. Figure 12 plots the effect of the prior response on the error of the JOF on trial *n*, while the prior stimulus and the current stimulus are held constant. In both feedback and no-feedback conditions, each factor varies at three levels, corresponding to one and two presentations, three and four presentations, and five and six presentations. An initial omnibus 3 (prior stimulus: within) × 3 (prior responses: within) × 3 (current stimulus: within) × 2 (feedback: between) mixed ANOVA was conducted. There were significant main effects of the current stimulus, $F(2, 122) = 1022.30$, $MSE = 1.15$, $\eta^2 = .68$, $p < .0005$; the prior response, $F(2, 122) = 48.55$, $MSE = 0.785$, $\eta^2 = .03$, $p < .0005$; and the prior stimulus, $F(2, 122) = 13.50$, $MSE = 0.870$, $\eta^2 = .007$, $p < .0005$. The main effect of feedback was not reliable, $F < 2.14$. However, feedback interacted with both the prior stimulus, $F(4, 244) = 19.37$, $\eta^2 = .003$, $p < .0005$, and the current stimulus, $F(4, 244) = 4.33$, $\eta^2 = .003$, $p = .015$. Feedback did not interact with the prior response, $F(4, 244) = 1.92$, $p = .15$. These analyses are consistent with the analyses reported previously. The effect of the prior response was observed in both feedback conditions, but the effect of the prior stimulus was dependent on the feedback condition.

To explore the interactions involving feedback, we next separately analyzed the feedback and no-feedback conditions. For the feedback condition, we conducted a 3 (prior stimulus: within) × 3 (prior responses: within) × 3 (current stimulus: within) ANOVA. There was a main effect of the current stimulus, $F(2, 86) = 1030.45$, $MSE = 1.06$, $\eta^2 = .74$, $p < .0005$. Relatively large stimuli tended to be underestimated, whereas the opposite was true for relatively small stimuli. More important, the error was affected by the prior response, $F(2, 86) = 38.50$, $MSE = 0.74$, $\eta^2 = .02$, $p < .0005$, and the prior stimulus, $F(2, 86) = 45.44$, $MSE = 1.03$, $\eta^2 = .03$, $p < .0005$. Inspection of Figure 12 indicates that there were significant positive sequential dependencies in the no-feedback condition between current response and both the prior response and the prior stimulus. These interpretations are consistent with the analyses reported earlier. There were also reliable interactions between prior stimulus and the current stimulus, $F(4, 172) = 8.10$, $MSE = 0.36$, $\eta^2 = .004$, $p < .0005$, and the prior response and current stimulus, $F(4, 172) = 3.46$, $MSE = 0.42$, $\eta^2 = .002$, $p = .01$. These interactions indicate that the error in JOF increased as the current stimulus increased to a greater degree when the prior stimulus magnitude and the prior response were relatively large.

We conducted the same set of analyses on the data from the no-feedback condition, where the prior analyses failed to reveal a main effect of the prior stimulus on the error in the current response. There were main effects prior response, $F(2, 36) = 26.17$, $MSE = 0.90$, $\eta^2 = .04$, $p < .0005$, and the current stimulus,

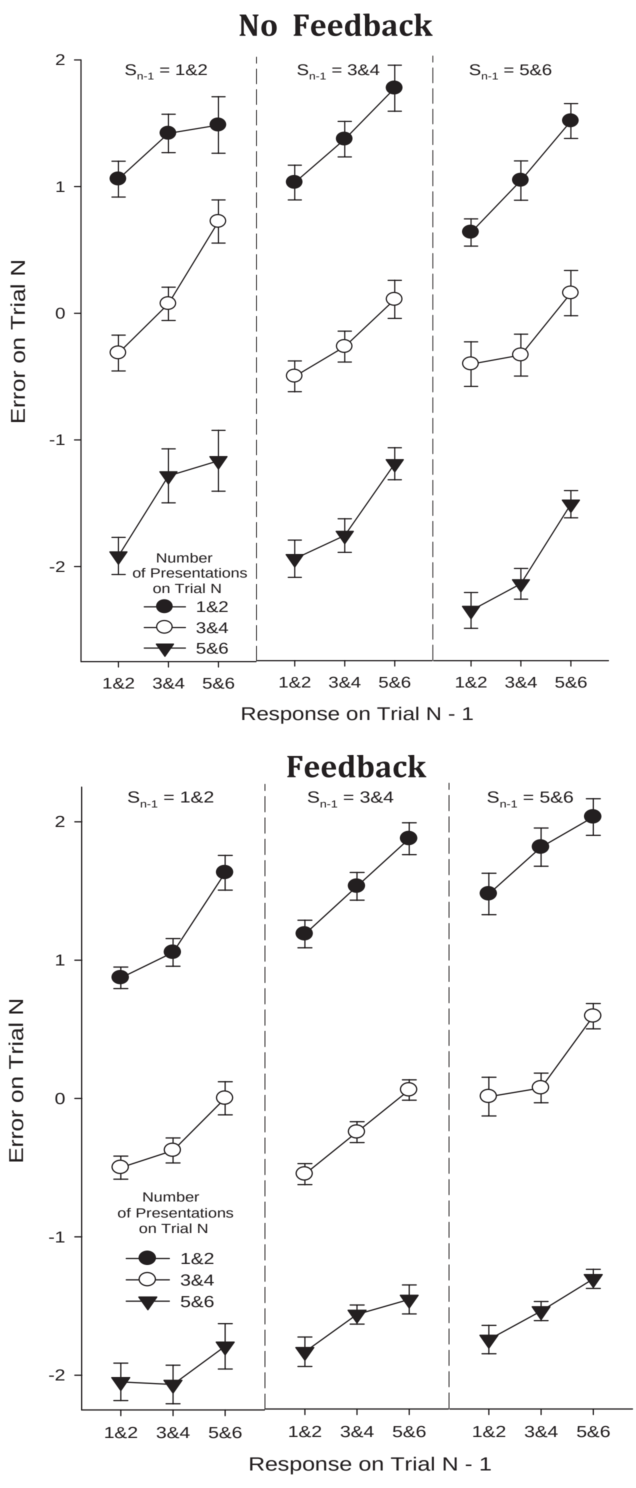

Figure 12. Sequential dependencies as a function of the prior stimulus at Lag 1 for Experiment 4. S_{n-1} is the value of the stimulus held constant on trial $n - 1$.

$F(2, 36) = 273.78$ $MSE = 1.37$, $\eta^2 = .68$, $p < .0005$. In contrast to when feedback was provided, there was no main effect of the prior stimulus, $F < 1$. There was, however, a reliable interaction between prior stimulus and the current stimulus, $F(4, 72) = 2.14$, $MSE = 0.55$, $\eta^2 = .008$, $p = .006$. Inspection of Figure 12 indicates a negative sequential dependency between the prior stimulus and the current response that is mostly evident when the prior stimulus was relatively large and the current stimulus was relatively small. The error in JOF became more negative as the current stimulus increased to a greater degree when the prior stimulus magnitude was relatively large. The interaction between the prior response and current stimulus was not reliable, $F < 1$.[1]

Again these analyses support the prior analyses insofar as positive sequential dependencies were observed between the prior response and the current response when feedback was provided. When feedback was not provided, there was also a positive sequential dependency between the prior response and the current response. However, there was also a negative sequential dependency between both the prior stimulus and the current response in the absence of feedback. These results from the no-feedback condition replicate the key results from Experiment 3.

