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Retrieval Dynamics of Priming in Recognition Memory: Bias and Discrimination Analysis

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We investigated semantic priming effects on item recognition from short (8-word) lists in one reaction-time and three interruption speed–accuracy trade-off (SAT) experiments. SAT priming conditions included modest (0.35-s) prime durations; prime as a final list member; and long (1.5-s) prime durations with special instructions. Analyses tested for *constant increment (bias) priming* (an equivalent increase in both hits and false alarms) and *enhanced discrimination priming* (differential priming for targets and lures). Constant increment (bias) priming was ubiquitous, but some subjects showed enhanced early discrimination in restricted conditions. In constant increment (bias) priming, the semantic relations between prime and test either additively increase familiarity or lower criterion. Only enhanced discrimination must imply an interaction between the prime and the retrieval process, due to either interaction or use of compound cues.

This article analyzes the nature of semantic priming in item recognition, focusing on the relative contributions of bias and discrimination enhancement. The retrieval dynamics of semantic priming in item recognition are measured with the interruption speed–accuracy trade-off (SAT) method and with standard reaction times. The interruption method measures accuracy at various times during retrieval (by cuing subjects when to respond) and separately assesses the speed of retrieval and accuracy late in the retrieval interval.

Standard Priming Paradigms

Priming is an extensively investigated phenomenon in some semantic and episodic memory domains. It has been used as a method for investigating a variety of issues in representation and retrieval, including such disparate topics as the structure of the lexicon (Becker, 1980; Forster, 1976; Meyer & Schvaneveldt, 1971, 1976; Morton, 1969; Warren, 1977), the nature of sentence representation (Ratcliff & McKoon, 1978), the separation of semantic and episodic stores (McKoon & Ratcliff, 1979), the separation of verbal and visual stores (Kroll & Potter, 1984), the existence of subliminal perception (Marcel, 1983), and interactions with attentional orientation (Neely, 1977; Ratcliff & McKoon, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977). In the classic paradigms, the subject might be asked, for example, to verify that *orange* is a word or that it appeared on a study list. A priming effect is said to obtain when processing a related word like *apple* immediately prior to lexical decision or recognition speeds the response to the target item. Trials on which *orange* follows either no prime or an unrelated word like *horse* provide the baseline for the assessment of priming.

Context, or priming, has been considered a major factor in memory retrieval. Providing context for recognizing an event or fact may facilitate retrieval from a memory of enormous capacity. Semantic priming effects on item recognition have been used as a key argument for the interactivity of semantic and episodic information in the memory system (McKoon & Ratcliff, 1979; McKoon, Ratcliff, & Dell, 1985, 1986). Recently, priming in item recognition has more generally received treatment in the literature (Johns, 1985; Lewandowsky, 1986; Macht & O'Brien, 1980; McKoon & Ratcliff, 1986; Neely & Durgunoglu, 1985; Neely, Schmidt, & Roediger, 1983). Semantic and episodic priming in recognition memory has provided a new focus for the testing of general quantitative models of memory retrieval (Dosher & Rosedale, 1989; Ratcliff & McKoon, 1988). Our goal here is to examine the mechanism(s) underlying semantic priming of item recognition.

Related-item, or semantic priming, effects have been given a number of different accounts. Consider, by way of illustration, the case of lexical decision. One class of models of which the logogen model is an example (Morton, 1969) claims that processing a related element either lowers the threshold on the word detector (logogen) for the target word or, equivalently, adds activation to that word detector. Norris (1986), in a more elaborated variant, claims that semantic context operates as a change in criterion in a postlexical-access checking phase. We label mechanisms of this type *constant increment* (or bias) explanations of priming. Other models (e.g., Becker, 1976, 1980; Forster, 1976) claim that the prime actually changes the processing of the subsequent target word. For example, in Becker's model of lexical decision, the prime word constrains a list of possible words to be matched with the visual presentation of the target word; this may result in the target word's actually being checked and verified earlier. We label mechanisms of this type *discrimination enhancement* explanations. For more complex computational models, such as Cottrell and Small's (1983) model of parsing disambiguation or Seidenberg and McClelland's (in press) model of

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lexical decision and naming, the nature of a prime's effect depends on the specifics of implementation.

The bias versus discrimination issue has been given several treatments in the lexical decision domain (Johnson & Hale, 1984; Norris, 1986; Schvaneveldt & McDonald, 1981). We reference the lexical decision literature here not to provide a resolution to the bias versus discrimination issue in that domain nor to suggest that a resolution in the domain of lexical access would necessarily constrain conclusions in the domain of short-term recognition. In fact, Neely and Durgunoglu (1985) have explicitly analyzed the dissociation between lexical decision and episodic recognition. Rather, we point out that very similar questions naturally arise when one considers possible mechanisms of priming in both lexical decision and recognition memory. Happily, in recognition the situation may be simpler than in lexical decision because the target and lures for recognition can be precisely equated either by presenting the same word or a controlled equivalent (whereas the words and nonwords of lexical decision can not). An answer to the bias versus discrimination question can place strong constraints on well formulated models of priming.

Constant Increment (Bias) Hypothesis

One possible explanation of semantic priming of item recognition is that priming adds a constant increment to the familiarity or strength of *both* related targets and lures or lowers criterion equally for targets and lures. Although adding equal strength increments or changing criterion equally are different mechanisms in a model description, they are essentially indistinguishable empirically.

Whether an increment or bias effect, exactly balanced for targets and lures, accounts for all of priming can be examined with the appropriate selection of controls. This is schematically illustrated in Figures 1 and 2, which outline hypothetical strength distributions for several conditions with the standard assumptions of signal detection theory. The four critical conditions include baseline target (true) and lure (false) tests, as well as tests of targets and lures following a related prime. Baseline conditions here measure performance following an unrelated prime. Given the difficulties in interpreting "neutral" primes (deGroot, Thomassen, & Hudson, 1982; Lewandowsky, 1986), we did not attempt to separately assess facilitation and inhibition.

The means of the hypothetical strength distributions shown in Figure 1 assume that priming simply adds a constant increment to the strength of both targets and lures. Thus, when the target following a related prime (RY, or related yes) condition is compared with the target following an unrelated prime (UY, or unrelated yes) condition, a higher strength value is indicated. This benefit for the RY condition, however, need not reflect any true improvement in discrimination of targets from lures, either in the ultimate discrimination performance or in the speed of discrimination (see Discrimination Enhancement Hypothesis below).

Here we introduce some mathematical formulations of the constant increment/bias mechanism, which preview the equations used in model-fits of data in the speed–accuracy experiments. We can formalize the constant increment hypothesis as follows:

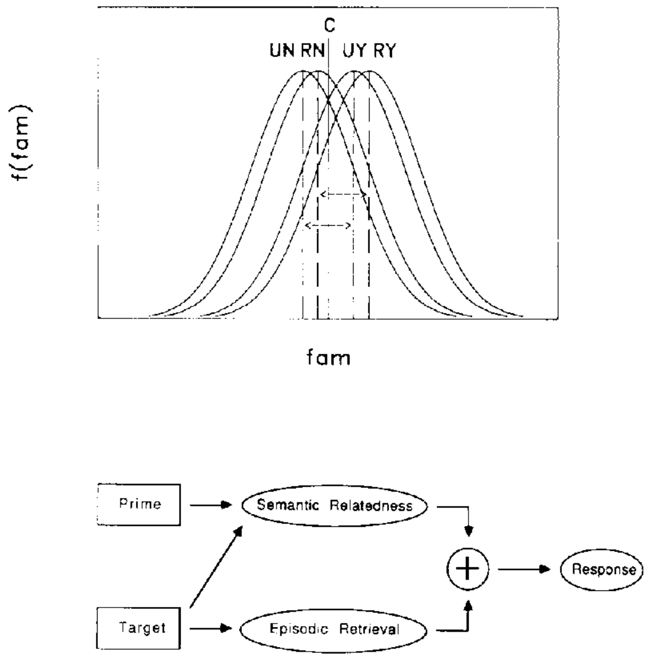

Figure 1. Top panel presents hypothetical strength distributions according to a "constant increment" formulation, along with a schematic illustrating accompanying processing assumptions. (According to this formulation, semantically primed targets [RY] and lures [RN] differ from unprimed targets [UY] and lures [UN], respectively, simply by a constant increment in the memory strength. The accompanying flow chart illustrates that memory strength is an additive combination of the independent assessment of semantic relatedness of prime and test item and episodic retrieval operations performed solely on the test item.)

$$fam = S_m(l) + S_r(k),\ l \in \{Y,N\},\ k \in \{R,U\}. \qquad (1a)$$

A decision is based on an overall familiarity variable, *fam*, which combines a retrieved memory strength component S_m and a pure relatedness based component S_r. The memory component S_m differs for targets ($l = Y$) and lures ($l = N$), while the component S_r depends on whether the prime and target are related ($k = R$) or not ($k = U$). Priming and episodic retrieval are independent because the relatedness component S_r is not a function of list status of the test, l, nor is the memory strength component S_m a function of the kind of prime k. By convention, $S_m(N) = S_r(U) = 0$, in order for the unprimed false condition to have a mean of zero. This assumes a pure common increment mechanism.

The increment formulation is interchangeable with a criterion formulation in which prime condition affects the setting of criteria, but not the evaluation of familiarity:

$$fam = S_m(l) \text{ AND } C_r(k),\ l \in \{Y,N\},\ k \in \{R,U\}. \qquad (1b)$$

Here, *fam* depends only on memory strength S_m, while criterion C_r depends on prime relatedness. We cannot discriminate

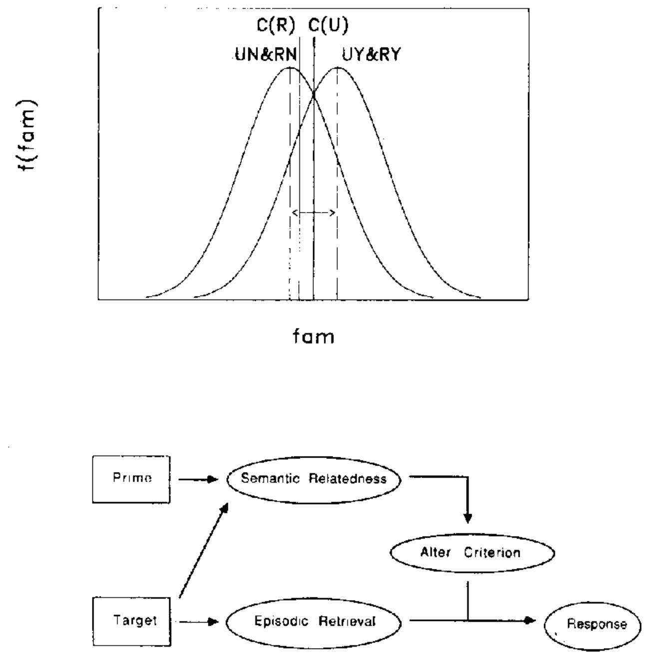

Figure 2. An analog criterion formulation of the model presented in Figure 1. (According to the criterion formulation, memory strength is determined by episodic processing of the target item. However, the criterion is lowered when prime and test item are semantically related [C(R)] relative to when it is unrelated [C(U)].)

between these two formulations in these experiments. For simplicity, we use the increment formulation in formal model fitting of the experimental results.

In either the increment or criterion shift formulation, the priming effect does not interact with the retrieved memory strength. Retrieval from episodic memory might be completely independent of the prime. This point is illustrated in the accompanying flow charts of Figures 1 and 2. Semantic relatedness between the test item and the prime might be evaluated by completely separate access to semantic information in a lexical store. These two separate pieces of information, S_m and S_r, might then be integrated subsequent to retrieval (the increment formulation schematically represented in Figure 1), or S_r might be used to adjust the criterion applied to S_m in the decision process (the criterion formulation schematically represented in Figure 2). An additive priming effect could occur following or outside episodic retrieval of the test item. Completely separate processing can never be rejected, given an empirical finding of additivity between memory and relatedness strengths. Independent effects do, however, place a temporal constraint on the process: It is necessary for semantic relatedness between the prime and test to be processed quickly enough relative to episodic retrieval to affect the response on a reasonable proportion of trials. It is not necessary for the semantic information to be processed consistently earlier than the episodic information, but the processing time distributions must overlap substantially.

