

Summation of Activation: Evidence From Multiple Primes That Converge and Diverge Within Semantic Memory

David A. Balota and Stephen T. Paul
Washington University

Six experiments addressed the combinatorial influence of multiple related primes in naming, lexical decision, and relatedness judgment performance. Primes either converged on a single semantic representation (e.g., *LION-STRIPES-TIGER*) or diverged onto distinct semantic representations (e.g., *KIDNEY-PLANO-ORGAN*). The facilitatory influence of 2 related primes was well predicted by the sum of the influences from the single-related-prime conditions (a) for both convergent and divergent primes, (b) in lexical-decision and naming, (c) across varying prime-target stimulus onset asynchronies, and (d) under target-degradation conditions that increased the priming effects. The relatedness-judgment task yielded an additive pattern of priming for convergent prime conditions; however, an underadditive pattern of priming was found for divergent prime conditions. Discussion focuses on the role of attentional systems that modulate the type of information used to perform a given task.

The semantic-priming effect refers to the observation that participants are faster, and often more accurate, in responding (e.g., name or make a lexical decision) to a target word (e.g., *BUTTER*) when it follows a related word (e.g., *BREAD*) compared with when it follows an unrelated word (e.g., *CHAIR*). This relatively simple observation was first demonstrated by Meyer and Schvaneveldt (1971) and has since generated well over 150 published articles addressing the mechanisms underlying this phenomenon (see, Neely, 1991, for a recent review).

The present series of experiments addresses two fundamental issues concerning semantic-priming effects: First, we attempt to provide evidence concerning how multiple primes influence target processing. Although there have been studies addressing multiple-word influences on target processing through sentential context (e.g., Stanovich & West, 1983), these studies included multiple types of constraint (e.g., syntactic, pragmatic, and semantic constraints). The majority of published studies that have focused on semantic priming have involved single-word primes. As we show below, the manner in which multiple primes converge on a target representation has important theoretical implications for current models of memory retrieval. The second issue that we address

concerns the difference in the obtained multiple-prime effect between conditions in which the primes converge onto the same semantic representation (e.g., *LION-STRIPES-TIGER*) versus conditions in which the primes diverge onto distinct semantic representations (e.g., *KIDNEY-PLANO-ORGAN*). As we show, the results of this comparison have the potential to provide information about the locus of semantic priming effects (i.e., lexical vs. semantic level) and the nature of the retrieval process.

Before turning to the two central issues addressed in the present series of experiments, it is important to note that there is currently considerable debate about the mechanisms underlying semantic-priming effects. The traditional view is that primes produce a forward spread of activation within a memory network that influences the availability of target representations. More recently, a number of researchers have suggested that the prime and target may be combined during encoding and that it is the familiarity of this compound cue that produces the priming effects (e.g., Doshier & Rosedale, 1989; McKoon & Ratcliff, 1988). In addition, there are connectionist models of priming (e.g., Masson, 1991, 1995; Sharkey, 1990), which assume distributed representations instead of the traditional localist representations (single node corresponding to a single word) that are assumed within the spreading-activation framework. For simplicity, we frame the present experiments within the spreading-activation framework; however, we believe that the results of the present experiments are also clearly relevant to these recent alternative models, and we return to this issue in the General Discussion section.

Multiple Primes: Additivity, Overadditivity, or Underadditivity?

Consider the traditional spreading-activation account of the semantic-priming effect: The notion is that concepts can be represented in memory by nodes interconnected via associative pathways. When a word is presented (e.g., *BUTTER*), its

David A. Balota and Stephen T. Paul, Department of Psychology, Washington University.

This research was supported by National Institute on Aging (NIA) Grants PO1 AG03991 and RO1 AG10193 and by a postdoctoral fellowship funded through NIA Training Grant AG00030. This work represents a collaborative effort. Portions of this research were presented at the 34th Annual Meeting of the Psychonomic Society in Washington, D.C., November, 1993. We would like to thank Marshall Cheney, Lisa Connor, and Shaden Marzouk for their help in various aspects of this research project, and Daniel Spieler and Chris ver Wys for helpful comments on a draft of this article.

Correspondence concerning this article should be addressed to David A. Balota, Department of Psychology, Washington University, Box 1125, St. Louis, Missouri 63130. Electronic mail may be sent via Internet to dbalota@artsci.wustl.edu.

underlying concept node becomes activated and activation spreads from this node to related areas in the network (e.g., *BREAD*). The resulting preactivation of related areas in the memory network is assumed to facilitate any subsequent process that requires access to information in that area of memory (Collins & Loftus, 1975), thereby producing the semantic-priming effect.

Certain predictions derived from the spreading-activation theory have already received empirical support. For instance, because activation is assumed to spread automatically, strategic control over what initially becomes activated should not be possible (cf. Balota, 1983; Neely, 1977; but see Balota, Black, & Cheney, 1992; Smith, Besner, & Miyoshi, 1994, for evidence challenging *strong* versions of this assumption). Also, because activation is assumed to spread automatically through the memory network, nodes should become activated that are not directly connected to the node from which activation originated. That is, although two nodes may not be directly connected (e.g., *LION* and *STRIPES*), it is possible that the two nodes are connected via an intermediate node (*TIGER*) through which activation can spread. Thus, one might expect to find mediated or multiple-step priming effects (e.g., from *LION* to *STRIPES*), as reported by Balota and Lorch (1986) and McNamara and Altarriba (1988).

One of the goals of the present series of experiments is to determine how multiple sources of activation influence target processing. In pursuit of this goal, we used an experimental paradigm in which two primes are sequentially presented and the participant is required to make a speeded response to a target word. There are four conditions of interest, which are produced by crossing prime-to-target relatedness (related vs. unrelated) with prime position (first vs. second), that is, related-related (RR), related-unrelated (RU), unrelated-related (UR), unrelated-unrelated (UU). Thus, within this paradigm, we can obtain an estimate of the facilitatory effects on target processing of each prime in each position (RU and UR) compared with the UU baseline, along with an estimate of the facilitatory effect when both primes are related (RR) compared with the UU baseline.

There are three simple ways to envisage the convergence of activation from multiple sources: additivity, underadditivity, or overadditivity. First, consider the simple additivity assumption. Here, the notion is that the facilitation derived from responding to a target following two related primes should be *equal* to the facilitation observed when only one related prime is presented plus the facilitation obtained when only the other related prime is presented. This simplistic assumption is implicit in network models of memory and is explicit in models such as those outlined by Anderson (1983) and Collins and Loftus (1975).

An underadditive view would be supported if the facilitation from two related primes presented together was *less than* the total facilitation of each related prime when presented separately. For example, consider the possibility that a single related prime produces sufficient activation to approach maximal preactivation of the target. Under these conditions, it is possible that multiple related primes will provide no more benefit than a single related prime if the threshold is surpassed by the activation produced from a single related prime word.

Indeed, evidence consistent with this possibility is available from studies that did not show category-dominance effects in lexical-decision performance (e.g., Lorch, Balota, & Stamm, 1986; Neely, Keefe, & Ross, 1989). That is, the strength of the semantic relationship between the prime and target does not consistently modulate performance, at least not within the lexical-decision task (LDT). However, low category-dominance exemplars do yield less priming than high category-dominance exemplars in naming (e.g., Keefe & Neely, 1990; Lorch et al., 1986).

An overadditive outcome would be supported if the facilitation observed with two related primes was *greater than* the total facilitation of each related prime presented separately. Essentially, this would be expected if it is assumed that the convergence of activation at a specific node serves to direct attention to specific locations in memory. Hence, the additional contribution of activation due to attention will likely result in greater facilitation than would be expected from a simple additive model. In fact, there is some evidence for such a synergistic effect with higher level sentential materials (Balota et al., 1985; Reder, 1983).

There have been only a few studies that have attempted to directly examine the influence of multiple primes on responses to related targets (e.g., Brodeur & Lupker, 1989, 1994; Klein, Briand, Smith, & Smith-Lamothe, 1988; Schmidt, 1976). These studies, in general, support a simple additive view of facilitatory influences of multiple primes. However, there are aspects of each of these studies that limit the extent to which definitive conclusions can be made regarding the way in which multiple primes influence target processing. For example, in each of the previous studies, the LDT was used (with the exception of Brodeur & Lupker, 1989, 1994, who also used a naming task). There is considerable discussion concerning the locus of semantic-priming effects in the LDT (Balota & Lorch, 1986; Neely, 1991; Seidenberg, Waters, Sanders, & Langer, 1984). Because only words are related to primes in the typical priming situation, participants may use the relation between the prime and target to bias their word response. Specifically, if a relation is found between the prime and target, the target must be a word; if no relation is found between the prime and target, the target could be an unrelated word or a nonword, thereby making the decision more difficult and slowing response latencies. The critical question, then, is to what extent are the effects observed with an LDT the result of initial spreading activation or of postlexical strategies specific to the decision components of the LDT. To examine this issue, the present series of experiments provides converging evidence concerning the manner in which multiple primes influence target processing in three different lexical processing tasks: lexical decision, naming, and relatedness judgments.

Another problem with the past studies is the time available for participants to process the prime before the target is presented. In many of the previous studies, the stimulus onset asynchrony (SOA) was long enough that the effects of the primes may have been primarily due to attentional predictive factors instead of to automatic spreading activation (Neely, 1977). To some extent, however, this possibility was addressed by Klein et al. (1988), who used both an 80-ms and 320-ms SOA. Additive influences of primes were observed at the

320-ms delay. However, Klein et al. found that there was no benefit of two primes over a single prime at the 80-ms SOA (i.e., an underadditive pattern of priming). Unfortunately, the inferences that one can draw from Klein et al.'s study regarding multiple-priming effects are somewhat limited by their use of the LDT.

A third problem in all previous studies is that the primes that were related to the targets have also been obviously related to each other (e.g., *FRUIT-PEAR-APPLE*). The problem here is that it is unclear whether the first prime's influence on target processing is direct or indirect (i.e., enhancing the second prime's influence on the target). Therefore, because of a relationship between the primes, one cannot determine the independent contribution of each prime on target recognition. This concern was minimized in the present experiment by capitalizing on mediated stimuli developed by Balota and Lorch (1986) and homographic stimuli in which both primes are related to the target but are not obviously related to each other (e.g., *LION-STRIPES-TIGER; KIDNEY-PIANO-ORGAN*).

Finally, it should be noted that in all previous studies, there was no independent estimate of the facilitatory effects of each prime at each position. Thus, one is unable to obtain an independent estimate of each of the sources of activation to determine the manner (e.g., additive, underadditive, overadditive) in which these separate influences were combined to affect target processing. As noted earlier, by crossing prime relatedness to the target with prime position, the present experiments avoid this problem and provide independent estimates of the influence of each prime in each position.

The Locus of Priming Effects: Semantic Overlap or Lexical-Level Associations?

The second major goal addressed in the present research was to provide information concerning the possible source of semantic-priming effects (i.e., lexical vs. semantic-level influences). More specifically, speeded identification of a target word following a related prime (i.e., priming) can presumably result from one or more levels of analysis (cf. Chiarello, Burgess, Richards, & Pollock, 1990; Fischler, 1977; Lupker, 1984; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Shelton & Martin, 1992). The words themselves may be associatively linked because of simple cooccurrence within natural language at the lexical level (e.g., *MOUSE-CHEESE*), or the concepts representing the words may be linked at the semantic or meaning level (e.g., *MOUSE-RAT*), or both. In the previous studies designed to localize the source of priming in the processing system, the approach taken has involved finding pairs of words that cooccur within a semantic category (e.g., *GLOVE-HAT*) but that do not occur in association norms (e.g., Lupker, 1984; Seidenberg et al., 1984). The argument has been that these prime-target pairs presumably have only a semantic relationship. Unfortunately, the results of these studies have produced inconsistent effects. For example, Lupker (1984) and Shelton and Martin (1992) argued that there was relatively little evidence of pure semantic priming, whereas Fischler (1977) and Seidenberg et al. (1984) argued that there was indeed pure semantic priming.