We performed a similar set of analyses to address the key question of how sequential dependencies are affected by lag. An initial 3 (lag: within) $\times$ 3 (prior stimulus: within) $\times$ 3 (prior responses: within) $\times$ 2 (feedback: between) mixed ANOVA was conducted. Figure 13 shows the effect of the response and the effect of the prior stimulus on the error at lag *k*. There were main effects of the prior stimulus, $F(2, 206) = 24.63$, $MSE = 0.40$, $\eta^2 = .03$, $p < .0005$; the prior response, $F(2, 206) = 39.05$, $MSE = 0.63$, $\eta^2 = 0.06$, $p < .0005$; and lag, $F(2, 206) = 4.13$, $MSE = 0.08$, $\eta^2 < .01$, $p = .001$. There was no main effect of feedback, $F < 1$. However, there was significant three-way interaction among the feedback, lag, and the prior stimulus, $F(4, 412) = 7.44$, $\eta^2 < .01$, $p = .008$. Feedback interacted with the prior stimulus, $F(2, 206) = 14.73$, $\eta^2 = .02$, $p < .0005$; and the prior response interacted with lag, $F(2, 206) = 5.10$, $MSE = 0.20$, $\eta^2 = .03$, $p = .026$. No other interactions were reliable.

To explore the interaction with lag, we conducted different analyses separately on the feedback and no-feedback conditions using a 3 (lag: within) $\times$ 3 (prior stimulus: within) $\times$ 3 (prior responses: within)

[1] We also conducted a series of linear contrasts. The top right panel of Figure 12 shows there was a main effect of the previous response when the previous number of presentations was 1 and 2, $F(1, 23) = 30.34$, $MSE = 0.648$, $\eta^2 = .06$, $p < .001$; 3 and 4, $F(1, 35) = 29.86$, $MSE = 0.88$, $\eta^2 = .04$, $p < .001$; and 5 and 6, $F(1, 32) = 38.68$, $MSE = 0.72$, $\eta^2 = .05$, $p < .001$. The bottom right panel of Figure 12 shows there was no main effect of the previous stimulus when the previous response was 1 and 2, $F(1, 32) = .05$, $MSE = 0.24$, $\eta^2 < .01$, $p = .819$, and when the previous response was 5 and 6, $F(1, 25) = .09$, $MSE = 0.43$, $\eta^2 < .01$, $p = .767$. There was a main effect of the previous stimulus when the previous response was 3 and 4, $F(1, 40) = 4.92$, $MSE = .42$, $\eta^2 < .01$, $p = .032$. When no feedback was given, the interaction between the previous response and the previous stimulus was not reliable, $F(1, 18) = .371$, $MSE = .32$, $\eta^2 < .01$, $p = .550$. The previous response by feedback interaction was not significant, $F(1, 61) = 2.494$, $MSE = 2.21$, $\eta^2 < .01$, $p = .119$. However, feedback did interact with the effect of the previous stimulus, $F(1, 61) = 29.10$, $MSE = 2.32$, $\eta^2 = .01$, $p < .001$. This suggests that only when feedback was given, was there an effect of the prior stimulus.

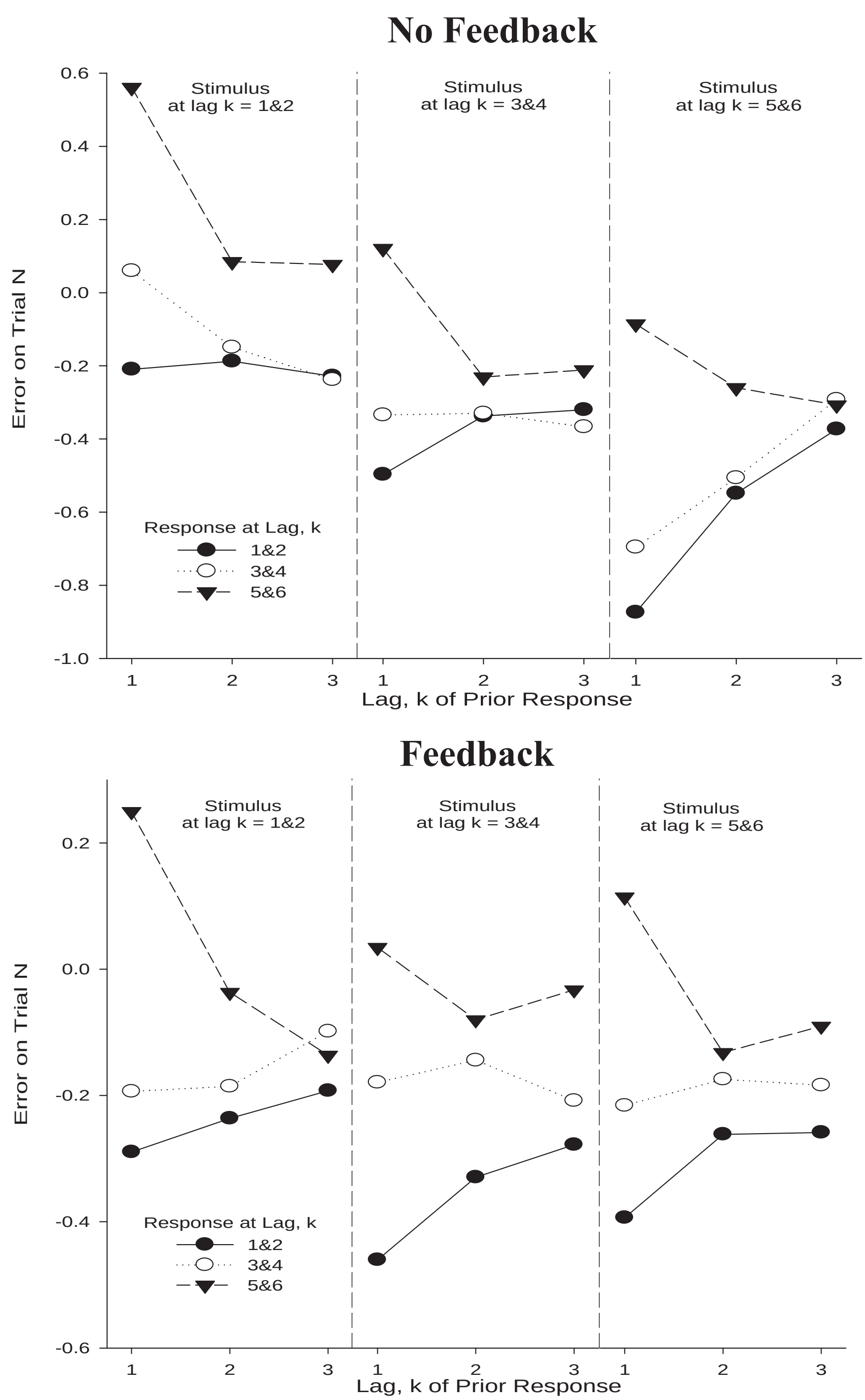

Figure 13. Sequential dependencies as a function of the prior stimulus and lag for Experiment 4. Error in the judgment of frequency is plotted as a function of the prior stimulus, the prior response, and lag = *k*. Assimilation at Lag 1 diminishes with increases in lag.

ANOVA. In the feedback condition, the only significant main effect was for the prior response, $F(2, 130) = 23.84$, $MSE = 0.52$, $\eta^2 = .06$, $p < .0005$. As the magnitude of the prior response increased, the error in the JOF became more positive on average, which is characteristic of assimilation. However, there also was a significant lag by prior response interaction, $F(2, 130) = 9.74$, $MSE = 0.21$, $\eta^2 = .02$, $p = .018$. Visual inspection of the interaction shown in the lower panel of Figure 13 does not reveal a reversal of the positive sequential dependencies. Hence, the positive sequential dependencies observed at Lag 1 diminished with increases in lag.

The same analyses were conducted for the no-feedback condition. There were main effects of both the prior response, $F(2, 76) = 15.79$, $MSE = 0.82$, $\eta^2 = .08$, $p < .0005$, and the prior stimulus, $F(2, 76) = 43.17$, $MSE = 0.28$, $\eta^2 = .07$, $p < .0005$. The key difference between the feedback and the no-feedback conditions is the presence of a main effect of the prior stimulus in the no-feedback condition. Moreover, the direction of the error in the current JOF changed as a function of the prior stimulus. At low levels of the prior stimulus, subjects tended to overestimate the current stimulus, but they tended to underestimate the current stimulus when the prior stimulus was large. This negative sequential dependency between the prior stimulus and the current response is characteristic of contrast.