Discriminative Enhancement Hypothesis

In the constant-increment/bias model above, the prime does not enhance discrimination of targets from lures. Enhanced discrimination (either in ultimate accuracy or in speed of retrieval) could result if the prime allowed a more efficient retrieval from memory. This could be analogous to earlier matching of the correct word against the visual encoding in Becker's (1976) model of lexical access. There are a number of ways of expressing discriminative enhancement formally. It would be possible to simply make memory strength a function of both list status l and kind of prime k: $fam = S_m(l, k)$, $l \in \{Y,N\}$, $k \in \{R,U\}$. Enhancement in this form requires that $S_m(Y,R) - S_m(N,R) > S_m(Y,U) - S_m(N,U)$. We choose a modification of Equation 1 above which maintains an estimate of the effect of prime relatedness on lures and treats the interaction of memory access and relatedness explicitly:

$$fam = S_m(l) + S_r(k) + S_{mr}(l,k),\ l \in \{Y,N\},\ k \in \{R,U\}. \quad (2)$$

Enhancement in this form would find $S_{mr}(Y,R)$ larger than all other S_{mr}. Discriminative enhancement suggests that the prime has an effect on the process of list retrieval.

In order to assess the effect of a prime on discrimination, it is necessary to compare the UY versus UN difference (hits compared with false alarms following an unrelated prime) with the RY versus RN difference (hits compared with false alarms following a related prime). These comparisons can be contrasted with those in an increment/bias analysis which compares RY with UY (difference in hits following related and unrelated primes) and RN with UN (difference in false alarms following related and unrelated primes). These two kinds of analyses—a constant-increment/bias analysis and a discrimination analysis—are used in examining data from the SAT experiments presented here. A discrimination analysis by itself would reveal retrieval enhancement (or decrement) following a prime. However, a failure to find discriminative effects may reflect either a constant increment mechanism of priming or the lack of priming effects of any kind. Hence, we also perform a bias analysis because it highlights the presence and size of basic priming effects even if discriminative effects are minimal.

Combinatorics and Specific Models

Pure increment and discriminative enhancement hypotheses outline mechanisms of information integration at a very general level (e.g., Anderson, 1981). They specify the nature of the combination of information about list status and prime relation. At a more specific level are models of memory representation and the retrieval process. Specific retrieval models may be of either the additive or interactive type. For example, CAS (Dosher, 1982) is a quantitative model based on a metaphor of (continuous) activation spread. Reading a prime activates the concept corresponding to the prime word directly, and (semantically) related words indirectly through spread of activation. When a test word is read, activation from that word adds to the residual activation from the prime. The residual activation is equal for the representation of targets and lures. Because of the strict linearity of the activation decay and cumulation in CAS, an equal initial prime increment for targets and lures is carried through to equal effects on final strength. (Spreading activation models that include a nonlinear transform prior to response would violate the independent combinatorics of the increment/bias model.) Alternatively, a model like CAS could equally well propose that priming does not affect the activation levels of the episodic representations, but instead affects the response criterion by an entirely separate process. Quantitative models may choose to describe an additive effect of semantic primes either as a criterion mechanism or as an early increment mechanism in the episodic memory system. This rewrite possibility is characteristic of increment/bias combinatorics. One quantitative model that is an example of nonadditive combinatorics of episodic strength and prime relation is the SAM model (Gillund & Shiffrin, 1984; Raaijmakers & Shiffrin, 1981). In this model, a prime is treated as an additional cue in memory access, and the recognition familiarity depends on the *product* of the strength of association between the prime and the memory image of a list item and the strength of association between the test and that memory image. In recall, or in a possible recall component of recognition, the product rule determines the search priority of possible list items. The SAM rule is a more restrictive version of the interactive formulation, in which the nature of the interaction is multiplicative.[1]

SAM is one example of a class of models that explain priming as the consequence of combined action of access cues at the time of retrieval—cue combination (Dosher & Rosedale, 1989; Murdock, 1982; Ratcliff & McKoon, 1988). Many recent quantitative models of memory most naturally account for priming as cue combination; each such model must be separately categorized as additive or interactive depending on the details of the model.

Priming in Item Recognition

In this section we briefly review some previous findings in the literature, primarily using standard reaction time methods. McKoon and Ratcliff (1979) found that a semantic associate presented as a prime affected the recognition of a previously learned target item compared with the case where the retrieval prime was neither a semantic nor a newly learned associate of the target item. The semantic associate caused an increase in the error rate (nonsignificant difference in reaction time) to related items which were not on a learned list (semantically primed *RT* = 738 +/− 16 ms; error = 20% +/− 3%; unprimed control *RT* = 743 +/− 7 ms; error = 14% +/− 1%). (On the basis of this finding, McKoon and Ratcliff concluded that semantic information could affect episodic tasks, which does not argue for the separability of semantic and episodic memory stores. See Durgunoglu & Neely, 1987; McKoon & Ratcliff, 1986; Neely & Durgunoglu, 1985; for subsequent findings and discussion.) In a delayed-recognition list paradigm, Macht and O'Brien (1980) found that preceding a target test item by a categorically related prime sentence resulted in faster reaction time, while it lengthened reaction time to lures in some but not all experiments. Neely, Schmidt, and Roediger (1983) report mixed effects of priming on lures in successive item recognition trials for categorized lists, depending on the number of prior "primes" in the test list. Johns (1985), also using categorized lists, found that priming from successive recognition trials yielded faster reaction times in rejecting lures. Lewandowsky (1986) proposed a taxonomy of priming tasks to account for these conflicting findings. He suggested that priming in item recognition would facilitate rejection of lures (relative to unrelated prime baselines) when the prime is analyzed episodically but would inhibit lure rejection when the prime is analyzed semantically.

Reaction Time

In a standard reaction time paradigm, when priming improves performance (shortens reaction time and lowers errors) on *both* targets and lures, then priming almost surely reflects a discriminative enhancement. We know from the results of Johns (1985) and Lewandowsky (1986) that priming causes discriminative enhancement for item recognition from categorized lists. However, other patterns of effects are less clearly interpretable. In the literature, lures are most frequently inhibited by semantic primes (see the review above). Even inhibition of lure rejection may be compatible with discriminative enhancement if improvement in performance on targets is sufficiently large. The presence of discriminative priming may be difficult to determine precisely in the context of a reaction time experiment. For example, does 20 ms of facilitation in target reaction time at approximately 800 ms and 85% correct exactly offset 20 ms of inhibition for lures at approximately 1,000 ms and 95% correct? Direct comparisons of facilitation and inhibition in reaction times for targets and lures (respectively) with different base reaction times and different error rates require very strong assumptions about the linearity of reaction time with difficulty and about the relation between times and error rates. An answer to the bias versus discrimination question requires just such a comparison. Speed–accuracy methods offer a collateral means of assessing the equivalence (or nonequivalence) of inhibitory and facilitatory effects.

Speed–Accuracy Trade-Off

Several of the priming experiments described here use the response-signal speed–accuracy trade-off (SAT) method. This method reveals the full time course of retrieval of the test item. Note that the time course of retrieval as measured by SAT is not the same time course typically measured by varying the prime duration (stimulus onset asynchrony, SOA). The former measures information availability following *test* onset, whereas the latter often claims to measure the conse-

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[1] Increasing variances of the SAM strength distributions for primed targets might offset some of the extreme interactivity of the model; however, it is unlikely that variance increases exactly offset the product rule in just such a way as to mimic additivity.

quences of processing the *prime* prior to test onset (but see Koriat, 1981).

The SAT method allows the comparison of facilitation and inhibition in error rates at a wide range of fairly precisely controlled processing times and also allows the independent assessment of ultimate accuracy levels and speed of processing. The subject is interrupted unpredictably by a tone at some time following the onset of the test item. The subject is trained to respond as quickly as possible after the interruption tone. Retrieval time is manipulated by interruption, and accuracy of the recognition judgment can be measured as a dependent variable. An idealized graph of recognition accuracy (here measured in d' units) against total processing time (time to interruption plus response latency) is shown in Figure 3. There are typically three aspects to these SAT curves: the intercept, or longest processing time when accuracy is at chance; a parameter reflecting speed of rise to ultimate accuracy levels; and the asymptote, or final level of accuracy given ample retrieval time. (In the short-term memory domain, there has been some evidence [Reed, 1973] that SAT curves may show declining accuracy at very long processing times. Also, other priming studies such as Dosher & Rosedale, 1989, have found more complex dual-process functions.)

If the presence of a prime affects the speed with which information becomes available, priming would affect early portions of the functions, while changes in ultimate accuracy of the memory would be reflected in the asymptotic performance. This distinction between prime effects early and late in the time course of recognition are easiest to discover in the context of the speed-accuracy paradigm. For a more complete discussion of the speed-accuracy trade-off method, see Dosher (1979, 1982).

Summary

We examine evidence for constant increment/bias or enhancement mechanisms in priming of judgments of item recognition by semantic (extralist) primes. This requires a comparison of the speed and accuracy of *both* lure and target judgments following related and unrelated primes. The question centers on whether primed targets are affected differently than primed lures. In Experiment 1, we perform a reaction time (RT) variant of the priming paradigm, using a range of prime durations, which demonstrates large priming effects on mean RT. The pattern of priming effects is generally consistent with a constant increment mechanism: Improvement in targets is approximately equally balanced by damage to lures, subject to the various assumptions concerning the trade-off of speed and accuracy in RT. Experiment 2 is an SAT variant of Experiment 1 (at a single intermediate prime duration) that directly supports the constant increment result across the entire time course of retrieval, although the effects of primes are shown to be greatest early in retrieval. Experiment 3 attempts to produce a discriminative effect of the prime via direct instructions to use the prime to generate the most likely list element during a long prime duration. Under direct instruction, some subjects showed an elevation of accuracy very early in retrieval for the single case where a target could be generated and matched—the matching signature. Experiment 4, another SAT experiment, extends the general results to a nonstandard priming experiment in which the prime is an element near the end of the learning list. Even here, where the subject could easily have generated the target on many trials, only a subset of subjects show any evidence of a discriminative component over and above the large priming increments for both targets and lures.

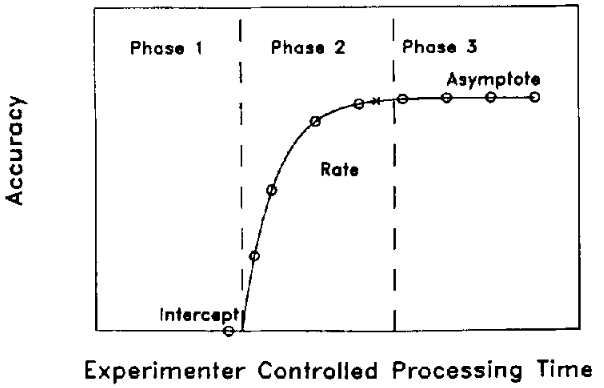

Figure 3. Idealized speed-accuracy trade-off function illustrating the three phases of retrieval: a phase prior to the availability of memory information, a phase of rapid accrual of information, and an asymptotic phase limited by the strength of the information in memory. (Circles represent possible observed points from a response-signal experiment, while the x represents a likely observation from a reaction time experiment.)

Experiment 1: Priming in Reaction Time

Experiment 1 used a study-test explicit priming paradigm. Subjects studied eight-word memory lists, under successive presentation. Test trials presented a prime word followed by a list word (target) or nonlist word (lure). The prime word is read, but no overt response is required. The test word is judged for list membership. Semantically related primes are contrasted with two types of unrelated primes: those that are unrelated to any list member and those that are semantically related to a list member but not to the test word. These are labeled *related, unrelated,* and *misleading (other-related)* primes.

Comparisons of target and lure performance with related primes to performance with unrelated primes index the distinction between constant increment (bias) and enhanced discrimination mechanisms in priming. Comparison of other-related primes to unrelated primes may help to identify whether primes have their effect by making contact with a list member. If other-related primes cause subjects to think of the related list element, they may be inclined to reject both the (unrelated) targets and lures which follow.