In addition to the inconsistent results regarding the locus of

semantic-priming effects, we feel that there is an inherent problem in the item-selection procedures used in the past studies that have attempted to differentiate between semantic and lexical priming. Specifically, it is unclear how one can be assured that there is no associative relationship between words that cooccur within a category but do not occur in association norms (McKoon & Ratcliff, 1992). It is possible that given extended time to generate associates, participants may in fact produce *GLOVE* when given the stimulus *HAT*. Indeed, because *CLOTHING* would be a mediator between *GLOVE* and *HAT*, one might expect mediated semantic-priming effects with such stimuli. Moreover, given the right context, one might predict that these two words do actually cooccur in the language as in the following sentence: *Don't forget your hat and gloves before going out and playing in the snow*. Thus, we do not feel that attempting to systematically isolate stimulus types that are orthogonal on associative and semantic relations is a strong test of the locus of priming effects.

Fortunately, the multiple-priming paradigm used in the present series of experiments can provide at least some evidence regarding the locus of priming effects without systematically attempting to select stimuli that are orthogonal on semantic and associative dimensions. Of course, the extent to which one is able to provide such evidence depends critically on the architectural assumptions concerning the underlying semantic and lexical systems. Although we consider alternative architectures in the General Discussion section, our first assumptions are based on a simple localist network representation that includes both facilitatory and inhibitory pathways in the spirit of McClelland and Rumelhart's (1981) interactive-activation model of letter processing and the assumptions of Cottrell (1989), Simpson and Kellas (1989), and Simpson and Kang (1994) concerning ambiguity resolution. It is important to note here that, as in the interactive-activation model, the facilitatory and inhibitory influences are presumed to be passive changes in activation rates. Here, by passive we intend to mean that as activation accrues at one representation, it either automatically increases or decreases activation at connected representations and that this pattern of facilitation and inhibition occurs without explicit attentional control. As noted above, we consider alternative architectural and processing assumptions after discussing the results of the present experiments.

The architectural assumptions that, in part, motivated the present experiments are displayed in Figure 1.¹ Here one can see localist representations for unambiguous targets and for ambiguous targets. As shown in this figure, there is only one lexical node needed to represent ambiguous and unambiguous

¹ It should be noted here that the inclusion of lexical-level associative pathways within the architecture displayed in Figure 1 is a departure from the classic localist logogen model of word processing (Morton, 1969). We have included lexical-level associative links because (a) as noted, there is at least some evidence that priming effects occur at the lexical level (e.g., Lupker, 1984; Shelton & Martin, 1992) and (b) there is some preliminary evidence that simple cooccurrence in language (as reflected by measures taken from the Associated Press news wire, Church & Hanks, 1989) can be a predictor of priming effects (see McKoon & Ratcliff, 1992, Experiment 3).

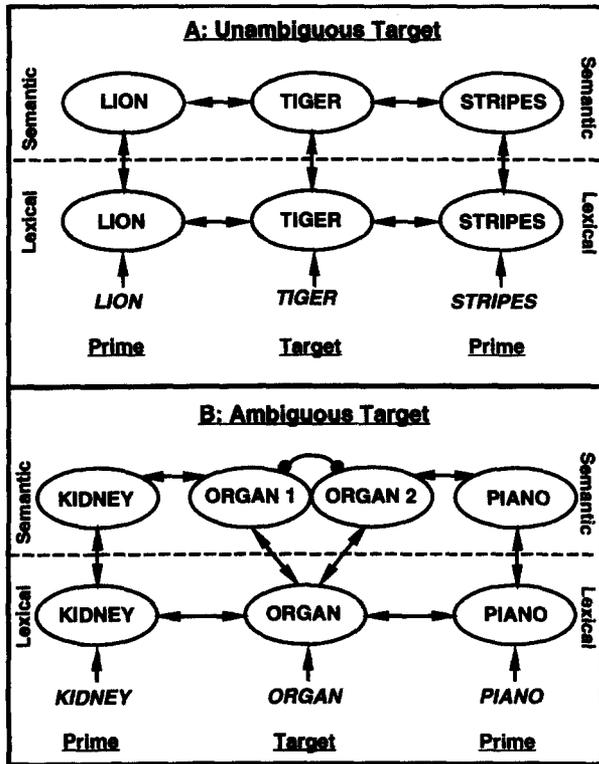


Figure 1. Lexical-semantic processing architecture representing the facilitatory connections (lines with arrows) between two related primes for unambiguous targets and for ambiguous targets. Lines ending with filled circles represent inhibitory connections.

target words. However, at the semantic level, the ambiguous word (e.g., *ORGAN*) requires at least two concept nodes (e.g., one node representing the body meaning and the other node representing the music meaning), whereas the unambiguous word (e.g., *TIGER*) requires only a single conceptual node. When two related primes are presented, both ambiguous and unambiguous conditions are equivalent in terms of lexical-level associations (two each), but at the semantic level, the architectures diverge. For ambiguous words, the prime concepts do not converge on a single semantic representation as they do for unambiguous stimuli. Rather, the concepts activated by each of the primes are entirely unrelated. The only facilitatory pathway between nodes is the one mediated by the lexical-level form of the homograph (i.e., the letter string *ORGAN*).

On the basis of this conceptualization, if priming effects are the result of spreading activation among nodes at the lexical level, the pattern of priming should be similar for responses to both ambiguous and unambiguous targets. Neither stimulus type differs in terms of the number and type of associations at this level of analysis. However, if priming reflects activation and inhibition influences at the semantic level, the pattern of priming effects might be different for ambiguous and unambiguous target conditions. As shown here, the manner in which priming effects differ depends critically on the existence of passive inhibitory connections between alternative interpretations of ambiguous words. As noted above, such inhibitory

connections have been postulated by a number of researchers in the field (Cottrell, 1989; Simpson & Kellas, 1989; Simpson & Kang, 1994) and may serve the important role of suppressing the alternative interpretation of an ambiguous word as the selected interpretation becomes active. In Figure 1B an inhibitory connection is represented by the curved line ending in filled circles that connects the two concept nodes of *ORGAN*. Because of this inhibitory connection, priming effects from two related primes should be larger for unambiguous target words compared with ambiguous target words. Very simply, as activation builds up from the first prime at the semantic level of one interpretation of an ambiguous word, this should have the effect of suppressing the alternative interpretation. Hence, when there is a second prime that is related to the alternative interpretation of an ambiguous word (as in the *KIDNEY-PIANO-ORGAN* example), the second prime word (*PIANO*) should have relatively little influence because its corresponding semantic representation (musical instrument) would have already been suppressed. Thus, on the basis of this architecture and these processing assumptions, one might expect an underadditive influence for the ambiguous targets. Of course, this prediction is based on relatively simple linear changes in the activation levels within this simplified network. Specifically, as one interpretation becomes activated to some extent, the alternative interpretation becomes inhibited to the same extent. Alternative activation frameworks are clearly quite plausible, and as noted, we return to this issue later.

Overview of the Present Experiments

There are two major issues addressed in the present experiments: The first issue addresses the manner in which activation from multiple primes combines to influence target processing (additivity, overadditivity, or underadditivity). Because of task-specific difficulties in inferences drawn from a single task used to measure priming, we investigate such multiple priming effects in lexical decision (Experiments 1 and 2), naming (Experiment 3, 4, and 5), and relatedness judgments (Experiment 6). The second major issue addressed in these experiments concerns the nature of multiple-priming effects under conditions in which the multiple primes converge onto the same semantic representations as opposed to conditions in which the multiple primes diverge onto distinct semantic representations. Thus, in each of the present experiments, we investigate multiple-priming effects with stimuli (semantic categories, unambiguous stimuli, and homographic stimuli) that have different lexical- and semantic-level representations.

Table 1 displays the three different classes of stimuli used in the present research. There are four major conditions within each class of stimuli that are produced by crossing prime relatedness to the target (related vs. unrelated) with prime position (first vs. second). As noted, this paradigm allows us to estimate the independent facilitatory effects of each of the individual primes in each position along with the conjoint effect when both primes are related. For example, if the RU condition produces a 10-ms facilitation effect and the UR condition produces a 20-ms facilitation effect, then a simple additive model would predict a 30-ms facilitation effect when both primes are related to the target.

Table 1
Sample Word Stimuli

Condition	Word stimuli		
	Prime 1	Prime 2	Target
Category label targets (Experiment 1)			
RR	COPPER	BRONZE	METAL
UR	ORDER	BRONZE	METAL
RU	COPPER	WOOL	METAL
UU	ORDER	WOOL	METAL
Ambiguous targets (All experiments)			
RR	KIDNEY	PIANO	ORGAN
UR	WAGON	PIANO	ORGAN
RU	KIDNEY	SODA	ORGAN
UU	WAGON	SODA	ORGAN
Unambiguous targets (Experiments 2-6)			
RR	LION	STRIPES	TIGER
UR	FUEL	STRIPES	TIGER
RU	LION	SHUTTER	TIGER
UU	FUEL	SHUTTER	TIGER

Note. The one-related-prime and two-related-prime conditions were created by replacing related primes with an unrelated word in the first, second, or both prime positions. R = related; U = unrelated.

Experiment 1

One of the goals in the first experiment was to extend the results of previous studies (described above) that obtained additive influences of interrelated primes but that used relatively slow prime-presentation sequences. Therefore, in this study we used relatively fast prime presentation sequences (133 ms per prime, followed by a 33-ms blank interval). Experiment 1 included the interrelated stimuli (category targets) and the ambiguous stimuli (homograph targets) displayed in Table 1. The interrelated stimuli were included to determine if the use of interrelated primes in past multiple-priming studies may have modulated the results. Specifically, in the *COPPER-BRONZE-METAL* example, not only are *COPPER* and *BRONZE* related to *METAL*, but *COPPER* is related to *BRONZE*. Thus, any influence of *COPPER* on the processing of *METAL* may be direct, indirect, or both through the *BRONZE* prime. Later experiments include unambiguous stimuli that do not include interassociations between the primes (e.g., *LION-STRIPES-TIGER*). In addition to the interrelated primes, there is also a set of ambiguous stimuli. On the basis of the assumption of passive inhibitory connections between alternative meanings of ambiguous words, as shown in Figure 1, one might expect relatively more of an underadditive pattern of priming for these targets compared with unambiguous targets.

Method

Participants. Forty participants were tested in this study (no participant was tested in more than one of the experiments). All participants were recruited from undergraduate courses at Washington University and were native English speakers.

Stimuli. Two sets of target stimuli were constructed (106 homographs and 94 category labels), samples of which can be found in Table 1. Ambiguous stimuli (homographs) were taken from Balota (1983),

and interrelated unambiguous stimuli were taken from available norms (e.g., Ashcraft, 1978; Battig & Montague, 1969; Hampton, 1984). Four prime conditions were constructed for each of the 200 possible word targets. An additional set of 200 nonword trials was constructed by taking real words and changing single letters to form pronounceable word-like letter strings that did not actually form English words. Each nonword target was preceded by two prime words never used in the word-target conditions. The primes were both unrelated to each other and unrelated to the target. Target stimuli were counterbalanced across conditions and participants, such that no participant received a stimulus word more than once and targets occurred equally in each of the four prime conditions.

Apparatus. All stimuli in the present experiments were displayed at the center of a NEC MultiSync 2a monitor that was controlled by an IBM-compatible computer. (The only exception is Experiment 5, discussed below.) Stimulus onsets were synchronized with the screen-refresh cycle such that presentation and timing (to the nearest millisecond) were determined from the onset of the target string to the detection of a response.

Procedure. Each trial began with a 100-ms warning tone followed 500 ms later by a visual warning signal consisting of three asterisks (each separated by two spaces) presented at the center of the computer screen. After a 500-ms blank-screen delay, Prime 1 was presented for 133 ms and was followed immediately by Prime 2 at the identical location for 133 ms. Following the offset of the second prime, there was a 33-ms blank screen, which was followed by the target letter string at the same position. Participants were instructed to respond with the computer keyboard as quickly and as accurately as possible by pressing either the Z key if the target stimulus was a nonword, or the / key if the target stimulus was a word. The target was presented for up to 3,250 ms if a response was not made. If a response was not detected within this 3,250-ms interval, then a TOO SLOW message was presented at the center of the screen for 500 ms prior to the onset of the next trial. The intertrial interval was 2 s.

