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Attention Constraints of Semantic Activation During Visual Word Recognition

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The reduction of semantic priming following letter search of the prime suggests that semantic activation can be blocked if attention is allocated to the letter level during word processing. Is this true even for the very fast-acting component of semantic activation? To test this, the authors explored semantic priming of lexical decision at stimulus onset asynchronies (SOAs) of either 200 or 1000 ms. Following semantic prime processing, priming occurred at both SOAs. In contrast, no priming occurred at the long SOA following letter-level processing. Of greatest interest, at the short SOA there was priming following the less demanding consonant/vowel task but not following the more attention-demanding letter search task. Hence, semantic activation can occur even when attention is directed to the letter level, provided there are sufficient resources to support this activation. The authors conclude that the default setting during word recognition is for fast-acting activation of the semantic system.

When a skilled reader is presented with a familiar word, is the processing of its meaning obligatory? Several studies have suggested that it is not and that access to the semantic system may be blocked or attenuated under certain circumstances. In this article we examine the influence of attentional demands on semantic activation.

The paradigm we have selected to assess semantic activation is semantic priming—the facilitated processing of a target word when it is preceded by a related prime word.[1] Although there has been some debate as to whether semantic priming depends on semantic processes or lexical associations, there is now considerable evidence for semantic involvement. For example, several investigators have demonstrated the priming of targets preceded by primes that were semantically but not associatively related, thereby implicating the involvement of semantic-level processes (e.g., Chiarello, Burgess, Richards, & Pollock, 1990; Chiarello & Richards, 1992; Fischler, 1977; Hines, Czerwinski, Sawyer, & Dwyer, 1986; Lupker, 1984; McRae & Boisvert, 1998; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Schreuder, Flores d'Arcais, & Glanzenborg, 1984; Seidenberg, Waters, Sanders, & Langer, 1984). In addition, simulation studies have been able to closely mimic semantic priming effects using only measures of semantic similarity (Lund, Burgess, & Atchley, 1995). The position we take in this article is that the facilitated processing of a target by the prior presentation of a semantically related prime is evidence that the prime has activated the semantic system.[2]

In contrast to the robust priming that typically occurs following the presentation of a semantically related prime when the task directs attention to word-level information (such as reading, naming, or categorization), semantic priming is reduced or eliminated

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[1] For the purposes of this article, it is not important whether cognitive representations within the semantic system are best conceptualized as being local or distributed and, consequently, whether facilitation results from a spread of activation between nodes (e.g., Collins & Loftus, 1975; Posner & Snyder, 1975) or from an overlap of semantic features shared by prime and target (Masson, 1991; McRae & Boisvert, 1998).

[2] Although some theorists have argued that some aspects of semantic priming may be accounted for by postlexical processes occurring after target presentation (e.g., de Groot, 1985; Neely & Keefe, 1989; Ratcliff & McKoon, 1997), we believe that the data presented in this article are best explained in terms of prime-related activation. This issue is elaborated on in the General Discussion.

if the prime task directs attention to the letter level (such as letter search or letter matching) (e.g., Besner, Smith, & MacLeod, 1990; Chiappe, Smith, & Besner, 1996; Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellogg, 1983; Henik, Tzelgov, Friedrich, & Tramer, 1994; Hoffman & MacMillan, 1985; Kaye & Brown, 1985; Maxfield & Chiarello, 1996; Smith, 1979; Smith, Meiran, & Besner, 1996; Smith, Theodor, & Franklin, 1983; Stolz & Besner, 1997, 1998). The elimination or reduction of semantic priming following letter search of the prime suggests that focusing attention at the letter level may interfere with activation of the semantic system.[3] To better understand how this may occur, consider the processes involved in word recognition, illustrated in Figure 1. When a word is read, orthographic analysis results in activation of the appropriate letter-level representations, which in turn activate first the lexicon, where whole word information is activated (via Pathway A), and then the semantic system, where conceptual information is activated (via Pathway B). In addition to this bottom-up activation there is top-down activation to the level below, as postulated, for example, in the interactive-activation model of McClelland and Rumelhart (1981).

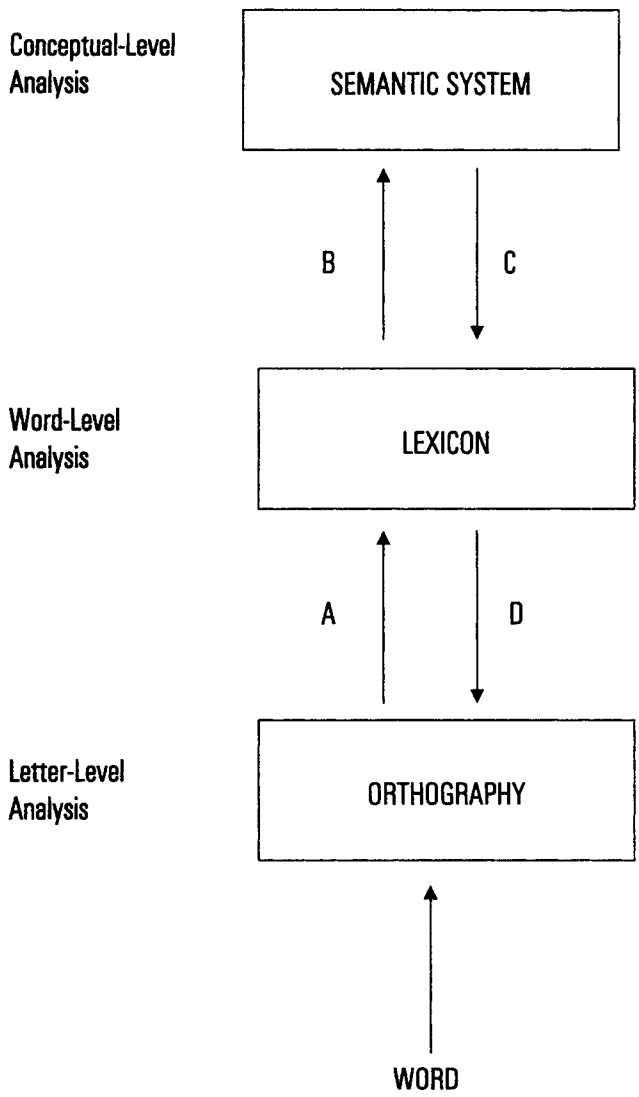

Figure 1. A framework for the processes underlying word recognition.

