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OBSERVATION

Testing the *Multiple* in the Multiple Read-Out Model of Visual Word Recognition

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This study provided a test of the multiple criteria concept used for lexical decision, as implemented in J. Grainger and A. M. Jacobs's (1996) multiple read-out model. This account predicts more inhibition (or less facilitation) from a masked neighbor when accuracy is stressed more but more facilitation (or less inhibition) when the speed of responding is emphasized more. The authors tested these predictions by stressing accuracy (Experiment 1) and response speed (Experiment 2). The results of Experiment 1 showed a stronger neighbor-inhibition effect in the stress-on-accuracy condition than in the control condition. The results of Experiment 2 showed facilitation because of the neighbor prime in the stress-on-speed condition relative to the control condition. These results corroborate the multiple criteria account.

Keywords: visual word recognition, lexical decision, masked neighbor priming, multiple criteria account, multiple read-out model

There is considerable evidence that orthographically similar words become coactivated in the process of identifying a word and affect word recognition. To study the operationalization of orthographic similarity, research has focused on neighbor words, words of the same length that differ in only one letter (Coltheart, Davelaar, Jonasson, & Besner, 1977). Investigations of neighbor effects have led to the observation of the following two effects. First, inhibition has been observed for words with a single higher frequency neighbor (e.g., Carreiras, Perea, & Grainger, 1997; Grainger & Jacobs, 1996; Grainger, O'Regan, Jacobs, & Segui, 1989; Grainger & Segui, 1990). This is called the *neighborhood-frequency effect.* The masked priming variant of this effect is the finding that a higher frequency neighbor prime leads to inhibition also (e.g., Bijeljac-Babic, Biardeau, & Grainger, 1997; Brysbaert, Lange, & Van Wijnendaele, 2000; De Moor & Brysbaert, 2000; Segui & Grainger, 1990); we refer to it as the *masked neighbor priming effect.* The second finding is that facilitation has been observed for words with many neighbors as compared with words with few neighbors (e.g., Andrews, 1989, 1992; Carreiras et al., 1997; Forster & Shen, 1996), the so-called *neighborhood-size effect.* However, for years, neighbor effects have been subject to debate for at least two reasons. First, the neighborhood-frequency effect and the neighborhood-size effect are contradictory in nature because words with many neighbors are more likely to have a higher frequency neighbor. Second, several failures to replicate both effects have been reported (for an overview, see Andrews, 1997).

Here, we concentrate on the masked neighbor priming effect and why it has not been replicated in all studies. This effect has usually been explained in terms of the interactive-activation model (IAM; McClelland & Rumelhart, 1981), which assumes lateral inhibition to resolve competition between simultaneously activated words. The fact that the inhibition is observed only for a neighbor of a higher frequency than the target can be explained by the model's assumption that the inhibitory capacity of a word depends on the baseline activation level of that word, which in turn is a function of frequency (high-frequency words have higher baseline activation levels than low-frequency words).

In an attempt to account for the discrepant neighbor findings, Grainger and Jacobs (1996) developed their multiple read-out model of lexical decision. This model is based on the IAM (McClelland & Rumelhart, 1981) but deviates from it in several respects. The most important difference for the present purpose is the use of three criteria to decide whether a stimulus is a word or a nonword. These are (a) the M criterion based on the activation (μ) of individual lexical units, (b) the Σ criterion based on the global or summed lexical activation (σ) in the orthographic lexicon, and (c) the T criterion, which is a temporal deadline used to make negative (nonword) responses. If either the M or the Σ criterion is reached before the T criterion, a stimulus is classified as a word; otherwise, it is classified as a nonword.

Whereas the M criterion is fixed, both the T and the Σ criteria are assumed to vary as a function of stimulus characteristics and task demands. When the distractor nonwords are very wordlike (evoking a high σ value) or when accuracy is stressed, the Σ criterion is set relatively high, and participants on average base their decisions more on the M criterion than if a lower Σ value had

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been set. If, on the other hand, less wordlike distractors (evoking a low σ value) are used or when the speed of responding is emphasized, the Σ criterion is lowered, and decisions are made on the basis of overall lexical activity. Hence, participants on average base their decisions more on the Σ criterion.

Within the multiple read-out model, inhibition originating from coactivated words is assumed to affect the time it takes for a word to reach the M threshold. Therefore, inhibitory neighborhood-frequency effects are found whenever participants use the M criterion. On the other hand, the number of coactivated words is assumed to affect the overall lexical activation (σ) so that facilitative neighborhood-size effects are found when the response choice is based on the Σ criterion.

Grainger and Jacobs (1996) tested these predictions by investigating the effect of stressing speed over accuracy in the participants' instructions on the neighborhood-size and the neighborhood-frequency effects. In Grainger and Jacobs's Experiment 1D, participants were instructed to respond as rapidly as possible even if this caused them to make a lot of errors. On the other hand, in Grainger and Jacobs's Experiment 1B, participants were instructed to respond as rapidly and as accurately as possible. Grainger and Jacobs reasoned that stressing speed should encourage participants to base their decision more often on the overall wordlikeness of the word (the Σ criterion; Experiment 1D) rather than on the lexical access to the word (the M criterion; Experiment 1B). The results of Experiment 1B showed no neighborhood-size effect and a significant neighborhood-frequency effect, whereas the results of Experiment 1D showed a facilitative neighborhood-size effect and an inhibitory neighborhood-frequency effect. Unfortunately, Grainger and Jacobs did not report statistical tests to verify whether there was a statistical difference in the neighborhood-frequency effect between both experiments even though this is the crucial test for the multiple read-out model.

Up to now, the experiment of Grainger and Jacobs (1996) has been the only empirical study on how the use of multiple response criteria affects neighbor effects. Other possible effects of shifts in response criteria have most of the time been reported post hoc (e.g., Carreiras et al., 1997; Huntsman & Lima, 1996; Sears, Hino, & Lupker, 1995; Snodgrass & Mintzer, 1993). Critically, all these reports have been restricted to single word presentation studies. However, the multiple criteria concept should also be valid for explaining (the absence of) neighbor effects in masked priming studies. In addition, with a masked priming design, a more stringent test of the multiple criteria concept (as implemented in the multiple read-out model) is possible because targets can be held constant across conditions. The combination of word-level lateral inhibition and multiple criteria (as implemented in the multiple read-out model) predicts similar neighbor effects in masked priming and in single word identification tasks. The aim of our study was to outline this prediction and to test it.

Consider a typical masked priming lexical decision experiment. Either a neighbor word or a control word is presented briefly before the target. According to the IAM, a neighbor prime remains more active during target presentation than a control prime because the target letters partly activate the neighbor prime's lexical node. Because any prime word inhibits the target word (all words have inhibitory connections in the IAM), the stronger activation of the neighbor word during the target presentation leads to a lower activation value of the target node when a neighbor prime is used rather than a control word. Hence, if the M criterion is used, an inhibitory masked neighbor priming effect can be expected. However, strictly speaking, this prediction does not always hold; for example, if lateral inhibition between words is very weak, there is a net facilitative effect of neighbor primes. What the multiple read-out model does always predict, however, is that if two Conditions A and B are compared and the M criterion is used more frequently in Condition A than in Condition B, the neighbor effect is more inhibitory (which can also mean less facilitative) in Condition A than in Condition B. On the other hand, presentation of a neighbor prime leads to a higher total activation (summed over all lexical nodes) relative to a control prime condition simply because a neighbor prime is more active during target presentation than a control prime. It follows that if the Σ criterion is used more often in one condition than in another, a neighbor prime should lead to a more facilitative effect in the first condition.

We further tested the multiple criteria account by implementing a version of the multiple read-out model that was as simple as possible yet captured the fundamental ideas, following the strategy of canonical modeling as advocated by Grainger and Jacobs (1996). An IAM was implemented for three 4-letter words, two of which were neighbors (henceforth, *neighbor prime* and *target*); the third word was orthographically unrelated (henceforth, *control prime*). Parameter settings were taken from McClelland and Rumelhart (1981), except that we removed word-to-letter activation as it was not relevant for the present purposes. Additional (multiple read-out) parameters were as follows. The M criterion was set equal to 0.55. The sum (Σ) criterion was set to 0.57. To allow for modeling errors, we introduced variability in the deadline (T) criterion. This criterion was set after 10 time steps. If total word activation at that time step was larger than 0.3, the deadline criterion was set to $25 + 5 * N$, where N is a value from a normal distribution with mean zero and standard deviation of one. Otherwise, it was set to $20 + 5 * N$. We performed 10,000 trials on both neighbor prime—target and control prime—target word pairs for both the M and the Σ criteria (hence, 40,000 in total). Using the M criterion, response times (RTs) were on average faster with a control prime than with a neighbor prime (16.7 and 18.4 time steps, respectively; effect size = −1.7). Responses were also more accurate with a control prime than with a neighbor prime (percentage correct = 86% and 76%, respectively; effect size = 10%). On the other hand, when using the Σ criterion, RTs were slower with a control prime than with a neighbor prime (14.0 and 10.0 time steps, respectively; effect size = 4.0). Responses were also less accurate with a control prime than with a neighbor prime (96% and 99% correct, respectively; effect size = −3%).

Our research strategy was very similar in the two experiments. In each experiment, we made one condition more M-criterion prone than the other condition. In Experiment 1, we gave participants online (trial-by-trial) error feedback in one condition. In the other condition, no online error feedback was given. This manipulation motivated participants to use the M criterion more often in the first than in the second condition. The first condition should therefore have shown more inhibition (or less facilitation). In Experiment 2, we gave participants in one condition online speed feedback if they reacted too slowly; in the other condition, no online speed feedback was given. We expected that in the first condition, participants would rely more often on the Σ criterion than in the second condition. Therefore, we expected to observe more facilitation (or less inhibition) in the first condition relative to the second condition. So, essentially, we predicted an interaction between condition and prime status for both experiments.

In both experiments, an offline feedback condition was used as the control condition against which we measured the effect of setting the Σ criterion higher or lower. In the offline feedback conditions, error feedback (Experiment 1) or speed feedback (Experiment 2) was provided between blocks in the sense that after each block, the mean number of errors or the mean RT in the preceding block was displayed on the screen. This offline information was also given in the online conditions. In this way, the test and the control conditions in each experiment differed only minimally.

Experiment 1: Stressing Accuracy

Method

Participants. Thirty-two psychology students at Ghent University, Ghent, Belgium, participated in the experiment on a voluntary basis. All participants were native Dutch speakers and had normal or corrected-to-normal vision. The students were randomly assigned to one of the two feedback conditions (16 per condition).

Materials. The Appendix gives an overview of the stimuli. For the words, frequency counts were based on the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993). The age-of-acquisition (AoA) measures were based on the student ratings collected by Ghyselinck, De Moor, and Brysbaert (2000; for a validation, see De Moor, Ghyselinck, & Brysbaert, 2000). One hundred twenty 4- and 5-letter stimuli were presented (60 Dutch words and 60 nonwords). All target words were low-frequency, late-acquired words (*M* logarithmic frequency on a total of 42,380,000 counts [log freq] = 1.9; *M* AoA = 9.8 years). The primes were either high-frequency, early-acquired neighbor words (*M* log freq = 3.4; *M* AoA = 5.2 years) or high-frequency, early-acquired unrelated control words (*M* log freq = 3.4; *M* AoA = 5.3 years). On the basis of a Latin square, we created two lists; half of the participants received the odd target with a neighbor prime and the even target with an unrelated word; for the other half of the participants, this combination was reversed. To avoid running short of high-frequency, early-acquired prime words, we used some primes twice (once as a neighbor prime for a word and once as a control prime for another word). However, by using two lists, we could make sure that no primes were presented twice to the same participant. Sixty legal nonwords were constructed by changing one letter of a word, using other than the experimental words. Half of the nonwords were preceded by a neighbor word, the other half by an unrelated control word.

Procedure. Stimuli were presented at the center of a video display connected to an IBM-compatible personal computer. On each trial, two vertical lines appeared at the center of the screen. Between these two lines, a forward mask in the form of five hash marks (#####) appeared for 500 ms. The forward mask was replaced by the prime (presented for 57 ms; exactly four refresh cycles of 14.3 ms each), and the prime was replaced by the target word. The target remained on the screen until participants indicated *word* or *nonword* by pressing one of two keys of a response box. To minimize physical similarity effects, prime words were presented in lowercase and target words in uppercase. The two vertical lines of the fixation stimulus remained on the screen during the entire trial, with the mask(s), the prime, and the target presented centrally to the fixation stimulus.

Participants were told that they would see two vertical lines on each trial and were instructed to fixate the gap between these two lines. In addition, it was made clear that a warning signal (#####) would appear, followed by the target word in uppercase. The presence of a prime word was not mentioned. Participants were instructed to respond as fast and as accurately as possible. Stimulus presentation was randomized with a different order for each participant. The hand used for responding to the word and the nonword trials was counterbalanced across participants.

In the online error feedback condition, a 1000-Hz feedback tone was given for 500 ms whenever participants made an error. In the offline error feedback condition, participants received no trial-by-trial feedback. In both conditions, the intertrial interval was 1,500 ms (within which the feedback tone was given). Before the experimental trials, three blocks of 20 practice trials each (10 words and 10 nonwords) were given. The experimental trials were presented in three blocks of 40 trials. After each block, participants in both conditions were informed by the computer of the mean number of errors made in the previous block. The experiment took about 20 min and was run in a dimly lit room. Each participant was tested separately.

Results

RTs were calculated on correct responses (12.0% incorrect word trials and 6.5% incorrect nonword trials were removed). RTs deviating more than two standard deviations from the condition mean were discarded (4.0%). Table 1 shows mean RTs and percentages of errors as a function of the prime–target relatedness for both feedback conditions. Mean correct RTs and mean percentages of error were analyzed using analyses of variance (ANOVAs) with orthographic relatedness (prime is a neighbor word or an unrelated control word) as a within-subjects variable and feedback condition (online error feedback vs. offline error feedback) as a between-subjects variable. To take into account the variance due to the two word lists (because stimuli were presented using a Latin square), we included participant group as a between-subjects variable. Because we counterbalanced items, only analyses treating participants as a random variable are reported (see Raaijmakers, Schrijnemakers, & Gremmen, 1999).

Table 1
Mean RTs (in Milliseconds) and Percentages of Errors in Experiment 1 as a Function of Whether Participants Received Offline or Online Error Feedback

Condition	*M* RT	*SE*	% error	*SE*
Words				
Offline feedback				
Orthographic Neighbor prime	675	11.7	15	1.71
Unrelated prime	662	16.56	14	1.73
Effect	−13		−1	
Online feedback				
Orthographic Neighbor prime	686	14.4	13	3.13
Unrelated prime	641	16.9	7	3.05
Effect	−45		−6	
Nonwords				
Offline feedback				
Orthographic Neighbor prime	705	17.18	6	1.61
Unrelated prime	724	21.9	6	1.39
Effect	19		0	
Online feedback				
Orthographic Neighbor prime	722	20.02	7	1.26
Unrelated prime	724	17.13	7	1.3
Effect	2		0	

Note. RT = response time.

Word trials. Analyses of the RTs showed no significant effect of feedback ($F < 1$, $MSE = 398$, *ns*). The effect of orthographic relatedness was significant, $F(1, 28) = 14.34$, $MSE = 13{,}475.00$, $p < .001$, indicating that participants were 30 ms slower to respond to the target when it was preceded by a neighbor word (e.g., *dier–KIER* [*animal–chink*]) than when it was preceded by an unrelated control word (e.g., *boom–KIER* [*tree–chink*]). Most important to note is that there was a significant interaction between feedback condition and orthographic relatedness, $F(1, 28) = 4.82$, $MSE = 4{,}530.00$, $p < .05$, indicating a stronger inhibitory masked neighbor priming effect when participants received online error feedback about their performance. There was a significant 45-ms inhibitory neighbor effect in the online error feedback condition, $F(1, 28) = 17.90$, $MSE = 16{,}815.70$, $p < .001$, and a nonsignificant difference of 13 ms toward inhibition in the offline error feedback condition, $F(1, 28) = 1.27$, $MSE = 1{,}189.35$, $p = .27$.

The error analyses showed no significant effect of feedback condition, $F(1, 28) = 1.9$, $MSE = 351.6$, $p = .18$. There was a significant effect of orthographic relatedness, $F(1, 28) = 9.94$, $MSE = 166.80$, $p < .05$, indicating a higher error rate when the prime was a neighbor word (14.0%) relative to the control condition (10.5%). Although the interaction between feedback condition and orthographic relatedness fell short of the conventional .05 level, $F(1, 28) = 3.73$, $MSE = 62.70$, $p = .06$, planned comparisons revealed a significant inhibitory masked neighbor priming effect in the online error feedback condition, $F(1, 28) = 12.97$, $MSE = 217.01$, $p < .01$, but not in the offline error feedback condition ($F < 1.0$, $MSE = 12.5$, *ns*).

Nonword trials. The RT analyses revealed no significant effect of feedback condition ($F < 1$, $MSE = 1{,}309$, *ns*); no significant effect of orthographic relatedness, $F(1, 28) = 2.40$, $MSE = 1{,}750.00$, $p = .13$; and no significant interaction between the two factors, $F(1, 28) = 1.53$, $MSE = 1{,}118.00$, $p = .22$. No effects were found in the error analyses (all Fs < 1, *ns*).

Experiment 2: Stressing Speed

Method

Participants. Twenty psychology students at Ghent University participated in the experiment in exchange for course credit. All participants were native Dutch speakers and had normal or corrected-to-normal vision. The students were randomly assigned to one of the two speed feedback conditions (10 per condition).

Materials. The same materials as in Experiment 1 were used.

Procedure. The masked priming procedure in combination with the lexical decision task as described in Experiment 1 was used.

In the online speed feedback condition, a 1000-Hz tone was given (for 500 ms) whenever participants responded later than 600 ms after the appearance of the word on the screen. To avoid effects of the beep on the response process, it was given after participants had made their choice. In the offline speed feedback condition, no tone was given. In both conditions, the intertrial interval was 1,500 ms (within which the tone was given). In both conditions, participants were instructed to respond as rapidly and accurately as possible. Additionally, in the online speed feedback condition, participants were instructed that they should try to respond within 600 ms after presentation of the target. If they did not succeed in responding within this 600-ms time interval, they would hear a beep immediately after they pushed one of the two response buttons. There were three practice blocks and three test blocks. After each block, in both the online speed feedback and the offline speed feedback conditions, participants received offline error feedback on the screen about their mean RT in the preceding block.

Results

Mean RTs and percentages of errors are reported in Table 2. The RT analyses were performed on correct RTs within two standard deviations of the mean RT in each condition (27% incorrect word trials, 18% incorrect nonword trials, and 3% of the data falling outside the two-standard-deviations range were omitted). Mean RTs and percentages of errors were analyzed using ANOVAs with orthographic relatedness (prime is a neighbor word or an unrelated control word) as a within-subjects variable and feedback condition (online speed feedback vs. offline speed feedback) as a between-subjects variable. Analyses treating participants as a random variable are reported.

Word trials. Analyses of the RTs showed a significant effect of feedback condition, $F(1, 16) = 18.2$, $MSE = 139{,}015.0$, $p < .001$, with 118-ms faster responses in the online feedback condition compared with the offline feedback condition. The effect of orthographic relatedness was not significant ($F < 1$, $MSE = 399$, *ns*). The critical interaction between feedback condition and orthographic relatedness was significant, $F(1, 16) = 5.86$, $MSE = 4{,}604.00$, $p < .05$. Planned comparisons showed a significant 28-ms facilitation in the online speed feedback condition, $F(1, 16) = 4.91$, $MSE = 3{,}856.38$, $p < .05$, and a nonsignificant 15-ms difference toward inhibition in the offline speed feedback condition, $F(1, 16) = 1.46$, $MSE = 1{,}146.50$, $p > .24$.

Analyses of the error percentages showed a significant effect of feedback condition, $F(1, 16) = 6.47$, $MSE = 1{,}210.00$, $p < .05$, with more errors in the online speed feedback condition (33%)

Table 2
Mean RTs (in Milliseconds) and Percentages of Errors in Experiment 2 as a Function of Whether Participants Received Offline or Online Speed Feedback

Condition	*M* RT	*SE*	% error	*SE*
Words				
Offline feedback				
Orthographic Neighbor prime	637	31.53	23	3.6
Unrelated prime	622	21.31	20	2.85
Effect	−15		−3	
Online feedback				
Orthographic Neighbor prime	498	11.8	30	4.05
Unrelated prime	526	5.54	35	4.1
Effect	28		5	
Nonwords				
Offline feedback				
Orthographic Neighbor prime	675	41.84	14	3.64
Unrelated prime	665	38.45	18	5.49
Effect	−10		4	
Online feedback				
Orthographic Neighbor prime	539	6.29	20	5.15
Unrelated prime	520	9.47	18	4.39
Effect	−19		−2	

Note. RT = response time.

compared with the offline speed feedback condition (22%). There was no masked neighbor priming effect ($F < 1.00$, $MSE = 4.44$, *ns*) and no interaction between the two factors, $F(1, 16) = 1.76$, $MSE = 134.44$, $p > .20$.

Nonword trials. The RT analyses revealed a significant effect of feedback condition, $F(1, 16) = 10.73$, $MSE = 197{,}793.00$, $p < .01$, and of orthographic relatedness, $F(1, 16) = 6.92$, $MSE = 2{,}020.00$, $p < .05$. There was no interaction between the two factors ($F < 1$, $MSE = 166$, *ns*). The error analyses showed no effect of feedback condition or orthographic relatedness (both Fs < 1, *ns*) and no interaction between the two factors, $F(1, 16) = 1.41$, $MSE = 90.00$, $p = .25$.

To compare the effects of the instructional manipulations in both experiments, we also performed an analysis with experiment (Experiment 1 vs. Experiment 2) as a between-subjects variable. The results showed a significant three-way interaction among experiment, feedback (online vs. offline feedback), and orthographic relatedness (neighbor prime vs. control prime), $F(1, 44) = 10.21$, $MSE = 9{,}020.00$, $p < .01$, indicating that our instructions to stress accuracy or speed of responding generated a different effect: Stressing accuracy led to neighbor inhibition (45 ms), and stressing speed led to neighbor facilitation (28 ms).

General Discussion

The purpose of this study was to evaluate the validity of the multiple criteria concept as implemented in the multiple read-out model (Grainger & Jacobs, 1996) in explaining masked neighbor priming effects. Our results were clear-cut: In corroboration of our predictions, there was an interaction between the feedback condition (online vs. offline feedback) and the masked neighbor priming effect for both experiments. The results of Experiment 1 showed a stronger inhibitory masked neighbor priming effect in the online error feedback condition compared with the offline error feedback condition. The data of Experiment 2 showed a facilitative effect in the online speed feedback condition compared with the offline speed feedback condition. These findings corroborate the validity of the multiple criteria concept as incorporated in the multiple read-out model because they clearly show that the opportunity to use the M or the Σ criterion results in different masked neighbor priming effects. Because we compared the effects of using the M or the Σ criterion relative to a stringent control condition, we can be sure that the different effects observed in the test and control conditions were due to a shift in the response criteria. More generally, our data support the idea that word reading is not necessarily accomplished by accessing the lexical representation of a word but that the overall activity evoked by the word in the lexicon can also be used to decide whether a given letter string is a word or a nonword.

Our findings are comparable to the results that Grainger and Jacobs (1996) observed in a single word presentation task but also go beyond them on several points. First, we showed not only the effect of setting the Σ criterion lower and thus making decisions on the basis of the Σ criterion (Experiment 2) but also the effect of setting the Σ criterion higher and thus making decisions on the basis of the M criterion (Experiment 1). Second, we statistically compared the effects in the feedback conditions with those in the control condition, showing that making a shift in the response criteria caused a reliable difference in the masked neighbor priming effect. Third, we showed that the concept of multiple response criteria holds not only for neighbor effects observed with single word presentation tasks but also for the masked neighbor priming effect, which allows for more stringent controls.

Besides the multiple read-out model, another prominent model of lexical decision is the recent diffusion model proposed by Ratcliff, Gomez, and McKoon (2004). According to this model, lexical decision consists of a diffusion process in which the response “word” is given when the diffusion process reaches an upper decision boundary and the response “nonword” is given when it reaches a lower boundary. The RT and accuracy are determined by a number of factors, two of which are (a) the drift rate, the tendency of the process to drift to one of the two boundaries; and (b) the height of the decision boundaries. We see the strengths of the multiple read-out model and the diffusion model as complementary: The multiple read-out model makes detailed architectural assumptions, from which the predictions outlined in this article were derived. However, it does not always account for the three main variables in lexical decision (accuracy, correct RTs, and error RTs; see Ratcliff et al., 2004, for discussion) at a detailed level. The diffusion model, on the other hand, can account for different effects in the three main variables. However, the diffusion model makes no representational assumptions, and for this reason, it is not possible to predict findings such as those reported in this article. For example, simply putting the decision boundaries further away from the starting point to model the accuracy conditions will not do. This manipulation does not predict more inhibition from neighbor words; it predicts only higher accuracy and slower RTs. Yet it would be possible to implement the present findings in the diffusion model by making the drift rate of each prime–target pair dependent on the prime, the target, and the condition (e.g., accuracy stressed or not). A particularly appealing idea discussed by Ratcliff et al. is to obtain these drift rates from a different (representational) model, such as the multiple read-out model; in this way, the advantages from the two classes of models could in principle be combined. Development of such a model remains an issue for future research.

From a methodological point of view, our results indicate that inhibitory masked neighbor priming effects are more likely to emerge when accuracy is stressed. For instance, in the masked priming study of Brysbaert et al. (2000), accuracy was not explicitly stressed, and there was an overall rather high error rate of 16% for the words manipulated for AoA, which might have been the reason why they failed to observe an inhibitory masked neighbor priming effect in the RTs. Our results show that providing error feedback increases the probability of capturing lexical competitive processes, although it may not be a necessary condition to observe the effect. For instance, Segui and Grainger (1990) observed a clear inhibitory masked neighbor priming effect, and no feedback was given in their study.

In conclusion, our results support the idea that earlier failures to observe inhibitory neighbor effects may have been due to the use of a variable response criterion (M vs. Σ) rather than to the nonexistence of these effects, an argument put forward by some authors (e.g., Sears et al., 1995). Usually, participants in the lexical decision task are instructed to respond as rapidly and accurately as possible. We would like to emphasize that researchers investigating neighbor effects should be careful in urging participants to respond as rapidly as possible because this motivates participants to use the Σ criterion more often, and inhibitory masked neighbor priming effects are thus harder to observe. On the other hand, researchers intending to study the use of the Σ criterion should emphasize the speed of responding. Our findings show that this can be established with minimal manipulations.

References

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 802–814.

Andrews, S. (1992). Frequency and neighborhood effects on lexical access: Lexical similarity or orthographic redundancy? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 234–254.

Andrews, S. (1997). The effects of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review, 4,* 439–461.

Baayen, R. H., Piepenbrock, R., & Van Rijn, H. (1993). The CELEX lexical database (Release 1) [CD-ROM]. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Bijeljac-Babic, R., Biardeau, A., & Grainger, J. (1997). Masked orthographic priming in bilingual word recognition. *Memory & Cognition, 25,* 447–457.

Brysbaert, M., Lange, M., & Van Wijnendaele, I. (2000). The effects of age-of-acquisition and frequency-of-occurrence in visual word recognition: Further evidence from Dutch. *European Journal of Cognitive Psychology, 12,* 65–85.

Carreiras, M., Perea, M., & Grainger, J. (1997). Effects of orthographic neighborhood in visual word recognition: Cross-task comparisons. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 857–871.

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Dornic (Ed.), *Attention & performance VI* (pp. 535–555). Hillsdale, NJ: Erlbaum.

De Moor, W., & Brysbaert, M. (2000). Neighborhood-frequency effects when primes and targets have different lengths. *Psychological Research, 63,* 159–162.

De Moor, W., Ghyselinck, M., & Brysbaert, M. (2000). A validation study of the age-of-acquisition norms collected by Ghyselinck, De Moor and Brysbaert. *Psychologica Belgica, 40,* 99–114.

Forster, K. I., & Shen, D. (1996). No enemies in the neighborhood: Absence of inhibitory neighborhood effects in lexical decision and semantic categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 696–713.

Ghyselinck, M., De Moor, W., & Brysbaert, M. (2000). Age-of-acquisition ratings for 2816 Dutch four- and five-letter nouns. *Psychologica Belgica, 40,* 77–98.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103,* 518–565.

Grainger, J., O'Regan, J. K., Jacobs, A. M., & Segui, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception & Psychophysics, 45,* 189–195.

Grainger, J., & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. *Perception & Psychophysics, 47,* 191–198.

Huntsman, L. A., & Lima, S. D. (1996). Orthographic neighborhood structure and lexical access. *Journal of Psycholinguistic Research, 25,* 417–429.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: 1. An account of basic findings. *Psychological Review, 88,* 375–407.

Raaijmakers, J. G. W., Schrijnemakers, J. M. C., & Gremmen, F. (1999). How to deal with "the language-as-fixed-effect fallacy": Common misconceptions and alternative solutions. *Journal of Memory and Language, 41,* 416–426.

Ratcliff, R., Gomez, P., & McKoon, G. (2004). A diffusion model account of the lexical decision task. *Psychological Review, 111,* 159–182.

Sears, C. R., Hino, Y., & Lupker, S. J. (1995). Neighborhood size and neighborhood frequency effects in word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 21,* 876–900.

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 65–76.

Snodgrass, J. G., & Mintzer, M. (1993). Neighborhood effects in visual word recognition: Facilitatory or inhibitory? *Memory & Cognition, 21,* 247–266.

(*Appendix follows*)

Appendix

Late-Acquired Low-Frequency Targets, Early-Acquired High-Frequency Primes, and Unrelated Control Words

Target	Log Fr	AoA	Test prime	Log Fr	AoA	Control prime	Log Fr	AoA
ZOOM (hem)	2.18	9.2	boom (tree)	3.76	3.5	dier (animal)	3.90	3.8
KIER (chink)	2.75	7.6	dier (animal)	3.90	3.8	boom (tree)	3.76	3.5
RUIS (noise)	1.88	9.5	muis (mouse)	2.95	4.2	teen (toe)	3.15	3.8
TEEF (bitch)	2.57	8.6	teen (toe)	3.15	3.8	muis (mouse)	2.95	4.2
POEN (dough)	2.28	9.6	poes (pussy)	2.94	4.0	dulm (thumb)	3.11	4.1
DUIT (penny)	2.06	9.9	duim (thumb)	3.11	4.1	poes (pussy)	2.94	4.0
VEEN (peat)	2.40	10.8	been (leg)	3.90	4.0	raam (window)	3.87	4.0
RAAF (raven)	2.40	7.8	raam (window)	3.87	4.0	been (leg)	3.90	4.0
LOEP (magnifyer)	2.21	9.7	soep (soup)	3.01	4.2	vijf (five)	3.89	4.3
VIJG (fig)	2.06	8.0	vijf (five)	3.89	4.3	soep (soup)	3.01	4.2
HUIG (uvula)	1.51	12.4	huis (house)	4.43	4.4	naam (name)	4.25	4.5
NAAD (seam)	2.15	9.9	naam (name)	4.25	4.5	huis (house)	4.43	4.4
KNOT (knot)	1.74	9.5	knop (button)	3.10	4.7	glas (glass)	3.81	4.7
VLAS (flax)	1.85	9.3	glas (glass)	3.81	4.7	knop (button)	3.10	4.7
BOEG (bow)	2.54	9.4	boek (book)	4.21	4.8	tuln (garden)	3.70	4.9
PUIN (rubble)	2.62	9.0	tuin (garden)	3.70	4.9	boek (book)	4.21	4.8
GONG (gong)	1.81	9.7	tong (tongue)	3.36	5.1	hart (hart)	3.91	5.1
HARP (harp)	1.84	8.6	hart (hart)	3.91	5.1	tong (tongue)	3.36	5.1
WAAS (haze)	2.43	10.4	kaas (cheese)	3.36	5.1	hoek (angle)	3.67	5.2
HOEN (hen)	1.69	9.6	hoek (angle)	3.67	5.2	kaas (cheese)	3.36	5.1
DRUG (drug)	2.74	10.7	brug (bridge)	3.34	5.4	klok (clock)	3.20	5.5
KLOS (bobbin)	1.59	9.8	klok (clock)	3.20	5.5	brug (bridge)	3.34	5.4
KELK (goblet)	2.23	8.6	kerk (church)	3.94	5.7	gang (passage)	3.90	5.8
GALG (gallows)	2.20	9.2	gang (passage)	3.90	5.8	kerk (church)	3.94	5.7
BERM (roadside)	2.46	8.4	berg (mountain)	3.37	5.8	kist (chest)	3.28	6.2
KILT (tartan)	0.60	11.5	kist (chest)	3.28	6.2	berg (moutain)	3.37	5.8
NERF (vain)	1.72	10.1	verf (paint)	3.06	6.1	hulp (help)	3.69	6.2
PULP (pulp)	1.67	10.9	hulp (help)	3.69	6.2	verf (paint)	3.06	6.1
PUNK (punk)	1.36	10.5	punt (point)	3.95	6.2	hals (neck)	3.39	6.3
HALM (stalk)	1.90	10.1	hals (neck)	3.39	6.3	punt (point)	3.95	6.2
POOK (poker)	1.64	10.8	rook (smoke)	3.45	6.7	baas (boss)	3.46	6.7
BAAI (bay)	2.78	9.4	baas (boss)	3.46	6.7	rook (smoke)	3.45	6.7
VAMP (femme fatale)	1.08	12.5	kamp (camp)	3.26	6.9	pols (wrist)	3.01	7.1
PULS (pulse)	0.90	11.9	pols (wrist)	3.01	7.1	kamp (camp)	3.26	6.9
GIER (vulture)	2.55	7.9	vier (four)	4.01	3.9	fout (fault)	3.48	4.7
BOUT (screw bolt)	1.97	9.5	fout (fault)	3.48	4.7	vier (four)	4.01	3.9
PEEN (carrot)	1.70	10.1	peer (pear)	2.63	4.9	ruit (window)	2.78	5.4
LUIT (lute)	1.94	11.0	ruit (window)	2.78	5.4	peer (pear)	2.78	4.9
KUIF (head of hear)	2.11	10.2	duif (dove)	2.92	5.5	hoed (hat)	3.24	5.6
HOES (cover)	2.01	9.8	hoed (hat)	3.24	5.6	duif (dove)	2.92	5.5
HINT (hint)	1.73	9.8	sint (St. Nicolas)	2.97	3.8	wolf (wolf)	2.86	5.7
KOLF (butt)	2.24	10.0	wolf (wolf)	2.86	5.7	sint (St. Nicolas)	2.97	3.8
GRIP (grip)	1.00	10.5	grap (joke)	3.01	6.5	slot (end)	3.48	6.8
KLIF (cliff)	1.34	11.1	klik (clack)	2.36	6.9	spar (spruce)	2.06	6.6
KLAD (draft)	1.81	7.5	klas (class)	3.31	4.2	ster (star)	3.42	5.6
KUUR (cure)	2.39	10.2	muur (wall)	3.79	5.0	lijn (line)	3.65	5.6
GEUT (dash)	0.90	10.2	geit (goat)	2.69	5.0	kaak (cheek)	2.91	5.2
TOLK (interpreter)	2.33	10.6	wolk (cloud)	3.31	5.3	dans (dance)	2.88	5.4
SNOB (snob)	1.68	10.6	snor (moustache)	2.88	5.3	vlek (spot)	3.06	5.2
SPIL (pivot)	1.96	10.5	spin (spider)	2.60	5.3	graf (grave)	3.16	5.6
KNUL (fellow)	2.41	8.9	krul (curl)	2.71	5.3	staf (staff)	3.09	5.8
KINK (kink)	1.30	10.1	pink (little finger)	2.38	5.4	vest (coat)	2.61	5.3
KEET (show)	1.99	11.2	keel (throat)	3.42	5.5	buur (neighbor)	3.06	5.6
LANS (lance)	2.35	9.60	land (land)	4.25	5.8	dorp (village)	3.76	5.9
LENS (lens)	2.42	9.40	mens (human)	4.76	4.8	park (park)	3.70	5.4
WIEK (sail)	2.10	9.30	week (week)	4.10	5.8	zoon (son)	3.90	5.1
VELG (rim)	1.41	11.5	veld (field)	3.38	6.0	jurk (dress)	3.25	6.2
GEUL (channel)	2.17	10.2	geur (smell)	3.99	6.7	paar (pair)	4.32	6.6
GROG (grog)	1.23	11.8	grot (cave)	2.82	6.7	klap (bang)	3.32	6.5
KRAM (cramp)	1.36	11.0	gram (gram)	2.82	6.8	stip (dot)	2.35	5.7
Average	1.90	9.80		5.20	3.4		5.3	3.4

Note. Log Fr = logarithm of the frequency on a total of 42,380,000 counts; AoA = age at which the word was acquired.

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