Another key question involves how the sequential dependencies are affected by lag. While the effect of lag was not reliable, lag did interact with the response, $F(4, 152) = 13.26$, $MSE = 0.24$, $\eta^2 = .04$, $p < .0005$, and the prior stimulus, $F(4, 152) = 8.74$, $MSE = 0.21$, $\eta^2 = .02$, $p < .0005$. To explore these interactions, we obtained a set of linear contrasts from ANOVAS with the prior response (1 and 2, 3 and 4, or 5 and 6) and lag as within-subject variables. These were conducted separately for each of the three levels of the prior stimulus. There was a main effect of the previous response at lag k for stimulus values 1 and 2, $F(1, 38) = 13.80$, $MSE = 0.86$, $\eta^2 = .17$, $p = .001$; 3 and 4, $F(1, 40) = 8.02$, $MSE = 0.59$, $\eta^2 = .10$, $p = .007$; and 5 and 6, $F(1, 40) = 17.81$, $MSE = 0.50$, $\eta^2 = .13$, $p < .001$. There was also a significant lag by response at lag k interaction for stimulus values 1 and 2, $F(1, 38) = 7.32$, $MSE = 0.29$, $\eta^2 = .03$, $p < .001$; 3 and 4, $F(1, 40) = 10.95$, $MSE = 0.24$, $\eta^2 = .06$, $p < .05$; and 5 and 6, $F(1, 40) = 12.94$, $MSE = 0.41$, $\eta^2 = = .08$, $p = .001$. However, visual inspection indicates that there is no sign of contrast; the positive sequential dependencies between the prior response and current response merely diminish with increases in lag.

In summary, the results of Experiment 4 indicate that there is a strong positive sequential dependency among adjacent JOFs made in the presence and in the absence of feedback. This sequential dependency diminishes but does not reverse with increases in the lag between responses. There is also a negative sequential dependency between the prior stimulus and current JOF, and this sequential dependency also diminishes with increases in lag. It occurs in the absence but not in the presence of feedback. As a package, this pattern of sequential dependencies is different from those commonly reported for absolute identification, where performance is often characterized by assimilation at Lag 1 and contrast at longer lags when feedback is provided.

Experiment 5

There are a number of differences between the procedures used to test perception and those used to test recognition memory. To directly compare the sequential effects of absolute identification and JOF tasks, we developed a two-phase experimental design and procedure combining both tasks. During the first phase, the subjects completed an absolute identification task in which the font size of the word stimuli was judged. During this phase, words were presented from one to six times, and feedback was provided after each trial. This absolute identification task is similar to those found in the literature insofar as the dimension on which the decision is made is purely perceptual, and the same stimuli are presented several times during testing. However, the classification does not require pre-experimental training since the category labels (i.e., font sizes) are not arbitrary, as is usually the case in absolute identification task. Since contrast has been observed in previous studies of absolute identification (Lockhead, 1984; Matthews & Stewart, 2009), we therefore expected to observe assimilation and contrast for the absolute identification task. In the second phase of the experiment, the subjects' memory for the word stimuli presented during the absolute identification task was tested using the same JOF task as the feedback condition of Experiment 4. On the basis of the results of that experiment, we expected to observe a pattern of results differing from those observed for absolute identification task: assimilation between responses.

Method

Subjects. One hundred and six undergraduate students at the University of South Florida participated in exchange for course credit.

Design and materials. With the following exceptions, this design is the same as that used in Experiments 3 and 4. Each subject was presented one list of 60 words. The stimuli were words drawn randomly and anew for each subject from the pool described earlier, and they were randomly assigned to conditions. Each word was presented in an Ariel font in one of the following font sizes: 19, 21, 23, 25, 27, and 29. Within each list, 10 words were presented, either one, two, three, four, five, or six times in a pseudorandom order with at least one intervening word between each repetition. The font size on given trial was determined randomly, although each of the six font sizes was presented equally often, and adjacent trials did not share the same font size. The JOF test list consisted of the 60 words presented during study.

Procedure. At the beginning of the experiment, we familiarized the subjects with the stimuli by presenting the phrase "font size *x*" in each of the font sizes, where *x* was the font size of the phrase. Subjects were instructed to study these font sizes before proceeding. Subjects then began the experimental trials. On each trial, a fixation cross was presented for 500 ms at the center of the screen where the word was to appear. Following the fixation, there was a 500-ms blank interval. The stimulus then appeared for 1 s. Subjects subsequently indicated the font size of each word by typing the appropriate number into the computer. The responses were limited to 19, 21, 23, 25, 27, or 29. Feedback indicating the correct font size was then presented for 500 ms.

Directly after the last trial of the font judgment task, subjects performed a math task consisting of adding digits mentally for 30 s. Following the math task, subjects completed a memory task in which each word from the font judgment task was presented one at a time. On each trial, a fixation cross was presented for 500 ms at the center of the screen where the word was to appear. Following the fixation, there was a 500-ms blank interval. The target word then appeared for 1 s in the median font size, 24. Subjects then indicated how many times the word was presented during the font judgment task by typing the appropriate number into the computer. The response choices were limited to 1, 2, 3, 4, 5, or 6. Feedback (as described for Experiment 4) was then presented for 500 ms, indicating the actual number of times the word was presented.

Results

Accuracy. The effects of font size on accuracy and mean judgment of font size are illustrated in the top two panels of Figure 14. The Figure 14A shows accuracy plotted as a function of font size for the absolute identification task. A linear contrast obtained from a one-way ANOVA showed a significant main effect of font size, $F(1, 104) = 97.10$, $MSE = 0.01$, $\eta^2 = .48$, $p < .001$. A similar contrast found the mean judgment of font sizes increased with increases in font size, $F(1, 104) = 4421.97$, $MSE = 1.10$, $\eta^2 = .98$, $p < .001$. The bottom panels of Figure 14 show the effect of the number of presentations on accuracy for the JOF task. Figure 14C shows accuracy plotted as a function of the number of stimulus presentations. A linear contrast from a one-way ANOVA found a significant main effect of the stimulus, $F(1, 104) = 15.4$, $MSE = 0.03$, $\eta^2 = .13$, $p < .001$. Figure 14D shows the mean JOF increased as the number of presentations increased, $F(1, 104) = 229.13$, $MSE = 0.74$, $\eta^2 = .69$, $p < .001$.

To assess the accuracy of these judgments independently of bias and range restrictions, we computed $d'_{i,\ i+1}$ scores for each task. A 2 (task: between) $\times$ 5 (stimulus: within) mixed factorial ANOVA revealed a main effect of task on $d'_{i,\ i+1}$, $F(1, 208) = 617.99$, $MSE = 0.45$, $\eta^2 = .75$, $p < .0005$; a main effect of the stimulus on $d'_{i,\ i+1}$, $F(1, 208) = 15.46$, $MSE = 0.46$, $\eta^2 = .07$, $p < .0005$; and a task by stimulus interaction, $F(1, 208) = 9.13$, $MSE = 0.46$, $\eta^2 = .04$, $p < .0005$. Accuracy was higher for the absolute identification task than for the JOF task, and the magnitude of the stimulus significantly affected performance. To assess the interaction of the task and stimulus, we obtained a series of one-way ANOVAs. The right panel of Figure 15 plots $d'_{i,\ i+1}$ for the absolute identification task as a function of font size. There was a main linear effect of font size on $d'_{i,\ i+1}$, $F(1, 104) = 38.48$, $MSE = 0.21$, $\eta^2 = .27$, $p < .0005$, and the quadratic trend was significant, $F(1, 104) = 122.02$, $MSE = 0.182$, $\eta^2 = .54$, $p < .0005$. The left panel of Figure 15 shows $d'_{i,\ i+1}$ for the JOF task. In contrast to the finding for absolute identification, there was no main linear effect of number of presentations on $d'_{i,\ i+1}$, $F(1, 104) = 1.45$, $MSE = 0.65$, $\eta^2 = .01$, $p = .232$. The quadratic trend was also not significant, $F(1, 104) = 3.54$, $MSE = 0.713$, $\eta^2 = .03$, $p = .063$, although it was very nearly so. It is possible that the flatter accuracy function for the JOF task when compared with that of the absolute identification task is related to the overall lower level accuracy obtained for the JOF task.