The experimental trials were preceded by 32 practice trials. The experimental stimuli were divided into four blocks of test trials containing the four priming conditions for both category targets and ambiguous targets, and each test block was preceded by four buffer trials (not analyzed). Participants were allowed to rest briefly prior to the start of each block. All stimuli within each block were presented in a random order (determined by the computer) that was unique for each participant.

Results

The following procedure was used to analyze the results of the present experiment and all subsequent experiments. A 2 (target type; unambiguous vs. ambiguous) \times 4 (prime type; RR, RU, UR, UU) within-subjects analysis of variance (ANOVA) was performed on subject (F_1) and item (F_2) mean response latencies, excluding errors and responses greater than 2.5 standard deviations of the means above or below each participant's mean response time. Because of a machine error, the first three experimental trials of Experiment 1 were lost. However, because of the randomization of trials, loss of these trials is unlikely to have systematically influenced the data. Elimination of errors and outliers together represented approximately 6.9% of the total data (1.7% of which were removed as outliers). Unless otherwise noted, effects reported as reliable in the present experiments produced $p < .05$.

Table 2 displays the mean of the participants' mean response latencies as a function of condition. As shown in Table 2, the results are quite straightforward. Specifically, for both

Table 2
Means and Standard Errors in Milliseconds and Error Proportion (*e*) For the Prime-Type and Target-Type Conditions of Experiment 1 (Lexical Decision)

Prime type	Target type					
	Ambiguous			Category label		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	601	14.2	.06	606	14.6	.06
UR	618	17.8	.07	616	15.6	.06
RU	630	16.1	.07	627	16.1	.07
UU	635	16.9	.09	640	15.4	.07

Note. R = related; U = unrelated.

unambiguous and ambiguous targets, the means are ordered from fastest to slowest in the following manner: RR, UR, RU, and UU. The ANOVAs yielded a highly reliable effect of prime type, $F_1(3, 117) = 18.31$, $MSE = 937.92$; $F_2(3, 594) = 7.37$, $MSE = 12,366.41$. All prime conditions differed significantly from one another by both subjects and items (all p s < .01), with the exception of the comparison between the RU and UU conditions, which was marginal ($p = .08$, by subjects and $p = .15$ by items), and the comparison between the RU and the UR conditions, which was marginal by items ($p = .065$). Of more importance, there was no evidence of a Target Type \times Prime Type interaction (both F s < 1), thereby suggesting that the pattern of priming effects was identical for ambiguous and unambiguous targets.

To more directly test the manner in which the primes combined to influence target processing (i.e., additive, overadditive, or underadditive), we separately determined the priming effect from the RU condition compared with the UU condition and the priming effect for the UR condition compared with the UU condition. The notion is that if the priming effect is additive then the sum of the facilitation produced by the single related conditions should equal the priming effect between the RR condition and the UU condition. In fact, this analysis indicated that the facilitation for two related primes (34 ms) was not different from the sum of the two individual facilitation effects for the one-related-prime conditions (9 ms + 21 ms = 30 ms), $F_1(1, 39) = 0.36$.

An analysis identical to the reaction-time analysis was performed on the percentage of errors. Although there were no significant effects in the error-rate data, as one can see in Table 2, the error rates mimicked the response-latency data, and hence, there is no evidence for a speed-accuracy trade-off.

Discussion

The results of Experiment 1 are quite clear: First, the overall pattern is in agreement with previous studies that suggest that the influence of multiple primes is simply additive. In fact, contrary to the prediction of an underadditive pattern for ambiguous target words, as shown in Table 2, the results yielded some evidence of an overadditive pattern for the ambiguous targets. Specifically, the facilitation from two related primes for the ambiguous targets (34 ms) was slightly more than one would expect from the sum of the single related

conditions (5 ms + 17 ms = 22 ms). However, it should be pointed out that this difference did not reach significance, and as discussed below, this pattern was not obtained in any of the subsequent experiments. Hence, we believe these results to be most consistent with a simple additive pattern of priming.

A second noteworthy aspect of the results of Experiment 1 is that there is an interesting pattern of priming effects across the UR and the RU conditions. Specifically, there was reliably more priming for the UR condition compared with the RU condition. Thus, the proximity of the related prime to the target does modulate the priming effect. This could be due to a number of factors: decay of priming, disruption of priming due to an intervening word, or the postlexical checking process discussed earlier that is imposed by the LDT (see Neely, 1991, for a discussion). Third, it is interesting to note that although the priming effect was reliably smaller in the RU condition compared with the UR condition, there was some evidence for priming in the RU condition. This pattern is further confirmed in the following experiments. Moreover, this pattern is important because there has been some debate in the literature concerning priming effects across intervening unrelated words (e.g., Joordens & Besner, 1992; Masson, 1991, 1995).

In addition to the above observations and on the basis of the assumed architecture, the results from Experiment 1 also suggest that semantic-priming effects appear to occur at the lexical level instead of the semantic level. This is indicated by the fact that both ambiguous and unambiguous targets produced identical patterns of priming. As discussed earlier, this would not be expected if responses were driven by semantic-level activation and passive inhibition. If indeed there are between-meaning inhibitory pathways for ambiguous words, one would have expected less of a difference between the RR conditions and the single related conditions for the ambiguous words than for the unambiguous words.

Experiment 2

The purpose of Experiment 2 was to extend the results observed in Experiment 1 to a situation in which we eliminate the interprime associations in the RR condition for the unambiguous words. We included the interrelated RR condition in Experiment 1 because this was the type of multiple-prime condition that was used in the past multiple-prime studies. In fact, we replicated the simple additive pattern observed in the past studies. The question, of course, remains whether one finds the same pattern for unambiguous stimuli when one eliminates potential priming from the first prime to the second prime in the RR condition. In Experiment 2, we attempted to minimize this concern by using primes for unambiguous words that do not have a direct relationship to each other. This was accomplished by replacing the unambiguous stimuli used in Experiment 1 with mediated triplets (cf. Balota & Lorch, 1986). With this method, the prime stimuli were not directly related to each other (e.g., *LION-STRIPES*), but both converged on a related target (e.g., *TIGER*). By comparing the results of Experiment 2 with those obtained in the first experiment, we can address whether the inclusion of interrelated primes may have modulated the pattern of priming effects in the past multiple-prime studies. In addition, this

study affords a more direct comparison of the priming effects for the unambiguous and ambiguous target conditions, because in both conditions the primes are unrelated to each other in the RR condition (see Table 1).

Method

Participants. A total of 48 participants were tested in this study. All participants were recruited from undergraduate courses at Washington University and were native English speakers.

Stimuli. Two sets of 48 word-target stimuli (ambiguous and unambiguous words) were used (see Table 1). As in Experiment 1, for each of the 96 possible target words, four prime conditions were generated (RR, RU, UR, and UU). An additional 96 nonword targets were selected, each of which was preceded by two primes. As in Experiment 1, the primes were both unrelated to each other and unrelated to the target word. Counterbalancing ensured that targets again occurred equally in each condition across participants and that no stimulus was seen more than once per participant.

Procedure. All aspects of the procedure were the same as in Experiment 1, with the following two exceptions: First, for Experiment 2, the experimental trials were preceded by a block of 16 practice trials. Second, the experimental stimuli were divided into two blocks, each preceded by four buffer trials.

Results

Table 3 displays participant means, standard errors of the means, and proportion of errors as a function of target type and prime type. The percentage of responses that were eliminated because of the screening procedure was 1.61%. As shown in Table 3, the results are quite similar to those observed for Experiment 1. Specifically, for both ambiguous and unambiguous words, the means are ordered from fastest to slowest in the following manner: RR, UR, RU, and UU. The main effect of prime type was again highly reliable, $F_1(3, 141) = 27.82$, $MSE = 920.53$; $F_2(3, 282) = 20.27$, $MSE = 1,388.39$. Individual comparisons indicated that all prime types reliably differed from each other. Also, as one can see in Table 3, responses to ambiguous words were slower overall than responses to unambiguous words, $F_1(1, 47) = 68.57$, $MSE = 1,066.03$; $F_2(1, 94) = 19.15$, $MSE = 4,494.89$. Of more importance, however, there was no evidence of a Prime Type \times Target Type interaction (both $F_s < 1$), thereby again suggesting that the pattern of priming effects was quite similar for ambiguous and unambiguous targets.

Table 3
Means and Standard Errors in Milliseconds and Error Proportion (*e*) for the Prime-Type and Target-Type Conditions of Experiment 2 (Lexical Decision)

Prime type	Target type					
	Ambiguous			Unambiguous		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	584	11.8	.05	550	9.1	.03
UR	597	10.4	.06	567	10.9	.02
RU	607	10.9	.04	583	9.9	.04
UU	616	11.1	.08	594	11.0	.07

Note. R = related; U = unrelated.

To further address the manner in which the multiple primes influenced target processing, we compared the facilitatory effects of each of the single prime conditions to determine if the sum of these facilitatory effects differed from those in the RR condition. The results of this analysis indicated that the facilitation for two related primes (38 ms) was not different from the sum of the two facilitation effects for the one-related-prime conditions (10 ms + 23 ms = 33 ms; $F_1 < 1$).

The results of the ANOVA on error rates yielded main effects of target type, $F_1(1, 47) = 6.01$, $MSE = 0.0053$; $F_2(1, 94) = 4.72$, $MSE = 0.0072$, and prime type, $F_1(3, 141) = 10.73$, $MSE = 0.0027$; $F_2(3, 282) = 7.24$, $MSE = 0.0038$. The target-type effect was due to more errors having occurred in the ambiguous-target condition compared with the unambiguous-target condition. For the prime-type main effect, the most errors were made in the UU condition; the fewest errors were made in the RR prime condition, and the single-related-prime conditions yielded relatively intermediate levels of accuracy. The interaction was not significant ($ps > .15$). As shown in Table 3, there was no indication of a speed-accuracy trade-off.

Discussion

Experiment 2 replicated the results of Experiment 1 despite the changes made in the stimuli. Because the same pattern of additivity was found in Experiment 2, in which primes were unrelated to each other but converged onto the target (e.g., *LION-STRIPES-TIGER*), it does not appear that the additive effects found in Experiment 1 for the category primes or the additive effects found in the past multiple-prime studies are due to priming from the first prime to the second prime.²

There are three further noteworthy aspects of the results of Experiment 2. First, the results replicated the pattern obtained in Experiment 1 in that the pattern of priming effects was equivalent for prime conditions that converge onto single semantic representations (unambiguous targets) and primes that diverge onto distinct semantic representations (ambiguous targets). Second, the temporal proximity of the single related prime affected responses (i.e., responses were 13 ms faster in the UR condition than in the RU condition). Finally, priming effects were again observed between a related prime and target when an unrelated item intervened (i.e., there was a reliable priming effect in the RU condition compared with the UU baseline).

² A possible concern is that because in both Experiments 1 and 2 the word primes for the nonword targets were both unrelated to each other and unrelated to the target nonword, participants may have had a bias to respond *word* when a relationship between the primes is detected. We decided to use unrelated word primes for the nonword targets because both for the primes used for the unambiguous targets in Experiment 2 (e.g., *LIONS-STRIPES*) and for the primes used for the ambiguous targets used in Experiments 1 and 2 (e.g., *KIDNEY-PIANO*), there is no obvious relation between the primes before the target is presented. Moreover, as described later, because similar results are found in naming experiments that do not include nonword trials, we are confident that the present additive pattern of data for both ambiguous and unambiguous targets is not due to a bias to respond *word* or *nonword* because of differences in the characteristics of the primes for word and nonword trials.