For reasons outlined above, precise conclusions concerning the presence or absence of discriminative enhancement are difficult in reaction time experiments. However, the reaction time results (a) should document the existence of standard priming effects on reaction time, (b) may suggest a tentative answer to the increment/discrimination question, and (c) provide a point of comparison to subsequent SAT experiments. Finally, (d) the experiment determines whether the pattern of priming depends strongly on the amount of time available for prime processing, the prime duration or SOA.

Method

Subjects. Ten subjects were paid for their services. All subjects had normal or corrected-to-normal vision and hearing and were native speakers of English. Each served for two 55-min sessions.

Design and stimuli. There were six stimulus conditions in the experiment, illustrated in Table 1. The six types were targets and lures following related primes (RY and RN), targets and lures following unrelated primes (UY and UN), and targets and lures following misleading (other-related) primes (MY and MN).

All lists were eight words long. Nine tests followed each list in such a way that each of the six test types occurred three times every two trials, in pseudorandom order which excluded multiple display of any word. Each condition was tested at seven prime durations, or SOAs: 0.10, 0.25, 0.35, 0.50, 0.70, 1.00, and 1.50 s, yielding 42 experimental conditions. The SOAs were assigned pseudorandomly, subject to the constraint that each condition was tested equally at each SOA in each block. Each session had five blocks of 14 study lists, each with 9 test trials, for 630 test trials per session. Subjects participated in two experimental sessions, for a total of 1,260 trials, or a sample size of 30 in each of the 42 conditions.

The study and test lists were constructed from lists of related word pairs based on the list used by Dosher (1984b). Words were no longer than 16 characters, judged by three undergraduates to be familiar, and the pairs were judged to be related. Because of the required length of the list, there were many bases of relatedness (synonyms, antonyms, strong associates, etc.) for the pairs. Random reorderings of the list were used in each session, so lures had not been seen within the same session. Words were assigned to conditions randomly and differently for each subject.

Procedure. Stimulus presentation and response collection for all trails was controlled by an 11-03 microcomputer with a Matrox MLSI-2428 video generator for display of alphanumeric characters on a Sanyo VM4209 screen. Words were centered on the screen, and characters were approximately 6 × 4 mm, viewed at a distance of approximately 40 cm.

Each session consisted of 630 trials, divided into five blocks. The subject initiated each block and was free to take a minute or so break between blocks. The following events occurred during the list study period.

1. A warning stimulus (+) appeared centered on the screen for 1 s, followed for 1 s by a blank screen.

2–9. The eight words of the short-term memory study list appeared in succession for 0.6 to 1.2 s each, depending upon subjects' prior performance.

10. A brief pause of 0.5 s followed presentation of the last list item.

Following the study period for each list, nine test trials appeared, each of which included: (a) A 0.5-s warning signal (+) appeared centered on the screen. (b) The prime word appeared for a variable SOA between 0.1 and 1.5 s (listed above). (c) The test word appeared on the screen and remained until the subject responded. (d) The subject executed a yes–no recognition response under instructions to respond as quickly as possible consistent with good accuracy. (e) The screen was blank for a 1-s intertrial interval.

Table 1
Experimental Conditions in Experiment 1

Condition	Prime	Test
Related target (RY)	couch	sofa
Related lure (RN)	trousers	pants
Unrelated target (UY)	apple	sofa
Unrelated lure (UN)	apple	pants
Misleading target (MY)	tortoise	sofa
Misleading lure (MN)	tortoise	pants

Note. The study list consisted of the following words: *hermit, curfew, turtle, dogma, candle, sofa, welfare,* and *tennis.* In the experiment, prime and test items were not repeated.

Results

Average reaction times and the proportion correct for the six main conditions at each value of prime duration or SOA are listed in Table 2. Because items were assigned to conditions differently for different subjects, subject variance includes item variance. Considering the reaction times, there was a significant effect of SOA, $F(6, 54) = 3.952$, $p \approx .002$: Reaction time was fastest at midrange SOAs (see the average column on the right of Table 2). However, SOA did not interact with list status (target/lure), $F(6, 64) = 1.203$, *ns*, or prime condition, $F(12, 108) = 0.939$, *ns*, or with the interaction of list status (target/lure) by prime condition, $F(12, 108) = 0.705$, *ns*. Hence, the *pattern* of priming did not depend on SOA in this experiment.[2]

The significant priming effects are summarized by the means shown at the bottom of Table 2 and graphed in Figure 4. Mean reaction time depends on the interaction of prime type with list status (target/lure), $F(2, 18) = 10.556$, $p \approx .000$. Neither prime type nor list status by themselves cause differences in reaction time, $F(2, 18) = 0.381$ and $F(1, 9) = 0.011$, respectively. The presence of a related prime speeds the reaction time for targets relative to unrelated primes but slows the reaction time for lures by an approximately equal amount. (When other-related primes are excluded from the analysis, $F[1, 9] = 14.900$, $p \approx .004$). Misleading (other-related) primes appears to have the opposite effect relative to unrelated primes; however, these differences were not significant. (When related primes are excluded from the analysis, $F[1, 9] = 3.325$, $p \approx .100$.) The proportion correct was quite different for targets (.81) and lures (.94), $F(1, 9) = 14.636$, $p \approx .004$. Further, prime condition interacted with list status (target/lure), $F(2, 18) = 5.553$, $p \approx .013$. These interactions reflect a pattern where presence of a related prime increases the proportion of "yes" responses (increases proportion correct) for targets but also increases the proportion of "yes" responses (decreases the proportion correct) for lures.

Discussion

This experiment demonstrates significant RT priming effects of moderate magnitude in this item recognition task. This is not surprising, given the literature on priming in item recognition reviewed above. A semantic relation between the

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[2] Although it appears from the RT data that priming of targets may be weak at SOAs of less than 500 ms, the same is not true in the error data nor in data for lures, and priming does not significantly interact with SOA. Although this may reflect a lack of power to detect complex interactions, we believe this is unlikely because 350-ms SOA produced large and stable priming in the expected direction in Experiment 2.

Table 2
Experiment 1: Average Reaction Times (RTs, in Seconds) and Proportion Correct (PC)

	Targets						Lures							
	Related		Unrelated		Misleading		Related		Unrelated		Misleading		Average	
SOA	*RT*	*PC*	*RT*	*PC*	*RT*	*PC*	*RT*	*PC*	*RT*	*PC*	*RT*	*PC*	*RT*	*PC*
0.10	0.865	.81	0.831	.78	0.870	.85	0.898	.90	0.882	.94	0.874	.95	0.870	.87
0.25	0.838	.84	0.828	.80	0.864	.79	0.869	.92	0.814	.97	0.834	.94	0.841	.88
0.35	0.814	.80	0.801	.82	0.874	.82	0.841	.91	0.831	.97	0.822	.95	0.831	.88
0.50	0.803	.85	0.837	.85	0.844	.80	0.889	.94	0.847	.95	0.835	.96	0.843	.89
0.70	0.842	.80	0.880	.78	0.853	.79	0.826	.93	0.866	.94	0.805	.96	0.845	.87
1.00	0.811	.86	0.886	.78	0.930	.79	0.874	.93	0.878	.97	0.863	.93	0.874	.87
1.50	0.838	.86	0.915	.80	0.903	.78	0.906	.93	0.847	.94	0.871	.94	0.880	.88
Aver	0.830	.83	0.854	.80	0.877	.80	0.872	.92	0.852	.95	0.845	.95		

Note. Aver = average; SOA = stimulus onset asynchrony.

test word and the prime improves speed and accuracy in responding to targets but decreases speed and accuracy by approximately the same amount in dealing with lures. This can be seen as, averaged across SOA and list status (target/lure), mean reaction times for the three prime conditions were essentially identical (related primes, 0.851 s; unrelated primes, 0.853 s; other-related primes, 0.860 s). Proportion correct for the three prime conditions was identical (0.88).

There was a nonsignificant tendency for other-related or misleading primes to speed responses to lures and slow responses to targets. Percent corrects for unrelated (U) and misleading (M) conditions did not differ. It seems likely that this nonsignificant difference would not replicate because unrelated and misleading primes are shown to be equivalent in the following SAT experiment.

The pattern of latency savings and error rates strongly suggests that priming is the result of constant increment (bias) mechanisms, with no visible enhancement of discrimination performance. We may be on firmer ground in this conclusion here than is usually the case because of the comparability of RT to targets and lures. Nonetheless, this conclusion requires the assumption that comparable RT differences do not depend on the error levels for targets and lures, which are very different here (.81 vs. .93), and the assumption that a difference between .83 and .80 proportion correct for targets exactly offsets a difference between .92 and .95 proportion correct for lures. This conclusion requires a model that specifies how RT and error rates interact, whether errors should be compared in raw values or as differences in z scores, and so forth.

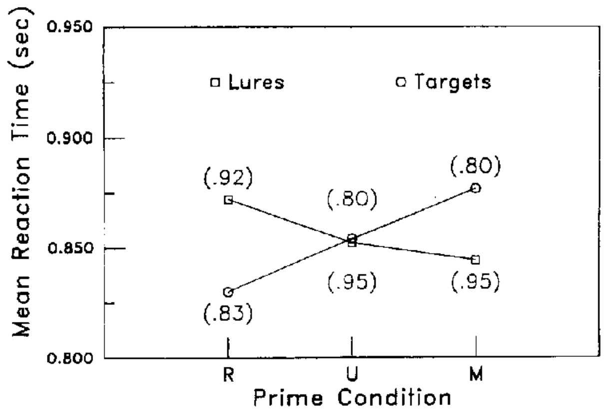

Figure 4. Mean reaction time (proportion correct in parentheses) for priming conditions in a reaction time paradigm (Experiment 1). (Related [R], unrelated [U], and misleading [M] primes have compensatory effects on performance for targets and lures.)

Finally, prime effects were not dependent on SOA. Experimental conditions with comparable SOA ranges and prime types reported in Ratcliff and McKoon (1981) and Neely and Durgunoglu (1985) show a similar independence of prime and SOA. If we had reduced SOA well below 0.1 s, limited processing (and ultimately limited visibility) of the prime would surely have eliminated differential priming effects. However, the important fact here is that the pattern of priming was not significantly different for SOAs normally associated with "automatic" priming (below 0.4 s; see McKoon and Ratcliff, 1979) and those where strategic priming is deemed possible (above 0.4 s). Although an experiment with greater power might have subtle differences at varying SOAs for different conditions, there is no particular reason on the basis of our data to suppose that discriminative priming would develop, given a longer time to process the prime. This suggests that we could select any midrange SOA in the subsequent SAT experiment, and it would be typical of a wide range of SOAs.

Experiment 2: Priming in SAT

This experiment was comparable to Experiment 1, except that it examined the time course of priming by the use of the interruption SAT methodology. SAT controls the time of response and measures accuracy as a dependent variable. This allows direct comparison of the elevation in the probability of a yes response for primed targets and lures at a whole range of times during recognition. Thus, SAT provides a more controlled test of the increment (bias) hypothesis, as well as localizing prime effects to particular times during retrieval.

Method

Subjects. Six subjects participated in the study. Two of subjects (BM and GR, the second and fourth authors) volunteered their services, while the other four were paid for their participation. All had normal or corrected-to-normal vision and hearing and were native speakers of English. They participated in five 50-min sessions, including practice.

Design, stimuli, and procedure. This experiment was formally equivalent to Experiment 1, except that the prime duration factor (SOA) was replaced by a point of interruption factor. The point of interruption (lag) controlled the time of the subject's response. The seven SOAs were replaced in the design by seven lags: at 0.1, 0.3, 0.5, 0.7, 1.0, 1.5, and 2.5 s, again yielding 42 experimental conditions. Here, subjects participated in four experimental sessions, for a total of 2,520 trials, or a sample size of 60 in each of the 42 conditions.