To assess the sequential dependencies, we binned the current stimulus at three levels. For the absolute identification task, these three bins corresponded to stimuli with font sizes of 19 and 21, 23 and 25, and 27 and 29. For the JOF task, the three bins corresponded stimuli presented one and two times, three and four times, and five and six times. An initial omnibus 2 (task) $\times$ 3 (current stimulus) $\times$ 6 (prior response) ANOVA was conducted. There were significant main effects of the task, $F(1, 30) = 7.78$, $MSE = 0.81$, $\eta^2 < .005$, $p = .009$; the current stimulus, $F(2, 60) = 258.96$, $MSE = 1.63$, $\eta^2 = .44$, $p < .0005$; and the prior response, $F(5, 150) = 42.11$, $MSE = 0.74$, $\eta^2 = .08$, $p < .0005$. There were also significant interactions between the task and the current stimulus, $F(2, 60) = 14.00$, $MSE = 1.32$, $\eta^2 = .02$, $p < .0005$; the task and prior response, $F(5, 150) = 9.24$, $MSE = 0.69$, $\eta^2 = .02$, $p < .0005$; and current stimulus and the prior response, $F(10, 300) = 3.16$, $MSE = 0.59$, $\eta^2 = .01$, $p = .001$. To explore these interactions, we next analyzed these sequential dependencies separately for each task.[2]

Sequential dependencies for absolute identification at Lag 1. Figure 16A plots the error in the font size judgment as a function of the prior response and three levels of the current stimulus, as described earlier. A 6 (prior response) $\times$ 3 (current stimulus) ANOVA revealed main effects of the prior response, $F(5, 520) = 198.43$, $MSE = 0.49$, $\eta^2 = .19$, $p < .0005$, and the current stimulus, $F(2, 208) = 318.89$, $MSE = 1.58$, $\eta^2 = .40$, $p < .0005$. The error in font size judgment became more positive as the current stimulus increased and the prior response increased. This is a typical pattern of assimilation between the prior response and the current response. The interaction between the prior response and current stimulus was also reliable, $F(10, 1040) = 18.31$, $MSE = 0.36$, $\eta^2 = .03$, $p < .0005$. When taken together with an inspection of Figure 16A, this interaction suggests that the error in the font size judgment grew at a slower rate with respect to the prior response when the current stimulus was relatively large compared with when the current stimulus was relatively small.

We conducted the same analyses by replacing the prior response with the prior stimulus. Figure 16B plots the error in the font size judgment as a function of the prior stimulus and three levels of the current stimulus. There were significant main effects of the prior stimulus, $F(5, 520) = 186.86$, $MSE = 0.47$, $\eta^2 = .17$, $p < .0005$, and the current stimulus, $F(2, 208) = 270.66$, $MSE = 2.01$, $\eta^2 = .42$, $p < .0005$. The error in the font size judgment became more positive as the current stimulus increased and the prior stimulus increased. The interaction between the prior response and current stimulus was also reliable, $F(10, 1040) = 19.38$, $MSE = 0.34$, $\eta^2 = .03$, $p < .0005$. Again, this suggests that the error in the font size judgment was smaller when the prior stimulus was relatively large and the current stimulus was relatively large compared with when the prior stimulus was relatively small.

Sequential dependencies for JOFs at Lag 1. Figure 16C plots the error in the JOF as a function of the prior response and three levels of the current stimulus, as described previously. A 6 (prior response) $\times$ 3 (current stimulus) ANOVA revealed main effects of the prior response, $F(5, 150) = 5.67$, $MSE = 1.08$, $\eta^2 = .3$, $p < .0005$, and the current stimulus, $F(2, 60) = 143.63$, $MSE = 2.01$, $\eta^2 = .49$, $p < .0005$. The error in the JOF became more positive as the current stimulus increased and the prior response increased. The interaction between the prior response and current stimulus was not reliable, $F < 1$. Thus, assimilation was observed between the prior response and the prior stimulus.

We conducted the same analyses by replacing the prior response with the prior stimulus. Figure 16D plots the error in the JOF as a function of the prior stimulus and three levels of the current stimulus. There were significant main effects of the prior stimulus, $F(5, 260) = 22.35$, $MSE = 0.94$, $\eta^2 = .04$, $p < .0005$, and the current stimulus, $F(2, 104) = 496.36$, $MSE = 1.50$, $\eta^2 = .61$, $p < .0005$. The error in JOF became more positive as the current stimulus increased and the prior stimulus increased, indicating assimilation between the prior stimulus and the current response.

[2] Due to insufficient data, we were unable to carry out the analyses controlling for the level of the prior stimulus and the level of the prior response as we reported for Experiments 3 and 4. We note, however, that the conclusions drawn from those analyses were consistent with each other.

