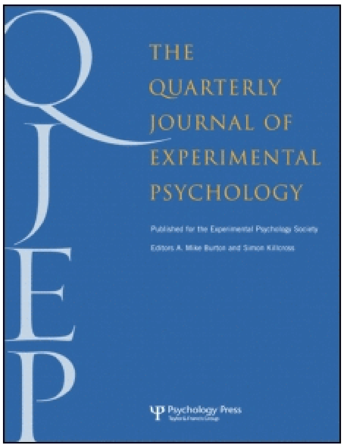

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Semantic activation and letter search: Blocking or suppression?

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Semantic activation and letter search: Blocking or suppression?

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Two experiments investigated associative priming with a letter-search prime task where either the prime and letter probe were presented simultaneously, or the letter probe appeared 200 ms (Experiment 1) or 300 ms (Experiment 2) after the prime. Weak associative priming was observed in both experiments, but unlike Stolz and Besner (1996) we found no evidence that priming was increased when the probe was delayed. However, strong associative priming was observed when a semantic decision had to be made on the prime (Experiment 3). Our results are consistent with an account where semantic activation of the prime occurs but its action on the target is suppressed by the prime task. The persistence of weak priming effects with the letter search task is explained in terms of the low-frequency items used.

Keywords: Associative priming; Letter search; Decision; Semantic activation.

In associative priming,[1] processing of a target word is facilitated when it is preceded by an associatively related prime, rather than an unrelated prime. Thus naming or making a lexical decision about a word target (e.g., "fork") is normally faster when this is preceded by a related prime (e.g., "spoon") than when it is preceded by an unrelated prime (e.g., "planet"). For extensive reviews see Neely (1991) and McNamara (2005).

One interpretation of associative priming explains this effect by automatic activation passing between the semantic representation of words, a process that occurs rapidly, without intention or awareness (Posner & Snyder, 1975). When the prime is presented, its semantic representation becomes activated, thereby automatically activating the meaning of its associates. Therefore, it will be easier, and faster, to respond

[1] Please note that we use the term "associative" priming as default when referring to the priming effect of a prime that is semantically associated to a target. However, we use the word "semantic" when citing studies where the authors used the term "semantic" instead of "associative".

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to a target following a related prime, because the target's semantic representation is preactivated. It is still unclear and controversial what the precise nature of this automatic mechanism is. According to early accounts, word meanings are represented by nodes in a semantic network. When a prime word is read, the corresponding node is activated, and the activation automatically spreads to nearby nodes in the network, representing related words, which may include the target (e.g., Collins & Loftus, 1975; Neely, 1977; Posner & Snyder, 1975). Alternative models are based on the feature overlap concept. According to this, the meaning of a word is represented by the representation of its component features (Masson, 1995; Plaut, 1995). Reading a prime will automatically activate all its features, and, consequently, any words sharing features with the prime will be at least partially activated.

If associative priming depends only on automatic processes, its effects should be relatively consistent across experimental conditions. However, associative priming is sensitive to experimental conditions in ways that suggest a role for strategic processes. One such process is prospective or prelexical priming, which occurs when forward associations based on the prime are used to generate an expectancy set of associated words. When the target is presented it is compared with items in the expectancy set. If there is a match, then a positive response can be given (Becker, 1980; Hutchison, Neely, & Johnson, 2001; Neely, Keefe, & Ross, 1989; Posner & Snyder, 1975). For this strategy to be effective there must be enough time to allow generation of the expectancy set before the target is presented. Another strategy is retrospective or postlexical priming, in which the semantic relationship between prime and target is used to facilitate target lexical decisions (de Groot, 1984; Neely, 1977). In this case, the semantic representation of the target is activated first and is then compared with that of the prime. The presence of a semantic match can be used to facilitate lexical decision, because if there is a match the target must be a word. Unlike prospective priming, retrospective priming can operate when the direction of association is from target to prime (Koriat, 1981; Seidenberg, Waters, Sanders, & Langer, 1984).

The role of strategic processes is demonstrated by evidence that priming increases with the *relatedness proportion* (RP), the proportion of related to unrelated prime–target pairs (e.g., de Groot, 1984; den Heyer, Briand, & Dannenbring, 1983; Seidenberg et al., 1984; Tweedy, Lapinski, & Schvaneveldt, 1977). Associative priming is also modulated by *stimulus onset asynchrony* (SOA)—that is, the time interval between the presentation of prime and target (Neely, 1991). Moreover, these two effects interact, such that relatedness proportion modulates priming more at long SOAs (>300 ms) than at short SOAs (e.g., Henik, Friedrich, Tzelgov, & Tramer, 1994). These results suggest that controlled processes are encouraged by increasing RP, but require relatively long SOAs to be effective, whereas automatic processes operate even at short SOAs (but see Bodner & Masson, 2003, for an exception).