Experiment 3

Before one can make strong inferences regarding the nature of the present priming results, one must ensure that task-specific processes associated with the LDT are not modulating the obtained pattern of priming effects. As mentioned earlier, priming effects in the LDT not only reflect forward influences of primes on target processing (as suggested by spreading activation models) but also reflect contributing influences of postlexical checking processes that occur as part of the binary-decision process inherent in the LDT (Neely, 1991). Experiment 3 addresses the possibility that the outcomes of the previous two experiments were influenced by task-specific decision strategies associated with the LDT by using a naming task, which presumably minimizes such postaccess decision processes (cf. Balota & Lorch, 1986; Keefe & Neely, 1990; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982).

Method

Participants. A total of 64 participants were tested in this study. All participants were recruited from undergraduate courses at Washington University and were native English speakers.

Stimuli. Two sets of 48 target stimuli (ambiguous and unambiguous) were constructed (see Table 1), along with an additional set of 48 filler trials to increase the number of total trials in approximation to the lexical-decision experiments. Again, there were four prime conditions. Finally, 44 additional target stimuli and accompanying primes were used as practice and buffer trials. Targets were again counterbalanced across participants in the manner described for the first two experiments.

Apparatus. To obtain voice-onset latencies, the computer was interfaced with a Gerbrands Model G1341T voice-activated relay.

Procedure. All aspects of the procedure were the same as in the previous two experiments with the following exceptions. First, this experiment did not include any nonwords. Second, participants made a naming response instead of a lexical decision to the target. Third, experimental trials were preceded by a block of 36 practice trials. Fourth, the experimental stimuli were randomly divided into two blocks of 72 trials, and within each block, each condition was equally represented. Finally, each block was preceded by four buffer trials, and there was a short rest break between test blocks.

Results

Table 4 displays the means, standard errors of the means, and proportion of errors as a function of target type and prime

Table 4
Means and Standard Errors in Milliseconds and Error Proportion (*e*) for the Prime-Type and Target-Type Conditions of Experiment 3 (Naming)

Prime type	Target type					
	Ambiguous			Unambiguous		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	510	8.4	.03	507	8.1	.02
UR	514	8.4	.02	509	8.3	.02
RU	519	8.1	.02	512	7.7	.02
UU	525	8.7	.04	520	9.3	.02

Note. R = related; U = unrelated.

type. As shown, the influence of the primes was again quite similar for the ambiguous and unambiguous target words. The results of the ANOVAs yielded a highly reliable effect of prime type in the subjects analysis, $F_1(3, 189) = 11.34, MSE = 421.16$, which was marginally significant in the items analysis, $F_2(3, 282) = 2.52, p = .06$. There was an effect of target type which reached significance only in the subjects analysis, $F_1(1, 63) = 9.47, MSE = 332.58; F_2(1, 94) = 1.26, MSE = 1,973.88, p = .26$. As shown in Table 4, the prime effect resulted in a pattern similar to that observed in Experiments 1 and 2. Separate examinations of the prime conditions (by subjects) were not significant for the RR-UR or RU-UR comparisons. The RR-UR comparison, however, was marginal by subjects, $F_1(1, 63) = 3.17, MSE = 122.30, p = .08$. The UR-UU and RR-UU comparisons were significant by items. Of more importance, there was no hint of a Target Type \times Prime Type interaction (both $F_s < 1.00$).

We again tested a simple additivity assumption by comparing the facilitation effects from the sum of the single-related-prime conditions with the facilitation effect observed from the RR condition. This analysis indicated that the facilitation for two related primes (14 ms) was not different from the sum of the two individual facilitation effects for the one-related-prime conditions (7 ms + 11 ms = 18 ms; $F_1 < 1$).

Analysis of errors revealed no significant effects in either the analysis by subjects or by items (all $p_s > .15$). There was no indication of a speed-accuracy trade-off.

Discussion

The results of Experiment 3 converged with the results of Experiments 1 and 2 in demonstrating that the influence of multiple primes produces additive effects. As is typical in the word-recognition literature, the priming effects were somewhat diminished in the naming task compared with the LDT used in the first two experiments. Although the overall effects were small, it is noteworthy that there was still reliable priming across an unrelated condition in the RU prime condition. In addition, there was again slightly more priming (a nonsignificant 4 ms) in the UR condition compared with the RU condition, suggesting that even in a naming task the proximity of the prime to the target does appear to modulate the size of the priming effect.

One somewhat surprising result from the first three experiments is that there is little difference between the priming patterns for conditions in which the primes activate different meanings of the target word versus conditions in which the primes activate the same meaning of the target word. These results indicate either that the assumed architecture displayed in Figure 1 is incorrect or that the observed priming effects are more likely to have been due to lexical-level associations instead of semantic-level involvement. However, before drawing strong inferences from the first three experiments, an attempt was made to increase the sensitivity of the experiments to detect a difference between ambiguous and unambiguous targets.

There are three factors that might have minimized the sensitivity to differences in the pattern of priming effects for ambiguous and unambiguous targets. First, the SOA between

the primes and the target was relatively short in the first three experiments. It may be the case that with relatively short prime durations (133 ms per prime) there is insufficient time for the prime to influence target processing at a semantic level. Possibly, participants are able to process and respond to the target before prime activation has made sufficient contact with semantic-level information to affect response latencies. This possibility is addressed in Experiment 4 by increasing the time allowed to process the primes. A second factor is that for skilled readers, as with those in the present experiments, target processing is relatively automatic, thereby minimizing the influence of context. This would be consistent with the interactive-compensatory model proposed by Stanovich and West (1983). Therefore, in Experiment 5, we attempted to increase the reliance on context by degrading the target by adding ampersands to the target-stimulus display (e.g., *TIGER* now was presented as *&T&I&G&E&R&*). Finally, it is possible that the present experiments involve tasks (naming and lexical decision) that direct attention to lexical-level processes instead of semantic-level processes. Thus, in Experiment 6, we required participants to attend to semantic-level information by using a relatedness judgment task.

Experiment 4

Experiment 4 was designed to allow more time for the processing of the first prime by increasing the exposure duration of this prime to 1,000 ms. Under these conditions, one should be more likely to observe differences in the pattern of priming effects for ambiguous and unambiguous target words. That is, there is now sufficient time for the first prime to access semantics, and this should then constrain the interpretation of the upcoming ambiguous word. Hence, there should be little benefit of a short-duration second prime that is unrelated to the more strongly biased interpretation of the ambiguous word. For example, increasing the exposure duration of the prime *KIDNEY* should result in activation of the meaning of *ORGAN* referring to a bodily organ, and hence there should be little benefit from a second prime (*PIANO*) presented for only 125 ms that is related to the alternative meaning of *ORGAN* (i.e., the RR condition should be very similar to the RU condition). An underadditive pattern is therefore predicted for the ambiguous-target condition. On the other hand, for unambiguous targets, there should be a convergence of activation both at lexical- and semantic-level representations, and one should again observe additivity.

Method

Participants. A total of 48 participants were tested in this study. All participants were recruited from undergraduate courses at Washington University and were native English speakers.

Stimuli. The stimulus set used in Experiment 3 was also used for the present experiment.

Procedure. With the exception of increasing the exposure duration of the first prime from 133 ms to 1,000 ms, all aspects of the procedure were the same as those in Experiment 3.

Results

Table 5 contains participant means, standard errors of the means, and proportion of errors as a function of prime and target type. The percentage of responses that were eliminated because of the screening procedure was 2.63%. As shown in Table 5, the results are again quite consistent with the previous experiments. Specifically, the effects overall are supportive of a simple additive model and are quite similar for both ambiguous and unambiguous target words. The results of the ANOVA yielded significant main effects of both prime type, $F_1(3, 141) = 10.81, MSE = 261.55; F_2(3, 282) = 5.72, MSE = 491.52$, and target type, $F_1(1, 47) = 15.70, MSE = 362.72; F_2(1, 94) = 3.20, MSE = 1,828.89, p = .077$. Direct comparisons of the means revealed that all but two differed significantly ($p < .01$). Specifically, the difference between the RR and the UR condition and the difference between the RU and the UR prime conditions did not reach significance in either the subjects or the items analysis. The interaction between prime type and target type did not approach significance (both $F_s < 1$).

We again tested whether the priming effect for the RR condition (13 ms) was different from the added effects of the two single-related-prime conditions (6 ms + 9 ms = 15 ms), and again there was no evidence of divergence from simple additivity ($F_1 < 1$).

An analysis identical to the latency analysis was also performed on errors. No significant differences were obtained (all $F_s < 1.2$). There was no evidence of a speed-accuracy trade-off.

Discussion

The results of Experiment 4 again clearly yielded an additive pattern of priming effects. Moreover, despite the increased duration of the first prime to a full second, Experiment 4 provided an equivalent pattern of priming effects for both ambiguous and unambiguous target words. It is particularly noteworthy that for the ambiguous targets, the presence of a second related prime word in the RR condition (*KIDNEY-PIANO-ORGAN*) still produced reliably more facilitation compared with the RU condition (*KIDNEY-CHAIR-ORGAN*), even though the second word (*PIANO*) in the RR condition was unrelated to the strongly biasing first word (*KIDNEY*) and was presented only for 125 ms.

Table 5
Means and Standard Errors in Milliseconds and Error Proportion (*e*) for the Prime-Type and Target-Type Conditions of Experiment 4 (Long Duration Prime 1)

Prime type	Target type					
	Ambiguous			Unambiguous		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	491	8.7	.04	483	8.3	.05
UR	495	8.5	.04	487	8.1	.05
RU	499	9.1	.06	489	7.7	.04
UU	502	9.0	.04	497	8.5	.05

Note. R = related; U = unrelated.

Experiment 5

In Experiment 5, an attempt was made to increase the participants' reliance on the contextual information available in the primes. It is possible that the relatively fluent lexical processing that occurs in college-aged readers allows them to complete target processing before a semantic influence of the primes can affect the target representations. This would of course eliminate the possibility of detecting a difference between target words with multiple and single semantic representations. In Experiment 5, we attempted to decrease the efficiency of target processing by degrading the target stimulus. The notion here is that when the target is degraded, there should be more time for the primes to engage semantic representations. As noted earlier, this prediction is quite consistent with an interactive-compensatory model in which slower lexical processing will lead to increased top-down (possibly semantic-level) influences (e.g., Stanovich & West, 1981). Thus, in Experiment 5, the targets were presented with ampersands flanking each letter in a word (e.g., *&T&I&G&E&R&*). We chose this type of degradation because there is evidence indicating that the interleaving of asterisks primarily influences the facilitatory effects of the primes compared with a neutral prime condition (cf. Durgunoglu, 1988). Because inhibitory effects are believed to be markers for attentional processes (e.g., Neely, 1977), we wanted to minimize the attentional processing that appears to accompany other forms of degradation, such as contrast reduction (cf. Durgunoglu, 1988; Stanovich & West, 1983). Finally, we also changed the prime durations to 250 ms per prime to maximize the likelihood of obtaining differences between the ambiguous and unambiguous target words.

Method

Participants. A total of 48 participants were tested in this study. All participants were recruited from undergraduate courses at Washington University and were native English speakers.

Stimuli. The target stimuli used in Experiment 4 were used in this experiment. The only exception is that this experiment did not include the filler trials. As we see below, the presence of the filler trials in Experiment 4 was unlikely to have compromised the results.

Procedure. Aspects of the procedure were the same as those of Experiment 4 with two exceptions: First, for Experiment 5, prime durations were adjusted to 250 ms each (to maximize the possibility of detecting differences between target conditions), and targets were presented with ampersands flanking each letter. Second, experimental trials were preceded by a block of 32 practice trials. Third, the experimental stimuli were divided into two blocks of 48 trials, each preceded by 4 buffer trials.

Results

Table 6 displays participant means, standard errors of the means, and proportion of errors as a function of target type and prime type. A total of 3.3% of the trials were identified as outliers. There are three points to note in Table 6. First, as one can see, overall response latencies are 150–200 ms slower than in the previous naming studies (Experiments 3 and 4). Hence, the degradation manipulation had the desired effect of decreasing the speed of target processing. In addition, the context

Table 6

Means and Standard Errors in Milliseconds and Error Proportion (e) for the Prime-Type and Target-Type Conditions of Experiment 5 (Degraded Targets)

Prime type	Target type					
	Ambiguous			Unambiguous		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	584	13.5	.05	571	12.1	.03
UR	603	15.6	.08	599	14.4	.05
RU	603	15.9	.07	591	13.5	.05
UU	620	16.1	.06	617	15.7	.08

Note. R = related; U = unrelated.

effects are 2 to 3 times larger in Experiment 5 compared with the previous naming studies (e.g., the difference between the RR condition and the UU condition was 14 ms in Experiment 3 and 13 ms in Experiment 4, whereas in Experiment 5, the difference was 41 ms). Thus, as expected (cf. Besner & Smith, 1992; Meyer, Schvaneveldt, & Ruddy, 1975; Stolz & Neely, 1995), the degradation manipulation did increase the context effects. Although the overall priming increased in this experiment, it is important to note that the pattern of priming effects was quite consistent with the previous experiments. Specifically, the facilitatory effects of the different prime conditions were again similar for ambiguous and unambiguous words, and the priming effects appear to best support a simple additive model. The results of the ANOVA yielded a main effect of target type that reached significance only by subjects, $F_1(1, 47) = 7.19$, $MSE = 859.85$; $F_2(1, 94) < 1.00$, and yielded a highly reliable main effect of prime type, $F_1(3, 141) = 24.58$, $MSE = 1,084.24$; $F_2(3, 282) = 29.28$, $MSE = 1,721.47$. Planned comparisons indicated that all prime conditions were reliably different from one another with the exception of the RU and the UR comparison. The Target Type \times Prime Type interaction did not approach significance, $F_1(3, 141) = 0.68$, $MSE = 958.00$; $F_2(3, 282) = 1.74$, $MSE = 1,721.47$. Finally, the comparison of the priming effect of the two-related-prime conditions (41 ms) against the sum of the priming effects of the single-related-prime conditions (18 ms + 21 ms = 39 ms) did not approach significance ($F < 1$). Hence, again the results supported the simple additivity assumption.

An ANOVA identical to the reaction-time analysis was performed on errors. This analysis yielded a main effect of prime type that was reliable only in the subjects ANOVA, $F_1(3, 141) = 4.51$, $MSE = 0.66$; $F_2(3, 282) < 1.00$. As shown in Table 6, this effect mimicked the pattern in the response-latency data, and therefore there is no evidence of a speed-accuracy trade-off.

Discussion

The goal of Experiment 5 was to slow lexical processing of the target to determine if there would be an increased reliance on contextual (possibly semantic) information, thereby increasing the likelihood of observing a difference between ambiguous and unambiguous target conditions. The degradation manipulation was successful in that overall response latency

was increased by 150 ms to 200 ms compared with the previous naming studies, and there was a threefold increase in the obtained priming effects. However, this study yielded results that were precisely the same as those the previous studies. Specifically, the results supported a simple additive model of priming both for target words that have distinct semantic representations (ambiguous words) and for target words that do not have distinct semantic representations (unambiguous words).

Experiment 6

In each of the five previous experiments, we used tasks that directed attention implicitly to lexical-level processing of the target (i.e., speeded naming and lexical decision). However, in natural language processing attention is not typically focused on lexical-level representations but rather is more likely directed to meaning-level integration processes. In the following study, we attempted to direct participants' attention to meaning-level representations by changing the task to a relatedness-judgment task. On each trial, participants were required to determine as quickly as possible whether at least one of the prime words was related to the target. Because participants were required to process the meanings of the words in this task, it was expected that this task would be more sensitive to the distinction between lexical- and semantic-level representations as depicted in Figure 1.

Method

Participants. Thirty-two native English-speaking participants were recruited from undergraduate courses at Washington University.

Stimuli. The stimuli used for Experiment 4 were again used for the present experiment. However, because participants were required to respond *related* when either or both of the primes were related to the target, three of the four priming conditions produced a *yes* response. To keep the types of responses made by participants proportional across trials (i.e., *yes* vs. *no*), an additional set of 48 UU filler trials were included. None of the words that were included in the buffer trials were used in the experimental trials.

Procedure. The procedure was similar to the procedures in the previous experiments with the following exceptions: First, as in Experiment 5, the exposure duration of each prime was 250 ms. Second, participants were instructed to press one mouse key if one or both of the primes were related to the target and to press the other mouse key if neither of the primes were related to the target. The *related* response key was keyed by each participant's preferred finger. Immediately following a response, the computer briefly displayed the word CORRECT if participants made the correct response or INCORRECT if participants made the incorrect response.

Results

Table 7 displays participants mean response latencies, standard errors of the means, and proportion of errors as a function of prime condition for the ambiguous and unambiguous target words. Only 0.42% of the trials were trimmed because of the outlier criteria. As shown in Table 7, the results from this experiment are quite different from those of the previous experiments in that there is a considerable difference between the pattern of priming effects for the unambiguous

Table 7
Means and Standard Errors in Milliseconds and Error Proportion (*e*) for the Prime-Type and Target-Type Conditions of Experiment 6 (Relatedness Judgment)

Prime type	Target type					
	Ambiguous			Unambiguous		
	<i>M</i>	<i>SE</i>	<i>e</i>	<i>M</i>	<i>SE</i>	<i>e</i>
RR	828	37.3	.10	718	30.1	.03
UR	865	37.9	.16	858	37.5	.15
RU	844	37.0	.21	839	40.3	.15
UU	1,028	55.5	.19	980	45.0	.13

Note. R = related; U = unrelated.

and ambiguous target words. For the unambiguous targets, there was a 131-ms difference between the two-related-prime condition and the single-related-prime conditions, whereas for the ambiguous targets, this difference was only 27 ms. This finding strongly suggests an underadditive outcome for the ambiguous words only. The results from the ANOVA yielded main effects of prime type, $F_1(3, 93) = 24.14$, $MSE = 24,857.66$; $F_2(3, 282) = 63.33$, $MSE = 16,653.18$, and target type, $F_1(1, 31) = 12.59$, $MSE = 9,176.71$; $F_2(1, 94) = 10.05$, $MSE = 24,175.87$. Of more importance, the results yielded a highly reliable interaction between prime type and target type, $F_1(3, 93) = 4.49$, $MSE = 8,694.87$; $F_2(3, 282) = 2.81$, $MSE = 16,653.18$.³ Direct examination of the pattern of priming for the unambiguous target conditions by subjects indicated that all priming conditions were reliably different ($ps < .05$), with the exception of the comparison between the UR condition and the RU condition ($F_s < 1$). An analysis of the ambiguous-word conditions indicated that all related conditions were reliably different from the UU condition ($ps < .05$). None of the comparisons among the related conditions were significant, although the RR versus UR comparison was marginal ($p < .07$).

We again tested a simple additivity assumption by comparing the facilitation effects from the sum of the single-related-prime conditions with the facilitation effects observed for the RR condition. Because the overall ANOVA yielded a Target Type \times Prime Type interaction, we conducted this separately for the unambiguous and ambiguous targets. For the unambiguous targets, the results were quite remarkably consistent with the additivity assumption. Specifically, the facilitation of the two-related-prime condition (262 ms) was identical to the sum of the two individual facilitation effects for the one-related-

³ One may be concerned that the UU condition is not an appropriate baseline because in this experiment participants were making a different response (i.e., *yes* vs. *no*) for the three related conditions compared with the single unrelated condition. Because we are comparing both ambiguous and unambiguous targets to the same UU baseline, we do not feel that this diminishes the strength of our arguments across target class. However, we also conducted ANOVAs that included only the three conditions that produced *yes* responses (i.e., RR, RU, and UR). The results were identical to those that included the UU conditions. Specifically, there were significant main effects of target and prime type and interactions between target and prime type for both subjects and items ANOVAs (all $ps < .01$).

prime conditions (141 ms + 122 ms = 263 ms; $F < 1$). The pattern was much different for the ambiguous targets. Specifically, the facilitation for the two-related-prime condition (200 ms) was 147 ms smaller than the sum of the single-related-prime conditions (184 ms + 163 ms = 347 ms), $F(1, 31) = 8.68$, $MSE = 39,851.00$. Hence, for the first time in the present set of six experiments, there is evidence of an underadditive influence of the multiple primes that was restricted to ambiguous targets.

The results of the error analyses yielded main effects of target type, $F_1(1, 31) = 13.60$, $MSE = 0.0128$; $F_2(1, 94) = 11.80$, $MSE = 0.0221$, and prime type, $F_1(3, 93) = 12.42$, $MSE = 0.0137$; $F_2(3, 282) = 13.47$, $MSE = 0.0190$. The interaction was not significant (both $ps > .14$). It should be noted here that although the interactions were not significant in the error-rate data, there was still less of a difference between the two-related-prime conditions and the mean of the single-related-prime conditions for the ambiguous targets (8.5%) compared with the unambiguous targets (12.0%). Thus, the absence of greater priming in the two-related-prime condition compared with the single-related-prime condition in the response-latency data for the homographs is not compromised by a larger difference in error rates.

Discussion

The results for Experiment 6 are quite clear: For the unambiguous target conditions, the results were consistent with the previous five experiments. Specifically, the facilitation produced by two related primes was nicely predicted by the sum of the facilitation of each of the single-related-prime conditions. Turning to the ambiguous target-word conditions, the pattern of results is quite different: Specifically, there is relatively little difference between the two single-related-prime conditions and the two-related-prime condition. This is in sharp contrast with the results of the previous five experiments wherein there were identical patterns of facilitation for both ambiguous and unambiguous words. Of course, this is consistent with the notion that because of the task demands engaged by the relatedness judgments used in Experiment 6, participants were forced to process the meaning of the prime-target relationships. It was only under these conditions that we were able to distinguish between the pattern of priming effects for conditions in which the primes converge onto a single semantic representation (unambiguous targets) and conditions in which primes diverge onto distinct semantic representations (ambiguous targets). For ambiguous target words, it appears that the first relationship found between the target and one of the primes drives response latency, with little influence from having an additional prime that is related to a different interpretation of the homograph.

Although the results of the relatedness judgment task in Experiment 6 clearly diverge from those of the previous lexical-decision and naming tasks, it is important to note that not only did we force participants to access meaning in Experiment 6, but we also forced participants to make a comparison between the target stimulus and the prime stimuli. It is possible that the difference in the obtained pattern is not due to access of meaning but rather is due to the fact that the relatedness task

forces a comparison process. There are two points to note here: First, as noted earlier, there is considerable work suggesting that the LDT also involves a comparison between the target and the prime, and yet there was no evidence of underadditivity in the LDT results of Experiments 1 or 2. Thus, it does not appear to be simply the presence of a comparison process that is sufficient to produce the underadditive effects for ambiguous words. Second, and more important, we believe that it may be quite important to engage explicitly the comparison process because this may be the only way to ensure that active selection has taken place. In fact, as discussed below, it may be only under conditions in which one forces explicit selection that one finds evidence for inhibition between alternative interpretations of ambiguous target words, thereby bringing into question the existence of the *passive* inhibitory pathways displayed in Figure 1. Thus, it may be the nature of the comparison process that is important, not merely its presence.

General Discussion

There were two major goals addressed in the present research. The first goal was to determine how multiple primes influence target processing. Across a relatively wide variety of manipulations, the present results clearly supported an additive model of priming. The second goal was to determine if there are differences in the pattern of multiple priming effects for conditions in which the primes converge on the same semantic representation (unambiguous targets) and conditions in which primes diverge onto distinct semantic representations (ambiguous targets). The results of the first five experiments yielded identical patterns of priming for unambiguous and ambiguous targets. If one assumes that the architecture displayed in Figure 1, along with its passive inhibitory connection for the multiple meanings of ambiguous words, is correct the present results appear most consistent with the notion that when tasks emphasize lexical-level representations (lexical decision and naming), "semantic" priming effects may be primarily due to associative-level information within the lexicon. We shall now turn to a discussion that critically evaluates these conclusions and describe alternative accounts of the present results.

The Influence of Multiple Primes: Additivity, Underadditivity, or Overadditivity?

One of the major goals of the present experiments was to determine the influence of multiple related primes on target processing. We were motivated to investigate this phenomenon by three issues: First, there are at least three possible outcomes (additivity, overadditivity, and underadditivity) concerning how multiple primes influence target processing. Each of these outcomes provides a unique constraint on the activation-threshold functions for extant theoretical models of semantic priming (e.g., spreading activation, compound cue, and parallel distributed processing models). Second, in natural language-processing situations, there appear to be multiple sources of information that might constrain the meaning of a given word within a context. Therefore, it is important to understand how

multiple sources of information influence target processing. Third, the previously existing data on multiple priming effects are limited by aspects of the past experimental paradigms and, hence, diminish the strength of the inferences that can be drawn from these studies.

On each trial in the present series of experiments, two primes were presented, which were followed by a target stimulus for a response. By crossing prime relatedness (related vs. unrelated) with position (first vs. second prime), we were able to obtain independent estimates of the influence of each prime at each position, along with the combined influence of both primes. The results of the first two experiments, which involved LDTs and very brief prime durations, clearly supported an additive model of the influence of multiple primes. Specifically, the facilitation observed in the RR condition was simply the sum of the facilitation observed in the RU condition and in the UR condition. Because postlexical processing could have influenced performance in the LDT, we turned to speeded naming performance in Experiment 3. The results again supported an additive model. The fourth experiment increased the duration of the first prime to determine the limitations of the additive model. Again, the results yielded support for the additive model. The fifth experiment included a manipulation that degraded the target stimulus to increase the influence of the prime items. The results of this experiment yielded an increased overall priming effect; however, the pattern of priming effects across conditions again supported the additive model.

Thus, across different tasks, prime durations, levels of target clarity, and different classes of target stimuli (ambiguous vs. unambiguous words), there was clear support for the additive model of priming effects. None of the first five experiments produced any reliable divergence from a simple additive model. Of course, it is always difficult to argue for the null hypothesis, but in the present case, we feel quite confident that the simple additive model is most appropriate in accounting for multiple priming effects. This confidence is based on the consistency of the observed priming effects across experiments. Table 8 displays the predicted and observed priming effects based on the additive model across the various experiments for both ambiguous and unambiguous targets. As shown, the only reliable departure from the additive function is in the relatedness judgments for ambiguous words in Experiment 6. In fact, if one collapses the results across Experiments 1–5 and simply adds the facilitation observed from the first related prime in the RU prime condition (10 ms) to the facilitation observed from the second related prime in the UR condition (16 ms), one finds that the predicted facilitation (26 ms) is only 1 ms away from the observed facilitation in the RR condition (27 ms). Because these estimates are based on 248 participants across five different experiments with varying experimental paradigms, we are confident in concluding that the simple additive model is the best account for the manner in which multiple primes influence target processing.⁴

It is interesting to note here that in addition to the present experiments, there are a number of published studies that are consistent with the notion that there are additive influences of primes along a number of distinct processing dimensions. For

Table 8
Mean Predicted and Observed Summation Priming Effects and the Difference Between These Two Measures as a Function of Experiments 1–5 Together and Experiment 6 by Itself

Experiment and target type	n	Summation priming effects		Difference
		(RU + UR) = predicted	(RR) = observed	
Experiment 1	40			
Ambiguous		(5 + 17) = 22	34	12 ^{ns}
Unambiguous		(13 + 24) = 37	34	-3 ^{ns}
Experiment 2	48			
Ambiguous		(9 + 19) = 28	32	4 ^{ns}
Unambiguous		(11 + 27) = 38	44	6 ^{ns}
Experiment 3	64			
Ambiguous		(6 + 11) = 17	15	-2 ^{ns}
Unambiguous		(8 + 11) = 19	13	-6 ^{ns}
Experiment 4	48			
Ambiguous		(3 + 7) = 10	11	1 ^{ns}
Unambiguous		(8 + 10) = 18	14	-4 ^{ns}
Experiment 5	48			
Ambiguous		(17 + 17) = 34	36	2 ^{ns}
Unambiguous		(26 + 18) = 44	46	2 ^{ns}
Weighted Average	248			
Ambiguous		(8 + 14) = 22	25	3 ^{ns}
Unambiguous		(13 + 17) = 30	29	-1 ^{ns}
Experiment 6	32			
Ambiguous		(184 + 163) = 347	200	-147**
Unambiguous		(141 + 122) = 263	262	-1 ^{ns}

^{ns}*p* > .27; ***p* < .01.

example, Forster (1989) has shown that there are additive influences of briefly presented orthographic primes in an LDT. Primes such as *FLANKMOIL*, *BRACHMALL*, and *BLOCK-FAIN* produced additive effects for the target stimulus *BLACK-MAIL* in an LDT. In addition, Blank and Foss (1978) found additive contributions of specific components of a sentence (verb and adjective) in a phoneme monitoring task. Reder (1983) has extended this simple additivity to a sentence completion task. Thus, on the basis of the convergence across different tasks and different types of primes, we believe that contextual constraints can produce simple additive influences on target processing.

It is noteworthy that although we have interpreted the present additive effects of multiple primes in naming and lexical-decision performance as consistent with the spreading-activation framework, it is likely that alternative models of priming will also be able to account for these simple additive

⁴ We also conducted an analysis to determine the power of detecting a reliable underadditive effect across the first five experiments. In this analysis, we used the reliable underadditive effect obtained in Experiment 6 as a basis for our power calculation. On the basis of Cohen's (1977) discussion, the underadditive pattern observed in Experiment 6 produced a medium effect size ($d = .52$). If we now apply this effect size ($d = .52$) to the results of the overall analysis from the first five experiments (which produced a 34.7-ms *SD*), our ability to obtain a similar medium effect size of underadditivity (18 ms) is greater than .99, one-tailed test. Moreover, to be conservative, if we consider the power to detect half of this effect size ($d = .26$), then our power of detecting an underadditive effect of 9 ms across the first five experiments is .86, one-tailed test.

effects. For example, using the parameter estimates available from Ratcliff and McKoon (1995), Ratcliff (personal communication) has shown that the compound cue model nicely predicts the simple additive effects in lexical decision (also, see McNamara & Diwadker, in press, for direct comparisons of the compound cue model and the spreading-activation model in accounting for the present lexical-decision results). Of course, it will be important to determine if this model also can be extended to the naming task and can also account for the present lack of a difference between ambiguous and unambiguous target words. We also see no a priori reason that Masson's (1995) PDP model will not be able to handle the simple additive effects of multiple primes. Thus, at this level, we believe that the additive effects obtained in the present naming and lexical-decision data are unlikely to discriminate among alternative theoretical frameworks. However, we do believe these results provide an important additional constraint, along with other well-established empirical observations, on any model of semantic priming. We shall now turn to possibly more constraining aspects of the present results: specifically (a) proximity effects of primes at relatively short SOAs, (b) priming effects across an unrelated intervening word, and of most importance, and (c) the similarity in the observed pattern of priming effects for ambiguous and unambiguous targets.

The Influence of Temporal Proximity of the Prime

In addition to the observation concerning additivity of multiple primes, it should be noted that the present results indicate that there was reliably more facilitation in the UR condition than in the RU condition. Thus, the proximity of the prime to the target did indeed modulate the observed priming effect, as one might expect on the basis of either temporally based decay of activation or the presence of an interfering unrelated word. This is particularly noteworthy because in the first three experiments the primes were presented very quickly (i.e., 133 ms per prime). In fact, because of forward masking of the first word onto the second, one might have expected to find less of a priming effect from the second word because of breakdowns in lower level perceptual operations. Obviously, this pattern was not observed in the present results.

Priming Across an Unrelated Intervening Word

Although the priming effect was larger when the second prime was related to the target compared with when the first prime was related to the target, it is important to note that the present results yielded consistent evidence for reliable priming for the RU condition compared with the UU condition. In fact, if one collapses across the first five experiments, the present results yielded a highly reliable 11-ms difference between the RU condition and the UU condition, $F_1(1, 247) = 45.49$, $MSE = 687.00$, $p < .001$. Clearly, these results provide substantial evidence that priming can occur across an unrelated intervening item. This is an important observation because early reports in the priming literature indicated that there is no reliable semantic priming across an unrelated intervening word (Gough, Alford, & Holley-Wilcox, 1981; Masson, 1991; Ratcliff & McKoon, 1988). However, as Joordens and Besner

(1992) have pointed out, in each of the previous studies there has been a nonsignificant tendency for priming to occur across an unrelated word. Moreover, Joordens and Besner (1992) and McNamara (1992) have recently reported evidence of priming across an unrelated word in naming and lexical-decision performance, respectively. It should be noted, however, that in both Joordens and Besner's study and McNamara's study, participants made responses to primes as well as to targets. Thus, on the basis of these studies, it is unclear whether overt responses to the primes and relatively long durations (e.g., 700–900 ms) to process the primes are necessary conditions to obtain priming across an unrelated word. It is possible that such effects were due to attentional processes because responses to the primes, relatively long prime durations, or both are likely to engage such higher level systems. In fact, Masson (1995, Experiment 1) has recently provided evidence from a naming task that there is no priming (a nonsignificant 3.3 ms) across an unrelated word under conditions of a very short SOA (200 ms). Masson's results would appear to run counter to the results of the present Experiment 3, wherein an even shorter SOA (133 ms) provided priming across an unrelated word in a naming task. In fact, the present series of experiments consistently produced priming across unrelated words across a wide variety of conditions. One possible difference between the present experiments and Masson's first experiment is that Masson included a forward mask (a row of Xs) before the first prime stimulus. This, of course, may have minimized processing of the first word compared with the present manipulations. The important point to note is that models that were initially motivated in part by the difficulty of the spreading-activation model to account for the lack of priming across an unrelated intervening word (e.g., Masson, 1991; Ratcliff & McKoon, 1988) will need to be modified to accommodate such effects. Although such models can be modified to account for priming across unrelated words (e.g., including two prime words in the compound-cue model), it is unclear how such an accommodation might influence the models' ability to account for other priming phenomena.

Multiple Primes for Ambiguous and Unambiguous Targets

As noted earlier, there has been considerable interest in the level of the cognitive architecture at which semantic-priming effects occur. On the basis of the architecture displayed in Figure 1, along with its passive inhibitory semantic connection, we expected to find differences in the pattern of priming effects for conditions in which the primes converged onto the same meaning of an ambiguous word versus conditions in which the primes diverged onto two different meanings of ambiguous words. Specifically, we suggested that if priming occurs at the semantic level, then one should find an increased tendency toward an underadditive pattern of priming for the ambiguous targets compared with the unambiguous targets. The assumed architecture and the subsequent predictions were based on (a) the growing evidence that suggests that there are inhibitory pathways between the multiple meanings of ambiguous words (Gernsbacher, Varner, & Faust, 1990; Simpson & Kang, 1994; Simpson & Kellas, 1989), (b) the inclusion of inhibitory pathways in connectionist models of lexical-ambiguity resolu-

tion (Cottrell, 1989), and (c) the fact that without such inhibitory pathways, as discussed below, it is unclear how selection of meaning occurs for such words.⁵ However, the present results did not support semantic involvement, at least not within the framework displayed in Figure 1. Specifically, the same additive pattern of priming effects occurred for ambiguous words in which the primes were related to distinct semantic interpretations as compared with unambiguous words in which the primes were related to the same semantic interpretation. The only divergence in the pattern of results for ambiguous and unambiguous words occurred when participants were forced to process the meaning of the words with the relatedness judgments used in Experiment 6. Although the interpretation of these results appears to be quite clear within the assumed architecture, it is important to consider alternative architectures, alternative processing assumptions, or both that may be consistent with the semantic locus of the observed priming effects. We shall discuss both of these issues in turn.

Multiple lexical representations for ambiguous words. As shown in Figure 2, consider the possibility that ambiguous words have multiple semantic and lexical representations. In fact, a number of researchers have suggested this possibility (e.g., Jastrzemski, 1981; Kellas, Ferraro, & Simpson, 1988; Rubenstein, Garfield, & Millikan, 1970; Rubenstein, Lewis, & Rubenstein, 1971; Seidenberg et al., 1982). If this were the case and there were no inhibitory connections between the multiple interpretations of ambiguous words, then it is possible

that one might find similar patterns of priming effects for ambiguous and unambiguous target words. More specifically, it is possible that the benefit of convergence on a single lexical representation from two related primes for unambiguous targets (*LION-STRIPES-TIGER*) would be equal to the benefit from a race between the two distinct primed lexical representations for ambiguous targets (*KIDNEY-PIANO-ORGAN*). Unfortunately, there are also a number of aspects of the architecture displayed in Figure 2 that are inconsistent with the extant literature and aspects of the current results. First and foremost, within this architecture it is unclear how selection of an appropriate meaning of a homograph might occur. For example, this model should predict that participants would be faster to recognize the word *PIANO* in the discordant condition, *KIDNEY-ORGAN-PIANO*, compared with an unrelated control condition, *HEART-PENCIL-PIANO*. However, under conditions in which participants named both primes, Balota and Duchek (1991) found no difference between these two conditions for either a 250- or a 1,250-ms response to stimulus interval. Similar findings have been reported in other studies (e.g., Schvaneveldt, Meyer, & Becker, 1976).

On the other hand, consider the possibility that the constraints of the present experiments functionally engaged an architecture as displayed in Figure 2. In fact, there may be some instances in which such an architecture is quite reasonable. Consider, for example, Swinney's (1979) oft-cited study. In this study, there was evidence that both interpretations of ambiguous words were quickly accessed and that only later was one of the interpretations selected. Thus, when there are very short delays, it is possible that the architecture displayed in Figure 2 is at least functionally engaged. Only after some delay is there evidence for selection. Although there is currently considerable controversy regarding the notion of exhaustive multiple access (e.g., Paul, Kellas, Martin, & Clark, 1992; Tabossi, 1988), even if this assumption were correct, it would have considerable difficulty in accounting for the results of the present Experiment 4. In this experiment, the first prime word was presented for a full 1,000 ms. Clearly, 1,000 ms should be sufficient time for the first prime to activate the relevant interpretation of an ambiguous word, and yet there was still a reliable benefit from the addition of a briefly presented second prime that was related to the alternate interpretation of the ambiguous word (compare the RR vs. the RU conditions in Table 5). Thus, one cannot simply argue that the reason for the absence of differences between the patterns of priming for ambiguous and unambiguous words is that the SOAs were simply too short for selective access to be engaged.

Finally, we need to consider the functional value of the multiple semantic-lexical architecture for ambiguous words displayed in Figure 2. First, it should be noted that such a representation would appear to pose some problems at a

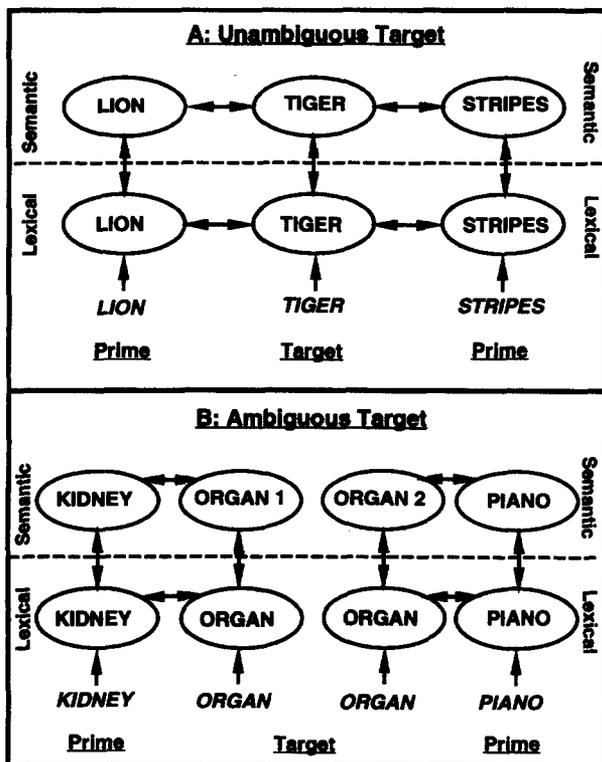


Figure 2. Alternative lexical-semantic processing architecture representing the facilitatory connections between two related primes for unambiguous targets and for ambiguous targets.

⁵ It should be noted that there are alternative interactive-activation models that do not include inhibitory pathways. One such model is Dell's (1986) model of speech production. Although it is quite possible that such a framework may be able to handle the wide variety of results in the ambiguity-resolution literature, we do not know of any currently implemented version of such a model that has been developed to accomplish this goal.

simple perceptual pattern-recognition level. Specifically, it is unclear how the visual-lexical system might represent two distinct and yet identical orthographic patterns for ambiguous words. In some sense, there would no longer be a unique identification point in lexical processing (see Marslen-Wilson & Welsh, 1978), because for these items there are always two highly activated orthographic-recognition devices. This would produce considerable difficulty for the pattern-recognition system; that is, when would the system be able to determine that a unique pattern was identified? Of course, the functional value of such multiple lexical representations may increase, at least in production, under conditions in which both interpretations of the ambiguous words are linked to different syntactic functions (e.g., the noun meaning of *deck* referring to a part of a boat vs. the verb meaning of *deck* referring to a blow to the head). However, even if this were the case, then one is still left with the problem of how the system selects from among multiple interpretations when the same orthographic patterns are represented by the input lexicon.

In summary, because of the above concerns, we do not believe that the architecture displayed in Figure 2 is a viable representation for ambiguous words. At the very least, even if one assumes two lexical and two semantic representations for ambiguous words, then it would appear that one would also need to include inhibitory connections between the semantic representations to account for the available data concerning ambiguity resolution and to provide a straightforward manner for the system to deal with highly activated identical lexical representations (but see Footnote 5). Once such inhibitory connections are assumed, then one must either (a) predict relatively less priming in the RR condition for the ambiguous words than for the unambiguous words because of this inhibition or (b) assume the semantic-level representations are not strongly engaged (see discussion below) in the present lexical-processing tasks. Because there was no support for this first prediction in the present results, we are in fact led to the same conclusion even if one assumes multiple lexical representations for ambiguous words (along with passive inhibitory semantic connections); that is, the present semantic-priming effects in both the LDT and the naming task do not strongly engage semantic-level representations. We now turn to the importance of the passive nature of these inhibitory connections.

The role of selection in the engagement of inhibitory suppression. A relatively simple alternative account of the present results is that the architecture of Figure 1 is, at least in part, correct but that the inhibition of alternative interpretations of ambiguous words is not engaged unless the participant is forced to *select* one interpretation of the ambiguous target. In the present experiments, because the ambiguous word was presented as the target item, there was no need for selection in order to make a speeded naming or lexical-decision response to the target, and hence, there was little evidence of semantic-level inhibition. However, in the relatedness judgment task of Experiment 6, participants were required to select an interpretation of the target word to determine if it was related to one of the prime items, and hence, semantic-level inhibition occurred. Moreover, because in Balota and Duchek's (1991)

experiment, described above, ambiguous words were presented in the second prime position (i.e., *KIDNEY-ORGAN-PIANO*) instead of the target position, the results of this earlier experiment could be viewed as simply indicating that under conditions in which participants have sufficient time to use the first context word to select an interpretation of the ambiguous word, one will find evidence of semantic-level inhibition. Thus, in this light, the present results could be viewed as either indicating that (a) there is no *passive* inhibitory connection between alternative interpretations of ambiguous words, and inhibition is not engaged until meaning selection is actively achieved, or (b) there is a passive inhibitory connection for ambiguous words at the semantic level as displayed in Figure 1, and the current priming effects in the LDT and the naming task are most likely due to lexical-level associative effects.

The argument that the present lexical-decision and naming results involve semantic-level representations and that selection is needed for the engagement of inhibition is further bolstered by two important patterns of data: First, there is an interesting pattern of interactions among degradation, word-frequency, and semantic context (i.e., priming effects). Specifically, context interacts with both word frequency and degradation, whereas word frequency produces additive effects with degradation. This pattern has been recently interpreted by Borowsky and Besner (1993) to indicate both that context influences an orthographic input lexicon (through feedback from the semantic system) and also that context effects reflect activity directly within the semantic system. For Borowsky and Besner, word frequency modulates the transfer between the orthographic-input lexicon and the semantic system. At the very least, these data appear to suggest that context can produce two distinct influences as reflected by the fact that context interacts with two variables (degradation and word frequency) and that when investigated in isolation these two variables produce additive effects. Although Borowsky and Besner's results are quite important in placing constraints on any model of word recognition and priming, we also believe that it is quite important to use more direct manipulations of semantic variables (e.g., concreteness or number of meanings as in the present study) to ensure that their results indeed reflect a semantic influence.

The second pattern of results that support a semantic-level influence is found in studies that involve direct manipulations of semantic variables in isolated lexical-decision and naming performance. For example, there is evidence that the number of meanings a word has available (e.g., Kellas et al., 1988) and target-word concreteness (e.g., Bleasdale, 1987; James, 1975) modulate both naming and LDTs (see Balota, Ferraro, & Connor, 1991, for a review). Although we believe that semantic variables (e.g., concreteness and word meaning) can play a role in isolated naming and lexical-decision performance, we also believe that the relative importance of these factors may be diminished in these tasks because both naming and lexical-decision performance place a relatively high priority on lexical processing, at least compared with tasks that place a higher priority on meaning-integration processes. This is nicely reflected in the comparison of the present naming and lexical-decision data, wherein there were no influences of target

ambiguity with the present relatedness-judgment data; however, there were large influences of target ambiguity.

In this light, we believe that it is important to recognize that skilled readers have considerable control over the influence of a given processing pathway, depending on the constraints of a given task. Obviously, skilled readers can process a visually presented word along a number of distinct processing pathways: Does the string of letters include the letters *t* and *n* (orthographic)? Does the string rhyme with the word *dog* (phonological)? Is the string a noun or verb (syntactic)? Does the word represent a concept that includes animateness (semantic)? The extent to which the task demands require output from a given processing dimension determines the degree of influence of this processing pathway. We would simply argue that the emphasis in both the LDT and the naming task is on speeded *lexical-level* processing, and therefore skilled readers are likely to primarily engage the processing pathway or pathways that are required by those task demands. On the other hand, when one turns to the relatedness decision task, the notion here is that participants primarily engage a semantic-processing pathway, and hence one finds the predicted differences between ambiguous and unambiguous words.

Interestingly, there is already evidence that participants have attentional control over task-appropriate processing pathways in the lexical domain. For example, work by Smith (1979), Smith, Theodor, and Franklin (1983), and Henik, Friedrich, and Kellogg (1983) has shown that the type of pathway engaged on the prime can control the influence of prime-target relationships on performance. Specifically, these researchers have demonstrated that when a letter search task is used, one can eliminate the semantic-priming effect (Smith et al., 1983). This is quite consistent with the notion that there is attentional control of relevant lexical-processing pathways and that if attention is focused on lower level orthographic pathways, even the lexical-level associations that appear to be involved in priming effects in lexical decision and naming can be disabled or at least greatly diminished. The importance of this observation is that it is inconsistent with the notion that there is exhaustive and equally automatic access to all codes available in lexical processing. It is also important to emphasize that we do not wish to argue that there is total control over processing pathways within a given task, but we do wish to argue that there is modulation of the weight placed on different processing dimensions depending on the task demands. In fact, we believe that with more connected discourse that directs attention to higher level structures, such as sentence contexts, it is possible that priming effects reflected by speeded-naming performance may reflect higher level semantic structures in lieu of low-level lexical-associative connections (see Hess, Foss, & Carroll, 1995, for recent evidence).

Conclusions

The results of the present research provide support for the following two conclusions: First, the influence of multiple primes within the semantic-priming paradigm are clearly

additive. We believe that any model of semantic priming will need to account for this simple additive function. Second, the present naming and lexical-decision results yielded identical patterns for conditions in which primes converged onto a single semantic representation for the target and for conditions in which primes diverged onto distinct semantic representations. If one assumes the relatively simple architecture displayed in Figure 1, we believe these results are most consistent with one of the following two conclusions: (a) Semantic priming effects in naming and lexical decision primarily reflect lexical-level associations, or (b) semantic-priming effects in naming and lexical decision indeed reflect semantic-level information, and the assumed passive inhibition in Figure 1 is not engaged until selection of a meaning for an ambiguous word actually is implemented. In either case, the present results provide further constraints on the development of an adequate model of lexical processing and priming.

References

- Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior*, 22, 261-295.
- Ashcraft, M. H. (1978). Property norms for typical and atypical items from 17 categories: A description and discussion. *Memory & Cognition*, 6, 227-232.
- Balota, D. A. (1983). Automatic semantic activation and episodic memory encoding. *Journal of Verbal Learning and Verbal Behavior*, 22, 88-104.
- Balota, D. A., Black, S., & Cheney, M. (1992). Automatic and attentional processing in young and old adults: A reevaluation of the two-process model of semantic priming. *Journal of Experimental Psychology: Human Perception and Performance*, 18, 485-502.
- Balota, D. A., & Duchek, J. M. (1991). Semantic priming effects, lexical repetition effects, and contextual disambiguation effects in healthy aged individuals and individuals with senile dementia of the Alzheimer's type. *Brain and Language*, 40, 181-201.
- Balota, D. A., Ferraro, F. R., & Connor, L. T. (1991). On the early influence of meaning in word recognition: A review of the literature. In P. J. Schwanenflugel (Ed.), *The psychology of word meanings* (pp. 187-218). Hillsdale, NJ: Erlbaum.
- Balota, D. A., & Lorch, R. (1986). Depth of automatic spreading activation: Mediated priming effects in pronunciation but not in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 12, 336-345.
- Balota, D. A., Pollatsek, A., & Rayner, K. (1985). The interaction of contextual constraints and parafoveal visual information in reading. *Cognitive Psychology*, 17, 364-390.
- Battig, W. F., & Montague, W. E. (1969). Category norms for verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology Monograph*, 80, 1-46.
- Besner, D., & Smith, M. C. (1992). Models of visual word recognition: When obscuring the stimulus yields a clearer view. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 468-482.
- Blank, M. A., & Foss, D. J. (1978). Semantic facilitation and lexical access during sentence processing. *Memory & Cognition*, 6, 644-652.
- Bleasdale, F. A. (1987). Concreteness-dependent associative priming: Separate lexical organization for concrete and abstract words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 582-594.
- Borowsky, R., & Besner, D. (1993). Visual word recognition: A

- multistage activation model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19, 813–840.
- Brodeur, D. A., & Lupker, S. J. (1989). *Investigating the effects of multiple primes: Does activation summate?* Paper presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, GA.
- Brodeur, D. A., & Lupker, S. J. (1994). Investigating the effects of multiple primes: An analysis of theoretical mechanisms. *Psychological Research*, 57, 1–14.
- Chiarello, C., Burgess, C., Richards, L., & Pollock, A. (1990). Semantic and associative priming in the cerebral hemispheres: Some words do, some words don't . . . sometimes, some places. *Brain and Cognition*, 38, 75–104.
- Church, K., & Hanks, P. (1989). *Word association norms, mutual information, and lexicography*. Paper presented at the 23rd Annual Meeting of the Association for Computational Linguistics, Vancouver, British Columbia, Canada: Association for Computational Linguistics.
- Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (Rev. ed.). Orlando, FL: Academic Press.
- Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, 82, 407–428.
- Cottrell, G. W. (1989). A model of lexical access of ambiguous words. In S. I. Small, G. W. Cottrell, & M. K. Tanenhaus (Eds.), *Lexical ambiguity resolution* (pp. 179–194). San Mateo, CA: Morgan Kaufman.
- Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production. *Psychological Review*, 93, 283–321.
- 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. (1988). Repetition, semantic priming, and stimulus quality: Implications for the interactive-compensatory reading model. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 590–603.
- Fischler, I. (1977). Associative facilitation without expectancy in a lexical decision task. *Journal of Experimental Psychology: Human Perception and Performance*, 3, 18–26.
- Forster, K. I. (1989). *Summation effects in lexical form-priming with masked primes: Direct evidence for activation models?* Paper presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, GA.
- Gernsbacher, M. A., Varner, K. R., & Faust, M. E. (1990). Investigating differences in general comprehension skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 430–445.
- Gough, P. B., Alford, J. A., & Holley-Wilcox, P. (1981). Words and contexts. In O. J. L. Tzeng & H. Singer (Eds.), *Perception of print: Reading research in experimental psychology* (pp. 85–102). Hillsdale, NJ: Erlbaum.
- Hampton, J. A. (1984). The verification of category and property statements. *Memory & Cognition*, 12, 345–354.
- Henik, A., Friedrich, F. J., & Kellogg, W. A. (1983). The dependence of semantic relatedness effects upon prime processing. *Memory & Cognition*, 11, 366–373.
- Hess, D. J., Foss, D. J., & Carroll, P. (1995). Effects of global and local context on lexical processing during language comprehension. *Journal of Experimental Psychology: General*, 124, 62–82.
- James, C. T. (1975). The role of semantic information in lexical decisions. *Journal of Experimental Psychology: Human Perception and Performance*, 1, 130–136.
- Jastrzemski, J. E. (1981). Multiple meanings, number of related meanings, frequency of occurrence, and the lexicon. *Cognitive Psychology*, 13, 278–305.
- Joordens, S., & Besner, D. (1992). Priming effects that span an intervening unrelated word: Implications for models of memory representation and retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 483–491.
- Keefe, D. E., & Neely, J. H. (1990). Semantic priming in the pronunciation task: The role of prospective prime-generated expectancies. *Memory & Cognition*, 18, 289–298.
- Kellas, G., Ferraro, F. R., & Simpson, G. B. (1988). Lexical ambiguity and the timecourse of attentional allocation in word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 601–609.
- Klein, R., Briand, K., Smith, L., & Smith-Lamothe, J. (1988). Does spreading activation summate? *Psychological Research*, 50, 50–54.
- Lorch, R. F., Balota, D. A., & Stamm, E. (1986). Locus of inhibition effects in the priming of lexical decisions: Pre- or post-lexical access? *Memory & Cognition*, 14, 95–103.
- Lupker, S. J. (1984). Semantic priming without association: A second look. *Journal of Verbal Learning and Verbal Behavior*, 23, 709–733.
- Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology*, 10, 29–63.
- Masson, M. E. J. (1991). A distributed memory model of context effects in word identification. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 233–263). Hillsdale, NJ: Erlbaum.
- Masson, M. E. J. (1995). A distributed memory model of semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 3–23.
- McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88, 375–407.
- McKoon, G., & Ratcliff, R. (1988). Contextually relevant aspects of meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 331–343.
- McKoon, G., & Ratcliff, R. (1992). Spreading activation versus compound cue accounts of priming: Mediated priming revisited. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 1155–1172.
- McNamara, T. P. (1992). Theories of priming: I. Associative distance and lag. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 1173–1191.
- McNamara, T. P., & Altarriba, J. (1988). Depth of spreading activation revisited: Semantic mediated priming occurs in lexical decisions. *Journal of Memory and Language*, 27, 545–559.
- McNamara, T. P., & Diwadker, V. A. (in press). The context of memory retrieval. *Journal of Memory and Language*.
- 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, 227–234.
- Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. G. (1975). Loci of contextual effects on visual word recognition. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and Performance V* (pp. 98–118). New York: Academic Press.
- Morton, J. (1969). Interaction of information in word recognition. *Psychological Review*, 76, 156–178.
- Moss, H. E., Ostrin, R. K., Tyler, L. K., & Marslen-Wilson, W. D. (1995). Accessing different types of lexical semantic information: Evidence from priming. *Journal of Experimental Psychology, Learning, Memory, and Cognition*, 21, 863–883.
- 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. (1991). Semantic priming effects in visual word recognition. In D. Besner & G. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.
- Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated

- expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14, 1003–1019.
- Paul, S. T., Kellas, G., Martin, M., & Clark, M. B. (1992). Influence of contextual features on the activation of ambiguous word meanings. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 703–717.
- Ratcliff, R., & McKoon, G. (1988). A retrieval theory of priming. *Psychological Review*, 95, 385–408.
- Ratcliff, R., & McKoon, G. (1995). Sequential effects in lexical decision: Tests of compound-cue retrieval theory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 1380–1388.
- Reder, L. M. (1983). What kind of pitcher can a catcher fill? Effects of priming in sentence comprehension. *Journal of Verbal Learning and Verbal Behavior*, 22, 189–202.
- Rubenstein, H., Garfield, L., & Millikan, J. A. (1970). Homographic entries in the internal lexicon. *Journal of Verbal Learning and Verbal Behavior*, 9, 487–494.
- Rubenstein, H., Lewis, S., & Rubenstein, M. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior*, 10, 635–647.
- Schmidt, R. (1976). On the spread of semantic excitation. *Psychological Research*, 38, 333–353.
- Schvaneveldt, R. W., Meyer, D. E., & Becker, C. A. (1976). Lexical ambiguity, semantic context, and visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, 2, 243–256.
- Seidenberg, M. S., Tanenhaus, M. K., Leiman, J. M., & Bienkowski, M. (1982). Automatic access of the meanings of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology*, 14, 489–537.
- Seidenberg, M. S., Waters, G. S., Sanders, M., & Langer, P. (1984). Pre- and post-lexical loci of contextual effects on word recognition. *Memory & Cognition*, 12, 315–328.
- Sharkey, N. E. (1990). A connectionist model of text comprehension. In D. A. Balota, G. B. Flores d'Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp. 487–514). Hillsdale, NJ: Erlbaum.
- Shelton, J. R., & Martin, R. C. (1992). How semantic is semantic priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 1191–1210.
- Simpson, G. B., & Kang, H. (1994). Inhibitory processes in the recognition of homograph meanings. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory mechanisms in attention, memory and language* (pp. 359–381). New York: Academic Press.
- Simpson, G. B., & Kellas, G. (1989). Dynamic contextual processes and lexical access. In D. S. Gorfein (Ed.), *Resolving semantic ambiguity* (pp. 40–56). New York: Springer-Verlag.
- Smith, M. C. (1979). Contextual facilitation in a letter search task depends on how the prime is processed. *Journal of Experimental Psychology: Human Perception and Performance*, 5, 239–251.
- Smith, M. C., Besner, D., & Miyoshi, H. (1994). New limits to automaticity: Context modulates semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 104–115.
- Smith, M. C., Theodor, L., & Franklin, P. E. (1983). On the relationship between contextual facilitation and depth of processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 9, 697–712.
- Stanovich, K. E., & West, R. F. (1981). The effect of sentence context on ongoing word recognition: Tests of a two-process theory. *Journal of Experimental Psychology: Human Perception and Performance*, 7, 658–672.
- Stanovich, K. E., & West, R. F. (1983). On priming by a sentence context. *Journal of Experimental Psychology: General*, 112, 1–36.
- Stolz, J. A., & Neely, J. H. (1995). When target degradation does and does not enhance semantic context effects in word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 596–611.
- Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior*, 18, 645–659.
- Tabossi, P. (1988). Accessing lexical ambiguity in different types of sentential contexts. *Journal of Memory and Language*, 27, 324–340.

Received January 24, 1995

Revision received September 19, 1995

Accepted October 4, 1995 ■