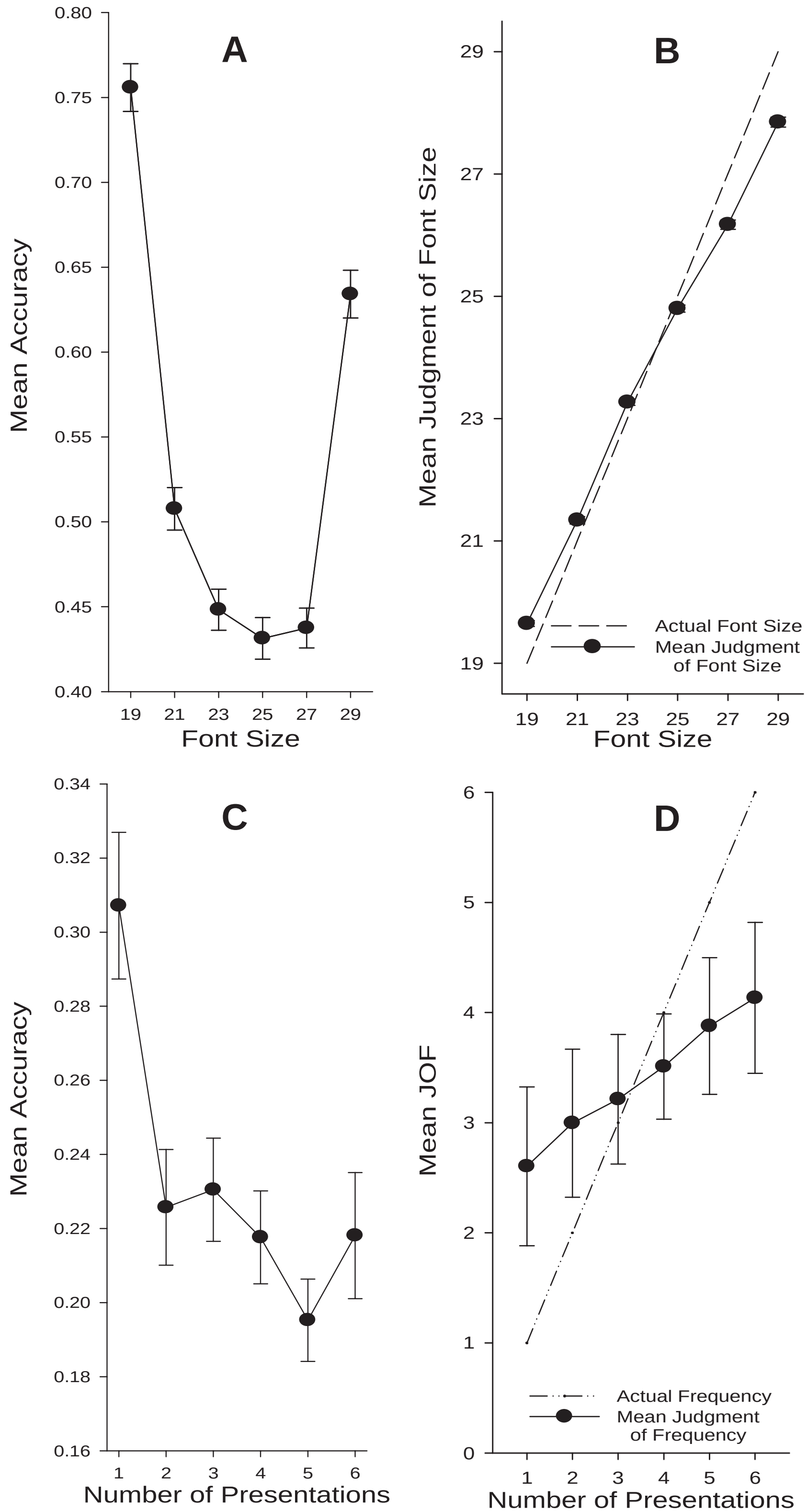

Figure 14. Accuracy as a function of the stimulus for Experiment 5. Panels A and B plot the mean accuracy and mean judgment of font size, respectively, as a function of font size for the absolute identification condition. Panels C and D do the same for judgment of frequency (JOF) task.

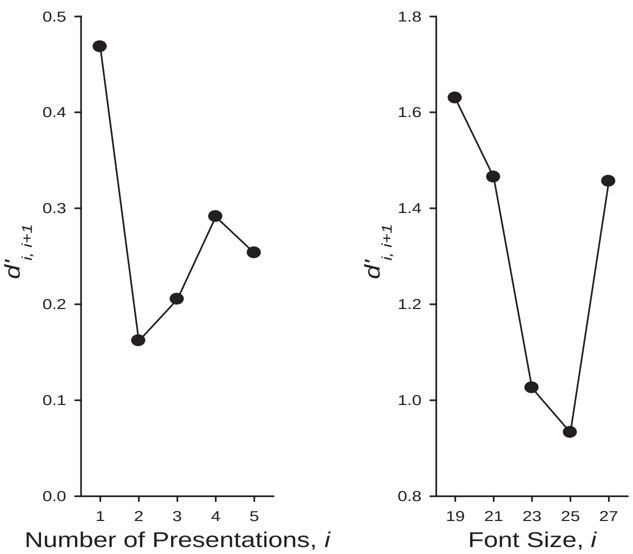

Figure 15. In Experiment 5, $d'_{i,\ i+1}$ was a function of the stimulus. Left panel plots sensitivity of the judgment of frequency (JOF) judgments, $d'_{i,\ i+1}$, as a function of the stimulus. Right panel plots sensitivity of the font-size judgments, $d'_{i,\ i+1}$, as a function of the stimulus.

This is similar to the results of the feedback condition in Experiment 4. The interaction between the prior stimulus and current stimulus was also reliable, $F(10, 520) = 2.96$, $MSE = 0.80$, $\eta^2 = .01$, $p < .0005$. Taken with an inspection of Figure 16D, this interaction suggests that the error in the JOF was greater in magnitude when the prior stimulus was relatively high and the current stimulus was relatively great compared with when the prior stimulus was relatively low.

Sequential dependencies as a function of lag. We initially explored the interaction of lag, with task and the prior response with omnibus ANOVA. There was no main effect of task, $F < 1$. There was a significant main effect of lag, $F(2, 206) = 27.27$, $MSE = 0.31$, $\eta^2 = .05$, $p < .0005$. The main effect of the prior response was not reliable, $F(2, 206) = 2.36$, $p = .10$. However, there was a significant interaction between lag and prior response, $F(4, 412) = 2.96$, $MSE = 4.65$, $\eta^2 = .05$, $p < .0005$, and a significant three-way interaction, $F(4, 412) = 19.74$, $MSE = 0.13$, $\eta^2 = .03$, $p < .0005$. A similar analysis was conducted by replacing the prior response with the prior stimulus. There was no main effect of task or lag, both $F < 1$. The main effect of the prior stimulus was reliable, $F(2, 208) = 4.85$, $MSE = 0.20$, $= .01$, $p = .009$. However, there was significant interaction between lag and task, $F(2, 208) = 23.81$, $MSE = 0.23$, $\eta^2 < .01$, $p < .0005$. There was also a significant interaction between lag and the prior stimulus, $F(2, 208) = 32.43$, $MSE = .11$, $\eta^2 < .04$, $p < .0005$, and significant three-way interaction, $F(4, 416) = 25.74$, $MSE = .09$, $\eta^2 = .03$, $p < .0005$. We explored these interactions with separate analyses of the prior response, prior stimulus, and task.

Contrast in absolute identification and JOFs. In the perception literature, contrast is more robustly observed when the effect of the prior stimulus is considered than when the effect of the prior response is considered. We first assessed how lag interacted with the task and the prior response with a 2 (task) × lag (3) × 3 (prior response) omnibus ANOVA. There was no main effect of task, $F < 1$. There was a main effect of lag, $F(2, 206) = 27.27$, $MSE = 0.31$, $\eta^2 = .05$, $p < .0005$. There was no main effect of prior response, $F(2, 206) = 2.36$, $p = .10$. However, there was a significant interaction between task and lag, $F(2, 206) = 3.30$, $MSE = 0.25$, $\eta^2 < .005$, $p < .001$, and between lag and the response made at lag k, $F(4, 412) = 38.04$, $MSE = 0.12$, $\eta^2 = .05$, $p < .0005$.

We began exploring these interactions with a 3 (lag) × 3 (prior response) two-way ANOVA for the font judgment task (see Figure 17A). There was a main effect of lag, $F(2, 208) = 18.95$, $MSE = 0.25$, $\eta^2 = .08$, $p < .0005$, but no main effect the prior response, $F(2, 208) = 1.64$, $p = .20$. However, the interaction was reliable, $F(4, 416) = 127.78$, $MSE = 0.06$, $\eta^2 = .24$, $p < .0005$. From the prior analyses, the positive sequential dependencies have been established at Lag 1. The question of whether contrast is implicated by the significant Lag × Prior Response interaction hinges on whether negative sequential dependencies exist at Lag 3. At Lag 3, the mean error on the current trial was higher when the prior response was 19 or 21 ($M = -.06$, $SD = .47$) than when the prior response was 27 or 29 ($M = -.24$, $SD = .46$), $t(104) = 5.92$, $d = 0.39$, $p < .0005$. Thus, the interaction between lag and the prior response is a crossover interaction characteristic of assimilation at Lag 1 and contrast at Lag 3. We conducted the same analysis replacing the prior response with the prior stimulus in the ANOVA (see Figure 17B). There was a main effect of lag, $F(2, 208) = 53.25$, $MSE = 0.00$, $\eta^2 < .005$, $p < .0005$, and a main effect of the prior response, $F(2, 208) = 5.79$, $MSE = 0.14$, $\eta^2 = .02$, $p < .02$. In addition, the interaction was reliable, $F(4, 416) = 114.68$, $MSE = 0.05$, $\eta^2 = .31$, $p < .0005$. At lags of 3, the mean error on the current trial was higher when the prior stimulus was 19 or 21 ($M = -.001$, $SD = .38$) than when the prior response was 27 or 29 ($M = -.29$, $SD = .38$), $t(104) = 8.66$, $d = 0.72$, $p < .0005$. Thus, contrast between the both prior response and the prior stimulus and the current response was observed at a lag of 3 for absolute identification.