There is considerable evidence that letter search of the prime does not impede Pathway A and consequently does not impair lexical activation. For example, whereas semantic priming (e.g., bread–BUTTER) is eliminated if participants perform a letter search in the prime, repetition priming of identical targets (e.g., butter–BUTTER) survives—provided the stimulus is a real word (Friedrich et al., 1991, Experiment 2). The absence of repetition priming of nonword targets following letter search of the prime means that repetition priming cannot result solely from orthographic priming at the letter level and that the word primes must be activating their lexical representations, even when participants search for letters. Top-down feedback from the lexical to the orthographic level (via Pathway D) serves to facilitate the letter search process. A second piece of evidence for the survival of lexical activation during letter-level processing comes from a comparison of the speed of letter search through words and nonwords: Participants can search a letter string more rapidly if it is a real word than if it is a nonword, even when sequential redundancy is controlled (e.g., Besner et al., 1990; Kreuger & Weiss, 1976). Again, the facilitated processing of words over nonwords during letter search indicates that lexical activation is not impaired by the directing of attention to the letter level. In addition to the preservation of lexical activation, two recent studies indicate that letter search does not interfere with activation of either morphological (Stolz & Besner, 1998) or pictorial (Smith, Meiran, & Besner, 2000) information.

These data may be explained in terms of attentional demands. The goal of normal reading is typically the attainment of meaning. Hence, despite the need for some implicit orthographic processing, most attentional resources are allocated by default to semantic processing. In contrast, because the letter search task requires explicit letter identification, increased resources must be deployed to the orthographic level. Assuming limited attentional resources (e.g., Anderson, 1976, 1983; Kahneman, 1973; Navon & Gopher, 1979), such deployment decreases the resources available for semantic processing of the prime. The invulnerability of lexical activation to the prime-processing task suggests that the flow of information from the letter level to the lexical level (Pathway A) can occur even when attention is focused at the letter level. In contrast, the elimination of semantic priming following letter-level analysis of the prime suggests that the flow of information from the lexical level to the semantic level (Pathway B) requires attentional support.

In the present study we examined the nature of this attentional support. If the mere direction of attention to the letter level per se is sufficient to prevent activation of the semantic system, then

[3] There are, however, certain conditions in which semantic priming of a target has been shown to survive the performance of letter search on the prime. For example, Henik et al. (1994) demonstrated that, in contrast to the elimination of semantic priming following letter search of the prime when 50% of the prime–target pairs were related, priming was reinstated when 80% of the pairs were related. Also, Stolz and Besner (1996) demonstrated that if participants are allowed a brief preview of a random half of the prime words prior to the prime letter search task, then semantic priming is reinstated for all the related targets—even those for which no preview was provided.

semantic priming (a) will not occur following letter-level processing of the prime under any circumstances and (b) will not be influenced by the prime–target stimulus onset asynchrony (SOA). With regard to the question of SOA, most of the studies that have demonstrated the elimination or reduction of semantic priming following letter search of the prime have used a long SOA between prime and target (necessitated by the fact that participants made the letter search decision about the prime prior to target presentation). Use of a long SOA makes the determination of whether semantic activation occurred very difficult: Earlier studies that have demonstrated the existence of uncontrolled fast-acting semantic activation found that such activation is also fast decaying (Neely, 1977; Posner & Snyder, 1975). Hence, even if letter-level processing of the prime had initiated rapid activation of the semantic system, this fast-decaying activation would have dissipated by the time the target was presented. Capturing the short-lived effects of the fast-acting activation would necessitate use of a very brief SOA. The question of whether there is semantic priming following letter search of the prime at a short SOA has not been answered unequivocally, despite several recent studies of this issue.

In a study conducted by Besner et al. (1990), the prime and target were presented simultaneously, and participants were required to determine whether the two words had any letters in common. With no SOA between prime and target, we would expect that fast-acting activation of the semantic system would produce faster letter search through pairs of words that are related than through pairs that are unrelated. However, this version of the letter search task is generally very slow (about 2 s), and the finding that letter search was actually slower through pairs of related words than through pairs of unrelated words suggests that inhibitory mechanisms may have developed during the search process that masked or negated any initial excitatory activation.

In a review of the literature we found three studies that examined semantic priming following letter search when prime and target were presented sequentially with a very short SOA. Friedrich (1993) instructed participants to decide whether the prime was a word (lexical decision) or whether it contained a particular letter (letter search). The target appeared after a short (250-ms) or long (1,000-ms) SOA, and participants named the target. Because the short SOA did not allow participants sufficient time to respond to the prime prior to target presentation, a *delayed dual response* procedure was used in which participants at both SOAs first named the target and then made their prime response. Target naming was not facilitated following letter search of a related prime at either SOA. Although this suggests that directing attention to the letter level can prevent even fast-acting semantic activation, this interpretation is called into question by the unusual finding that in this study there was no semantic priming following lexical decision to the prime at the long SOA.

