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Making Things Difficult in Lexical Decision: The Impact of Pseudohomophones and Transposed-Letter Nonwords on Frequency and Semantic Priming Effects

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Performance in a lexical decision task is crucially dependent on the difficulty of the word–nonword discrimination. More wordlike nonwords cause not only a latency increase for words but also, as reported by Stone and Van Orden (1993), larger word frequency effects. Several current models of lexical decision making can explain these types of results in terms of a single mechanism, a mechanism driven by the nature of the interactions within the lexicon. In 2 experiments, we replicated Stone and Van Orden's increased frequency effect using both pseudohomophones (e.g., BEEST) and transposed-letter nonwords (e.g., JUGDE) as the more wordlike nonwords. In a 3rd experiment, we demonstrated that simply increasing word latencies without changing the difficulty of the word–nonword discrimination does not produce larger frequency effects. These results are reasonably consistent with many current models. In contrast, neither pseudohomophones nor transposed-letter nonwords altered the size of semantic priming effects across 4 additional experiments, posing a challenge to models that would attempt to explain both nonword difficulty effects and semantic priming effects in lexical decision tasks in terms of a single, lexically driven mechanism.

Keywords: nonword difficulty, lexical processing, pseudohomophones, transposed-letter nonwords, frequency effects, semantic priming

Since its introduction in the early 1970s (e.g., Rubenstein, Garfield, & Millikan, 1970), the lexical decision task has become the most commonly used task for studying how people identify words. The task is quite simple. A string of letters is presented to an observer, and that person must decide whether that letter string is a word in his or her language, responding by pressing one of two buttons. Because, in theory, people should be able to determine that a letter string is a word as soon as they have located a representation for the word in lexical memory, the initial hope was that this task would provide a relatively pure way of investigating the lexical access process. Although that hope appears to have been somewhat overstated, the task has provided, and continues to provide, many insights about the nature of the word identification process (e.g., Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004).

Most of these insights have been derived, of course, by determining the variables that affect performance in the lexical decision task and by building models that can explain those effects. The list of such variables is now quite large (e.g., word frequency, semantic context, concreteness; see Balota et al., 2004, for an extensive evaluation of the effects of these and other factors). In the present research, the focus is on the factor of nonword type, a factor that has attracted research interest because it provides a means of studying the potential for flexibility or modulation of the processes within the word recognition system. Specifically, there are two basic results involving nonword type manipulations that models of the lexical decision-making processes must explain: (a) why nonword latencies are longer when the nonwords are more wordlike and (b) why word latencies are also longer when the nonwords are more wordlike. The dimension of wordlikeness has been manipulated in a number of ways, typically by altering either the orthographic or phonological characteristics of the nonwords. The specific wordlikeness manipulations central to the present research are described below when discussing the relevant literature. The important point here is that the existence of such effects does indicate that when the task context changes, because of a change in the nature of the nonwords used, participants make adjustments in processing—adjustments that need to be explained by any successful model of the lexical decision-making process.

One of the earliest and more influential models that can explain nonword type (i.e., wordlikeness) effects, as well as a number of other effects, in the lexical decision task is the multiple read-out

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model (MROM) of Grainger and Jacobs (1996). According to this model, each word is represented by a unit in lexical memory. When a letter string is presented, it activates lexical units of words with similar spellings. When the activation of a particular lexical unit reaches a threshold (the μ criterion), a word response can be made. The resting activation level of each lexical unit is a direct function of the word's frequency. Hence, the lexical units for higher frequency words would reach this criterion more rapidly. A word response can also be made once the overall level of activity in the lexicon reaches a specified threshold (using what Grainger & Jacobs, 1996, referred to as the Σ criterion). Nonword responses are made when neither criterion has been reached before a time deadline expires.