Contrast has not so far been observed in recognition judgments. We began exploring the present data with a 3 (lag) × 3 (prior response) two-way ANOVA (see Figure 17C). There was a main effect of lag, $F(2, 206) = 15.24$, $MSE = 0.30$, $\eta^2 = .06$, $p < .0005$, but no main effect the prior response, $F(2, 206) = 1.02$, $p = .33$. Although the magnitude of the error of the JOF diminishes with increases in lag, the interaction was not reliable, $F(4, 412) = 127.78$, $MSE = 0.06$, $\eta^2 = .24$, $p < .0005$. At lags of 3, the mean error on the current trial was higher when the prior response was 5 or 6 ($M = -.03$, $SD = .53$) than when the prior response was 1 or 2 ($M = -.19$, $SD = .49$), $t(104) = 2.34$, $d = 0.32$, $p < .05$. The same analysis was conducted replacing the prior response with the prior stimulus in the ANOVA (see Figure 17D), and the results were the same. There was a main effect of lag, $F(2, 208) = 6.98$, $MSE = .00$, $\eta^2 < .005$, $p < .001$. There was no significant main effect of the prior response, $F(2, 208) = 1.36$, $p = .26$, or the interaction, $F < 1$. From the prior analyses, the positive sequential dependencies have been established at Lag 1. At lags of 3, there was no significant difference between the mean error on the current trial when the previous stimulus was 1 or 2 and when the previous stimulus was 5 or 6, $t(104) = 0.456$, $p = .650$. As the prior analyses indicated the positive sequential dependencies at Lag 1, this analysis provides only little support for a reduction in assimilation with in-

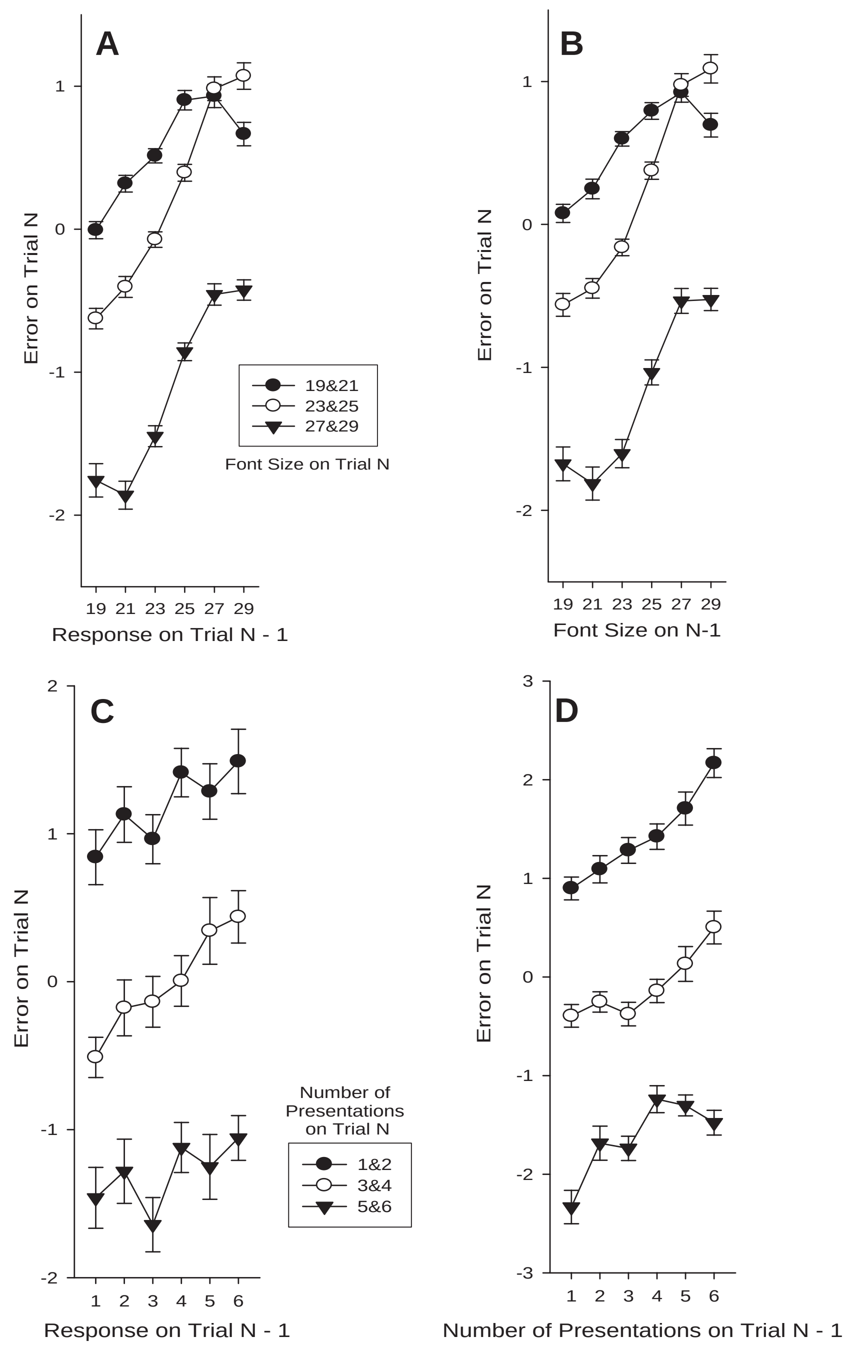

Figure 16. Sequential dependencies at Lag 1 for Experiment 5. Panels A and B plot the error in the font-size judgment as a function of the prior response and the prior stimulus, respectively. Panels C and D plot the error in the JOF judgment as a function of the prior response and the prior stimulus, respectively. Error bars are standard errors.

creases in lag and no support for the reversal of positive sequential dependencies.

In summary, the results of the absolute identification condition replicate the results in the perception literature. Assimilation was observed in the judgment of font size responses at Lag 1, and a reversal of the positive sequential dependencies (i.e., contrast) was observed between the prior stimulus and the current response at Lag 3. Moreover, the results showing assimilation but no negative sequential dependencies in the recognition data replicate those from Experiment 4. Insofar as the decision structures of absolute identification and JOFs are the same, this key difference in the patterns of sequential dependencies in perception and recognition is difficult to reconcile with models that assume that negative sequential dependencies arise from fluctuations in response bias.