Associative priming is greatly reduced or eliminated when attention is focused on orthographic features of the prime (e.g., Friedrich, Henik, & Tzelgov, 1991; Henik, Friedrich, & Kellogg, 1983; Henik et al., 1994; Kaye & Brown, 1985; Smith, Bentin, & Spalek, 2001; Smith, Theodor, & Franklin, 1983). Typically this is achieved using the letter search task, in which the prime is presented together with a probe letter (usually displayed repeatedly above each letter of the prime), and the observer decides whether the probe letter is present in, or absent from, the prime (Smith, 1979). The reduction in priming has important implications for associative priming and word recognition, but its interpretation critically depends on assumptions made about the prime task. Typically, the letter-search prime task is carried out with a relatively long prime–target SOA. Thus there would be time for strategic processes to operate, but also competition between the demands of the prime task and priming processes. In particular, expectancy generation based on the prime would produce a cognitive load at the same time that letter search was taking place. Some support comes from evidence that the extent of priming depends on the attentional demands of the prime task, whether this is orthographic (Smith et al., 2001) or not (Otsuka & Kawaguchi, 2007).

In an attempt to resolve the issue of whether automatic priming took place with letter search, Henik et al. (1994) and later Smith et al. (2001) showed that a letter search prime task reduced priming to nonsignificant levels when the SOA was short (240 or 200 ms), although priming could be detected with high RP or reduced load on the prime task. They interpreted this result as an elimination of priming, suggesting that semantic activation of the prime was prevented by letter search, at least if resources were directed at the prime task. However, Tse and Neely (2007) argue that in these cases there may be priming effects that remained undetected due to low statistical power. Nevertheless, if there is priming under these conditions, it appears to be relatively weak.

According to the activation blocking account, orthographic processing prevents semantic activation of the prime and thereby eliminates associative priming. However, repetition priming and morphological priming both survive an orthographic prime task, suggesting that the prime is activated at least to a lexical level (Friedrich et al., 1991; Stolz & Besner, 1998). If so, the block on semantic activation must occur between the lexical and semantic levels. Without any semantic activation of the prime, expectancy-based and automatic priming could not take place.

An alternative to the activation blocking account is the activation-based suppression account, whereby semantic activation of the prime occurs automatically, but priming is suppressed by an orthographic prime task (Maxfield, 1997). According to this account it is possible to show semantic activation of the prime in the absence of semantic priming. Hutchison and Bosco (2007) used a letter search task where prime word meaning (e.g., present/absent) was congruent or incongruent with the response. Prime congruence affected letter search RT, implying that the meaning was activated, but no semantic priming was observed on named targets. Further evidence comes from event-related potential (ERP) studies. Heil, Rolke, and Pecchinenda (2004) combined a lexical decision task with a letter-search prime task and found no evidence of semantic priming with response time (RT) measures, but N400 amplitude, an index of semantic processing, was sensitive to the relatedness of prime and target (see also Mari-Beffa, Valdes, Cullen, Catena, & Houghton, 2005). Kuper and Heil (2009) studied the N400 response to priming at short (240 ms) and long (800 ms) latencies, by delaying the prime task response until after the target response. Although there was no priming of the target response itself, the N400 was sensitive to prime–target relatedness even at short SOAs. This suggests that semantic activation occurs rapidly and automatically in response to the prime and persists for at least 800 ms when letter search is taking place.

A problem for the activation-suppression account is posed by intriguing results obtained by Stolz and Besner (1996). They reported an absence of associative priming with a conventional letter-search prime task, but massive priming emerged when the prime was presented 200 ms before the letter probe. They explained their results in terms of activation blocking, using an interactive activation model. With a normal letter search task, activation is restricted to the letter and word levels and cannot pass to the semantic level. However, a brief preview of the prime before the letter probe appears is sufficient to allow full semantic activation and full-blown priming effects. It is difficult to reconcile this finding with the activation-suppression account. During the brief preview, some process would need to occur that would be resistant to the suppressive effects of letter search. It is unlikely that this could be the generation of an expectancy set, because the preview was of such short duration. Equally, it seems unlikely that the prime preview would encourage priming by a retrospective strategy. Stolz and Besner (1996) concluded that automatic priming occurs ballistically during the preview and survives both the prime task and the relatively long SOA.

Curiously, in a second experiment where preview of the prime (0 ms or 200 ms) was randomized across trials, modest but significant associative priming was found in both conditions. Thus, compared to the first experiment, there was an increase in priming in the simultaneous letter-probe condition, but a decrease in the delayed condition. Stolz and Besner explained this result in terms of mental set, the "internal world of the participant" that, in their particular experimental setting, affects "how activation flows throughout the system" (Stolz & Besner, 1996, p. 1175). In other words, the process of activation blocking itself appears to be under strategic control. Exactly how or why this occurs as a result of mixing the simultaneous and the delayed trials is not made clear, but throughout their paper they seem to anticipate carryover effects (cf. p. 1170). However, the modulation of the prime task effect by changing the task demands, the attention modulation hypothesis, is not in question and can be incorporated into either account. It is the Stolz and Besner (1996) Experiment 1 result, the release of priming with letter probe delay, that is critical for the activation-suppression account.

Stolz and Besner's (1996) finding that semantic priming critically depends on the timing of the letter probe is also of practical interest because it suggests a simple and effective method to modulate the behavioural expression of associative priming. If their view is correct, then priming can be switched on (at least in blocked conditions) by retarding the probe letter by 200 ms. Our interest originally was in how modulation of associative priming could affect performance in a subsequent memory task.

However, before developing this method we attempted to confirm the release of associative priming following a delayed letter probe, since to our knowledge there is no other published account of this phenomenon. In Experiment 1 we adhered to the procedure of Stolz and Besner (1996) as closely as possible, using a letter search task where the prime was presented in lowercase, and the letter probe was in uppercase. In Block 1 the prime and letter probe were simultaneous, whereas in Block 2 the letter probe was delayed by 200 ms. In Experiment 2, the method was similar, but the prime and probe letter were presented in the same case, either simultaneous or with a delay of 300 ms. Our aim was to confirm that priming would be determined by the letter probe delay. However, in Experiments 1–2 delaying the presentation of the letter probe did not lead to an increase in associative priming. In Experiment 3 we included a semantic decision as the prime task in the second block of trials, while leaving Block 1 the same as that for Experiment 1. This was done to rule out the possibility that some feature of Experiments 1 and 2 constrained the expression of associative priming in the second block of trials.

EXPERIMENT 1

Method

Participants

A total of 16 students from the University of Essex, with mean age 24 years took part in the experiment. One participant was replaced because of low accuracy on target responses (<90%). All participants were native English speakers or fluent English speakers educated in English.

Apparatus

Stimuli were displayed on a Mitsubishi Diamond 19″ colour monitor driven by a Macintosh G3 computer at a refresh rate of 75 Hz. Software was written in C, incorporating the VideoToolbox subroutines (Pelli, 1997). Primes, probe letters, and targets were displayed in 30-point Courier font, so that upper-case letters were approximately 6 mm high and 6 mm apart.

Materials

The stimulus set consisted of 176 word–word pairs and 176 word–nonword pairs. The word–word pairs were selected from two databases: The University of South Florida norms (Nelson, McEvoy, & Schreiber, 2004) and the Birkbeck word association norms (Moss & Older, 1996). Associated pairs were chosen if the forward association strength was at least 0.4, and the prime and target items were between 4 and 7 letters in length.

The word–word pairs were divided into four sets of 44 pairs. Within each set, unrelated pairs were formed by randomly recombining the primes and targets. The allocation of each set to the four conditions (related or unrelated primes at each of two delays) was rotated across participants. The relatedness proportion was .5.

For each prime word a matching and a mismatching letter probe was provided. For matching probes, the position of the letter (first, middle, and last) within the word was balanced. Where possible, only letters whose upper-case form was a different shape from the lower-case form were used as probes—that is, A B D E F G L M N R T—but there were a few exceptions when these letters were not part of the prime (e.g., kiwi).

Nonword targets were made from words taken from the Nelson associative norms by changing two letters. All nonwords were at least four and no more than seven letters long and were pronounceable.

The total number of word–nonword pairs was 176. Of these, half had a matching target letter, and the other half had a nonmatching target letter. Half of the pairs of each kind were presented in the simultaneous and delayed conditions.

Procedure

Each trial started with a fixation point ("+"), in the centre of the screen for 1 second. Then the prime appeared in lower case, above which was displayed the target letter string, the same length as the prime, in upper case. In the simultaneous condition, prime and letter probe appeared simultaneously and remained visible until a response was given. In the delayed condition the prime was first shown for 200 ms, and then the letter probe appeared above the prime (which remained visible). Participants had to decide whether or not the letter probe was part of the word by pressing a "Yes" key (with the left hand) or a "No" key (with the right hand). In both conditions, prime and letter probe remained visible until a response was given. Then, after a delay of 200 ms the target was displayed requiring a lexical decision.

Following Stolz and Besner (1996), participants always started with the simultaneous condition (176 trials, with a rest after 88 trials), preceded by a practice of 40 trials. The delayed condition followed a brief pause, during which participants were informed that the appearance of the display would change slightly, but otherwise the task was the same. In each condition 176 trials were presented (88 word–nonword pairs and 88 word–word pairs).

Results and discussion

Lexical decision

Trials were excluded if probe RTs were less than 300 ms or exceeded 1,500 ms (3.1% of trials). For the accuracy data analysis, also trials where the prime response was incorrect were excluded, while for the RT analysis we excluded trials where either the prime or the probe responses were incorrect (a further 3% of trials). Mean accuracies and RTs in the lexical decision task are shown in Table 1. Both accuracy data and RTs were analysed with a 2 (prime type) × 2 (probe delay) within-subjects analysis of variance (ANOVA).

The analysis on accuracy showed that performance was significantly better for related trials, $F(1, 15) = 8.6$, $MSE = 56.1$, $p < .05$, suggesting that the presence of a related prime increased accuracy in processing the following probe. The effect of delay was not significant, $F < 1$, and, most importantly, the interaction between prime type and delay was not significant, $F(1, 15) = 1.6$, $MSE = 8.8$, $p > .2$, showing that the advantage due to the related prime was independent of the delay condition.