The list presentation in Parts 1–10 was identical to that of Experiment 1. The test procedure was identical to Experiment 1 except for Parts a–f below, which were modified for the SAT methodology. Following the study period for each list, nine test trials appeared, each of which included: (a) A 0.5-s warning signal (+) appeared centered on the screen. (b) The prime word always appeared for 0.35 s, one of the midrange SOAs of Experiment 1. (c) The test word appeared on the screen. At 0.1, 0.3, 0.5, 0.7, 1.0, 1.5, or 2.5 s following the onset of the test item, the screen was erased and a tone, the cue to respond, sounded for 25 ms. (d) The subject executed a yes–no recognition response as quickly as possible *following* the onset of the tone cue-to-respond. (e) Latency feedback appeared centered on the screen for 0.5 s to allow the subjects to monitor their performance. Subjects were instructed that times under 120 ms were anticipations and that times over about 270 ms were too long. (f) The screen was blank for a 1-s intertrial interval.

Subjects typically require one session of practice in the SAT method to bring their latencies to the response cue at short interruption times within acceptable limits. The accuracy levels at asymptote are reviewed every few sessions in order to inform the subject about performance levels.

Results

Main data summaries. The latency and proportion-yes data from the six conditions of the experiment are listed in Table 3 for the average over subjects. (Individual subject data comparable to all tables and figures are available from the authors.) Trials with latencies under 120 ms or over 500 ms were omitted from the analyses. The two analyses of interest—the constant increment (bias) analysis and the discrimination analysis—were derived by appropriate comparison from the data for these main conditions. All important analyses discussed below were based on individual subject data and only summarized by data averaged over subjects. Note that because different subjects saw different stimuli in each condition, subject measures include item variation.

Interruption (lag)-latency analysis. An examination of the latencies shown in Table 3 shows the equality of latency across prime condition, $F(2, 10) = 0.52$, *ns*), as well as the typical dependence of latency on point of interruption, $F(6, 30) = 32.1$, $p \approx .0000$. Additionally, latency varied with response type, $F(1, 5) = 8.95$, $p \approx .030$, with targets producing shorter latencies than lures. Although lag differences in latency affect absolute time estimates, they do not impact upon the comparison of various conditions (Dosher, 1976, 1981, 1982, 1984a, 1984b). By convention, the speed–accuracy trade-off curves will be graphed as accuracy against total processing time (interruption time plus latency).

Summarizing retrieval functions. The pattern of the observed points on the retrieval functions (SAT curves) are summarized by using descriptive equations. We use a retrieval function (Equation 3a) which assumes a time-bounded random walk process (Ratcliff, 1978). One possible alternative assumes that the retrieval function is an exponential approach to a limit, consistent with sampling without replacement (see Dosher, 1979; Wickelgren, 1977). For simple retrieval functions, the two formulations are essentially interchangeable. We use the random walk here because it is easy to generalize to a two-process variation (Ratcliff, 1980).

$$d'(t) = \frac{\lambda}{\sqrt{1 + \nu^2/(t - \delta)}}, \; t > \delta. \qquad (3a)$$

Table 3
Experiment 2: Average Latency and Proportion of Yes Responses

Condition, latency, and proportion	Lag						
	0.1	0.3	0.5	0.7	1.0	1.5	2.5
RY							
RT	0.240	0.180	0.161	0.163	0.156	0.155	0.155
p(yes)	0.647	0.786	0.878	0.892	0.872	0.867	0.881
UY							
RT	0.240	0.185	0.168	0.160	0.156	0.152	0.156
p(yes)	0.614	0.700	0.828	0.822	0.864	0.836	0.828
MY							
RT	0.241	0.196	0.163	0.158	0.152	0.151	0.156
p(yes)	0.595	0.678	0.842	0.861	0.842	0.861	0.845
RN							
RT	0.243	0.196	0.170	0.163	0.154	0.156	0.149
p(yes)	0.509	0.322	0.175	0.147	0.114	0.147	0.083
UN							
RT	0.251	0.196	0.167	0.164	0.161	0.152	0.155
p(yes)	0.517	0.303	0.100	0.100	0.069	0.078	0.075
MN							
RT	0.246	0.198	0.168	0.162	0.155	0.152	0.155
p(yes)	0.494	0.286	0.117	0.092	0.070	0.058	0.072

Note. RT = reaction time; *p*(yes) = proportion of yes responses; RY = related target; UY = unrelated target; MY = misleading target; RN = related lure; UN = unrelated lure; MN = misleading lure.

In Equations (3a–c), λ is the asymptotic accuracy level and δ is the intercept, the time before which accuracy is at chance level. The parameter ν^2 is a combined random-walk variance term that indexes the speed with which accuracy rises from chance to asymptotic level.

The data in Figure 5 show that the impact of priming was larger earlier than later in retrieval (see later discussion). In order to summarize these data satisfactorily, it was necessary to consider two-process models, where the information being integrated changes sometime during retrieval.[3] The equation assumes that the effective strength of information driving the random walk changes at some time t^* mid retrieval ($t^* > \delta$). Prior to t^*, the effective strength is λ_1, and after t^* it is λ_2. The resulting formulas are in Equations 3b and 3c:

$$d'(t) = \frac{\lambda_1}{\sqrt{1 + \nu^2/(t - \delta)}}, \quad \delta < t < t^* \tag{3b}$$

and

$$d'(t) = \frac{\lambda_1 + ((\lambda_1 - \lambda_2 (t^* - \delta)/(t - \delta))}{\sqrt{1 + \nu^2/(t - \delta)}}, \quad t > t^*. \tag{3c}$$

The quality of a model fit was summarized by the statistic

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (d_i - \hat{d}_i)^2/(n - k)}{\sum_{i=1}^{n} (d_i - \bar{d})^2/(n - 1)}, \tag{4}$$

where the d_i are observed d' values, the $\hat{d}_i$ are the predicted values, $\bar{d}$ is the mean, n is the number of data points, and k is the number of free parameters. This is the goodness of fit adjusted for the number of free parameters, or the mean square error accounted for by the model.

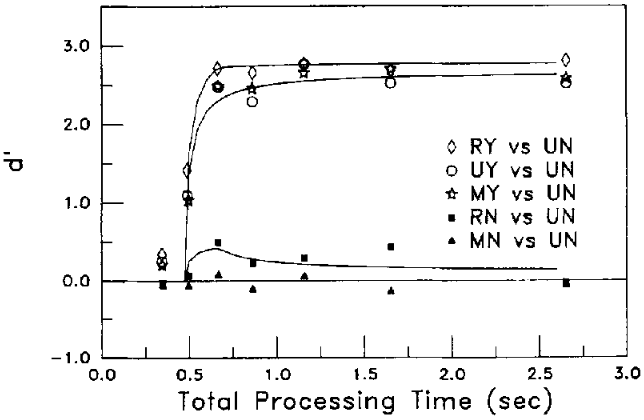

Figure 5. Observed speed–accuracy trade-off (SAT) curves for the increment analysis for priming in an SAT paradigm (Experiment 2). (All conditions are scaled against the unrelated lure [UN] baseline condition. Positive d's for RN or MN conditions represent *decreased* accuracy relative to the baseline. Smooth curves are the best fitting additive increment model. Unrelated and misleading primes do not differ.)

Constant increment (bias) analysis. The first analysis examined empirical speed–accuracy trade-off curves with the "accuracy" measure, d', reflecting the difference of each condition from a single baseline condition, here taken to be lures following an unrelated prime (UN). In the case of related lures (RN vs. UN) and misleading lures (MN vs. UN), any positive d' indicates an increased tendency to say yes to lures relative to the unrelated lure (UN) condition. In the case of RN versus UN, it reflects an increment (bias) that depends on the semantic relation between the prime and the lure. Positive d's to lure conditions actually reflect worse than baseline performance but are convenient because they can be taken to illustrate the relative ordering of the various strength distributions, with the normal lure or UN condition located at 0. If the SAT curve for RY versus UN lies above the curve for UY versus UN, it may be due either to a priming increment (bias), true improvement in discrimination performance, or both.

Figure 5 shows the average (over subjects) SAT curves for this increment/bias analysis. Here and elsewhere, average data is based not on pooling but represents the average of d' computed separately for each subject. There are three main points concerning these data. There is a noticeable impact of a related prime on lures, seen in elevated d's for the RN versus UN condition (solid squares). For some subjects, elevation of false alarms on lures is very substantial. The effect of the prime appears to increase early yes responses, followed by late correction. Because there is a substantial effect of a related item on responses to lures, it is not surprising that there is an effect of the priming stimulus on the response pattern to target (true) items as well (open diamonds). Thus, the constant increment analysis has served one of its purposes, which was to reveal the size and temporal pattern of changes in performance consequent to priming.

Whether this pattern of priming in fact reflects *discriminative enhancement* over and above bias is determined in the following discrimination analyses. Finally, there is no notable difference between unrelated and other-related primes. This is seen both in performance to targets and lures: The UY versus UN (open circles) and MY versus UN (open stars) data do not differ systematically, and the comparison of MN versus UN yields d's which fall near zero (solid triangles).

These results were quantified by examination of sets of descriptive model fits applied to individual and average data. (In the descriptions below, recall that all conditions in this analysis were scaled against unrelated lures.) Models that ignored differences between related targets and unrelated or misleading targets or between related lures and misleading lures yielded lower R^2s and introduced systematic deviations between the model and data. A model that ignored priming differences allowed only two asymptotes (one for true condi-

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[3] The fitted random-walk function has an intercept that excludes the slightly above-chance initial points. This is due to an asymmetry between intercept and rate under this model. The exponential yields slightly better fits, but the random walk is used because of the necessity for the two-process form.

Table 4
Experiment 2: Parameter Estimates for Constant Increment/Bias and Discriminative Models

		Subject					
Parameter	Average	AK	BS	BM	CL	GR	LB
			Bias model				
λ_{1RY}	3.16	3.06	2.55	2.76	3.09	2.46	4.34
λ_{2RY}	2.78	2.19	2.47	2.45	2.68	3.06	3.48
λ_{1RN}	0.49	0.65	0.22	0.45	0.61	−0.23	0.69
λ_{2RN}	0.11	−0.21	0.14	0.14	0.20	0.36	−0.17
$\lambda_{UY=MY}$	2.67	2.41	2.32	2.31	2.48	2.69	3.65
ν^2	0.064	0.016	0.111	0.054	0.071	0.068	0.073
δ	0.477	0.477	0.465	0.487	0.482	0.487	0.430
t^*	0.668	1.166	0.500	0.500	0.500	0.500	0.619
R^2	0.984	0.827	0.944	0.851	0.930	0.924	0.954
			Discriminative model				
λ	2.73	2.21	2.53	2.55	2.54	2.69	3.86
ν^2	0.074	0.022	0.186	0.193	0.065	0.095	0.087
δ	0.473	0.477	0.471	0.370	0.482	0.480	0.424
R^2	0.939	0.801	0.938	0.580	0.914	0.881	0.875

tions and one for false), one "rate" parameter, and one intercept (2λ, $1\nu^2$, 1δ) yielding average R^2 of .973.[4]

The common increment (bias) hypothesis is that familiarity is an additive combination of a memory strength S_m and a relatedness increment S_r, where S_m (N) = S_r (U) = 0. If this were true, the unrelated lure condition UN would have mean familiarity zero, related lures RN would have mean familiarity S_r, unrelated targets UY would have mean familiarity S_m, and related targets RY would have mean familiarity $S_m + S_r$. This specifies a model in which $\lambda_{RY} = \lambda_{UY} + \lambda_{RN}$. Thus, λ_{RN} estimates S_r, λ_{UY} estimates S_m, and λ_{RY} embodies the additive rule. Further, $\lambda_{MY} = \lambda_{UY}$ and $\lambda_{MN} = 0(=\lambda_{UN})$. These final assumptions are supported by nonsignificant differences between conditions UY and MY and between UN and MN in the analysis of the proportion yes data, $F(1, 5) = 0.091$, *ns* and $F(1, 5) = 0.241$, *ns*, respectively. This simple increment model yielded a reasonable fit. However, the data were better described by a somewhat more complex, two-process model.