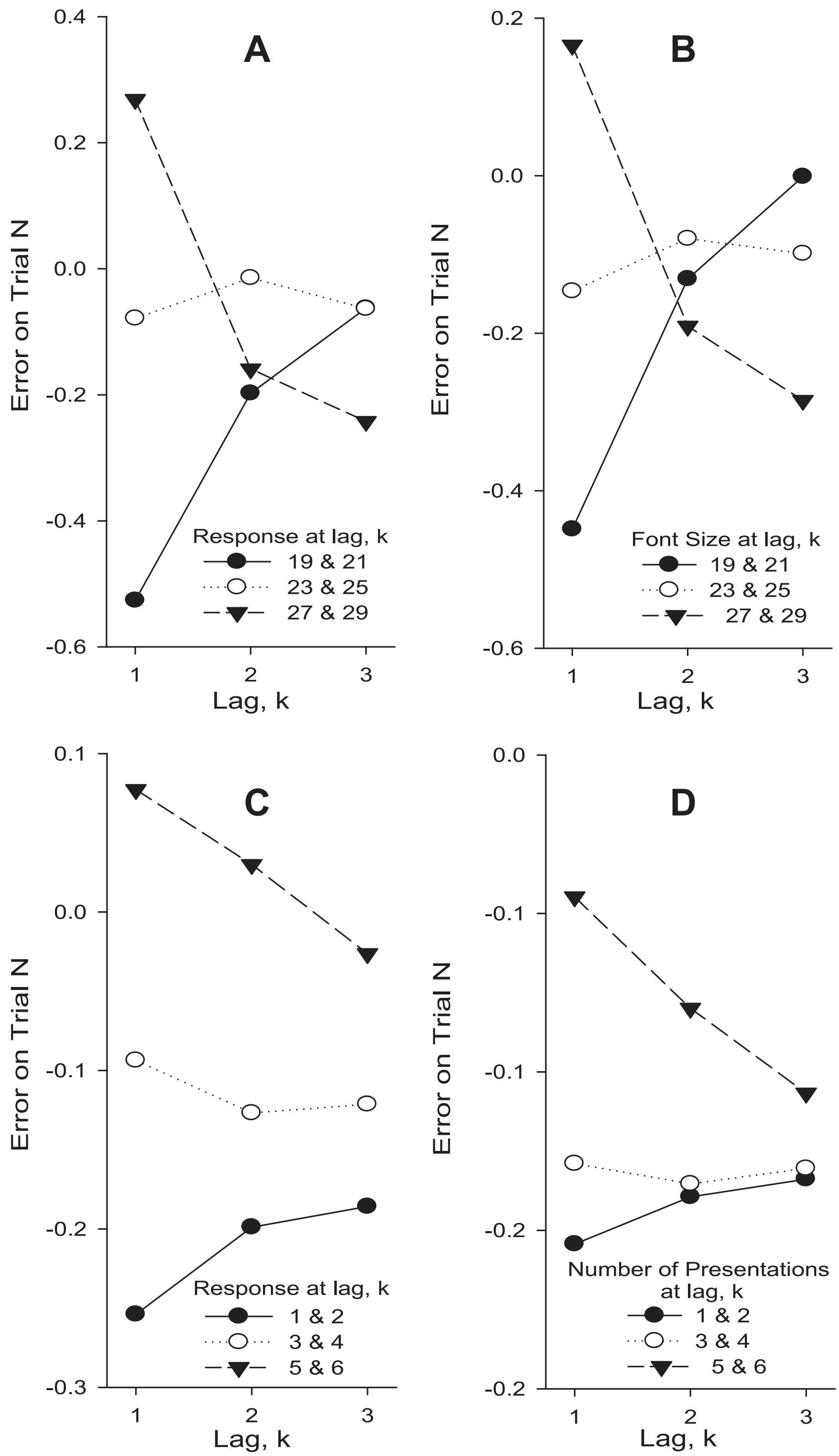

Figure 17. Sequential Dependencies as a Function of Lag for Experiment 5. Note. Panels A and B plot the error in the font-size judgment as a function of the prior response and the prior stimulus, respectively. Panels C and D plot the error in the judgment of frequency (JOF) judgment as a function of the prior response and the prior stimulus, respectively.

General Discussion

This research documents a wide range of sequential dependencies in recognition memory testing for the first time. Old responses are more likely to follow old responses than new responses. Assimilation is robust to variations in stimuli, and it occurs for both studied and unstudied items. Therefore, it cannot be attributed to variability in the state of memory during study or enhanced memory during testing (cf. Schwartz et al., 2005). We also observed assimilation between adjacent old–new responses using several recognition procedures, including yes–no, ratings testing, and studies of pairs and single items. Assimilation between adjacent responses diminished with increases in the lag between test positions but did not reverse. These results extend to an absolute JOF task, creating some similarities between the present results and those in the perception literature on absolute identification. Unlike absolute judgments in perception, contrast between responses at greater lags was not observed in JOFs, even in the presence of feedback. However, contrast was observed at Lag 1 between the prior stimulus and the current response in the absence of feedback, whereas assimilation between the prior stimulus and the current responses was observed at Lag 1 when feedback was provided.

Implications for Models of Memory

Sequential dependencies challenge all models of recognition (Malmberg, 2008, for a review). This is not because sequential dependencies are beyond the ability of the models to make predictions. Indeed, extant models make a very specific prediction: Sequential dependencies should not be observed. The problem is, as the present research suggests, that memory research has disproportionately emphasized the effects of variables manipulated during study and has paid less attention to the consequences of testing memory. As a result, recognition models have not been designed or extended to account for sequential dependencies.

The lack of interest in sequential dependencies by memory researchers is surprising in light of fact that many models of memory were patterned after those originally applied to perception tasks and that sequential dependencies are so pervasive in the perception literature (cf. Green & Swets, 1966). Notable exceptions to this generalization include the recent research in the educational setting on the enhanced benefits for learning of testing memory (e.g., Roediger & Karpicke, 2006) and on interference caused by retrieval from memory (e.g., Anderson, Bjork, & Bjork, 1994; Criss, Malmberg, & Shiffrin, 2011; Malmberg, Criss, Gangwani, & Shiffrin, 2011; Tulving & Arbuckle, 1966).

As a package, the results from these lines of research indicate that testing memory can have a positive or negative effect on subsequent memory. In contrast, the present findings suggest that sequential dependencies do not impact overall recognition accuracy, positively or negatively (at least under the conditions investigated to this point). This is not to say that individual test trials are not impacted by sequential dependencies. By definition, quite the opposite is in fact the case. Rather, after the first test, sequential dependencies may exert a constant influence on individual tests throughout the course testing that influences the tendency to respond with a certain judgment. This will decrease the accuracy of the judgments on some trials, and on other trials it will enhance the accuracy. Sequential dependencies may not have a large impact on overall accuracy because sequential dependencies are observed for trials on which targets and foils are tested. On the assumption, for instance, that shifts in the tendency to respond "old" are consistent in magnitude over the course of testing and that bias is independent of sensitivity, the overall accuracy of recognition performance should not be affected by sequential dependencies.

One exception to this generalization may be when the order in which items are studied is the same as the order in which items are tested. Experiment 1, for instance, showed that sequential dependencies for targets were slightly more robust when the order in which stimuli were presented at study and test was the same, especially when targets were tested consecutively. However, it seems doubtful that the greater tendency for a hit following a hit when the items were studied in nearby temporal proximity is due to recollection of the occurrence of the second target when the first target was used to probe memory (e.g., Atkinson & Juola, 1974). It is difficult to explain why an item would not elicit a hit when tested following an item from a distant serial position at study, given that the prior occurrence of the item in the study context is represented strongly enough to generate a recollection of the event. That is to ask, why are some items strongly associated to other items but not the test context? And if they are not strongly associated to the test context, then how does the subject recollect that the items were studied in that context? Moreover, the sequential dependencies extend to both high- and low-confidence prior responses. Hits are less likely following a miss than following either a high- or a low-confidence hit. It seems unreasonable to assume that an individual recollects studying Targets A and B together in response to testing on Target A, yet that individual has little confidence that A was studied.

Because sequential dependencies are present in the responses to both targets and foils, it might be difficult to determine whether the sequential dependencies are due to fluctuation in bias or due to fluctuations in the evidence on which decisions are made. Indeed, this is a classical debate in the perception literature (e.g., Triesman & Williams, 1984, vs. Brown et al., 2008). However, given the patterns of the sequential dependencies are different for recognition and perceptional tasks, it might seem more parsimonious that they arise at least primarily from predecisional processing of the stimulus and that perceptual processing and mnemonic processing are different in some fundamental way. Thus, the present findings may be as important for understanding the nature of perception as they are for understanding the nature of memory.