The lexical decision RT analysis was carried out with both subjects (F_1) and items (F_2) as random variables. The analysis by subjects showed a main effect of priming, where RTs to related targets were faster than those to unrelated targets, $F_1(1, 15) = 4.9$, $MSE = 3,378$, $p < .05$. However, RTs were not affected by delay condition, $F_1(1, 15) = 1.4$, $MSE = 3,890$, $p > .2$, and the interaction between prime type and delay was not significant, $F_1(1, 15) < 1.0$, even though the advantage for related words was smaller in the

Table 1. *RTs and mean accuracies in the simultaneous and delayed conditions in the lexical decision task in Experiment 1, for unrelated, related, and nonword targets*

	Unrelated		*Related*		*Nonword*	
Condition	*RT*	*Accuracy*	*RT*	*Accuracy*	*RT*	*Accuracy*
Simultaneous	656 (115)	96 (4.6)	644 (117)	98.6 (1.9)	716 (150)	97.5 (2.6)
Delayed	643 (90)	97.1 (2.9)	626 (106)	98.2 (1.8)	677 (132)	97.2 (2.4)

Note: RTs = reaction times in ms. Percentages of accuracy were calculated on the number of trials left after removing trials with incorrect prime and trials with target outliers. Standard deviations are in parentheses.

simultaneous condition (12 ms) than in the delayed condition (17 ms).

The item analysis showed a significant main effect of delay, $F_2(1, 174) = 5.06$,[2] $MSE = 500{,}061$, $p < .03$, a marginally significant main effect of priming, $F_2(1, 174) = 3.63$, $MSE = 45{,}154$, $p < .06$, and a nonsignificant interaction, $F_2 < 1$.

The RTs in the simultaneous and delayed conditions were also analysed separately. Paired *t* tests showed that the difference between related and unrelated RTs approached significance with simultaneous probes, $t(15) = 2.0$, $p < .07$, but there was no evidence of priming in the delayed condition, $t(15) = 1.5$, $p > .1$. Thus overall the lexical decision task with letter search showed a small associative priming effect, but no evidence that this was modulated by delay of the letter probe.

Letter search

In the letter search task, response times were measured from the letter probe onset. For each participant, trials were excluded if the response time was more than 2 standard deviations above the mean, or if the response time was faster than 300 ms (4% of all trials). For the RT analysis, trials where the prime response was incorrect were also discarded (2.6% of all trials). Data on accuracy and RTs were analysed with a 2 (probe delay) × 2 (matching condition) within-subject ANOVA.

Performance was slightly worse when the presentation of prime and letter probe was simultaneous (97%) than when the letter probe was delayed (98%), $F(1, 15) = 5.3$, $MSE = 6.8$, $p < .05$, and worse for matching letter probes (97%) than for mismatching letter probes (98%), though this only approached significance, $F(1, 15) = 3.9$, $MSE = 30.2$, $p < .07$. The interaction between the two factors was significant, $F(1, 15) = 12.9$, $MSE = 48$, $p < .05$. In the delayed condition accuracies were comparable with matching and mismatching letter probes (98%), while in the simultaneous condition participants were more accurate with mismatching letter probes (99%) than with matching targets (96%). This may reflect a change in response bias with practice (the delayed condition was always second).

Letter search RTs, measured from probe onset, were slower in the simultaneous condition (1,032 ms) than in the delayed condition (865 ms), $F(1, 15) = 61.7$, $MSE = 447{,}393$, $p < .01$. This was expected because in the delayed condition participants had 200 ms to process the prime before the appearance of the letter probe. RTs were also faster with matching letter probes (905 ms) than with mismatching letter probes (992 ms), $F(1, 15) = 48.9$, $MSE = 121{,}365$, $p < .01$. The interaction between the two factors was not significant, $F(1, 15) = 1.7$, $MSE = 777$, $p > .2$.

Thus in Experiment 1, we obtained a weak associative priming effect with letter-searched primes on lexical decision. The effect was small and within the range reported in previous studies. However, there was no significant modulation of the priming effect with delay of the letter probe.

[2] Note that degrees of freedom are less than 175, as some items (one in Experiment 1 and two in Experiment 3) were discarded because they did not contribute to one of the conditions.

This result is clearly not in accord with Stolz and Besner (1996, Experiment 1) and as such provides no support for the activation blocking account of the prime task effect. However, although the effect of letter probe delay on priming was non-significant, the change was in the right direction, with slightly greater priming in the delayed condition. We therefore attempted a further replication with some modifications in Experiment 2.

EXPERIMENT 2

In Experiment 2 we made the following changes to the procedure. First, primes and letter probes were both presented in upper case. This should make letter search easier because now the letter probes and matching prime letters would have identical shapes. Matching the letter shapes should reduce the load of the prime task and, if anything, should encourage priming. Secondly, we increased the delay of the target letter to 300 ms in the delayed condition. It is possible that in Experiment 1, 200 ms was insufficient for full semantic activation of the prime, although this was sufficient in the case of Stolz and Besner's (1996) participants. This increased delay should allow sufficient time for semantic processing of the prime before letter search begins, while discouraging unwanted strategic processes (de Groot, 1984; den Heyer et al., 1983).

Method

The apparatus, stimuli, and procedure were identical to those described in Experiment 1, except that prime and probe letters were both presented in upper case, and, in the delayed condition, presented in the second block of trials, the probe letter delay was increased to 300 ms.

Participants

The participants were 16 students form the University of Essex (mean age was 21 years). Of these, 6 were replaced because accuracy on target responses was lower than 90%. None of these participants took part in Experiment 1. All were native English speakers or fluent English speakers educated in English.

Results and discussion

Lexical decision

The data were filtered in the same way as for Experiment 1: A total of 4.3% of trials were discarded because lexical decision RTs were outside the acceptable range, and a further 2% were discarded because either the prime or the target responses were incorrect. Mean accuracies and latencies are shown in Table 2.

Analysis of accuracy data showed that the main effect of letter probe delay was not significant, $F < 1$, and neither was the main effect of prime type, $F(1, 15) = 2.9$, $MSE = 5.2$, $p > .1$. The interaction also failed to reach significance $F(1, 15) = 2.0$, $MSE = 2$, $p > .1$.

With respect to RTs analysis by subjects, there was a significant main effect of probe delay, $F_1(1, 15) = 10.8$, $MSE = 31{,}506$, $p < .01$: RTs were faster in the delayed condition than in the simultaneous condition. There was also a significant main effect of priming, $F_1(1, 15) = 8.6$,

Table 2. *RTs and mean accuracies in the simultaneous and delayed conditions in the lexical decision task in Experiment 2, for unrelated, related, and nonword targets*

	Unrelated		*Related*		*Nonword*	
Condition	*RT*	*Accuracy*	*RT*	*Accuracy*	*RT*	*Accuracy*
Simultaneous	698 (97)	98.5 (2.1)	680 (98)	99.5 (1)	817 (125)	95.7 (4.6)
Delayed	651 (96)	98.5 (2.3)	638 (95)	98.6 (2.2)	735 (122)	96.5 (3.7)

Note: RTs = reaction times, in ms. Percentages of accuracy were calculated on the number of trials left after removing trials with incorrect prime and trials with target outliers. Standard deviations are in parentheses.

MSE = 3,906, $p < .05$, with faster RTs to related items. However, associative priming was not affected by the delay between prime and probe, $F_1 < 1$. The item analysis, as in Experiment 1, showed a significant main effect of delay, $F_2(1, 175) = 28.54$, *MSE* = 339,202, $p < .001$, a main effect of priming just significant, $F_2(1, 175) = 3.912$, *MSE* = 53,825, $p = .05$, and a nonsignificant interaction, $F_2(1, 175) \leq 1$.

These results are very similar to those obtained in Experiment 1. We found a main effect of prime type, reflecting a rather weak associative priming effect, which again did not interact with probe delay on the prime task. Priming did not increase in the delayed condition, and the trend was in the opposite direction. When separate analyses were performed for simultaneous and delayed trials, the 19-ms difference between unrelated and related pairs approached significance in the simultaneous condition, $t(15) = 2.1$, $p < .055$, but the 12 ms of priming in the delayed condition failed to reach significance, $t(15) = 1.3$, $p > .2$.

Letter search

Trials were excluded if the RT was less than 300 ms or more than 2 standard deviations above the mean (4% of the total).

The analysis of accuracy data showed that there was a significant main effect of the matching condition, $F(1, 15) = 22$, *MSE* = 31.2, $p < .01$, with participants being less accurate with matching probes (97%) than with nonmatching probes (99%). The effect of delay was not significant, $F < 1$ (98% in both conditions), neither was the interaction between the two factors, $F(1, 15) = 3.2$, *MSE* = 5.0, $p < .10$. These results were slightly different from those found in Experiment 1, where main effects and interaction were all statistically significant (however, differences in accuracies in the different conditions were in the same direction).

For the RT analysis only correct responses were considered, excluding a further 2% of trials. The analysis of the response times showed a significant effect of delay, $F(1, 15) = 95.6$, *MSE* = 11,051, $p < .01$, with faster responses in the delayed condition (M = 846 ms) than in the simultaneous condition (M = 1,100 ms). There was a significant effect of matching conditions, $F(1, 15) = 76.9$, *MSE* = 179,352, $p < .01$ (924 ms with matching letter probes and 1,000 ms with nonmatching letter probes) and a significant interaction of the two conditions, $F(1, 15) = 5.7$, *MSE* = 2,475, $p < .05$ (RTs in the simultaneous condition were 1,049 and 1,168 ms when letter probes were matching and nonmatching, respectively, but in the delayed condition the corresponding RTs were 789 ms and 892 ms). These results were comparable to those in Experiment 1, although the interaction in that experiment failed to reach significance.

The accuracy and RT results on the letter search task were thus very similar to those of Experiment 1. There is no reason to believe that the changes between the two experiments (the extended delay and the use of upper-case targets in Experiment 2) affected the way the prime task was performed. Although there appears to be a small associative priming effect when this lexical decision task is performed in conjunction with a letter search prime task, we have found no evidence that priming is affected by letter probe delay.

EXPERIMENT 3

In Experiments 1 and 2 we found evidence of a weak associative priming effect when a letter search was performed on the prime. Contrary to the claim of Stolz and Besner (1996), delaying the presentation of the letter probe did not lead to an increase in semantic priming. One concern is that possibly only weak semantic priming can be observed under the conditions of our experiments. Possibly some unknown feature of the present experiments (for example, the word lists used, or the requirement for two rapid responses in succession, or the cognitive load of the prime task, or the fact that the critical manipulation was always in the second block of trials, or low statistical power) minimizes the effect of associative priming. If so, then no manipulation would be expected to bring about a large increase in priming. To investigate this, in Experiment 3 we included a semantic decision as the prime task in the second block of trials. The first block of Experiment 3 required a letter search on the prime, as in Experiments 1 and 2, but in the second block participants had to make a living/nonliving decision on the prime, followed by a lexical decision on the target. This prime task is known to encourage associative priming (Smith et al., 1983). Experiment 3 was identical to Experiment 1 in all respects, except for the semantic prime task decision in the second block of trials. This would allow us to directly compare the second block of Experiment 1 (letter search with delayed presentation, preceded by a letter search task with simultaneous probe presentation) with the second block of Experiment 3 (semantic classification, preceded by a letter search task with simultaneous probe presentation). If semantic activation is suppressed by letter search, we would again expect to see little or no associative priming in the first block, but strong associative priming encouraged by the semantic decision in the second block, confirming that our procedure is not generally insensitive to associative priming, and that the failure to find evidence of associative priming with a delayed letter probe is not an artefact. On the other hand if in Block 2 no larger associative priming than that detected in Block 1 is observed, then this outcome would suggest that the methodology used in the present study is inappropriate to induce increased associative priming in Block 2 compared to Block 1 irrespectively of the prime task used.

Method

The apparatus and stimuli were identical to those described in Experiment 1. The experiment was again presented in two blocks. The procedure of the first block was identical to the procedure of the same block in Experiment 1, where participants had to perform a letter search with prime and letter probe simultaneously presented. However, in the second block, participants had to make an animacy decision, deciding whether the prime was living or nonliving. The word lists were not devised with this semantic judgement in mind, and living primes were in a minority (cf. Smith et al., 1983). Moreover, in some cases it is not clear whether a prime is living or nonliving, either because the prime was polysemous (e.g., crook) or because it might represent a nonliving part of an organism (e.g., thorn, antlers). To increase the consistency of decisions in this prime task, participants were instructed to respond "yes", if the prime "referred to a living thing, a type of animal or plant, or a person, or a part of a living organism". With this criterion, 28% of word-word pairs and 27% of word-nonword pairs were classified as living.

Participants

A total of 16 native English speakers, mean age 25.4 years ($SD = 10.2$) were recruited from the Psychology Department volunteer panel. A total of 8 were male, and 8 were female; 4 participants were replaced because they showed error rates of more than 10% on lexical decisions, or high error rates on the letter search task.

Procedure

The apparatus and stimuli were identical to those described in Experiment 1. The procedure of the first block was identical to the procedure of the same block in Experiment 1, where participants had to perform a letter search with prime and probe simultaneously presented. However, in the second block, participants had to decide whether the prime referred to something living or nonliving. Instead of probe letters, an asterisk was displayed above each letter of the prime, simultaneously. Because the two tasks were different, participants received instructions and a practice of 40 trials using the letter search prime task, before the letter search experimental trials, and then received instructions and a practice using the semantic prime task before completing the second block of experimental trials.

Results

Trials were excluded if the target lexical decision RTs were less than 300 ms or greater than 1,500 ms (1.9% of trials). For the accuracy analysis, trials were also excluded if the prime response (letter search or semantic decision) was incorrect: a further 5.6% of trials. For the RT analysis we excluded trials where the prime or target responses were incorrect, excluding a further 3.2% of trials. Table 3 shows mean RTs and accuracy values.

The analysis of accuracy measures showed that performance was marginally more accurate following the letter search task ($M = 98.0$) than following the semantic judgement ($M = 97.0$), $F(1,\ 15) = 3.61$, $MSE = 4.72$, $p = .08$. The effect of priming also approached significance, with higher scores in the related than in the unrelated conditions, $F(1,\ 15) = 3.02$, $MSE = 12.42$, $p = .1$. However there was no interaction between prime task and priming on the accuracy measure, $F(1,\ 15) < 1.0$.

Lexical decision

RT analysis by subjects showed a main effect of priming, whereby RTs to related targets were faster than those to unrelated targets, $F_1(1,\ 15) = 30.08$, $MSE = 0.001$, $p < .001$. There was a large effect of prime task type, $F_1(1,\ 15) = 17.85$, $MSE = 0.003$, $p < .001$, such that target responses were about 50 ms slower following the semantic judgement on the prime. Importantly the interaction between prime task and priming was significant, $F_1(1,\ 15) = 37.17$, $MSE = 0.0003$, $p < .001$. The advantage for related primes was 6 ms in the letter search condition, much smaller than the 61-ms priming seen in the semantic condition. The item analysis showed effects comparable to those of the RT analysis by subjects. The effect of prime task was largely significant, $F_2(1,\ 173) = 67.63$ (see Footnote 2), $MSE = 827{,}371$, $p < .001$, and so were the effects of priming, $F_2(1,\ 173) = 28.37$, $MSE = 264{,}515$, $p < .001$, and the interaction of the two factors, $F_2(1,\ 173) = 17.4$, $MSE = 160{,}162$, $p < .001$.

Response times in the letter search and associative priming conditions were analysed separately. Paired t tests showed that the difference between related and unrelated RTs was not significant when the prime was letter searched, $t(15) < 1.0$, but the effect of priming was highly significant when the semantic task was performed on the prime, $t(15) = 7.7$, $p < .001$. A total of 15 participants showed greater priming following the semantic decision than following the letter search task.

Letter search

For each participant, trials were excluded if the response time was more than two standard deviations above the mean, or if the response time was faster than 300 ms (4.3% of trials). Again there was a tendency for accuracy to be higher when the letter search probe was absent from the prime (97.8%) than when the letter was present in the prime (96.0%), $t(15) = 2.54$, $p < .05$. To examine letter search RTs, trials were excluded if the prime response was incorrect, a further 3.2% of trials. As expected the response time to detect a match (875 ms) was faster than response time to detect a mismatch (973 ms), $t(15) = 7.39$, $p < .001$.

Table 3. *RTs and mean accuracies in the letter search and semantic decision tasks in Experiment 3, for unrelated, related, and nonword targets.*

	Unrelated		*Related*		*Nonword*	
Task	*RT*	*Accuracy*	*RT*	*Accuracy*	*RT*	*Accuracy*
Letter search	597 (97)	97.2 (3.6)	591 (83)	98.8 (2.1)	707 (134)	94.9 (3.5)
Semantic decision	683 (113)	96.2 (4.2)	622 (96)	97.7 (3.1)	688 (111)	97.1 (2.7)

Note: RTs = reaction times in ms. Percentages of accuracy were calculated on the number of trials left after removing trials with incorrect prime and trials with target outliers. Standard deviations are in parentheses.

Semantic task

Again, trials were excluded if the response time was more than two standard deviations above the mean, or if the response time was faster than 300 ms (4.8% of trials). Accuracy for living ("yes") responses were less accurate (83%) than that for nonliving ("no") responses (96.3%), a difference that was significant, $t(15) = 5.67$, $p < .001$. This is not surprising because animate primes were in a minority. Response times to living and nonliving primes were calculated for correct prime responses only, excluding a further 7.1% of trials. The response times to animate and inanimate primes were roughly equal: 863 ms and 876 ms, respectively. These did not differ significantly, $t(15) = 1.1$. It should be noted that the response times to the semantic task are comparable to those reported for the letter search task. The differences in priming cannot be explained by the duration of the prime.

In Experiment 3, no associative priming was found when a letter search task was performed on the prime with a simultaneous letter probe, further confirming the findings of Experiments 1 and 2. Most importantly, when, in the second block, participants performed a semantic decision, a strong and consistent effect of priming was found, confirming that, in the appropriate conditions, semantic activation of the prime affects lexical decision on the target. It appears that strong semantic activation of this kind did not arise when the letter search probe was delayed.

GENERAL DISCUSSION

In these experiments we have followed up an investigation by Stolz and Besner (1996) that reported nonsignificant associative priming with a letter search prime task, when the prime and letter target were presented simultaneously, but a large and significant associative priming effect when the target letter was presented 200 ms after prime onset. Stolz and Besner argued that their findings supported an activation-blocking account of the letter search prime task: When prime and letter probe were simultaneous, activation was blocked, but when the letter probe was delayed full semantic activation of the prime took place.

In Experiments 1 and 2 we obtained results that differed markedly from those of Stolz and Besner (1996). When prime and letter target were presented simultaneously we found small priming effects (12 ms in Experiment 1, 19 ms in Experiment 2) that were marginally significant. Crucially, we found that associative priming was not increased by delaying the letter probe in the prime task. In fact, associative priming did not reach significance in the delayed condition in either of the two experiments. Thus the most striking finding of the Stolz and Besner (1996) study, the large associative priming effect that emerged with delayed letter probes, was not reflected at all in our results.

After our failure to find this effect in Experiment 1, we made two changes to the prime task for Experiment 2: The prime and target letter were now presented in the same case, and the delay of the target letter was increased to 300 ms. However, these procedural changes had no effect either on the amount of priming or on the effect of delay. This was confirmed by a further analysis where experiments were added as a third factor. A 2 (Experiments 1–2, between subject) × 2 (probe delay, within subject) × 2 (prime type, within subject) mixed design ANOVA was performed. This showed that the only significant effects were the main effect of probe delay, $F(1, 30) = 9.9$, $MSE = 28{,}770$, $p < .01$, and the main effect of priming, $F(1, 30) = 12.7$, $MSE = 7{,}275$, $p < .01$. Two further analyses, assessing priming irrespectively of the experiment, showed significant associative priming for simultaneous trials $t(31) = 2.9$, $p < .01$, while the results approached significance for delayed trials $t(31) = 2$, $p < .055$.

Thus we failed to find an increase in associative priming in the delayed conditions of the first two experiments, which, following Stolz and Besner (1996) were always presented in the second block of trials. According to Stolz and Besner, a delay in presenting the probe letter allows activation from the prime to pass through the letter level to the semantic level, and once the semantic level is activated, the subsequent letter search is ineffective, because letter search only blocks semantic activation, it does not suppress it once activation has occurred. Consequently full associative priming occurs with a delayed probe, but not with a simultaneous probe. Our results provide no support for this view. The presence of the probe delay did not change the extent of priming with the letter search task. Our results, together with those of other studies (Friedrich et al., 1991; Heil et al., 2004; Henik et al., 1983, 1994; Kaye & Brown, 1985; Küper & Heil, 2009; Smith et al., 2001; Smith et al., 1983) suggest that the letter search prime task suppresses priming. If a letter search is initiated on the prime before presentation of the target, then priming is reduced or eliminated. A minor discrepancy between our results and those of previous studies is that we observed a small amount of priming in Experiments 1 and 2. We deal with this issue below. In Experiment 3 in the second block of trials we encouraged semantic processing of the prime by a living/nonliving semantic classification task. Again, we found little if any associative priming with the letter search prime task in Block 1, but massive associative priming in Block 2. The letter search prime task, with or without a probe delay, therefore appears to reduce priming relative to the semantic prime task.

Many studies have shown very small or absent priming effects when a letter search prime task is used, and it is often claimed that the letter search prime task eliminates associative priming (Friedrich et al., 1991; Smith et al., 1983), although there are some exceptions (e.g., Kaye & Brown, 1985). One possible reason for this is that the sensitivity of targets to priming processes depends on target word frequency (Tse & Neely, 2007). For reasons that lie outside the scope of the present paper, we selected items (a) that were strong forward associates (we did not control for backward associative strength), (b) where the prime and target were from 4 to 7 letters long, and (c) where the targets were mostly concrete nouns. These constraints resulted in a sample of targets that are relatively low frequency. Tse and Neely (2007) reported priming effects of 15–22 ms with low-frequency targets (mean logHAL = 9.3, Experiment 1; mean logHAL = 8.57, Experiment 2),[4] but not with high-frequency targets. Across all our stimuli, the mean logHAL frequency was 9.45, closer in frequency to Tse and Neely's low-frequency targets. Moreover, the trend to greater priming for low-frequency targets was present in our data. We performed a median split on the items by logHAL frequency. Pooling from both conditions of Experiments 1 and 2, we found priming of 23 ms with the low-frequency items, $t(31) = 3.21$, $p < .05$, but only 7 ms with high-frequency items, $t(31) = 1.24$, $p > .05$. Thus the presence of a small but significant priming effect is consistent with our use of relatively low-frequency items.

One interpretation of the absence of associative priming with a letter search prime task was that the letter search task prevented semantic activation of the prime. However, recent evidence suggests that semantic activation of the prime can occur in the absence of priming (e.g., Heil et al., 2004; Hutchison & Bosco, 2007; Küper & Heil, 2009; Mari-Beffa et al., 2005). This could occur if the action of the orthographic prime task is not to prevent semantic activation of the prime but to suppress priming before presentation of the target (Maxfield, 1997). It is difficult to reconcile this account with Stolz and Besner's (1996) finding that associative priming occurs if the probe letter is delayed relative to prime onset, because the prime task in their Experiment 1 was carried out efficiently yet did not suppress priming.

A more detailed analysis of the effects of the letter search task is provided by Tse and Neely (2007).[3] Their account rests on the observation

[3] In their otherwise thorough discussion of the mechanisms of semantic priming, and how these relate to the letter search task, Tse and Neely (2007) discuss Stolz and Besner's (1996) activation blocking model and the results obtained in the simultaneous letter probe condition. However, Tse and Neely exclude from consideration the effects of delaying the letter probe.

[4] LogHAL is the natural log of the HAL (Hyperspace Analogue to Language) frequency count.

that semantic priming effects are more easily detected with low-frequency targets. Their studies compared forwards-only and bidirectional associations, with prime tasks of letter search and prime reading. With forwards associations and low-frequency targets they found the same small extent of priming with letter search and reading prime tasks, which they attributed to automatic priming. But with bidirectional associations they found much greater priming when reading was the prime task, and they attributed the increase to retrospective priming. It is curious that they did not find an increase in priming for forwards associations when the primes were read, since here an expectancy strategy could operate, and strategies were encouraged by the instructions. They explain this by saying that there was not enough time to generate low-frequency targets in the 1,200-ms SOA. Consequently they argue that the small priming effects observed (equal for reading and letter search tasks) are due to automatic priming. This priming effect was relatively small because in their account activation decayed between prime and target onset, although similarly small priming effects have been reported with a letter search prime task using much shorter SOAs (Henik et al., 1994; Smith et al., 2001), where automatic activation should be at its full extent.

Throughout their account, Tse and Neely (2007) argue that letter search prevents strategic priming from operating, presumably because of its high cognitive load. They compared only letter search (a high load orthographic task) with reading (a low-load semantic task). In our Experiment 3 we used a semantic classification task that was reported by participants to be no less difficult than letter search, and produced similar response times, and yet found greatly increased priming compared to letter search. According to the Tse and Neely account, the greater semantic activation obtained with our semantic prime task would be attributed to strategic priming, but we then would require an explanation why strategic priming is possible with the demands of the semantic task, but not with the letter search task.

According to the activation-suppression account, a letter search prime task suppresses the semantic activation that supports associative priming. As we have indicated, there is independent evidence that with a letter search prime task the prime is processed semantically (Hutchison & Bosco, 2007), and an ERP signal contingent on the semantic relationship between prime and target can be detected (e.g., Heil et al., 2004; Küper & Heil, 2009). Thus recent evidence suggests that the letter search prime task does not prevent all semantic activation of the prime, but it disables the behavioural effects observed in responses to the target. Stolz and Besner (1996) proposed that under the right circumstances letter search could prevent semantic activation and reported that delaying the letter search probe allowed the restoration of associative priming. Our results do not support this interpretation and suggest that the timing of the letter probe is not critical. Together with other results they suggest that associative priming is suppressed if a letter search is initiated on the prime before presentation of the target.

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