The model which perhaps best accounts for the retrieval curves under the bias analysis assumes that relatedness strength increment S_r is higher early in retrieval. This leads to elevated false alarms for lures following a related prime but also to elevated hits for targets. However, the relation between prime and test is not properly part of the judgment that the test was from the study list. It appears that some suppression of this information (correction) occurs late in retrieval.

In order to generalize the increment analysis to both the early and late phases of retrieval, we constrained the model so that $\lambda_{1RY} = \lambda_{UY} + \lambda_{1RN}$, $\lambda_{2RY} = \lambda_{UY} + \lambda_{2RN}$. In this pure increment account, elevation in targets exactly equals elevation in lures both early and late in retrieval. This model, like the simple one, assumes that unrelated targets are equivalent to misleading targets, $\lambda_{UY} = \lambda_{MY}$, and that misleading lures are equal to unrelated lures and hence have d' approximately of zero, $\lambda_{MN} = 0$. This account of the data is summarized in the parameter estimates listed in the bias (top) part of Table 4. Two asymptotic parameters each are listed for related true and for related false conditions. The model assumes that the effective strength driving the random walk accumulator shifts at time t^* (dual process), as summarized in Equations 3b and 3c. This reflects suppression (or decay) of priming increments midway through retrieval. Unrelated conditions are fit with a single asymptote (single process). If the additional complication of the dual asymptote fits were unnecessary, then the estimates of the two asymptotes would show no stable pattern over subjects and would differ by a small random amount within subjects. Examination of the bias (top) model of Table 4 shows a pattern of late decrements in asymptote of 5 of the 6 subjects.[5]

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[4] R^2 indexes the quality of fit corrected for the number of estimated parameters. Even models that ignore systematic differences between conditions may have quite high R^2 because they accommodate the overall rising character of retrieval functions. Condition differences are by definition small relative to the large range of d' from chance to asymptote. Additional estimated parameters always maintain or improve r^2, but may lower R^2 if the gains do not outweigh the parameter correction.

[5] In data for primed lures, we use a two-process model, with early and late asymptotes, because it can account for nonmonotonicity in speed–accuracy trade-off curves. In order to observe strong nonmonotonicity with Equations 3b and 3c, $\lambda_1 \gg \lambda_2$, and the achieved d' level by time t^*, $d(t^*)$, must be noticeably higher than the final asymptotic level λ_2. When nonmonotonicity is strong, one is forced to a dual-process account. In the data for primed targets, nonmonotonicity cannot be observed unless $d(t^*) \gg \lambda_2$, a state of affairs that is very unlikely unless t^* is quite late in the retrieval interval, when $d(t^*) \approx \lambda_1$. Hence, it is usually possible to account for dual-process performance on targets by a single-process model that allows rate (ν^2) differences. This alternative would have been possible here. We could

In this case, the discrimination analysis discussed below suggests that the pure increment model is the proper account of the data.

Discrimination analysis. In the complementary analysis, d's are computed in order to assess the ability of the subjects to discriminate between targets and lures, *given identical priming information.* If both a target and a lure were presented following a related prime, was the target retrieved faster—that is, discriminated faster—than when an unrelated prime was present? Figure 6 shows the d's for the discrimination analysis averaged over subjects. In this analysis, RY is scaled against RN, UY versus UN, and MY versus MN. If the constant increment hypothesis were true, prime type would have no effect on these discrimination measures. In fact, the discrimination data do not differ significantly with priming condition, $F(1, 10) = 0.788$, *ns.* The parameter estimates for individual subjects of the simple three-parameter (no condition differences) fit are listed in the discrimination (bottom) part of Table 4. Priming does not enhance discrimination. This conclusion holds for all individual subject analyses, except Subject CL, who may have shown a modest discrimination enhancement resulting from related primes, restricted to early retrieval. CL's best model estimates an early asymptote for related prime conditions of 4.16, the late asymptote equal to that for unrelated and other related primes of 2.54, ν^2 of .0899, δ of .483, t^* of .526 ($R^2 = .923$).[6]

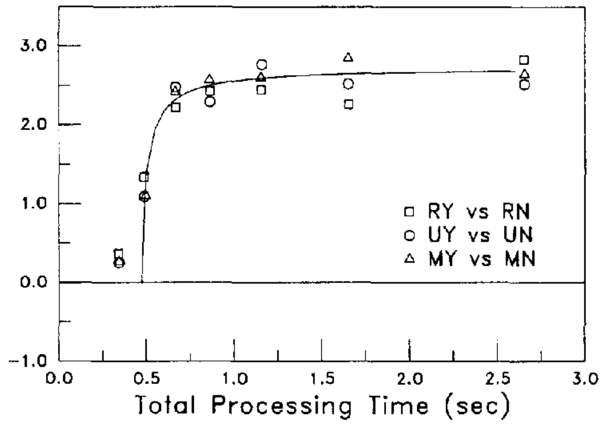

Figure 6. Observed speed-accuracy trade-off (SAT) curves for the discrimination analysis for priming in SAT (Experiment 2). (Targets are scaled against lures matched on priming condition. The three conditions do not differ significantly, consistent with the pure increment model.)

Discussion

In this item recognition experiment there were large and significant increases in yes responses (both hits and false alarms) following related primes. However, *constant increment* (bias) resulting from a semantic relation between prime and test word appeared to be the only mechanism of priming: The increments in hits to targets were purchased at the cost of an exactly equivalent increment in false alarms to lures. With the possible exception of one subject, there was no evidence for *discriminative* priming.

The increment in strength based on prime-target relatedness apparently underwent either suppression or decay sometime after recognition information began to be available. The model we used to summarize the retrieval functions assumes that suppression occurs quantally, at a particular time t^* ($t^* > \delta$), but we cannot actually distinguish this from a more gradual elimination of semantic relatedness information. Late retrieval suppression or decay of priming may be obligatory or may be strategic, reflecting a lack of cue validity between prime relation and correct response.

The notion that pure increment (bias) priming is independent of retrieval of items from the list was supported by the equivalence of unrelated and misleading primes. If subjects used the prime to retrieve or generate a list item, unrelated and misleading primes might function differently. Although misleading primes are not related to the subsequent test (whether target or lure), they are related to a list member; unrelated primes are not related to the test, but neither are they related to a list member. Hence, misleading primes could have resulted (but apparently did not) in the generation of an expectation for a particular list member, which might have made subsequent targets harder to retrieve. Because of the lack of discriminative effects and because of the equivalence of unrelated and misleading primes, it appears that priming effects in these experimental circumstances are not mediated by active, list-based expectations.

Experiment 3: Instructed Priming

In Experiment 3 we investigated whether it is possible to find evidence of discriminative priming when the subject is explicitly instructed to process the relation between the prime and list members. Subjects were instructed to use the prime to try to generate a related word on the study list. We used a lengthy prime duration (1.5 s) in order to allow full processing of the prime. As in Experiment 1, we measured full retrieval

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have treated lures following related primes with a dual-process equation, and targets following related primes with a single-process equation, where the early elevation due to priming was captured by a faster rate parameter for the related targets. The same qualitative fact, early elevation in proportion yes responses, is simply being accounted for, approximately equally well, in somewhat different ways. We elected to treat both related targets and related lures with a constrained form of dual process model; this choice allowed a theoretically coherent treatment of the data.

[6] In the case of discriminative priming, the theoretical motivation for choosing a dual-process account ($\lambda_1 > \lambda_2$) over a simple speed of retrieval explanation ($\nu^2_R < \nu^2_U$) is less strong than for accounts of common increment effects. We choose the dual-process account for convenience.

functions to precisely estimate constant increment (bias) and discrimination effects.

Method

Subjects. Six subjects participated in the experiment. Five were paid for their participation while 1 (BM, the second author) volunteered his services. None of subjects, except BM, served in any of the other experiments. All had normal or corrected-to-normal vision and hearing. They participated in five 55-min sessions, including practice.

Design, stimuli, and procedure. The design, stimuli, and procedure were identical to Experiment 2 with two exceptions. (a) The prime duration was 1.50 s rather than 0.35 s (see Part b in procedure of Experiment 2). (b) The subjects were explicitly instructed to use the prime to make contact with a semantically related list element.

Results

Data summaries. Latency and proportion-yes data for the six main conditions of the experiment are listed in Table 5, averaged over subjects. All important analyses were performed on individual subject data.

Lag-latency functions. The latencies listed in Table 5 depended on point of interruption (lag), $F(6, 30) = 27.5$, $p \approx .0000$, but not on prime condition, $F(2, 10) = 0.970$, *ns*. Latency marginally varied with response type, $F(1, 5) = 4.05$, $p \approx .10$. Again, retrieval functions plot accuracy (d') against average total processing time (lag plus latency).

Increment (bias) analysis. The increment analysis was performed exactly as in Experiment 2. The d' measure scaled all conditions against the unrelated lures. As previously, positive d's for RN and MN lure conditions reflect worse performance than the UN baseline. The speed–accuracy tradeoff functions based on d's from the increment analysis are shown in Figure 7. As in Experiment 2, when the prime and test words are semantically related, the effective strength was higher than unrelated prime conditions; this elevation was especially prominent early in retrieval. Parameter estimates for the same model which summarized the increment data in Experiment 2 (Table 4) are shown in the bias (top) part of Table 6. This model was a generalization of the pure increment (bias) hypothesis to accommodate differences between early and late effects. The model assumed that $\lambda_{1RY} = \lambda_{UY} + \lambda_{1RN}$, $\lambda_{2RY} = \lambda_{UY} + \lambda_{2RN}$, $\lambda_{UY} = \lambda_{MY}$, and $\lambda_{MN} = 0$. The d' value for related lures (RN vs. UN) and the d' difference between related targets (RY vs. UN) and unrelated targets (UY vs. UN) were assumed to estimate the same additive relatedness increment, S_r. The pure increment model generated the smooth curves seen in Figure 7. Two things deserve comment. First, all 6 subjects showed asymptotic increments following related primes, as well as late suppression or decay of this semantic relatedness factor. Second, the estimated intercept of the model fit excludes a significantly above-chance point for the related target condition RY (which is circled in Figure 7). These earliest responses to targets following a related prime (d' for the average data of 0.65; and of 0.77, 1.18, 0.25, 0.35, 0.67, 0.68 for individual subjects) represent a systematic deviation from the model fit. As the subsequent discrimination analyses show, the pure increment model reported in Table 6 is an oversimplification of the data.

Discrimination analysis. The discriminative analysis scaled targets against lures in the same priming condition. Retrieval functions based on discrimination d's are shown in Figure 8. There are two effects of a related prime. First, related primes significantly *lowered* the asymptotic discrimination level, $F(2, 10) = 6.471$, $p \approx .016$, in an analysis of d' for longest three lags. Forcing subjects to attempt to generate a list member related to the prime damaged their overall mem-

Table 5
Experiment 3: Average Latency and Proportion of Yes Responses

Condition, latency, and proportion	Lag 0.1	0.3	0.5	0.7	1.0	1.5	2.5
RY							
RT	0.219	0.180	0.168	0.166	0.162	0.159	0.156
p(yes)	0.604	0.743	0.812	0.794	0.786	0.795	0.817
UY							
RT	0.244	0.192	0.173	0.162	0.157	0.160	0.154
p(yes)	0.411	0.628	0.785	0.776	0.805	0.771	0.775
MY							
RT	0.238	0.192	0.170	0.164	0.161	0.158	0.159
p(yes)	0.387	0.567	0.765	0.754	0.787	0.788	0.824
RN							
RT	0.239	0.202	0.180	0.164	0.158	0.164	0.160
p(yes)	0.393	0.337	0.254	0.168	0.175	0.140	0.167
UN							
RT	0.248	0.206	0.167	0.163	0.161	0.158	0.161
p(yes)	0.368	0.263	0.118	0.105	0.104	0.092	0.097
MN							
RT	0.241	0.196	0.167	0.165	0.164	0.156	0.161
p(yes)	0.366	0.270	0.115	0.125	0.089	0.097	0.072

Note. RT = reaction time; *p*(yes) = proportion of yes responses; RY = related target; UY = unrelated target; MY = misleading target; RN = related lure; UN = unrelated lure; MN = misleading lure.

Table 6
Experiment 3: Parameter Estimates for Constant Increment/Bias Model and Discriminative Model

Parameter	Average	AM	BM	DW	RS	PJ	PW
		Subject					
			Bias model				
λ_{1RY}	3.00	3.77	3.95	2.20	3.29	2.35	3.55
λ_{2RY}	2.37	2.41	2.24	1.73	3.52	1.65	2.89
λ_{1RN}	0.73	1.69	1.38	0.50	0.37	0.58	0.060
λ_{2RN}	0.09	0.33	−0.34	0.03	0.60	−0.12	−0.06
$\lambda_{UY=MY}$	2.28	2.08	2.58	1.70	2.92	1.77	2.95
ν^2	0.061	0.048	0.035	0.065	0.019	0.470	0.096
δ	0.481	0.516	0.488	0.465	0.481	0.522	0.476
t^*	0.625	0.522	0.661	0.588	1.199	1.200	0.662
R^2	0.966	0.885	0.859	0.825	0.926	0.861	0.883
			Discriminative model				
λ_{RY}	2.06	1.38	2.34	1.68	2.68	1.36	2.95
$\lambda_{UY=MY}$	2.37	2.38	2.68	1.74	3.04	1.63	3.26
ν^2	0.705	0.068	0.051	0.192	0.029	0.304	0.237
δ	0.478	0.507	0.479	0.443	0.478	0.449	0.437
R^2	0.930	0.740	0.747	0.713	0.906	0.748	0.776

ory performance when the prime was related to the test element. In particular, related primes damaged performance on lures more than they improved performance on targets (see Table 5). Second, related primes caused differentially improved performance at the earliest point of interruption, even in discrimination performance. This point (circled in Figure 8), as discussed above, is excluded by the model fit shown by the smooth curves. The RY versus RN Lag 1 d' is significantly greater than the UY versus UN Lag 1 d' (Δ = 0.47, $t[5]$ = 7.455, $p \approx .001$). We believe this to be a *matching* related increment. This was not seen in the discrimination data of Experiment 2, where the comparable d' difference was nonsignificant (Δ = 0.10, $t[5]$ = 0.838). (The difference between these differences in the two experiments was also significant: $F[1, 10]$ = 5.702, or equivalently, $t[10]$ = 2.391, $p \approx .038$. This is the same test as the interaction between prime type and experiment performed directly on the d' data.)

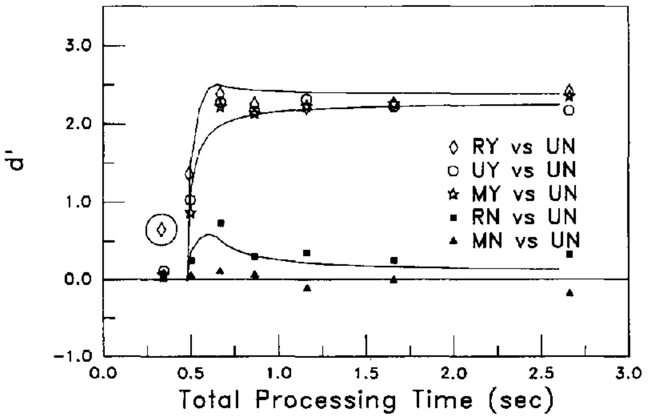

Figure 7. Observed speed–accuracy trade-off (SAT) curves for the increment analysis for priming in the SAT paradigm under instructions to generate a list element from the prime (Experiment 3). (Smooth curves are the best fitting additive increment model. The circled data point of condition RY vs. UN at Lag 1 represents a systematic misfit of the increment model that is attributed to a match between the test and the generated list element.)

Discussion

In this experiment we examined list recognition performance when subjects were instructed to think of a list element that was related to the prime, if one existed. As in the earlier uninstructed experiment, a related prime caused an increment in strength that was larger earlier in the retrieval interval. This is shown by the elevation of related lures (RN vs. UN) above zero and by the elevation of related targets (RY vs. UN) compared with unrelated targets (UY vs. UN). Additionally, however, using the prime to try to think of a list member caused an especially high Lag 1 discrimination d' and late damage to asymptotic performance following related primes (RY vs. RN).

The Lag 1 elevation of RY versus RN d's was localized to related targets by the increment (bias) analysis. We believe it is the consequence of a fast matching strategy. This is the only condition in which the subject can generate a related list member that matches the test word.

The related prime (RY vs. RN) discrimination decrement in performance at asymptote relative to unrelated primes (UY vs. UN) was an unexpected finding. It resulted from an elevation of false alarms to lures greater than the elevation of hits to targets, especially later in retrieval. During the prime processing interval, subjects must engage in several activities. First, the prime word must be read. Next the list is searched for a related word. In the case of related lures, the prime is unrelated to any list word. Perhaps during this process the prime acquires some episodic status and, when the subsequent

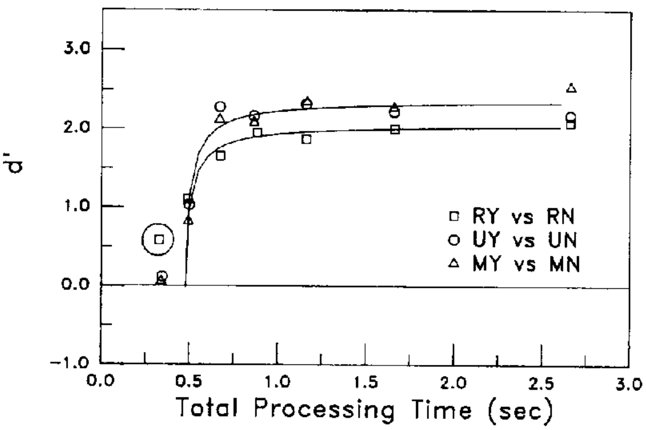

Figure 8. Observed speed–accuracy trade-off curves for the discrimination analysis for instructed priming (Experiment 3). (Because the conditions differ significantly, the pure increment model fails. The smooth curves represent a modified model with differential effect of a related prime. The circled data point again represents a very early accuracy increment that reflects successful generation of the test word.)

lure is related to the prime, a low level of episodic strength attaches to the lure via semantic generalization. This would lower asymptotic performance. This is, of course, merely a post hoc elaboration and restatement of the observed pattern of the data.

There are two important aspects of the failure of the pure increment hypothesis in this experiment. First, active generation of the test word from the prime (a match) has a clear "signature"—a very early accurate response to the test. We take this as a signature of an early matching strategy because it was notably absent in the uninstructed (short SOA) study. Second, generation may also be associated with late episodic confusion between related tests and lures when active generation of a list member is impossible. Again, this pattern of late decrements was not observed in the uninstructed priming experiments.

Experiment 4: Priming From List Elements

In Experiment 4 a priming manipulation is employed in which the "prime" is not identified as such but occurs in the terminal positions of the study list. We report this experiment here because it generalizes our findings to a situation where the prime has higher validity and to a different, somewhat unusual, priming paradigm. The "prime" here is never misleading. If it is related to an earlier list item, then—with the exception of a few filler trails—the following test word was always the matching target. In principle, subjects could have programmed a yes response prior to test presentation. Hence, the matching strategy would have been especially valuable. We demonstrate that some subjects, though not all, spontaneously use matching strategies under these circumstances.

Method

Subjects. Five subjects were paid for their participation. All had normal or corrected-to-normal vision and hearing. They participated in from ten to sixteen 55-min sessions, including practice, depending on scheduling constraints.

Design. All study lists were eight words in length. A related "prime" word (or unrelated word) appeared in either the 7th or 8th list position. There were six main experimental stimulus conditions, illustrated in Table 7. Labeling of the conditions is analogous to that in the prior experiments, except that related conditions are indexed by the list position of the related "prime". Because primes appear in terminal positions of lists, only one test trial follows the learning of each list.

In the experimental trials, the tested *target* words were studied in Position 4. The six stimulus conditions were crossed with seven points of interruption at 0.1, 0.3, 0.5, 0.7, 1.0, 1.5, and 3.0 s, yielding 42 main experimental conditions. In addition, there were a variety of fillers that varied both the positions of the target and of related words (primes), tested randomly at one of the seven interruption times. There was one filler for every six experimental trials. (In debriefing, no subject reported strategic focusing on Position 4 of the study list or, except MH, awareness of the special status of Position 4.) Tokens of the 42 experimental conditions and seven filler conditions (one replication of the experimental design) were presented as one block of 49 trials in a random order, subject to the constraint that no more than four target or lure trials appear in sequence. Each session had five blocks of 245 trials. Sample sizes were as follows: for Subject SO, n per cell = 75, total trials N = 3,150 (plus 525 fillers); for GR, n = 70, N = 2,940 (+490); for YL and TI, n = 70, N = 2,940 (+490). MH ran Prime Position 7 and 8 trials in separate experiments. For MH, n = 40 for each related condition and n = 80 for unrelated conditions, N = 2,240 (+560).

Stimuli. The study lists were constructed from two word lists, one a list of 3,450 unrelated words (see Dosher, 1984a) and the other a 300 pair subset of the related word list used in the previous experiments. The targets and primes were drawn from the related word list (if used on any given trial's list), and all other background words were selected from the unrelated word list. This allowed us to minimize stimulus repetition in the experiment despite the low ratio of test to study trials. There were four random reorderings of each of these lists, pseudorandomly paired in a different way for each session.

Procedure. The apparatus was identical to prior experiments, and the procedure was very similar. Study lists were displayed as in the prior experiments, one over the other for 1 s per word, with a 1 s pause between the last study item and test. Test items, enclosed in brackets five character positions to the left or right, appeared one line below the list items. The procedure was otherwise identical to that of Experiments 2 and 3.

Table 7
Main Trial Types of Experiment 4

	Trial type					
Position	UY	UN	RY8	RN8	RY7	RN7
1						
2						
3						
4	TABLE		TABLE		TABLE	
5						
6						
7					CHAIR	CHAIR
8			CHAIR	CHAIR		
Test	TABLE	TABLE	TABLE	TABLE	TABLE	TABLE

Note. Position refers to the eight elements of a study list; UY = unrelated target; UN = unrelated lure; RY8 = related target with prime in List Position 8; RN8 = related lure with prime in Position 8; RY7 and RN7 are equivalent for prime in Position 7. *Table* and *chair* are examples of related items, and blanks represent filler items.

Results

Data summaries. The latency and proportion-yes data from the six main conditions of the experiment are listed in Table 8, averaged over subjects.

Lag-latency analysis. The latencies in Table 8 differed little across stimulus condition, $F(24, 96) = 1.552$, $p \approx .08$, and, typically, depended on point of interruption, $F(6, 24) = 70.5$, $p \approx 0$.

Constant increment (bias) analysis. The RY and RN data from Prime Positions 7 and 8 showed approximately the same pattern of priming effects when analyzed separately, so we shorten and simplify presentation by reporting a single combined condition. Figure 9 shows the average SAT curves based on d's for the increment or bias analysis. This compares all conditions with the baseline UN condition. The average results are strikingly similar to those of Experiment 3. A semantic relation between "prime" and test increases yes responses to both targets and lures early in retrieval. Smooth curves represent the fit of the pure increment model, with parameters appearing in the bias (top) part of Table 9. In this experiment, late suppression of the relatedness-based increment, S_r, is nearly complete. The potential match process can be seen as a substantial elevation of the Lag 1 d' for RYs that is systematically misfit by the smooth curves.

In this paradigm, there is some nonmonotonicity, even in unrelated prime conditions, which we ignore in the smooth fits. This nonmonotonicity probably reflects forgetting during the retrieval interval—tests in this experiment appeared just after list presentation. A similar pattern of nonmonotonicity was observed by Reed (1973) in a Peterson-Peterson paradigm. The nonmonotonicity causes small systematic deviations from the fitted function which lower R^2.

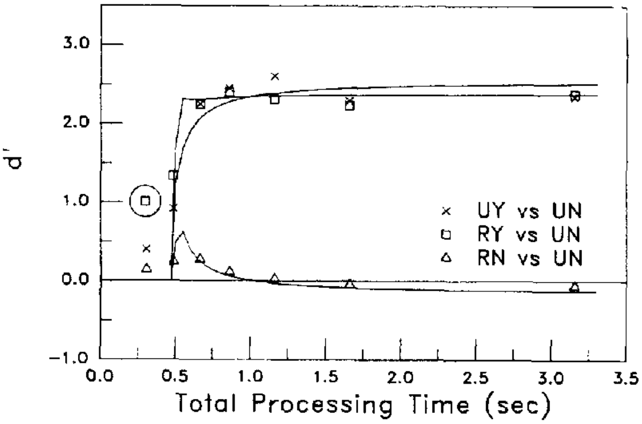

Figure 9. Observed speed–accuracy trade-off curves for the increment analysis for list element priming (Experiment 4).

Discrimination analysis. Figure 10 shows the results of the discrimination d' analysis. In this case, final asymptotic levels were independent of priming. Discrimination d's for the longest three lags showed no significant effects of condition, lag, or the interaction, $F(2, 8) = 0.699$, $F(2, 8) = 1.089$, $F(4, 16) = 1.342$, respectively. The list variant of the priming experiment also shows early discriminative (matching) improvement following related primes. This is largest at Lag 1 (circled), with perhaps a small effect at Lag 2. Best fitting parameters for each subject are listed in the discrimination (bottom) part of Table 9. In this case, most of the discriminative enhancement (the match process) is not captured by the model fit. Again, high early primed points and slight function nonmonotonicity lower the quality of the fits.

Unlike the previous experiment, however, the matching increment in discrimination performance did not occur for all subjects. On the basis of a set of competitive model fits, we identified 3 subjects (GR, SO, and YL) who appear to exhibit discriminative priming. The remaining 2 subjects (TI and MH) do not appear to exhibit discriminative enhance-

Table 8
Experiment 4: Latency and Proportion of Yes Responses

Condition, latency, and proportion	Lag 0.1	0.3	0.5	0.7	1.0	1.5	3.0
UY							
RT	0.204	0.184	0.165	0.160	0.156	0.157	0.154
p(yes)	0.364	0.537	0.786	0.795	0.828	0.803	0.766
UN							
RT	0.207	0.191	0.164	0.159	0.158	0.156	0.153
p(yes)	0.266	0.234	0.118	0.079	0.074	0.083	0.065
RY8							
RT	0.200	0.189	0.173	0.162	0.162	0.158	0.158
p(yes)	0.562	0.643	0.737	0.699	0.740	0.755	0.757
RN8							
RT	0.213	0.196	0.170	0.167	0.162	0.161	0.158
p(yes)	0.268	0.293	0.164	0.107	0.065	0.073	0.055
RY7							
RT	0.183	0.173	0.159	0.155	0.153	0.158	0.152
p(yes)	0.614	0.742	0.836	0.848	0.755	0.794	0.821
RN7							
RT	0.201	0.179	0.160	0.155	0.153	0.154	0.155
p(yes)	0.312	0.312	0.210	0.112	0.103	0.125	0.071

Note. RT = reaction time; *p*(yes) = proportion of yes responses; UY = unrelated target; UN = unrelated lure; RY8 = related target with prime in List Position 8; RN8 = related lure with prime in Position 8; RY7 and RN7 are equivalent for prime in Position 7.

Table 9

Experiment 4: Parameter Estimates for Constant Increment/Bias and Discriminative Models

Parameter	Average	Subject				
		SO	YL	GR	TI	MH
			Bias model			
λ_{1RY}[a]	3.21	3.36	4.22	2.55	2.74	3.51
λ_{2RY}[b]	2.88	3.16	3.82	2.47	2.11	2.45
λ_{1RN}[a]	0.30	0.20	0.40	0.05	0.62	1.02
λ_{2RN}[b]	−0.03	−0.10	0.00	−0.03	−0.01	−0.04
λ_{UY}	2.91	3.26	3.82	2.50	2.12	2.49
ν^2	0.420	0.523	0.546	0.562	0.125	1.136
δ	0.260	0.283	0.211	0.250	0.297	0.419
t^*	0.764	0.840	0.400	0.665	0.685	0.793
R^2	0.934	0.892	0.879	0.773	0.913	0.830
			Discriminative model			
λ_{1RY}	3.10	3.44	4.25	2.66	2.10	1.97
$\lambda_{UY=2RY}$	2.84	3.20	3.61	2.46	2.18	2.47
ν^2	0.436	0.571	0.547	0.614	0.100	0.125
δ	0.269	0.276	0.231	0.250	0.303	0.264
t^*	0.856	1.167	0.846	0.855	0.547	0.400
R^2	0.727	0.650	0.594	0.580	0.689	0.774

[a] λ_{1RY} and λ_{1RN} jointly estimated such that $\lambda_{1RY} = \lambda_{UY} + \lambda_{1RN}$.
[b] λ_{2RY} and λ_{2RN} jointly estimated such that $\lambda_{2RY} = \lambda_{UY} + \lambda_{2RN}$.

ment at all. (In fact, they may show slight estimated decrements due to priming.) Using the model fits to partition the subjects into two sets, we verified the conclusions of those fits. Discrimination *d*'s for the enhancement group indicate a marginal effect of priming condition, $F(2, 4) = 4.604$, $p \approx .09$, an effect of lag, $F(6, 12) = 60.727$, $p \approx 0$, and, most important, a Prime × Lag interaction, $F(12, 24) = 3.026$, $p \approx .01$. The interaction is a meaningful measure here because the three conditions do not differ in asymptote. Net priming scores (*d'* for related prime conditions minus *d'* for unrelated condition for each lag) yield significant effect of lags, $F(6, 12) = 3.308$, $p \approx .03$, but no significant effect of prime position (List Position 7 or 8) or Position × Lag interaction. Direct comparison of net priming scores at Lags 1 and 2 to zero indicate significant priming (mean = 0.669 *d'* units, $F = 31.604$, $p \approx 0$). Equivalent analyses for the no-enhancement subjects yield no effect of prime condition on discrimination scores.

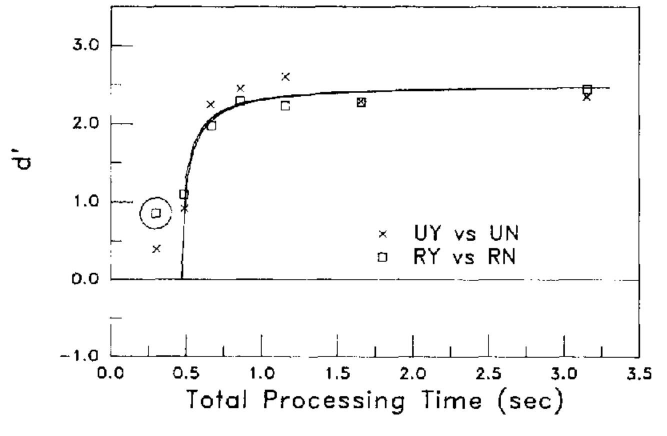

Figure 10. Observed speed–accuracy trade-off curves for the discrimination analysis for list element priming (Experiment 4).

Discussion

When the prime item is included as a terminal or penultimate list member, and the test item follows the list directly, some subjects showed discriminative enhancement as well as common increment effects on item recognition. However, increment effects are the more basic because they are observed for all subjects. No misleading primes were included in this experiment. With the exception of a very small number of fillers, the presence in a list of a related word pair was always followed by the first member of the related pair (a target) as a test. This situation, then, was conducive to the use of an accurate matching strategy on those occasions when a related pair appeared on the list. In this situation, subjects could essentially "precompute" the answer. As in the prior experiment, it is our belief that this kind of simple matching strategy, or something like it, was the basis of discriminative enhancement. This would explain the unusually high *d'* values at the shortest lag for targets following related primes (the elbow in the retrieval functions): It was shown by Wickelgren and Corbett (1977) that yes/no recall matching could be accomplished within 0.2 s or so, well within the range of responses on even the earliest interruption point.

The lack of effect at asymptote means that the presence of a related item in the list neither causes special interference with the target item nor does it elicit special rehearsal of the target item. Intuitively it might seem that the presence of a highly related prime on the study list should increase false alarms even at asymptote due to similarity-based confusion.

However, these factors may be especially weak at short retention intervals where the surface information about words is still strongly represented. For comparison, Gillund and Shiffrin (1984, Figure 4) report a set of recognition experiments where false alarms to synonyms of list members was approximately at control levels.

General Discussion

Empirical Summary

When a semantically related prime precedes a test item presented for a recognition (list-membership) judgment, we consistently observed an improvement in performance on targets but also a decrement in performance on lures. A decrement in performance on lures, by itself, does not exclude the possibility of a prime-based enhancement of retrieval (discrimination). However, with some exceptions, the improvement was not larger than the decrement, and little or no discrimination enhancement was observed. The pattern of priming did not appear to depend strongly on the prime duration. Generally, then, we conclude that in the absence of specific generation instructions, semantic priming in item recognition leads to bias (increment) effects but not to improvement in discrimination (Experiments 1 and 2).

Effects over and above increment effects were limited to situations in which the subjects were instructed to process list elements with reference to the prime (Experiment 3) and, less frequently, occurred spontaneously when a list-prime relation had high cue validity with the response (Experiment 4). Subjects in Experiment 3 were instructed to find a list member that was related to the prime, and they complained that this generation strategy was frequently unproductive because of the inclusion of misleading primes. Misleading primes were related to list elements but unrelated to the tagets or lures which followed. Instructed generation and matching led to a characteristic elevation of discrimination at the earliest interruption point following releated primes. This is a form of discriminative enhancement that we labeled the *matching signature.* Some (but not all) subjects in Experiment 4 spontaneously processed the prime in such a way as to lead to enhancement in discrimination measures at the earliest interruption point. A spontaneous generation strategy may have been more likely in this experiment because of the exclusion of misleading primes, which would have allowed subjects, at the cost of a very few errors on fillers, to entirely precompute the response on those trials where they remember that a related element was present earlier in the list. Even when this simple strategy was available, subjects did not always utilize it. We conclude that bias or increment effects are ubiquitous in semantic priming of item recognition and that any discriminative enhancement is small and task specific. Judging from the current studies and previous reaction time reports, this conclusion may hold for many situations involving semantic priming of episodic judgments, with the special exception of retrieval from short categorized lists. Preretrieving the related list element (which is associated with discriminative matching enhancements) may be more likely when a semantic prime and target are studied together, but because studying a prime and test word together guarantees that the test is a target, appropriately controlled lure conditions are problematic.

Enhanced discrimination may reflect generate-and-match strategies that are specialized to a particular experimental situation. That the pattern of priming effects may depend on details of experimental design has been documented in other situations (i.e., Durgunoglu & Neely, 1987). The matching benefit appears to be restricted to the earliest portions of the retrieval functions. By fairly early in retrieval, the generated information would typically be replaced or exceeded by information from direct recognition. It is not unexpected that this is so because cued generation of a list member by the prime (cued recall) would almost never be followed by a failure to recognize that list member (recognition).

Prime May Not Interact With Item Retrieval

Pure increment mechanisms are at least compatible with the notion that the mechanism of semantic priming in simple item recognition does not change the process of episodic retrieval. The increment model can always be recast as a criterion shift model in which semantic relatedness is evaluated by lexical access processes and is integrated with the *output* of a separate episodic memory process. If this view is correct, the interpretation of some priming effects in very similar task situations is called into question. For example, the fact that semantic primes affected episodic list-membership judgments (McKoon & Ratcliff, 1979) was used to argue against the separability of episodic and semantic stores. However, if the semantic component were the consequence of late integration of semantic and episodic information, one might conclude that information from both semantic and episodic stores is accessed in an episodic task, but not that semantic information *interacted* with episodic retrieval. (McKoon & Ratcliff, 1979, acknowledged this possibility.) The results also call into question the multiplicative strength rule of the SAM model (Gillund & Shiffrin, 1984) as applied to priming in these paradigms (see Dosher & Rosedale, 1989; Ratcliff & McKoon, 1988). One explanation is that the multiplicative rule obtains, but the larger increment for targets happens to be exactly offset by increases in strength variability. Alternatively, the SAM model could treat semantic and episodic associations as occurring in separate systems whose output undergoes additive integration late in the recognition process.