Implications for Models of Absolute Identification

The recognition tasks investigated here are in many important respects similar to those used to study perception. The binary recognition task used in Experiment 2 has the same decision structure as the binary detection task used in many early perceptual detection tasks in which sequential dependencies were observed (Collier, 1954a, 1954b; Collier & Verplanck, 1958; Verplanck et al., 1952). The JOF task and the absolute identification task commonly used to study perception also share the same decision structure, where the task is to relate *n* classes of stimuli to *n* responses (*n* is usually greater than 3; cf. Miller, 1956). The similarity between the tasks used to test memory and perception is important if one assumes that tasks that have the same decision structure are based on the same decision processes. This is a standard assumption underlying the application of SDT to memory and perception tasks, for instance (Egan, 1958; Green & Swets, 1966). If so, one may conclude that the differences in the pattern of sequential dependencies observed in recognition and perception reflect differences in memory and perceptual processing. For this reason, the present results have broader implications for models of absolute identification; especially those that assume decision processes are the loci of sequential dependencies.

Models of absolute identification may be distinguished by whether they assume decision versus perceptual processes produce sequential dependencies. Teasing apart changes in performance due to fluctuations in sensitivity and bias was the motivation for the SDT models described at the outset (Green & Swets, 1966), and the methods derived from SDT have been widely used in both memory and perception research. Their utility in memory and perception research is based on the assumption that recognition and perception tasks are signal detection tasks. If so, bias should be affected by similar variables, regardless of whether the task is a perceptual or mnemonic one. For instance, changes in bias for both recognition and perception decisions are induced by changes in the prior probabilities of the signal and the costs and rewards associated with different outcomes (see Green & Swets, 1966; Macmillan & Creelman, 2005, for reviews).

On the assumption that memory and perception tasks are based on different sources of information—be they auditory, visual, or mnemonic—but share the same decision processes, our results have immediate implications for extant models that assume sequential dependencies are the result of variability in response bias (Treisman & Williams, 1984). It is in this sense, that Treisman and Williams further proposed the processes of tracking and stabilization as mechanisms to locate the decision criterion in response to short-term and long-term changes in the environment. According to that model, assimilation is the result of tracking recent responses, and contrast is the result of stabilization of the criterion to a preferred long-term location. As this model is an extension of SDT, there is no reason a priori that tracking and stabilization would be limited to perception tasks. However, assimilation between the prior response and the current response is observed in recognition for both binary decision and absolute judgment tasks, but contrast at lags greater than 1 is not observed, even in the presence of feedback. Moreover, contrast between the prior stimulus and current response is observed at Lag 1 in absence of feedback. To the best of our knowledge, such a finding has not been reported in the perception literature. The uncomfortable conclusion reached within the Treisman and Williams framework is that tracking of recognition and perceptual responses occurs but long-run stabilization occurs only when the signal is received from an external source and short-term stabilization occurs only at Lag 1 for recognition. There is no apparent reason for this. Indeed, this is somewhat of a circular explanation. Thus, the present findings provide no converging evidence that high-level strategies produce the pattern of sequential dependencies reported in the perception literature.

The discord between the patterns of sequential dependences in recognition and perception testing is also problematic for the assumption that feedback causes contrast in perception testing. According to the RJM (relative judgment model; Stewart et al., 2005), for instance, prior test trials are represented by newly stored memory representations of the difference in the magnitudes of adjacent stimuli. These representations influence the current response. The current response is also influenced by confusions among the difference between the prior stimulus and the current stimulus and by the prior response. When feedback is provided, RJM assumes that confusions arising from the prior responses are reduced since the current judgment is influenced by the feedback instead. That is, confusions among sources of information produce assimilation in RJM on the assumption of *positive* sequential dependencies of the prior feedback at Lag 1, and contrast at greater lags on the assumption of *negative* sequential dependencies of feedback at greater lags. However, these findings do not extend to recognition, and there is no a priori, or even a good, reason for the mnemonic sources of information about prior trials, which produce assimilation and contrast at Lag 1 in judgments of perception, to not produce different patterns of sequential dependencies in recognition testing. For instance, the results of Experiment 5 in which feedback was provided for both absolute identification and JOFs produced different patterns of sequential dependencies. Hence, feedback is not sufficient to induce a particular pattern of sequential dependencies.

However, one may take a different view of the effect of feedback. Note that feedback in perception tasks often occurs after each test. Thus, feedback may affect either the percept on the subsequent trials or on the decision on subsequent trials. While the present data are difficult to explain with the latter hypothesis, as one would have expected recognition findings similar to those reported in the perception literature, it is possible that feedback may affect how subsequent stimuli are perceived. The goal of feedback is to adjust or fine-tune performance, and in absolute identification tasks, the mapping of stimuli to responses must be learned during an initial phase of experimentation. For instance, learning plays a crucial role in the ANCHOR model of absolute identification (Petrov & Anderson, 2005). Presumably, the percept-to-label association learned during the initial phase of experimentation is subject to interference like many other forms of learning and memory, particularly perceptual classification (e.g., Jones et al., 2006; Ratcliff & McKoon, 1988). If so, feedback may buffer the stimulus–response encoding through additional periodic relearning. In contrast, feedback in recognition testing may not influence the states of traces of untested items, and thus, one would not expect it to produce contrast if it is indeed the cause of contrast. A problem for this hypothesis is that no pretraining for the font-size judgment task was necessary in Experiment 5, and the patterns of sequential dependencies for absolute identification and JOFs were different.

Other models take the intermediate but more complicated position that sequential dependencies arise from a combination of perceptual processes and decision processes. In the SAMBA model (Brown et al., 2008), for instance, assimilation arises from decision processes, and contrast arises from attention bands supporting perceptual processes. Therefore, a lack of contrast in recognition testing is not problematic for SAMBA, since mnemonic and perceptual processes may have different properties. To produce assimilation, SAMBA assumes the evidence associated with a set of accumulators on trial $n - 1$ diminishes in an exponential fashion over time. Those accumulators that accrued the greatest amount of evidence on trial $n - 1$ begin trial n with an advantage or head start in a ballistic decision process. This produces a positive correlation between the responses on trials *n* and $n - 1$ that diminishes with the time between the prior response and present response.

Assimilation that diminishes with increases in lag but not with the passage of time is inconsistent with these assumptions. This is what was observed in recognition testing (Experiment 2). A straightforward modification is to assume that the evidence decays with increases in lag rather than time. However, Matthews and Stewart (2009) reported that assimilation in absolute identification does decrease with increases in the amount of time between test trials. While it is doubtful that decision processes are responsible for these interactions, it is quite possible that the evidence provided by perceptual and memory processing has different decay properties. It is also possible that during long periods between test trials that information unrelated to the test interferes with the perceptual information that would normally carryover from the prior trial. If so, the decay associated with time by Matthews and Stewart may actually be decay associated with perceptual interference, not unlike a mask.

Noting that the attention-band mechanism for producing contrast in SAMBA may not be applicable to mnemonic tasks should not imply that it is not applicable to perceptual tasks. As we have assumed, perceptual and mnemonic systems supporting task performance almost certainly have different properties, and these systems interact with the shared system that supports decisions. In fact, the recognition memory literature contains several models of the processes and representations involved in recognition (see Malmberg, 2008, for a review), and thus, it may be possible to pair one of these models with SAMBA's ballistic decision process to produce assimilation in recognition testing.

Conclusions

We presented the results of several recognition memory experiments in which a variety of procedures and stimuli were used to test the independence assumption. The independence assumption was disconfirmed in all experiments. It is important to note the pattern of sequential dependencies was different from that reported in the perception literature. Indeed, when the sequential dependencies for perception and recognition were directly compared, significant differences were obtained. We considered two classes of models to account for our findings. Models that assume that sequential dependencies are the result of fluctuations in response bias are difficult to reconcile with different patterns of sequential dependencies for memory and perception. Moreover, the specific pattern of sequential dependencies obtained for recognition is inconsistent with extant models of perception. Hence, it is probable that mnemonic and perceptual processing give rise to sequential dependencies and differences in these processes produce the different patterns of sequential dependencies that we report.

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