The way the model explains the wordlikeness effect on nonword latencies is to claim that the setting of the time deadline is based on how wordlike the nonwords are. More wordlike nonwords require longer deadlines. The wordlikeness effect on word latencies is explained in terms of changes in the Σ criterion. When the nonwords are not wordlike, a modest level of lexical activation would be a good indication that the letter string is a word (because such a level could not be generated by nonwordlike nonwords). Thus, the Σ criterion would be set low, and many word trials would produce rapid responses (i.e., responding could be done before the μ criterion had been reached). When wordlike nonwords are used, the Σ criterion would be set substantially higher, causing it to play only a minor role in the process. Hence, most word responses would be generated by the μ criterion, leading to longer latencies.

A second model that has had considerable success accounting for lexical decision phenomena, including the impact of nonword type, is Ratcliff, Gómez, and McKoon's (2004) diffusion model. According to this model, once a letter string has been perceived, lexical processing produces a uni-dimensional measure of wordlikeness. That measure then acts as a drift rate to drive a random walk process until it reaches either a word boundary or a nonword boundary. To the extent that the nonwords are wordlike, their drift rates toward the nonword boundary will be smaller, leading to longer latencies for wordlike nonwords. In addition, to the extent that the nonwords are wordlike, the drift rates for words will also be smaller, leading to longer word latencies. Although the processing details by which these drift rates are arrived at are not specified (see Yap, Balota, Cortese, & Watson, 2006, for some ideas of how that might be done), as Ratcliff et al. have demonstrated, the model does a good job of simulating the data from a number of experiments in which nonword difficulty and word frequency were examined.

Norris's (2006) Bayesian reader model is another model that has had success in explaining lexical decision data. According to the model, when a letter string is presented, evidence concerning the item's lexical status accumulates over time allowing participants to continuously calculate the probability that the input (i.e., the letter string) is a word [$P(w|i)$] versus a nonword [$P(nw|i)$]. The latter probability is driven by how close the reader's representation of the nonwords being used in the experiment is to word representations in the reader's lexicon, the *nonword distance*. (Norris, 2009, provides a slightly different way of thinking about the concept of nonword distance than Norris, 2006; however, for present purposes, the differences are not important.) When either the word probability or the nonword probability reach a threshold (e.g., .95), an appropriate response can be given. The closer the representation of the nonwords is to word representations—that is, the more wordlike the nonwords being used are—the longer it takes for $P(w|i)$ to reach the threshold when a word is presented—or for $P(nw|i)$ to reach the threshold when a nonword is presented. Again, the model does a reasonably good job of simulating wordlikeness effects in a number of lexical decision experiments.

These models are, of course, not the only models that have a way of explaining the impact of wordlikeness on both word and nonword latencies in lexical decision tasks. For present purposes, however, the important point is that what they share with each other and with most other models of the lexical decision-making process is the idea that wordlikeness effects are due to normal parameter changes within the basic lexical system. In that sense, they are what one can call single-mechanism models. That is, although the models would be flexible enough to allow numerous factors to contribute to the process of making a lexical decision (including factors that may be, as yet, undiscovered), they do not incorporate the assumption that there is a qualitative change in processing when the wordlikeness of nonwords is manipulated. Further, the process that is crucial to producing the effect is a lexically based process—either lexical activation in the case of the MROM, the lexically derived drift rate parameter in the case of the diffusion model, or the lexical distance measures in the Bayesian reader model.

There are, in contrast, some models of lexical decision making that are not single-mechanism models. For example, Balota and Chumbley (1984; see also Balota & Spieler, 1999) suggested that lexical decision making often involves two processes. The first is a familiarity evaluation. If this process returns a high score, a "word" response can be made, and if it returns a low score, a "nonword" response can be made. An intermediate score initiates a second process that is essentially a spell-checking process. If the nonwords are not particularly wordlike, this second process may not need to be used. Hence, if a model of this sort were correct, what a nonword difficulty manipulation would be doing is causing a qualitative change in processing, that is, a change from a single-mechanism to a two-mechanism operation.

There is, of course, nothing preventing any of the single-mechanism models from adding a second mechanism—for example, one involving a spell-checking process—for situations in which the word–nonword discrimination is highly difficult. (The value of adding such a process in response to the present data is evaluated in the General Discussion section.) The point is simply that, at present, these models do not incorporate a second process. Rather, their successes at explaining lexical decision making have been accomplished within the context of a single mechanism.

The assumption that nonword type impacts processing by altering parameters within a single, lexically based mechanism allows a further prediction. Single-mechanism models of this sort also predict that nonword type should interact with other factors that impact lexical processing, for example, word frequency, a prediction that is quite consistent with the available data (James, 1975; Stone & Van Orden, 1993; Yap et al., 2006). Specifically, Stone and Van Orden (1993) contrasted responses to a set of low- and high-frequency words, reporting that the resulting frequency effect was small when using orthographically illegal nonwords (e.g., BTESE), somewhat larger when using more standard orthographically legal nonwords (e.g., DEEST), and largest when using pseudohomophones (e.g., BEEST). (*Pseudohomophones* are orthographically legal nonwords that, when pronounced, sound like real words. Hence, they are wordlike in terms of both orthography and phonology.)

Although the MROM does not specifically integrate phonology into the word recognition process, a more recent version of it, the MROM-p (Jacobs, Rey, Ziegler, & Grainger, 1998), does, allowing it to easily explain Stone and Van Orden's (1993) complete pattern. Specifically, the Σ criterion would have been low in the BTESE condition, higher in the DEEST condition, and highest in the BEEST condition. Further, high-frequency words, with high-activation levels in their lexical units, would be relatively unaffected by changes in the Σ criterion. Rather, responses to high-frequency words would rely mainly on the μ criterion in all conditions. Hence, response latencies to high-frequency words would be affected only minimally by changes in nonword type. In contrast, responses to low-frequency words would be affected noticeably by the changes in the Σ criterion with latencies increasing from the BTESE condition to the DEEST condition and again to the BEEST condition. As a result, the frequency effect would also increase across these three nonword conditions.

With respect to the diffusion model, in Ratcliff et al.'s (2004) study, the authors showed that their model can account for the increase in the size of the frequency effect between the BTESE condition and the DEEST condition. Essentially, this is due to the nonword type manipulation having a larger effect on the drift rate for low-frequency words than on the drift rate for high-frequency words. Specifically, when the nonwords are orthographically legal, the difference in drift rates between high- and low-frequency words is larger (and the rates themselves, smaller) than when the nonwords are illegal. Although the authors have provided no processing explanation for why this occurs, it would seem to be a fairly simple task to extend the logic to the BEEST condition, a condition that should produce lower overall drift rates for the words and, hence, a large difference in drift rates for low- versus high-frequency words.

The Bayesian reader model would also have no problem explaining the Frequency × Nonword Type interaction when considering just the BTESE and DEEST conditions. To explain the further increase in the size of the frequency effect in the BEEST condition, there would need to be a way to integrate phonology into the word identification process. In theory, this should not be a problem (cf. Wagenmakers et al.'s, 2004, Bayesian model of lexical decision making). In practice, however, because phonology was purposely given no role in this process in the Bayesian reader model, integrating it after the fact may not be completely straightforward.

As noted, in the present research, our main focus was on the factor of nonword difficulty. Specifically, using the "standard nonword" condition (i.e., DEEST) as the baseline condition, we used two manipulations designed to increase nonword difficulty: pseudohomophones (i.e., BEEST) and transposed-letter nonwords (e.g., JUGDE). Unlike Stone and Van Orden (1993), we did not use the less difficult orthographically illegal nonword condition in our manipulations of nonword difficulty. We specifically avoided the contrast between the orthographically illegal nonword condition and the standard nonword condition because the former condition may present the opportunity for participants to use a very shallow processing strategy, one that, to some degree, bypasses lexical processing (i.e., responding "nonword" when the letter string is illegal and "word" otherwise; Shulman & Davidson, 1977; Stone & Van Orden, 1992) and, hence, potentially bypasses the basic mechanisms that the various models propose. Because the goal in the present experiments was to specifically examine those mechanisms, it seemed to be crucial to avoid any situations in which participants might be able to minimize lexical processing in any of the nonword conditions.

In both Stone and Van Orden's (1993) and Yap et al.'s (2006) experiments, the nonword type manipulation was a between-subject manipulation. Although there is no reason to question the validity of their results (in fact, between-subject manipulations are typically less sensitive than within-subject manipulations), our plan in the present research was to use a within-subject manipulation of nonword type to maximize the sensitivity of the manipulation and analysis in all of the present experiments. Therefore, it seemed necessary to demonstrate initially that using a within-subject design does not alter the basic pattern observed by Stone and Van Orden. As such, in Experiment 1 we attempted to replicate Stone and Van Orden's results in the DEEST and BEEST conditions using a within-subject manipulation of nonword type.

In Experiment 2, a somewhat different manipulation of nonword type was used to increase word and nonword latencies with the question being whether this manipulation also alters the size of the frequency effect. Specifically, in Experiment 2, nonword type was manipulated by using transposed-letter nonwords (e.g., JUGDE) versus standard orthographically legal nonwords (e.g., JUPTE). As Perea and Lupker (2004) have demonstrated, using transposed-letter nonwords increases both word and nonword latencies. If these effects are lexically based effects, as pseudohomophone effects are presumed to be, frequency should also interact with nonword type in Experiment 2. Further, the models described above would be able to explain these effects in much the same way that they could explain the impact of pseudohomophones (e.g., a change in the Σ criterion, a change in the measures of wordlikeness produced by the lexical system, shorter nonword distance). Therefore, the empirical question in Experiment 2 is whether there will be a larger frequency effect when using transposed-letter nonwords.

Experiment 3 was an attempt to rule out a simple alternative account of the interaction between nonword type and frequency. It is possible that the increased frequency effects when more difficult nonwords are used are merely artifacts of longer latencies. That is, it is possible that when word latencies are increased in any fashion, effect sizes grow. If there was an increase in the frequency effect that was merely due to an increase in word latency, an increase that was unrelated to a change in the difficulty of the word–nonword discrimination, that would cast some doubt on the models' explanation of Stone and Van Orden's (1993) results. In Experiment 3, we used a manipulation known to increase lexical decision latencies without altering the difficulty of the word–nonword discrimination: task alternation (Lupker, Kinoshita, Coltheart, & Taylor, 2003). Between lexical decision trials, participants were presented with trials of a sum verification task (e.g., $6 + 8 = 13$). The expectation derived from the models discussed above is that simply producing longer word latencies without affecting the difficulty of the word–nonword discrimination in the lexical decision task will not lead to a larger frequency effect.

Experiment 1

Method

Participants. There were 24 participants in Experiment 1. In this and all subsequent experiments, participants were University of Western Ontario undergraduate students who received partial course credit for their participation, and they all reported normal or corrected-to-normal vision and proficiency in English.

Stimuli. All stimuli, both words and nonwords, were five letters long. Forty high-frequency words (CELEX [Baayen, Piepenbrock, & van Rijn, 1993] median frequency = 246.5 per million, mean frequency = 324.4 per million; Coltheart, Davelaar, Jonasson, & Besner, 1977, mean neighborhood size [N] = 3.25) and 40 low-frequency words (CELEX median frequency = 3.05 per million, mean frequency = 8.4 per million, mean N = 3.0) were selected. These words were arbitrarily divided into Sets A and B for counterbalancing purposes.

To create the nonwords, 80 words were first selected from which one could create a five-letter pseudohomophone, typically by the substitution of a single letter (e.g., AMBER–AMBUR). Eighty standard nonwords were also created from these words by substituting a different letter (e.g., AMBER–AMTER). The two sets of nonwords were matched on Coltheart et al.'s (1977) average N (3.35 for the pseudohomophones, 3.30 for the standard nonwords). (The mean total bigram frequencies were 1092 and 1157, respectively.) The stimuli from all of the experiments are listed in the Appendices.

The list of base words was then arbitrarily divided into two sets of size 40. Half of the participants received the pseudohomophones created from one set of base words and the standard nonwords created from the other set in their two nonword conditions. The other half of the participants received the other half of the pseudohomophones and the other half of the standard nonwords in their two nonword conditions. This way, no participant saw the two nonwords created from any given base word (e.g., AMBUR and AMTER) in the experiment.

Equipment. All experiments were run using DMDX experimental software produced by Forster and Forster (2003). Stimuli were presented on a SyncMaster monitor (Model No. 753DF). Presentation was controlled by an IBM-clone Intel Pentium. Stimuli appeared as black characters on a white background. Responses to stimuli were made by pressing one of two keys on the keyboard.

Procedure. Participants were tested individually. Each participant received a short practice block of eight trials followed by two blocks of experimental trials with a short break between blocks. One block contained one set of the high- and low-frequency words and a set of standard nonwords. The other block contained the other set of high- and low-frequency words and a set of pseudohomophones. The order of the blocks, the set of words assigned to standard nonwords versus pseudohomophones, and the set of pseudohomophones versus standards nonwords used were counterbalanced between participants. Thus, there were eight counterbalancing groups each consisting of three participants.

Participants sat approximately 18 in. [45.72 cm] in front of the computer screen. Participants were instructed to make decisions about strings of letters presented on the computer screen by pressing one key (the right key) if the letters spelled an English word and another key (the left key) if the letters did not spell a word. They were also told to respond to each target as quickly and as accurately as possible. On each trial, the participants saw a fixation point for 550 ms followed by the presentation of the target, which remained on the screen for either 3 s or until the participant responded. The intertrial interval was 1,100 ms.

Results

Error trials and trials involving latencies greater than 1,500 ms (2.1% of the word trials and 4.5% of the nonword trials) were removed from the latency analyses.[1] In an effort to remove variance due to the fact that different words appeared in different conditions for different groups of participants (Pollatsek & Well, 1995), a Groups/Lists factor was included in all analyses of variance (ANOVAs) as a dummy factor. The essential word trial analysis involved a 2 (Frequency) × 2 (Nonword Type) ANOVA. Both variables were within-subject variables. Nonword Type was a within-item variable, and Frequency was a between-item variable. The nonword trial analyses involved a two-level, within-subject but between-item contrast (i.e., Nonword Type). The results from the subject analyses are presented in Table 1.

Word latencies. Both main effects and the interaction were significant: Frequency, $F_s(1, 22) = 141.55$, $MSE = 1{,}957.6$, $p < .001$; $F_i(1, 76) = 73.18$, $MSE = 6{,}512.9$, $p < .001$; Nonword Type, $F_s(1, 22) = 4.81$, $MSE = 2{,}304.1$, $p < .05$; $F_i(1, 76) = 7.37$, $MSE = 2{,}384.2$, $p < .01$; Frequency × Nonword Type, $F_s(1, 22) = 4.69$, $MSE = 1{,}090.1$, $p < .05$; $F_i(1, 76) = 3.46$, $MSE = 2{,}384.2$, $p < .07$. High-frequency words were responded to faster than low-frequency words, latencies were longer when the nonwords were pseudohomophones, and, most importantly, the frequency effect was 30 ms larger when pseudohomophones were used than when standard nonwords were used.

Word errors. The main effect of Frequency was significant, $F_s(1, 22) = 18.47$, $MSE = 0.003$, $p < .001$; $F_i(1, 76) = 9.12$, $MSE = 0.011$, $p < .005$. The main effect of Nonword Type—$F_s(1, 22) = 0.66$, $MSE = 0.001$, *ns*; $F_i(1, 76) = 0.59$, $MSE = 0.003$, *ns*—and the Frequency × Nonword Type interaction—$F_s(1, 22) = 0.17$, $MSE = 0.002$, *ns*; $F_i(1, 76) = 0.38$, $MSE = 0.003$, *ns*—were not.

Nonword latencies. Latencies were longer for the pseudohomophones than for the standard nonwords, $F_s(1, 22) = 10.89$, $MSE = 3{,}282.7$, $p < .005$; $F_i(1, 156) = 29.75$, $MSE = 4{,}265.5$, $p < .001$.

Nonword errors. Error rates were higher for the pseudohomophones than for the standard nonwords, $F_s(1, 22) = 4.07$, $MSE = 0.005$, $p < .06$; $F_i(1, 156) = 7.68$, $MSE = 0.009$, $p < .01$.

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[1] In all of the experiments reported here, analyses were also conducted using a latency cutoff of 2,000 ms instead of 1,500 ms. With this higher cutoff value, there were no changes in the patterns of significance in any of the experiments. Note also that in Experiments 4–7, in which the impact of removing trials could, potentially, have crucially affected the pattern of results, the use of a 2,000-ms cutoff meant that the percentages of the word trials that were removed were 0.1%, 0.2%, 0.2%, and 0.4% in Experiments 4–7, respectively (the actual numbers of word trials removed were 3, 4, 5 and 10, respectively).

Table 1
Mean Latencies (in Milliseconds) and Error Percentages (in Parentheses) for the Words and Nonwords in Experiments 1, 2, and 3

Frequency	Experiment 1: With standard nonwords	Experiment 1: With pseudohomophones
High	592 (1.9)	599 (2.1)
Low	684 (6.5)	721 (7.4)
Effect	92 (4.6)	122 (5.3)
Nonwords	773 (6.1)	827 (10.2)

Frequency	Experiment 2: With standard nonwords	Experiment 2: With TL nonwords
High	577 (1.8)	642 (1.1)
Low	627 (2.8)	734 (3.5)
Effect	50 (1.0)	92 (2.4)
Nonwords	699 (2.1)	845 (13.2)

Frequency	Experiment 3: Nonalternating	Experiment 3: Alternating
High	602 (0.1)	730 (2.8)
Low	694 (2.3)	811 (5.9)
Effect	92 (2.2)	81 (3.1)
Nonwords	760 (4.5)	866 (9.3)

Note. TL = transposed-letter.

Discussion

These results provide a nice replication of the results reported by Stone and Van Orden (1993), here using a within-subject design. Pseudohomophones, compared with standard nonwords, led to both longer word and nonword latencies and, more importantly, a larger frequency effect. Thus, at least when one is considering pseudohomophones, the implication is that increasing the difficulty of the word–nonword discrimination is more harmful to low-frequency words than to high-frequency words.

As argued previously, this result seems to pose no problem for the single-mechanism models discussed above. For example, proponents of MROM and MROM-p can argue that pseudohomophones, with their real-word phonology and wordlike orthography, decrease the usefulness of the Σ criterion—something that harms low-frequency words more than high-frequency words. Proponents of the diffusion model could extend the argument they have made when contrasting standard nonwords with orthographically illegal nonwords. That is, they could argue that because pseudohomophones are even more wordlike than standard nonwords, they have smaller drift rates as well as creating smaller drift rates for words—a situation that is more harmful for low-frequency words than for high-frequency words. For the Bayesian reader model to explain this result, a phonological component would need to be implemented in the model. As noted, this model is an evidence accumulation model. Presumably, the phonological code of the letter string could be regarded as one source of evidence. When the nonwords are pseudohomophones, however, that source would be useless (because a familiar phonological code would not provide any evidence in this regard). Thus, the evidence accumulation process would be slower for both words and nonwords—a process that, as with the other models, should have more impact on low-frequency words than on high-frequency words.

Experiment 2

The purpose of Experiment 2 was to extend this logic. Although the models being examined can explain the impact of pseudohomophones in terms of a change in the nature of lexical processing, other assumptions concerning the locus of pseudohomophone effects have also been proposed. For example, Azuma and Van Orden (1997) and Rodd, