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Long-Term Priming of Neighbours Biases the Word Recognition Process: Evidence from a Lexical Decision Task

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Abstract The role of orthographically similar words (i.e., neighbours) in the word recognition process has been studied extensively using short-term priming paradigms (e.g., Colombo, 1986). Here we demonstrate that long-term effects of neighbour priming can also be obtained. Experiment 1 showed that prior study of a neighbour (e.g., TANGO) increased later lexical decision performance for similar words (e.g., MANGO), but decreased performance for similar pseudowords (e.g., LANGO). Experiment 2 replicated this bias effect and showed that the increase in lexical decision performance due to neighbour priming is selectively due to words from a relatively sparse neighbourhood. Explanations of the bias effect in terms of lexical activation and episodic memory retrieval are discussed.

Résumé Le rôle de mots semblables d'un point de vue orthographique (c.-à-d. des mots voisins) dans le processus de reconnaissance du mot a été étudié de façon exhaustive à l'aide de paradigmes d'amorçage à court terme (par ex., Colombo, 1986). Ici nous démontrons que des effets à long terme à la l'amorçage du mot voisin peuvent également être obtenus. L'expérience 1 montre que l'étude préalable d'un mot voisin (par ex., TANGO) améliorait plus tard le rendement de décision lexicale pour des mots semblables (MANGO), mais diminuait le rendement pour des pseudo-mots semblables (LANGO). L'expérience 2 a répété cet effet de biais et montré que l'amélioration du rendement à la décision lexicale à cause de l'amorçage du mot voisin est sélectivement attribuable aux mots d'un voisinage relativement épars. Les explications de cet effet de biais en termes d'activation lexicale et de récupération en mémoire épisodique font l'objet de discussions.

In the last decade, effects of orthographic similarity in visual word recognition have been studied extensively (see Andrews, 1997, for a review, and Grainger & Jacobs, 1996, for a model). It is generally accepted that in the initial stages of processing, a word stimulus will activate not only its own representation in lexical memory, but will also partly activate word representations that are orthographically similar to it (cf. Pecher, Zeelenberg, & Wagenmakers, 2005). The detailed consequences of the co-activation of orthographically similar representations have been subject to considerable debate. One of the reasons for this ongoing discussion lies in the fact that the impact of "neighbours" (i.e., words of the same length differing from each other in one letter such as MANGO-TANGO, Coltheart, Davelaar, Jonasson, & Besner, 1977; Landauer & Streeter, 1973) on the word recognition process has turned out to be subtle and task-dependent. That is, the influence of neighbours is generally considered to decrease performance in both auditory word recognition (e.g., Goldinger & Luce, 1989) and perceptual identification (e.g., Grainger & Segui, 1990). In contrast, neighbourhood effects in naming are generally facilitatory (e.g., Andrews, 1997), and results for lexical decision have been mixed.

Two methods are generally used in lexical neighbourhood research, matching and short-term priming. With the matching method, neighbourhood characteristics are highly correlated with several other variables such as word frequency and bigram frequency that are known to affect word recognition performance. Experiments that use matching equate stimuli on all variables thought to affect performance except the variable of interest (i.e., the neighbourhood characteristic). The disadvantage of matching is that one can never be sure that the stimuli have been equated on every variable that may confound the results (e.g., imagineability, body-rhyme consistency, etc.). Also, for some variables, the quality of the matching procedure depends on the reliability of norms or frequency counts. Finally, matching is a procedure that is arguably sensitive to experimenter bias effects (cf. Forster, 2000).

In short-term priming, also called form-related priming, the participant is usually presented with a briefly displayed "prime" word (e.g., TANGO or FLOOR) that is replaced by a target word (e.g., MANGO) to which a response is required (e.g., Colombo, 1986). This method circumvents the potential problems associated with the matching procedure, since every stimulus can be used in all conditions according to a counterbalanced design. However, the results obtained in short-term priming could be due to processes other than the increase in activation for the prime word, such as source confusion (Huber, Shiffrin, Lyle, & Ruys, 2001) or phonological competition (e.g., O'Seaghdha & Marin, 2000). In addition, Andrews (1997) has argued that results from a short-term priming paradigm do not necessarily generalize to the more standard paradigms in which a neighbour is not visually presented immediately before the target stimulus.

In this article, we explore the usefulness of a relatively novel paradigm in the study of neighbourhood effects: We aim to experimentally increase the availability of a neighbour through long-term priming instead of through short-term priming. This approach was pioneered by Monsell and Hirsh in an auditory word recognition paradigm (Monsell & Hirsh, 1998). In both experiments presented here we used the lexical decision task, since it is in this task that the empirical state of affairs is still in flux (Andrews, 1997; Grainger & Jacobs, 1996).

Experiment 1

Experiment 1 consisted of a study phase and a test phase. In the study phase, participants made five lexical decisions to each stimulus (e.g., the word TANGO or the pseudoword BANGO). In the subsequent test phase, participants made lexical decisions to stimuli that were or were not orthographically similar to stimuli encountered in the study phase (e.g., the similar word MANGO, the similar pseudoword LANGO, or stimuli orthographically dissimilar to any stimulus from the study phase, for instance WHEAT or WHEAM). The choice of lexical decision for a study task was motivated by the fact that effects of long-term repetition priming fluctuate with the overlap in processes between study and test (transfer-appropriate processing, e.g., Jacoby, 1983; Roediger, 1990). In addition, Ratcliff, Hockley, and McKoon (1985) showed that long-term repetition priming in lexical decision is larger when the study task is also a lexical decision task than when the study task is a recognition task. In this experiment, it is crucial that facilitation of a neighbour due to long-term repetition priming in the study phase is still present in the test phase. In the event of a null effect of prior study of a neighbour, it is necessary to show that the manipulation of interest, that is, increasing the availability of a neighbour through prior study, was in fact successful. This objective was accomplished by including additional stimuli to estimate the amount of long-term repetition priming present in the test phase.

Method

Participants. Thirty-two students of the University of Amsterdam participated for course credit. The data of four participants were discarded from the analyses because either their error rate or their mean correct reaction time exceeded that of the other participants by more than two standard deviations. All participants were native speakers of Dutch.

Design and materials. Experiment 1 consisted of a short practice block, a study phase, and a test phase. In the study phase, participants were presented with five blocks of 210 trials each. These 210 study trials consisted of 168 words and pseudowords that either differed in one letter from a stimulus in the subsequent test phase or not. The remaining 42 stimuli were 21 seven-letter words and 21 seven-letter pseudowords, and these served to assess the repetition priming effect. The test phase began with presentation of 30 filler trials in order to return the possibly adjusted criteria for responding to normal. Following these 30 filler trials, 168 word and pseudoword stimuli were presented, randomly intermixed with 84 seven-letter stimuli. The latter stimuli were used to estimate the amount of repetition priming, 42 previously studied and 42 new. These seven-letter stimuli were presented in a counterbalanced design, such that half of the participants studied one half of the materials, and the other participants studied the other half of the materials.

The word (e.g., HEAT) and pseudoword (e.g., REAT) test phase stimuli were preceded by one of three different study phase stimuli: orthographic neighbours (e.g., MEAT), orthographic *pseudoneighbours* (i.e., pseudowords such as LEAT that differ from the target in one letter), or orthographically unrelated stimuli (e.g., TOSS or GOSS). When the experiment was designed, the orthographically unrelated stimuli from the study phase were treated as two distinct categories: words (e.g., TOSS) and pseudowords (e.g., GOSS). As stimuli from both categories are unrelated to any stimuli in the test phase, these conditions are conceptually identical, and hence the later analyses will collapse over these two conditions. Thus, the design was such that for both word and pseudoword test phase stimuli, the factors "study phase word status" and orthographic relatedness were manipulated. Each of the eight conditions consisted of 21 trials made up of 7 four-letter words, 7 five-letter words, and 7 six-letter words. Thus, a total of 168 trials was obtained. Using a counterbalanced design, four lists of 168 prime-target pairs were created. Each list contained the same test phase stimuli but the type of study phase stimulus was dependent on the list. No stimulus occurred more than once in a list. The frequency of the test phase stimuli, as documented by the CELEX lexical database (Baayen,

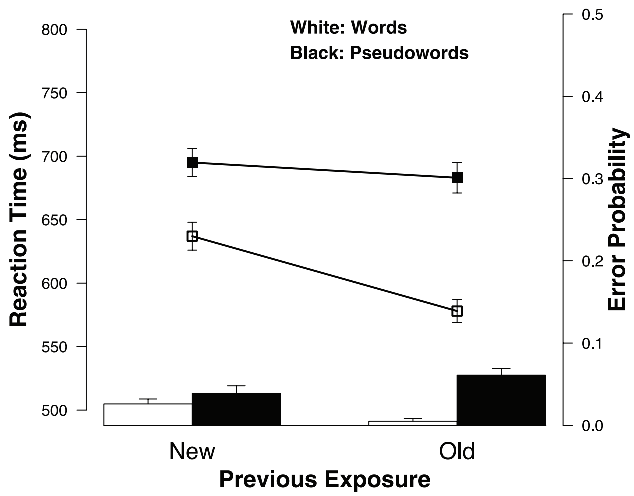

Figure 1. Mean reaction times (lines) and error rates (bars) for word and pseudoword stimuli in the test phase of Experiment 1 as a function of previous exposure (i.e., identity priming). Error bars are standard errors of the mean.

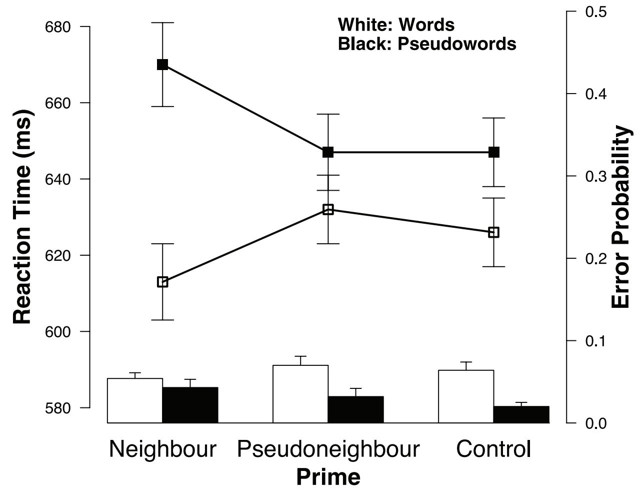

Figure 2. Mean reaction times (lines) and error rates (bars) for word and pseudoword stimuli in the test phase of Experiment 1 as a function of prime type. Error bars are standard errors of the mean. *Note:* In the control condition, none of the prime words and prime pseudowords were orthographically similar to any target stimulus.

TABLE 1
Mean Reaction Times (in Milliseconds) and Error Rates (Proportion) for Words and Pseudowords in the Study Phase of Experiment 1

	Study Block				
Target	1	2	3	4	5
Word					
RT	621 (10)	600 (9)	589 (9)	587 (9)	577 (9)
Error	.027 (.003)	.032 (.004)	.027 (.004)	.036 (.006)	.038 (.006)
Pseudoword					
RT	705 (15)	651 (11)	628 (10)	621 (10)	609 (8)
Error	.029 (.005)	.026 (.004)	.021 (.004)	.022 (.004)	.022 (.003)

Note: Standard errors of the mean are in parentheses.

Piepenbrock, & Van Rijn, 1993), was between 6 and 100 occurrences per million (mean about 29 per million). The frequency of the study phase stimuli was higher than 6 per million (mean about 44 per million). Orthographically regular and pronounceable pseudowords were created by changing one letter of a word stimulus. In addition, 15 seven-letter words with a mean frequency of 16 per million and 15 seven-letter pseudowords were used as fillers. Furthermore, 42 seven-letter words with a mean frequency of 15 per million and 42 seven-letter pseudowords were used to establish the amount of repetition priming in the eventuality of a null effect. All word stimuli were common Dutch words.[1]

Procedure. Participants received spoken and written instructions explaining the lexical decision task. Participants were instructed to respond as quickly and accurately as possible. For both the study phase and the test phase, the target remained visible in the centre of the screen until the participant responded or 2,500 ms elapsed. A "pseudoword" response was given by pressing the "v" key of the keyboard with the left index finger and a "word" response was given by pressing the "n" key with the right index finger. When the participant committed an error or 2,500 ms elapsed before a response was given, appropriate feedback was presented for 1,500 ms. Twenty-four practice trials preceded the study phase. The order of the trials was randomly determined for each participant. Participants were allowed a short break after each block in the study phase and after completing half of the trials in the test phase. The average time between the final presentation of a given item in the study phase and the

[1] The stimuli used in Experiment 1 can be found at http://users.fmg.uva.nl/ewagenmakers/neighbor1.html

presentation of an orthographically related item in the test phase was about nine minutes plus the time of the short break, which usually lasted about one or two minutes. The number of items presented in this time period averages 231.

Results

The results of Experiment 1 are presented in Table 1 and Figures 1 and 2. Repeated measures analysis of variance (ANOVAs) were performed on the geometric mean latencies of correct responses. Word and pseudoword data were analyzed separately.

Analyses of reaction times. In the study phase, a facilitatory repetition effect was obtained for word targets, $F(4, 108) = 13.12$, $MSE = 591$, $p < .001$, as well as for pseudoword targets, $F(4, 108) = 39.98$, $MSE = 1{,}005$, $p < .001$ (see Table 1). In the test phase, words previously encountered in the study phase were responded to faster than words not previously encountered in the study phase, $F(1, 26) = 75.25$, $MSE = 650$, $p < .001$. This effect of repetition priming was absent for pseudowords, $p > .2$ (see Figure 1).

Figure 2 shows that study of a neighbour caused a decrease in response time for word targets, $F(1, 24) = 5.72$, $MSE = 367$, $p < .05$, compared to prior study of orthographically dissimilar stimuli. Pseudoword targets showed the opposite effect: Response time increased as a result from prior study of a neighbour, $F(1, 24) = 21.97$, $MSE = 356$, $p < .001$, compared to prior study of orthographically dissimilar stimuli. All other effects were not significant, $F < 1$.

Analyses of errors. In the study phase, error rates for pseudoword targets did not change over study blocks, $F(4, 108) = 1.23$, $MSE = 251$, $p > .3$. For word targets, the slight increase in error rate with study was marginally significant, $F(4, 108) = 2.39$, $MSE = 299$, $p < .1$. In the test phase, words previously encountered in the study phase were responded to more accurately than words not previously encountered, $F(1, 26) = 10.55$, $MSE = 558$, $p < .01$. Pseudowords showed the opposite: Pseudowords previously encountered in the study phase were responded to *less* accurately than pseudowords not previously encountered, $F(1, 26) = 4.76$, $MSE = 1{,}418$, $p < .05$ (see Table 1). All other effects were not significant, $F < 1$.

Discussion

Experiment 1 showed that prior study of a neighbour (e.g., TANGO) biases lexical decision performance for orthographically similar stimuli: Performance for similar words (e.g., MANGO) increases whereas performance for similar pseudowords (e.g., LANGO) decreases. This is a novel result, since previous work either failed to find an effect of long-term neighbour priming (e.g., Tenpenny, 1995, pp. 356-357) or did not include the condition in which a neighbour of a pseudoword target was studied (e.g., Bowers, 2000; Bowers, Damian, & Havelka, 2002). Only by including this condition (e.g., presentation of TANGO in the study phase followed by presentation of LANGO in the test phase) is it possible to see that the effect of prior study of a neighbour can be characterized as a bias effect. We will elaborate on the theoretical relevance of this new finding in the General Discussion. Note that although prior study of a neighbour resulted in a pattern of costs (i.e., for pseudowords targets) and benefits (i.e., for word targets), study of a pseudoneighbour (i.e., a pseudoword that differs from a target letter string in only one letter) had no effect. This null effect is consistent with other findings in lexical decision that show small and variable effects of repetition priming for pseudowords (e.g., Wagenmakers, Zeelenberg, Steyvers, Shiffrin, & Raaijmakers, 2004; Zeelenberg, Wagenmakers, & Shiffrin, 2004). One possible explanation for the absence of a pseudoneighbour priming effect is that pseudowords have no representation in lexical/semantic memory; if lexical decision is based primarily on accessing lexical/semantic memory, little effect of pseudoword priming is to be expected. Although the overall bias effect (costs plus benefits) due to repeated study of a neighbour was a robust 36 ms, the separate effects of benefits (13 ms) and costs (23 ms) merit replication, and this was the primary objective of Experiment 2. In addition, Experiment 2 included a manipulation of both word frequency (high and low) and overall lexical neighbourhood activity (high and low).

Experiment 2

Experiment 2 used a slightly different design and different stimuli than Experiment 1. Word targets were divided in four categories using two factors: Word frequency (either high or low) and summed logarithmic neighbourhood frequency (either high or low). Words from a sparse neighbourhood with low-frequency neighbours will have a low summed logarithmic neighbourhood frequency, whereas words from a dense neighbourhood with high-frequency neighbours will have a high summed logarithmic neighbourhood frequency. Thus, the measure of summed logarithmic neighbourhood frequency (e.g., Massaro & Cohen, 1994) is an overall measure of neighbourhood activity, taking both neighbour frequency and neighbourhood size into account. We did not have any clear predictions of the interaction of either of these latter two variables in isolation and the long-term neighbour

TABLE 2
Mean Reaction Times (in Milliseconds) and Error Rates (Proportion) for Words and Pseudowords in the Study Phase of Experiment 2

	Study Block				
Target	1	2	3	4	5
Word					
RT	597 (14)	578 (11)	576 (12)	567 (10)	558 (9)
Error	.077 (.009)	.049 (.004)	.041 (.005)	.044 (.006)	.042 (.006)
Pseudoword					
RT	667 (16)	638 (13)	626 (13)	603 (11)	589 (11)
Error	.055 (.008)	.058 (.007)	.051 (.006)	.040 (.006)	.037 (.005)

Note: Standard errors of the mean are in parentheses.

TABLE 3
Mean Reaction Times (in Milliseconds) and Error Rates (Proportion) in the Test Phase of Experiment 2 as a Function of Prime Type, Target Word Status, Target Word Frequency, and Target Neighbourhood Activity

			Neighbour Prime		Dissimilar Word Prime	
Target			RT	P(error)	RT	P(error)
Words	HF	HN	554 (11)	.019 (.010)	557 (11)	.016 (.008)
	HF	LN	557 (13)	.023 (.009)	574 (13)	.020 (.009)
	LF	HN	672 (17)	.181 (.027)	666 (15)	.189 (.027)
	LF	LN	650 (15)	.125 (.023)	682 (15)	.198 (.025)
Pseudowords		HN	695 (16)	.066 (.012)	682 (14)	.074 (.014)
		LN	682 (14)	.051 (.011)	661 (15)	.040 (.008)
Mean for words			608 (8)	.087 (.011)	620 (8)	.106 (.012)
Mean for pseudowords			689 (11)	.058 (.008)	671 (10)	.057 (.008)

Note: Dissimilar word: prime words that are orthographically dissimilar to the target; HF: high frequency word; LF: low frequency word; HN: high neighbourhood activity; LN: low neighbourhood activity. Standard errors of the mean are in parentheses.

priming effect, and decided to pursue the priming effect at a more general level. Of course, for pseudoword targets, the only factor available was summed logarithmic neighbourhood frequency. For each stimulus in the test phase, the participant either encountered a neighbour in the study phase or not.

If the bias effect of neighbour activation is again observed, it is likely to be larger for low-N items than for high-N items, since the relative increase in neighbourhood activity due to prior study of a neighbour is larger for low-N items. That is, we expect that if a test word only has few neighbours of low or medium frequency, prior study of one of these neighbours will change the processing of the test word to a greater extent than if the word had many neighbours of relative high frequency (cf. the density constraint observed in masked form priming; Forster, Davis, Schoknecht, & Carter, 1987; Perea & Rosa, 2000).

Method

Participants. Forty students of the University of Amsterdam participated for course credit or payment. The data of four participants were discarded from the analyses because either their error rate or their mean correct reaction time exceeded that of the other participants by more than two standard deviations. All participants were native speakers of Dutch, and none had participated in Experiment 1.

Design and materials. One hundred and twenty triplets were created, consisting of a target word (e.g., HEAT), a target pseudoword (e.g., LEAT), and an orthographic neighbour (e.g., MEAT). This was done by changing the same letter in each of the three letter strings. In order to obtain a counterbalanced design, the 120 neighbours were divided into two lists. The lists were created subject to the constraints of word frequency and summed logarithmic neighbour frequency outlined below. In addition, the lists contained an equal amount of four-letter words, five-letter words, and six-letter words. In the study phase of the experiment, each participant was presented with five blocks of 120 trials for lexical decision. The 120 study items consisted of 60 neighbours from either List 1 or List 2 and 60 pseudowords that were orthographically unrelated to the material used in the test phase. In the subsequent test phase, participants had to perform a lexical decision task of 120 trials. Thus, 60 test stimuli had a neighbour that was encountered five times in the study phase, whereas the remaining 60 stimuli did not have a neighbour presented in the study phase. On each trial in the test phase, the decision of whether to

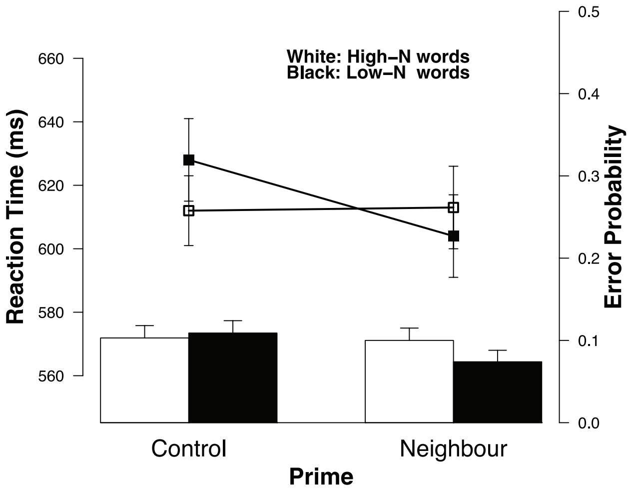

Figure 3. Mean reaction times (lines) and error rates (bars) for word stimuli in the test phase of Experiment 2 as a function of neighbourhood activity and long-term priming of a neighbour. Error bars are standard errors of the mean.
Note: In the control condition none of the prime words and prime pseudowords were orthographically similar to any target stimulus.

present the target word (e.g., HEAT) or the target pseudoword (e.g., LEAT) was made semi-randomly (i.e., under the constraint that the number of words and pseudowords did not differ by more than three items). Target words were either high-frequency words (mean about 208 per million) or low-frequency words (mean about 2.4 per million). In addition, word targets had either a high (greater than 10) or a low (smaller than 2.5) summed logarithmic neighbour frequency. A more specific post-hoc analysis of the word targets showed that every low-N word had one neighbour only, whereas high-N – low-frequency words and high-N high-frequency words averaged 7.8 and 7.6 neighbours, respectively. Low-N low-frequency words and low-N high-frequency words averaged 0.65 and 0.0 neighbours of higher frequency. High-N low-frequency words and high-N high-frequency words averaged 6.5 and 1.1 neighbours of higher frequency. Orthographically regular and pronounceable pseudowords were made by changing one letter of an existing word. All word stimuli were common Dutch words of 4, 5 or 6 letters.[2]

Procedure. The procedure was identical to that of Experiment 1.

[2] The stimuli used in Experiment 2 can be found at http://users.fmg.uva.nl/ewagenmakers/neighbor2.html

Results

The results of Experiment 2 are presented in Figure 3 and Tables 2 and 3. Repeated measures ANOVAs were performed on the geometric mean latencies of correct responses, and included all relevant variables (e.g., for words in the test phase these variables were prior study, word frequency, and neighbourhood activity) except when calculating simple main effects to specifically investigate an interaction. Word and pseudoword data were analyzed separately. Because of the inclusion of two item-specific factors, namely word frequency and summed logarithmic neighbourhood frequency, a completely counterbalanced design was not possible. The correct test statistic in such cases is *min F'*, a combination of the two F values obtained from a subject-analysis and an item-analysis (see Clark, 1973; Raaijmakers, 2003; Raaijmakers, Schrijnemakers, & Gremmen, 2000; Rouder & Lu, 2005, for a detailed discussion). Hence, for analyses comparing conditions where item-variability could not be experimentally controlled for, we calculated *min F'* values.

Analyses of reaction times. In the study phase, repeated exposure again resulted in a decrease of RT for word targets, $F(4, 140) = 11.61$, $MSE = 663$, $p < .001$, as well as a decrease in RT for pseudoword targets, $F(4, 140) = 36.33$, $MSE = 926$, $p < .001$ (see Table 2).

With regard to the test phase, prior study of a neighbour resulted in a decrease in response time for word targets, $F(1, 34) = 5.89$, $MSE = 1{,}705$, $p < .05$ (see Table 3), and resulted in an increase in response time for pseudoword targets, $F(1, 34) = 9.24$, $MSE = 1{,}174$, $p < .01$, replicating the bias effect found in Experiment 1. High-frequency words were responded to faster than low-frequency words, $min\ F'(1, 120) = 93.92$, $p < .001$. The difference in RT between words from a high-N neighbourhood and words from a low-N neighbourhood was not significant, $min\ F' < 1$. As can be seen from Figure 3, there is an interaction between neighbourhood activity, that is, a high versus a low summed logarithmic neighbourhood frequency, and prior study of a neighbour, $F(1, 34) = 6.35$, $MSE = 1{,}885$, $p < .05$. Simple main effects showed that the effect of prior study of a neighbour was present for words from a low-N neighbourhood, $F(1, 34) = 10.87$, $MSE = 2{,}022$, $p < .01$, but absent for words from a high-N neighbourhood, $F < 1$. In other words, the facilitatory effect of studying a neighbour for word targets was only observed for words from a low-N neighbourhood. All other effects were not significant (all ps > .1).

Analyses of errors. In the study phase, successive repetitions resulted in a decrease of the error rates for words, $F(4, 140) = 9.98$, $MSE = 836$, $p < .001$, as well as pseudowords, $F(4, 140) = 4.07$, $MSE = 839$, $p < .05$. In the test phase, differences in error rates for both word and pseudoword targets caused by study of a neighbour were not reliable, $p > .1$ (see Table 3). High-frequency words had lower error rates than low-frequency words, $min\ F'(1, 136) = 37.95$, $p < .001$. However, the interaction between target word frequency and study of a neighbour was marginally significant, $F(1, 34) = 3.33$, $MSE = 9{,}991$, $p < .1$. The three-way interaction between target word frequency, study of a neighbour, and neighbourhood activity was also marginally significant, $F(1, 34) = 3.04$, $MSE = 6{,}363$, $p < .1$. These interactions can for the most part be attributed to a 7.3% decrease in error rate as a result of study of a neighbour, which was only observed for low-frequency targets from a low-N neighbourhood. All other effects were not significant (all *p*s > .1).

Discussion

Experiment 2 replicated the finding from Experiment 1: Prior study of a neighbour (e.g., TANGO) resulted in an increase in performance for words (e.g., MANGO) and a decrease in performance for pseudowords (e.g., LANGO). In addition, this pattern of costs and benefits (i.e., bias) was observed solely for words from a sparse neighbourhood. The latter finding is reminiscent of Forster's density constraint, according to which form priming and repetition priming effects are more pronounced for words that have few neighbours than for words that have many neighbours (e.g., Forster et al., 1987; Perea & Rosa, 2000). The present results suggest that the density constraint may also hold in long-term priming. The overall size of the bias effect (i.e., 30 ms) as well as the sizes of the component processes of costs for pseudoword targets (18 ms) and benefits for word targets (12 ms) are comparable to those obtained in Experiment 1.

General Discussion

In both experiments reported here, we found that long-term study of a neighbour (e.g., TANGO) affected later lexical decision performance. More specifically, orthographically related words targets (e.g., MANGO) were responded to faster relative to a control condition in which no orthographically similar material had been encountered in the study phase. This result demonstrates that effects of long-term priming are not limited to the level of morphemes as asserted by Morton's logogen model (Morton, 1969; Murrell & Morton, 1974) – Morton found that prior presentation of CARS primed CAR but did not prime CARD (see also Bowers, 2000; Tenpenny, 1995). In a recent study, Bowers et al. (2002) also found that prior study of a neighbour facilitated later lexical decision performance for word targets. However, Bowers et al. did not include the condition in which neighbours of pseudowords targets were studied. In both Experiment 1 and 2, we found that prior study of a neighbour increased response times for orthographically related pseudowords presented in the test phase.

Thus, prior study of a neighbour leads to a pattern of both costs for pseudoword targets and benefits for word targets. A similar pattern of results is observed in the two-alternative perceptual identification task, where prior study of one of the response alternatives biases the decision process (e.g., Bowers, 1999; Ratcliff & McKoon, 1997; Wagenmakers, Zeelenberg, & Raaijmakers, 2000). The observed results are in agreement with models for lexical decision that incorporate some form of overall lexical activation or familiarity that may serve as a basis for the decision (cf. Wagenmakers et al., 2004). For instance, in both the multiple read-out model (MROM; Grainger & Jacobs, 1996) and the dual-route cascaded model (DRC; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), a "word" response is given when (1) the activation level of a specific word representation reaches threshold (i.e., the M-criterion), or if (2) the summed activation over all word representations reaches a certain threshold value (i.e., the Σ-criterion). These models therefore predict that an increase in the activation level of a neighbour word such as TANGO due to prior study brings the summed activation closer to the Σ-criterion. This effectively nudges the decision process toward the "word" response, producing the observed pattern of results. In addition, the null effect of prior study of a pseudoneighbour such as BANGO can be explained because BANGO will be relatively unsuccessful in increasing the activation level of word representations (since these differ from BANGO in at least one letter).

The memory-recruitment account of priming (e.g., Bodner & Masson, 2001, 2004; Bodner, Masson, & Richard, in press; Whittlesea & Jacoby, 1990) offers a different interpretation of the present findings.[3] In this account, each encounter with a prime leads to the storage of a separate episodic memory trace (cf. Logan, 1988). The stored memory traces can later be unconsciously retrieved and affect processing of a subsequent target. Thus, the memory-recruitment account assumes that priming phenomena are based on concrete, episodic memories rather than abstract, semantic representations.

The memory-recruitment account could explain the current findings as follows. During the study phase,

[3] We thank Jennifer Stolz for bringing this to our attention.

presentation of TANGO leads to the storage of an episodic memory trace for TANGO. This memory trace also contains information about the associated response (i.e., “TANGO is a word”; cf. Logan, 1988). During the test phase, presentation of related material, be it the word MANGO or the pseudoword BANGO, will sometimes lead to the automatic retrieval of the stored memory trace for the prime TANGO. As the TANGO memory trace contains the information that it is a word, retrieval of this information may effectively support the “word” response. This account is consistent with the current findings.

Upon first consideration, it may appear problematical for the memory-recruitment account to explain the absence of a bias effect due to the study of a pseudoneighbour (e.g., LANGO). If the study of LANGO leads to the storage of a memory trace containing the information “LANGO is a pseudoword,” automatic retrieval of this information should lead to a bias in favour of the “pseudoword” response. However, Zeelenberg et al. (2004) and Wagenmakers, Zeelenberg, et al. (2004) have shown that the study of pseudowords does not just lead to the storage of episodic information, but also results in an increased feeling of familiarity. The locus of this familiarity effect may reflect the fact that an episodic representation exists (i.e., “I have seen something very similar before, so this letter string will probably be a word”). Study of pseudowords such as LANGO therefore results in two counteracting effects that may well cancel out: a bias in favour of the “pseudoword” response due to the *content* of the stored episodic trace for LANGO, and a bias in favour of the “word” response due to the *presence* of an episodic trace for LANGO.

Regardless of the specific interpretation (i.e., lexical activation or episodic retrieval) for our findings, the present results underscore the need for “symmetric” experimental designs: Without including the pseudoneighbours in the test phase, the facilitatory effect of long-term neighbour priming for word targets might have led to the premature conclusion that prior study of a neighbour increases the rate of feature extraction for target items similar to it. We would like to note that this conclusion is not strictly falsified by the data from Experiments 1 and 2: It is possible that effect of enhanced encoding due to prior study of a neighbour exists but is overshadowed by larger bias effect (see Bowers, 1999; Wagenmakers, Zeelenberg, Schooler, & Raaijmakers, 2000; Zeelenberg, Wagenmakers, & Raaijmakers, 2002, for a detailed discussion of these issues). In perceptual identification, a small but reliable effect of enhanced discriminability is observed for repeated stimuli (e.g., Wagenmakers et al., 2000). That is, in a two-alternative forced choice perceptual identification task, participants perform better after prior study of both response alternatives than after prior study of neither of the response alternatives (e.g., Zeelenberg et al., 2002). Given that the effects of enhanced discriminability due to repetition priming are already small (i.e., about 5%), it might be a tall order to detect effects of enhanced discriminability due to neighbour priming.

The bias effect of long-term neighbour priming illustrates that a selective focus on results for word targets in lexical decision can lead one to disregard important information. Moreover, it is plausible that exclusion of pseudoneighbour targets in the test phase would have led to an increase of the neighbour priming effect for words, since responding based on some indication of global familiarity such as the Σ-criterion in the MROM and the DRC models is less likely to result in an erroneous “word” response.

In sum, this study demonstrates that prior study of a neighbour (e.g., TANGO) results in a bias to respond “word” to similar stimuli, producing a performance benefit for similar words (e.g., MANGO) and a performance cost for similar pseudowords (e.g., BANGO). This result can be accounted for by two kinds of models for lexical decision. The first kind of model assumes that priming effects stem from the activation of lexical/semantic traces (e.g., Grainger & Jacobs, 1996; Wagenmakers et al., 2004). The second kind of model assumes that priming effects reflect the automatic retrieval of episodic memory traces (e.g., Bodner, Masson, & Richard, in press).

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