Henik et al. (1994) also explored the effect of letter search on the prime at both short (240-ms) and long (840-ms) SOAs, using a delayed dual-response procedure similar to that of Friedrich (1993). The target task was always lexical decision. The reaction time (RT) data did not reveal any priming following letter search at either SOA; however, the error data did indicate significant priming at the short SOA in the letter search condition. The occurrence of accuracy priming in this condition makes Henik et al.'s (1994) conclusion that there was no priming in the short-SOA letter search condition somewhat equivocal. Further doubt about the interpretation of these data arises from their manipulation of relatedness proportion. When prime and target were related on 80% of the trials, RT priming occurred for both SOAs and both prime tasks. In contrast, no priming was found for either SOA or prime task when only 20% of the pairs were related. In light of the fact that other studies have reported the occurrence of semantic priming following word-level processing of the prime even when the proportion of related items was low (see Neely, 1991, for a review), whether there is priming at the short SOA following letter-level processing remains an open question.

Finally, Maxfield and Chiarello (1996) investigated the attenuation of semantic priming at a short SOA using a novel procedure that they hoped would avoid possible problems associated with the delayed dual-response procedure. Prime task—silent reading or letter search—was a between-subjects variable, and all prime displays consisted of a word with a probe letter replicated above it. No immediate overt response was ever made to the prime. The target was presented after either a short (300-ms) or long (1,700-ms) SOA. In the silent reading condition the target was always a letter string to which participants made a lexical decision. In the letter search condition two different types of targets were used, each requiring a different response. If the target was a letter string (as it was on 33% of the trials), participants made a lexical decision. If the target was a row of question marks, participants indicated whether the probe letter had been present in the prime. Consequently, only a single response was made on any trial, with the response relating either to the target or to the prime. In contrast to Henik et al.'s (1994) results, reliable priming did occur following letter search, although it was significantly reduced from the amount of priming found following silent reading. Once again, however, interpretation of the results is problematic, for several reasons. First, there was differential uncertainty as to the target response required following the two prime processing tasks: After silent reading participants always performed the lexical decision, whereas the target response following letter search depended on the particular stimulus array presented. This differential uncertainty makes it difficult to directly compare priming in the two conditions. A second difficulty relates to the unusual occurrence in this study of priming following letter search at the long SOA as well as at the short SOA. Indeed, the interaction between priming and SOA was not significant. Maxfield and Chiarello (1996) further explored the surprising occurrence of priming following letter search at the long SOA in a second experiment and found that whether semantic priming was eliminated or attenuated depended on the nature of the prime–target relation: Priming was eliminated with word pairs related solely by association but was only reduced with word pairs related by both association and semantic similarity. However, the short-SOA condition was not investigated further.

In summary, previous studies have not provided an unequivocal answer as to whether there is semantic priming at a short SOA when the prime task requires letter-level processing. This is a very important question with regard to the issue of strategic control during reading.

A related issue concerns the extent to which fast-acting semantic activation operates in an all-or-none fashion or is resource dependent. If activation of the semantic system is disabled by the mere act of directing attention to the letter level per se, then no priming

is expected regardless of SOA. Alternatively, the occurrence of semantic priming at a short SOA following letter-level processing of the prime may depend on the attentional demands of the letter search task. Because more attention is required at the orthographic level, less will be available to activate Pathway B, thereby reducing the likelihood of semantic priming. If the absence of semantic priming results from the lack of sufficient available resources for semantic activation, then use of a less demanding letter-level task may result in facilitated target processing. Experiment 1 was designed to explore this hypothesis.

Experiment 1

In light of the fact that Henik et al.'s (1994) data provide the strongest evidence to date for the absence of semantic priming following letter search of the prime, even at a brief SOA, Experiment 1 is a conceptual replication of their experiment, using a less demanding letter-level task. Participants either categorized the prime as representing something that was living or nonliving (a task that would focus attention at the semantic level) or performed a variation of the letter search task that required them to decide whether the first letter in the prime was a consonant or a vowel (a task that would focus attention at the letter level).

As in Henik et al.'s (1994) study, no response was made to the prime until after the target response had been made. Following either a short (200-ms) or a long (1,000-ms) SOA, participants made a lexical decision to the target, withholding the prime response until a signal was given. On the basis of previous research, we expected semantic priming at both SOAs following semantic categorization of the prime, whereas we expected priming to be reduced or eliminated at the long SOA following the letter-level task. The major question of interest concerned the short-SOA letter identification condition. If focusing attention at the letter level per se prevents semantic activation, no priming is expected, even with the less demanding version of the letter-level task used in this experiment. However, if semantic activation can occur even when attention is directed to the letter level, provided there are sufficient resources available for activation of Pathway B, we may find evidence of semantic priming at the short SOA.

Method

Participants. The participants were 64 undergraduate students at the University of Toronto who received bonus credit for their participation.

Tasks and stimuli. Two words were presented sequentially on each trial, first the prime and then the target. The related stimuli were semantic associates that belonged to the same semantic category (e.g., *string–rope, aluminum–bronze, pond–lake*). Very few of the semantically related pairs were close associates. Two tasks were designed for the prime. The letter-level task was to decide whether the first letter of the prime was a vowel or a consonant. Each response type was assigned to a different key on a computer keyboard (*Z* for consonants and the / key for vowels). The word-level task was to decide whether the prime word denoted a concept that was living or nonliving. As before, a different response key was assigned to each category (*Z* for nonliving and the / key for living). The target task was lexical decision: Participants were instructed to press the / key if the target was a word and the *Z* key if it was not.

Each participant completed 192 trials with each of the two prime tasks. All 384 primes were words, of which 32 began with a vowel and 52 were "living." The targets were 192 words and 192 nonwords, with nonwords constructed by substituting one or two letters in words that were not used in the present study. The word and nonword targets were equally distributed between the two prime tasks. Hence, in each prime task there were 96 word targets and 96 nonword targets. On half the trials the SOA was short (200 ms), and on half it was long (1,000 ms). Half of each of the word and nonword targets were presented on short-SOA trials, with the other half on long-SOA trials. Among the word targets, half were presented in the related condition, and half were presented in the unrelated condition. Hence, for each prime task there were 24 related and 24 unrelated word targets in each of the short- and long-SOA conditions. Although a given participant saw each target only once, across participants each target appeared equally often in all conditions.

Procedure. Each participant was tested in a single session, with the two prime tasks presented in separate blocks. Half the participants started with the consonant–vowel prime task, and half started with the living–nonliving task. Within each block, short- and long-SOA trials were randomly presented. Participants were instructed to withhold the prime response until after making the lexical decision for the target, at which time a question mark appeared on the screen as a signal to respond to the prime task. For the lexical decision task, speed and accuracy were emphasized equally. The sequence of events and timing within each trial was as follows. First, the prime appeared for 200 ms. In the short-SOA condition the target immediately replaced the prime. In the long-SOA condition a blank interstimulus interval of 800 ms followed the prime. The target was exposed for 1,000 ms, followed by a 1,500-ms blank screen and then by a question mark. Hence, a total time of 2.5 s was allowed for each lexical decision. The question mark remained on the screen until the participant made an overt prime decision. The intertrial interval was 1 s.

A practice block with 12 short-SOA and 12 long-SOA trials preceded each test block. As in the test blocks, half the targets were words, and half the words in each SOA condition were related to the prime. At the end of each practice block, participants were informed about their speed and accuracy and were given the option of repeating the practice if desired. All participants repeated the practice block prior to the first test block, but only 3 participants repeated the practice block prior to the second test block.

Results

Mean lexical decision times to the target following short and long SOAs and the percentages of errors in each experimental condition are presented in Table 1. The RT values represent mean latencies trimmed to two standard deviations. The trimming procedure was based on the individual participants' means, separately in each condition. Fewer than 3% of the RTs were outliers.

We analyzed the word target data with a three-way analysis of variance (ANOVA) and a priori planned comparisons of semantic priming effects. The factors in the ANOVA were prime task (consonant–vowel or living–nonliving), SOA (short or long), and semantic relation between the target and the prime (related or unrelated). With RT as the dependent variable, the ANOVA indicated that all three main effects were reliable. Lexical decisions for the target were slower (a) when the prime task was the living–nonliving decision (1,198 ms) compared with when it was the consonant–vowel decision (1,116 ms), $F(1, 63) = 8.7$, $p < .01$, $MSE = 100{,}154$; (b) when the SOA was short (1,211 ms) compared with when it was long (1,103 ms), $F(1, 63) = 70.9$, $p < .01$, $MSE = 20{,}848$; and (c) when the targets were unrelated to the prime (1,170 ms) compared with when they were related (1,143 ms), $F(1, 63) = 15.3$, $p < .01$, $MSE = 6{,}212$. The SOA × Prime Task interaction was also significant, $F(1, 63) = 8.0$, $p < .01$, $MSE = 5{,}187$, with a larger effect of SOA on lexical decision time following the living–nonliving decision (125 ms) than following

Table 1
Experiment 1: Mean RTs (in Milliseconds) and Percentage Errors for Lexical Decisions to Targets at Short and Long SOAs Following the Two Different Prime Tasks

	Consonant–vowel				Living–nonliving			
	200-ms SOA		1,000-ms SOA		200-ms SOA		1,000-ms SOA	
Target type	RT	% Errors	RT	% Errors	RT	% Errors	RT	% Errors
Unrelated word	1,179	5.8	1,068	5.5	1,288	7.5	1,147	4.4
Related word	1,143	4.6	1,074	4.8	1,233	4.7	1,124	4.5
Priming effect	**36**	**1.2**	**−6**	**0.07**	**55**	**2.8**	**23**	**−0.1**
Nonword	1,213	11.5	1,119	9.1	1,268	12.4	1,162	9.5

Note. RT = reaction time; SOA = stimulus onset asynchrony.

the consonant–vowel decision (90 ms). Semantic relatedness interacted significantly with SOA, $F(1, 63) = 6.4$, $p < .015$, $MSE = 6{,}685$, indicating more semantic priming at the short SOA than at the long SOA (46 ms vs. 9 ms). The interaction between semantic relatedness and prime task approached significance, $F(1, 63) = 3.5$, $p < .065$, $MSE = 5{,}320$, with greater priming following the living–nonliving task than following the consonant–vowel task (39 ms vs. 15 ms). The SOA × Prime Task × Relatedness effect was not significant ($F < 1$).

Of primary interest in this experiment was whether any semantic priming would occur when the prime task required only letter-level analysis. A planned t test indicated that when the SOA was long, priming following the consonant–vowel distinction (−6 ms) was not reliable, $t(63) = 0.346$, a finding that replicates the typical absence of priming following letter-level processing of the prime reported in the literature. In contrast, when the SOA was short, the 36-ms effect of relatedness following the consonant–vowel distinction was significant, $t(63) = 6.13$, $p < .02$. Although there was less priming in the consonant–vowel condition than in the living–nonliving condition when the SOA was short (36 ms vs. 55 ms), this difference was not significant, $t(63) = 1.03$, $p < .305$. Priming following the semantic classification task was significant at both the short and long SOAs, $t(63) = 8.54$, $p < .01$, and $t(63) = 9.02$, $p < .01$, respectively.

Analysis of the nonwords showed that lexical decisions were faster at the long SOA (1,141 ms) than at the short SOA (1,241 ms), $F(1, 63) = 87.1$, $p < .01$, $MSE = 6{,}519$. The prime task had no reliable influence on the RTs to nonwords, $F(1, 63) = 2.7$, $p < .11$, $MSE = 45{,}562$, neither was there a reliable SOA × Prime Task interaction, $F(1, 63) = 2.1$, $p = .15$, $MSE = 3{,}475$.

The accuracy data showed the expected semantic priming effect: Lexical decisions were significantly more accurate for targets following related primes (4.7% errors) than following unrelated primes (6.2% errors), $F(1, 63) = 10.6$, $p < .01$, $MSE = 29$. Hence, the RT prime task effects and their interaction with SOA were not a consequence of a speed–accuracy trade-off. No other effects were significant. The analysis of errors made to nonwords revealed that there were more errors at the short SOA (12.0%) than at the long SOA (9.3%), $F(1, 63) = 15.0$, $p < .01$, $MSE = 30.3$, and that the prime task did not influence accuracy, $F(1, 63) < 1.0$.

No RT data were recorded for the prime responses, because they were arbitrarily withheld until the question mark appeared. Accuracy of prime responses was similar for the consonant–vowel (83.2%) and the living–nonliving (83.6%) tasks. However, the SOA had a significant effect: Across tasks, prime responses were more accurate at the short SOA (96.1%) than at the long SOA (70.7%), $F(1, 63) = 848.8$, $p < .01$, $MSE = 48.6$. The interaction between prime task and SOA was not significant, $F(1, 63) = 1.9$, $p = .17$, $MSE = 17.2$. In our analyses, lexical decision responses to the target were not conditionalized as a function of whether the response to the prime was accurate because, regardless of accuracy, the prime *process* was either letter classification or semantic categorization. In this experiment we were concerned with the effect of process—the level of analysis required by the prime task—rather than with prime accuracy.

Discussion

The most important finding in this experiment was the occurrence of significant semantic priming at the short SOA, regardless of whether the prime was processed at a word-meaning level or at a letter level. The existence of significant semantic priming following the consonant–vowel classification of the prime provides evidence that the semantic representation of the prime had been accessed, even though the task required that attention be directed to the letter level of analysis.

In contrast to the short-SOA condition, in which there was priming following both prime tasks, priming at the long SOA occurred only when the prime was processed at the word-meaning level. If one assumes that activation declines at the same rate in both conditions, then the differential occurrence of priming at the long SOA in the two conditions may be the result of different initial levels of semantic activation. By this argument, the initial level of activation at the short SOA was relatively high following word-level processing (55 ms of priming), with the result that there was still sufficient semantic activation to support priming at the long SOA (23 ms of priming). In contrast, because more attention had to be allocated to letter-level processing in the consonant–vowel task there was less initial semantic activation (36 ms of priming) and, consequently, no detectable priming at the long SOA. Evidence for comparable rates of decline of semantic activation in the two conditions is provided by the absence of a significant SOA × Priming × Task interaction.

As suggested previously, the finding of semantic priming with a short SOA in our experiment, and the absence of such priming in Henik et al.'s (1994) study, may be due to the different letter-level

tasks used in the two experiments. In our experiment, participants were asked to decide only about the first letter in the prime (is the first letter a consonant or a vowel?), whereas in Henik et al.'s (1994) study a given letter was replicated above every letter in the prime—for example,

HHHHHH
FATHER,

the task being to indicate whether the replicated letter was present in the prime. To test whether the type of letter-level prime task could account for the difference between that study and the present one, in Experiment 2 we directly compared the priming effects induced by the two letter-level tasks at a short SOA.

Experiment 2

Both the consonant–vowel task and the letter search task require letter-level processing. One difference between them is the number of letters that participants must screen: only one in the former and several in the latter. It is therefore likely that the letter search task will require that more attention resources be deployed to the letter level, leaving fewer resources available for semantic activation. In this experiment we directly compared semantic priming at a short SOA in the two versions of the letter-level prime task. This comparison was made within subjects, using identical materials. As in Experiment 1, a word-level prime-processing task was also included. Note that it is not prime task difficulty per se that affects semantic activation—the critical factor is whether attentional resources are drawn away from semantic processing of the word. For example, Chiappe et al. (1996) examined semantic priming of targets in a lexical decision task at a long SOA following color naming of the prime. By varying discriminability of the two colors in which the prime was presented, the color judgment was made either easy or difficult. Although time to name the color of the prime was longer in the difficult-discrimination condition, semantic priming was unaffected. Chiappe et al. argued that color judgments fall into a different domain than reading and consequently do not make demands on the resources that drive the visual word recognition machinery. Hence, even though the living–nonliving decision may be more difficult than the consonant–vowel decision greater priming is expected in the word-level condition than in the consonant–vowel condition because of the continuous deployment of attention to the semantic level in the former, as suggested by the data of Experiment 1.

Method

Participants. Seventy-two University of Toronto undergraduates participated in this experiment for course credit. None had participated in the previous experiment.

Tasks and stimuli. One word-level and two letter-level prime-processing conditions were included in this study. The word-level task was the living–nonliving distinction. The two letter-level tasks were the consonant–vowel distinction used in Experiment 1 and the letter search task used by Henik et al. (1994) in which participants indicated whether the probe letter replicated above each letter in the prime word was present in the prime. The probe letter was randomly chosen on each trial, either from the letters composing the prime (25% of the trials) or from among all other letters of the alphabet (75% of the trials). This 3:1 ratio of yes–no responses approximated the ratio of yes–no responses in the consonant–vowel task. As in Experiment 1, the task for the target was lexical decision.

The stimuli were the same 384 pairs used in Experiment 1, equally distributed among the three prime tasks. Among the 128 pairs used in each prime task condition, half the targets were words, and half were nonwords. Half the word targets (32) were related to the prime, with unrelated pairs formed by randomly rearranging primes and targets.

Procedure. Each participant received all 384 prime–target pairs over the three blocks of trials, with the blocks differentiated by the prime-processing task required. Order of presentation of the three blocks was counterbalanced across participants. Across participants, each word target appeared equally often in a related and in an unrelated pairing and in each of the prime tasks. Within blocks, each participant received a different random ordering of items.

As in Experiment 1 and in the experiments conducted by Friedrich (1993) and by Henik et al. (1994), participants were instructed to delay the prime decision until after they had made the lexical decision to the target. The sequence of events and their timing in a trial was as follows. The prime was exposed for 160 ms, followed, after a 40-ms blank screen, by the target, resulting in an SOA of 200 ms. The target, to which participants were to respond immediately, was then exposed for 1,000 ms, followed after 1,500 ms by a question mark, which constituted the signal to respond to the prime. Hence, the lexical decision response occurred during the 2,500-ms SOA between the target and the question mark. The question mark remained on the screen until the prime response had been made. After receiving the relevant instructions, there was a 24-trial practice session, which was repeated on request. After practice, the entire test block was presented without breaks. Speed and accuracy of lexical decisions were emphasized equally.

Results

Percentage errors and mean lexical decision latencies trimmed to two standard deviations are presented in Table 2. The effect of prime task significantly affected lexical decision latency to word targets, $F(2, 142) = 8.4$, $p < .001$, $MSE = 47{,}725$. Decision latencies for targets in the prime letter search condition (1,037 ms) were significantly slower than in the prime consonant–vowel condition (934 ms), $F(1, 71) = 19.3$, $p < .001$, $MSE = 159{,}172$, but did not differ significantly from the living–nonliving condition (1,003 ms), $F(1, 71) = 1.5$, $p < .23$, $MSE = 229{,}929$. The effect of relatedness was also reliable, $F(1, 71) = 27.3$, $p < .001$, $MSE = 3{,}443$, indicating faster processing of related targets (976 ms) than of unrelated targets (1,006 ms). There was a significant Task × Relatedness interaction, $F(2, 142) = 5.1$, $p < .008$, $MSE = 3{,}159$, indicating that the magnitude of priming depended

Table 2
Experiment 2: Mean RTs (in Milliseconds) and Percentage Errors for Lexical Decisions to Related and Unrelated Targets Following the Three Different Prime-Processing Tasks

	Consonant–vowel		Letter search		Living–nonliving	
Target type	RT	% Errors	RT	% Errors	RT	% Errors
Unrelated word	946	5.6	1,043	6.5	1,029	9.3
Related word	922	5.0	1,031	5.5	976	7.4
Priming effect	**24**	**0.6**	**12**	**1.0**	**53**	**1.9**
Nonword	1,005	9.6	1,103	10.8	987	7.9

Note. Stimulus onset asynchrony = 200 ms. RT = reaction time.

on the particular prime-processing task used. Post hoc univariate tests that compared related and unrelated RTs in each prime task condition showed that the 12-ms effect in the letter search task was not reliable, $t(71) = 1.3, p < .187$. In contrast, priming following both the living–nonliving decision (53 ms) and the vowel–consonant decision (24 ms) was significant, $t(71) = 5.3, p < .001$, and $t(71) = 2.5, p < .015$, respectively. Finally, magnitude of priming was significantly greater following the living–nonliving task than the consonant–vowel task, $t(71) = 2.3, p < .05$.

The analysis of RTs to nonwords also revealed a significant effect of prime task condition, $F(2, 142) = 18.3, p < .001, MSE = 15{,}255$, with significantly longer nonword RTs in the letter search condition than in either the consonant–vowel condition, $F(1, 71) = 20.4, p < .001, MSE = 33{,}570$, or the living–nonliving condition, $F(1, 71) = 34.6, p < .001, MSE = 27{,}784$. The last two conditions did not differ significantly from one another, $F(1, 71) < 1.0$.

Analysis of errors to word targets revealed a reliable effect of prime task, $F(2, 142) = 10.0, p < .001, MSE = 33$, with more errors in the living–nonliving condition (8.2%) than in the consonant–vowel (5.2%) or letter search (5.9%) conditions. The effect of priming was also reliable, with more errors on unrelated (7.0%) than on related (5.8%) trials, $F(1, 71) = 12.8, p < .001, MSE = 11$. The Task × Relatedness interaction was not significant, $F(2, 70) < 1.0$.

The percentages of incorrect prime responses in the three prime task conditions are presented in Table 3. For primes followed by word targets, there was a significant effect of task, $F(2, 142) = 39.3, p < .001, MSE = 216$, with more errors in the letter search condition (19.6%) than in the living–nonliving condition (16.4%) or the consonant–vowel condition (4.4%). Post hoc univariate F tests showed that performance in the consonant–vowel condition was better than in the other two tasks, which were not significantly different: $F(1, 71) = 85.1, p < .001, MSE = 722$; $F(1, 71) = 47.0, p < .001, MSE = 805$; and $F(1, 71) = 2.7, p = .11, MSE = 1{,}070$, respectively. The effect of relatedness also affected accuracy of prime responses, with fewer errors when the target was related to the prime, $F(1, 71) = 59.0, p < .001, MSE = 114$. A significant Task × Semantic Relatedness interaction, $F(2, 142) = 43.1, p < .001, MSE = 68$, reflected the fact that prime responses were more accurate when targets were related to the prime in both the consonant–vowel task, $t(71) = 6.1, p < .001$, and the living–nonliving task, $t(71) = 8.0, p < .001$, whereas relatedness did not affect prime response accuracy in the letter search condition, $t(71) = 0.6, p = .55$. The absence of any effect of relatedness on prime accuracy in the letter search condition, together with the absence of any semantic priming of targets in this condition, converges on the conclusion that semantic processing of the prime was impeded in the letter search condition. Analysis of the prime decisions when targets were nonwords revealed a significant task effect, $F(2, 142) = 109.3, p < .001, MSE = 776$, with more errors in the letter search condition than in the other two conditions.

Table 3
Experiment 2: Mean Percentage Errors On the Three Different Prime Tasks as a Function of Target Type

Target type	Consonant–vowel	Letter search	Living–nonliving
Unrelated word	7.5	19.9	25.4
Related word	2.4	19.2	7.4
Nonword	4.4	25.0	10.6

Discussion

The results of this experiment replicated two important findings of Experiment 1. First, there was significant semantic priming at a short SOA following a consonant–vowel decision about the first letter of the prime. The replication of semantic priming in this condition convincingly establishes that use of a letter-level prime-processing task does not in and of itself provide a sufficient condition for the elimination of semantic priming at a short SOA. Second, the magnitude of the priming effect was attenuated in the consonant–vowel condition relative to the living–nonliving condition. Although this attenuation was not reliable in Experiment 1, it was significant in the present experiment. Finally, these data replicated the results of Henik et al. (1994) in demonstrating the elimination of reliable semantic priming at a short SOA following a letter search task in which participants must examine every letter in the prime.[4]

The present data suggest that although semantic activation at a short SOA is not prevented by letter-level processing per se, it may be controlled by factors associated with the particular prime task used. Whereas semantic priming was eliminated following letter search in the entire prime, it was merely attenuated when it was limited to the first letter of the prime. An important difference between these two tasks may be the amount of attentional resources required at the letter level. To establish that the two letter-level tasks did in fact differ in terms of the amount of processing required (and hence in the amount of attention required at the orthographic level), in Experiment 3 we directly compared performance on the two tasks.

Experiment 3

In this experiment participants were shown only a single word on each trial: the words that had served as primes in Experiment 1. Each participant performed three different processing tasks: the semantic-level animacy task and the two letter-level tasks, the consonant–vowel distinction, and letter search. Our primary interest was in comparing performance in the two variations of the letter-level task.

Method

Participants. Twenty-four University of Toronto undergraduates participated in this study. They were paid $3 (Canadian) for their participation.

Stimuli. The stimuli consisted of the primes used in Experiments 1 and 2, divided into three equal sets.

Procedure. The experiment consisted of three blocks of trials; each block contained one of three tasks: the vowel–consonant task (does the word start with a vowel?), the letter search task (is the letter repeated above

[4] Our replication of Henik et al.'s (1994) results suggests that the semantic priming observed by Maxfield and Chiarello (1996) using the same letter search paradigm may have resulted either from the particular stimulus set used, as they themselves suggest, or from the different response procedure they used.

the word present in the word?), and the animacy judgment task (does the word represent a living thing?). The order of these three blocks of trials was counterbalanced across participants.

Before each block of experimental trials participants were given 24 practice trials with that task. The trial sequence for all three tasks was as follows: A 500-ms fixation point appeared on the screen, followed by a 500-ms blank screen. The stimulus then appeared on the screen for 200 ms, followed immediately by a 1-s ampersand mask (to mimic any masking effects that may have been produced by the target in the previous experiments). The screen then remained blank until a response was made. If a response was made prior to the blank screen, the next trial began immediately after the mask disappeared. Otherwise, it began immediately after the participant's response.

Results and Discussion

We trimmed the data to 2.5 standard deviations, resulting in a loss of 2% of the data for the two letter-level tasks and a loss of 3% of the data for the animacy task. Mean RTs and percentage errors for the three conditions are presented in Table 4. An ANOVA of the latency data indicated that speed of responding differed significantly in the three tasks, $F(2, 36) = 43.6$, $p < .001$, $MSE = 16{,}366$. RTs were fastest in the consonant–vowel condition (495 ms), slower in the animacy condition (687 ms), and slowest in the letter search condition (839 ms). A series of planned t tests indicated that all conditions differed significantly from one another: For consonant–vowel versus letter search, $t(23) = -7.2$, $p < .001$; for consonant–vowel versus animacy, $t(23) = -7.7$, $p < .001$; for letter search versus animacy, $t(23) = 4.0$, $p < .001$. The main effect of order was not significant and did not interact significantly with task. Errors also differed significantly across conditions, $F(2, 36) = 32.3$, $p < .001$, $MSE = .001$. The error rate was significantly greater in the animacy condition than in either the consonant–vowel condition, $t(23) = 7.0$, $p < .001$, or the letter search condition, $t(23) = 7.0$, $p < .001$. Accuracy rates were comparable in the two letter-level tasks, $t(23) = 0.96$, $p > .34$.

Hence, these data clearly demonstrate that the letter search task requires more extensive processing than the consonant–vowel task. This may result from the fact that all the letters must be examined in the letter search task, whereas only the first letter must be identified in the consonant–vowel task. Furthermore, presentation of the repeated letter above the word may make it more difficult to parse the display, compared to the consonant–vowel task, in which no additional letters are presented. Either or both of these factors would necessitate more attention at the letter level.

General Discussion

The results of this study help to clarify the processes involved in semantic activation during visual word recognition. Most important, the demonstration of semantic priming at a short SOA in the consonant–vowel condition provides compelling evidence that rapid activation of the semantic system is possible even when the prime task requires that attention be directed to the letter level. This finding implies that the default setting in word recognition is for semantic activation. However, the absence of priming following the letter search task indicates that this activation may be modulated by attention: If full attention must be deployed to the letter level for orthographic analysis, as in the demanding letter search task, there are insufficient resources available for semantic activation of the prime's representation. Consequently, no semantic priming of a related target will occur. In contrast, with a less demanding letter-level task, such as the consonant–vowel classification, some resources are still available for semantic activation, and priming will occur.

To determine whether use of the delayed dual-response procedure, in which participants withhold the prime response until after the target response has been made, may have influenced semantic priming in some unforeseen way, we conducted an additional experiment in which we compared semantic priming using both an immediate and a delayed prime response at a long SOA. Although lexical decisions for the target were significantly slower and more error prone when the response to the prime was delayed until after the target response had been made, neither the magnitude nor the pattern of semantic priming were affected by this delay. This result suggests that the requirement of keeping information about the prime in memory imposes a cognitive load, slowing target processing, but does so without affecting semantic priming. Pashler (1998) suggested that maintaining a memory load may make people perform other tasks more slowly, because rehearsing the memory load prevents them from optimally preparing for the other task (p. 370). Regardless of the reason, the absence of any statistical interaction between semantic relatedness and response delay suggests that use of the delayed dual-response procedure is unlikely to be an important factor in explaining discrepant experimental priming results from different experiments following letter search at a short SOA.

Although RT—the amount of time required to perform a given task—is a fairly reliable indicator of the amount of processing required to perform the task, it is not amount of processing per se that determines whether resources will be drawn away from the semantic system. As suggested earlier, difficulty of the prime task will affect semantic activation only if both the prime and target task share a common pool of resources, as is the case when both tasks involve elements of word recognition (as in the two tasks used in these experiments). If the two tasks involve different domains of processing, such as color identification and word recognition (Chiappe et al., 1996), then varying difficulty of the prime task will not differentially influence semantic activation of the target word. Furthermore, even when both prime and target tasks do use the word recognition system the level of processing within the system to which attention must be directed is important. For example, the living–nonliving task requires extensive processing, as indicated by the relatively long RT to this task in Experiment 3. However, unlike the two letter-level prime tasks, the living–nonliving task relies on semantic-level processing, with very little capacity needed for letter-level processing. Hence, semantic activation and the resulting semantic priming are maximal.

Table 4
Experiment 3: Mean RTs (in Milliseconds) and Percentage Errors for the Three Stimulus Processing Tasks

Measure	Consonant–vowel	Letter search	Living–nonliving
RT	495	839	687
% Errors	2.6	2.0	9.5

Note. RT = reaction time.

In contrast to the attention-modulation proposal espoused here, Besner et al. (1990) suggested an alternative explanation for the absence of priming following letter-level prime processing. Besner et al. postulated an inhibitory mechanism that blocks or attenuates semantic activation of related conceptual representations when participants engage in letter search. By this argument, the activation of related conceptual representations within the semantic system produces top-down activation of orthographic and letter features of related words (as shown in Figure 1) that is helpful for normal word reading and may be the basis for the semantic priming effect that typically follows the normal reading of related primes. However, if the processing of the prime requires extensive letter-level processing, top-down activation of the letters of related words may be deleterious for prime processing and, therefore, inhibited. As a result of this inhibition, semantic priming is attenuated or completely prevented. We believe that the attention-modulation mechanism proposed here can better account for the present data than the all-or-none inhibitory mechanism postulated by Besner et al. More specifically, if readers were inhibiting semantic activation when the task involves letter-level processing, there should be no semantic priming in either letter-level task. Inhibition cannot explain the different priming effects in the two letter-level tasks. Furthermore, if semantic activation is blocked whenever letter-level information is required there should never be semantic priming following letter-level processing, even when the SOA is very brief. The finding of priming in the consonant–vowel short-SOA condition speaks against this suggestion. If one were to argue that it takes time to institute an inhibitory block, then priming should always be found at a short SOA, regardless of prime task. Here again, the absence of priming at the short SOA following letter search of the prime argues against this suggestion. Consequently, we suggest that the resource-dependent modulation of semantic activation provides a better account of the present data.

Whereas we prefer to explain the semantic priming results in terms of prime-related semantic activation that occurs prior to target presentation, others have suggested that semantic priming of lexical decision is better explained in terms of postlexical decision processes that occur after target presentation (e.g., de Groot, 1985; Neely & Keefe, 1989; Ratcliff & McKoon, 1997). By this account, when participants note that a prime and target are related, it follows that the target must of necessity have been a word, and hence the correct response in the lexical decision task is "word." Such a strategy would provide for faster responses on related trials than on unrelated trials, because unrelated trials could result either from word or from nonword targets and thus require more extensive processing. By this rationale, priming could be accounted for entirely by decision processes occurring after target presentation rather than from prime-related activation. We believe, however, that such a decision mechanism cannot provide an adequate explanation for the present data, for several reasons. First, if semantic priming resulted entirely from strategic, postlexical decision processes, then why should the particular task performed on the prime affect priming? In particular, how could differential semantic priming following the two different letter-level tasks be explained in terms of postlexical decision processes? Second, if priming was the result of processes that occurred only after target presentation, it is not clear why SOA should play such an important role. Because the postlexical decision process would be the same regardless of whether the prime–target SOA was long or short, semantic priming should not be different for the two SOA conditions—but it is. Third, we found in Experiment 2 that the percentage of errors for the prime task was greater when prime and target were unrelated than when they were related for both the consonant–vowel and animacy conditions, but not for the letter search condition. Prime–target relatedness had no effect on prime accuracy in the letter search condition. This result is consistent with the suggestion that there was semantic activation of the prime representation in the first two conditions, but not in the latter. If priming in lexical decision resulted entirely from processes that occurred following target presentation, this result would be difficult to explain. For all these reasons, we believe that differential priming following word- and letter-level prime tasks is better explained in terms of prime-related activation than of postlexical decision processes.

The studies reported in this article suggest that access to a word's meaning is the default setting of the visual word recognition system, with fast-acting activation of the semantic system occurring even when attention is deployed at the letter level. However, even this fast-acting activation requires attention and hence is influenced by the amount of attention required for the letter-level processing. It should be noted that Pashler (1998) came to similar conclusions with regard to the attentional demands of visual search, suggesting that even "automatization of search does not eliminate capacity demands on visual attention" (p. 365). If a great deal of attention is required at the orthographic level, no semantic activation occurs. If the attentional demands at the orthographic level are reduced, semantic activation is reinstated, although it is reduced relative to that achieved when most of the attention is allocated to the semantic level throughout prime processing. One implication of this proposal is that one determinant of reading skill may be the amount of attention that must be allocated for orthographic-level processing: Less skilled readers may allocate more attention to orthographic-level processing, leaving fewer resources available for semantic processing.[5] Further research along such lines may prove fruitful.

[5] We thank Christine Chiarello for making this suggestion.

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