Late Suppression

We accounted for the biphasic nature of priming seen in the increment analyses by assuming a midretrieval shift in the treatment of the prime. We assume that a relation between prime and target causes a (probably unavoidable) increment in familiarity early in recognition. We suggest that the subject recognizes the relation between the target and the prime and attempts to correct for the likely familiarity increment. Often the suppression of the relatedness increment is nearly complete late in retrieval. In a bias account of the data, the initial familiarity increment and its subsequent suppression occur in the same way for targets and lures.

Late-retrieval correction might be specialized to this experiment and others where the existence of a prime–target relation is not a perfectly valid cue to a yes response. In most standard priming paradigms, such as lexical decision, a related prime and target occur only when the subject should say "yes," and hence there is no reason for a correction mechanism (see Neely, 1977). A similar late-retrieval suppression of semantic relatedness between members of a test pair was observed by Dosher (1984b) in episodic judgments of association. In that situation, semantically related pairs could be either episodic pair targets or lures. A related example was reported by Ratcliff and McKoon (1982).

Enhancement in Item Recognition

As described earlier, there have been several reports of semantically (categorically) related primes resulting in facilitation of both targets and lures, and hence discrimination enhancement. All of these cases (Johns, 1985; Lewandowsky, 1986; Macht & O'Brien, 1980; Taylor & Juola, 1974) involve sequential item recognition from categorized lists. Lewandowsky (1986) proposed that facilitation of lures would result following episodic processing of a related prime stimulus and that inhibition of lures would result following semantic processing of a related prime stimulus, relative to the case of unrelated primes. This proposition, at least in simple form, is violated by the results of Experiments 3 and 4. In these experiments the prime stimulus, either by instruction or by requiring study, was processed episodically. In both cases, there is substantial inhibition to lures following a semantically related prime.

In episodic priming, Neely and Durgunoglu (1985) and others either find no effect or find inhibition to single item targets following intralist episodic primes. Yet when episodically related primes precede episodic judgments of associations, Dosher and Rosedale (1989) observed pure discriminative priming: substantial prime effects which were limited to targets and no effect of prime relation on lures. It is apparent that the definition of boundary conditions for bias versus discriminative priming in recognition needs further work. More research will be required to determine whether response characteristics—semantic or episodic nature of the prime—or list characteristics, or all of these, are critical in determining whether bias or discriminative priming will operate in other priming paradigms.

Facilitation on targets and lures virtually guarantees discriminative priming. However, inhibition on primed lures may still be compatible with discriminative priming if facilitation on targets exceeds inhibition on lures. Thus, the distinction we draw between bias and discriminative priming is logically related to, but not identical with, the distinction between lure inhibition and lure facilitation (e.g., Lewandowsky, 1986). We describe some data that show discriminative enhancement in the face of lure inhibition. However, this may reflect matching strategies that may be distinct from enhancement of normal retrieval processes. Further work on semantic priming of item recognition may indicate that the observation of nonmatching-based discriminative priming is equivalent to the observation of lure facilitation, at least within the domain of item recognition.

Related Results in Lexical Decision

Both constant-increment/bias and retrieval enhancement are reasonable mechanisms of priming in lexical decision experiments. Consider the experiments by Meyer and Schvaneveldt (1971) which demonstrate an interaction in reaction time between semantic priming of lexical decision and visual masking of the test string. They found that the semantic priming effect was smaller (in milliseconds of reaction time) for unmasked test strings than for masked test strings. Meyer and Schvaneveldt proposed that semantic primes lowered the threshold for related words and that masking slowed the rate of accumulation of evidence. These assumptions are sufficient to account for the observed interaction. Norris (1986), on the basis of the interaction of word frequency and semantic context, also argues that context operates as a change in criterion, although in this case the criterion change occurs in a postlexical checking operation. In contrast, Becker (1976, 1980) supposed that the prime altered the order in which words were top-down compared with the visual representation of the test item. Discriminating between these two requires finely detailed and theory-dependent observations having to do with sizes of primed sets of words (Becker, 1976, 1980). Seidenberg and McClelland (in press) do not treat semantic context effects in their model of word recognition and naming, and it is not clear how semantic context would be incorporated. They do treat orthographic and phonemic priming as changes in state of the learned weights in the internal memory representation. In either case, a simulation aimed at the issues of bias and discrimination is necessary to determine the status of such a complex system.

It is difficult to construct pure discrimination versus bias comparisons in lexical decision comparable to those reported here for item recognition. In lexical decision, it is possible to test primed nonwords in a variety of ways (Schvaneveldt & McDonald, 1981), but the difficulty is that the nonwords by definition differ from words in a number of complex respects. Further, the performance patterns may depend critically on the judgment required of the subject. The closest analog to the current study in the lexical domain is that of Johnson and Hale (1984), which examined same-different matching performance between a briefly presented and masked word and a matching word, where the correct prime was a self-preexposure. In this context, priming primarily altered bias. Only when short, low-intensity unmasked stimulus presentations were used did priming appear to affect discrimination performance in addition to bias.

Although it is not obligatory that bias and enhancement mechanisms operate identically in the lexical and recognition domains, the parallel between these domains is suggestive. In both domains, it appears that a bias mechanism is fundamental, with some subjects or circumstances allowing retrieval enhancement mechanisms to operate as well.

References

Anderson, N. H. (1981). *Foundation of information integration theory.* New York: Academic Press.

Becker, C. (1976). Semantic context and word frequency effects in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 556–566.

Becker, C. (1980). Semantic context effects in visual word recognition: An analysis of semantic strategies. *Memory & Cognition, 8,* 493–512.

Cottrell, G. W., & Small, S. L. (1983). A connectionist scheme for modelling word sense disambiguation. *Cognition and Brain Theory, 6,* 89–120.

deGroot, A. M. B., Thomassen, A. J. W. M., & Hudson, P. T. W. (1982). Associative facilitation of word recognition as measured from a neutral prime. *Memory & Cognition, 10,* 358–370.

Dosher, B. A. (1976). The retrieval of sentences from memory: A speed–accuracy study. *Cognitive Psychology, 8,* 291–310.

Dosher, B. A. (1979). Empirical approaches to information processing: Speed–accuracy tradeoff or reaction time. *Acta Psychologica, 43,* 347–359.

Dosher, B. A. (1981). The effect of delay and interference: A speed–accuracy study. *Cognitive Psychology, 13,* 551–582.

Dosher, B. A. (1982). Sentence size, network distance and sentence retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 173–207.

Dosher, B. A. (1984a). Degree of learning and retrieval speed: Study time and multiple exposures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 541–574.

Dosher, B. A. (1984b). Discriminating preexperimental (semantic) from learned (episodic) associations: A speed–accuracy study. *Cognitive Psychology, 16,* 519–555.

Dosher, B. A., & Rosedale, G. (1989). Integrated retrieval cues as a mechanism for priming in retrieval from memory. *Journal of Experimental Psychology: General, 118,* 191–211.

Durgunoglu, A. Y., & Neely, J. H. (1987). On obtaining episodic priming in a lexical decision task following paired-associate learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 206–222.

Forster, K. (1976). Accessing the internal lexicon. In R. J. Wales & E. Walker (Eds.), *New approaches to language mechanisms* (pp. 257–287). Amsterdam: North-Holland.

Gillund, G., & Shiffrin, R. M. (1984). A retrieval model for both recognition and recall. *Psychological Review, 91,* 1–67.

Johnston, J. C., & Hale, B. L. (1984). The influence of prior context on word identification: Bias and sensitivity effects. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 243–255). Hillsdale, NJ: Erlbaum.

Johns, E. E. (1985). Effects of list organization on item recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 605–620.

Koriat, A. (1981). Semantic facilitation in lexical decision as a function of prime target association. *Memory & Cognition, 9,* 587–598.

Kroll, J., & Potter, M. C. (1984). Recognizing words, pictures, and concepts: A comparison of lexical, object and reality decisions. *Journal of Verbal Learning and Verbal Behavior, 23,* 39–66.

Lewandowsky, S. (1986). Priming in recognition memory for categorized lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 562–574.

Macht, M. L., & O'Brien, E. J. (1980). Familiarity-based responding in item recognition: Evidence for the role of spreading activation. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 301–318.

Marcel, A. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15,* 197–237.

McKoon, G., & Ratcliff, R. (1979). Priming in episodic and semantic memory. *Journal of Verbal Learning and Verbal Behavior, 18,* 463–480.

McKoon, G., & Ratcliff, R. (1986). Automatic activation of episodic information in a semantic memory task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 108–115.

McKoon, G., Ratcliff, R., & Dell, G. S. (1985). The role of semantic information in episodic retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 742–751.

McKoon, G., Ratcliff, R., & Dell, G. S. (1986). A critical evaluation of the semantic–episodic distinction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12,* 295–306.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90,* 227–243.

Meyer, D. E., & Schvaneveldt, R. W. (1976). Meaning, memory structure, and mental processes. *Science, 192,* 27–32.

Morton, J. (1969). Interaction of information in word recognition, *Psychological Review, 76,* 165–178.

Murdock, B. B. (1982). A theory for the storage and retrieval of item and associative information. *Psychological Review, 89,* 609–626.

Neely, J. H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited capacity attention. *Journal of Experimental Psychology: General, 106,* 226–254.

Neely, J. H., & Durgunoglu, A. Y. (1985). Dissociative episodic and semantic priming effects in episodic recognition and lexical decision tasks. *Journal of Memory and Language, 24,* 466–489.

Neely, J. H., Schmidt, S. R., & Roediger, H. L. (1983). Inhibition from related primes in recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9,* 196–211.

Norris, D. (1986). Word recognition: Context effects without priming. *Cognition, 22,* 93–136.

Raaijmakers, J. G., & Shiffrin, R. M. (1981). Search of associative memory. *Psychological Review, 88,* 93–134.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85,* 59–108.

Ratcliff, R. (1980). A note on modelling accumulation of information when the rate of accumulation changes over time. *Journal of Mathematical Psychology, 21,* 178–184.

Ratcliff, R., & McKoon, G. (1978). Priming in item recognition: Evidence for the propositional structure of sentences. *Journal of Verbal Learning and Verbal Behavior, 17,* 403–417.

Ratcliff, R., & McKoon, G. (1981). Automatic and strategic effects in recognition. *Journal of Verbal Learning and Verbal Behavior, 20,* 204–215.

Ratcliff, R., & McKoon, G. (1982). Speed and accuracy in the processing of false statements about semantic information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 16–37.

Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming in memory. *Psychological Review, 95,* 385–408.

Reed, A. V. (1973). Speed–accuracy trade-off in recognition memory. *Science, 181,* 574–576.

Schvaneveldt, R. W., & McDonald, J. E. (1981). Semantic context and the encoding of words: Evidence for two modes of stimulus analysis. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 673–687.

Seidenberg, M. S., & McClelland, J. L. (in press). A distributed, developmental model of word recognition and naming. *Psychological Review.*

Taylor, G. A., & Juola, J. F. (1974). Priming effects on recognition performance. *Bulletin of the Psychonomic Society, 3,* 277–279.

Tweedy, J. R., Lapinski, R. H., & Schvaneveldt, R. W. (1977). Semantic context effects on word recognition: Influence of varying the proportion of items presented in an appropriate context. *Memory & Cognition, 5,* 84–89.

Warren, R. (1977). Time and spread of activation in memory. *Journal of Experimental Psychology: Human Learning and Memory, 3,* 458–466.

Wickelgren, W. (1977). Speed–accuracy tradeoff and information processing dynamics. *Acta Psychologica, 41,* 67–85.

Wickelgren, W. A., & Corbett, A. T. (1977). Associative interference and retrieval dynamics in yes–no recall and recognition. *Journal of Experimental Psychology: Human Learning and Memory, 3,* 189–202.

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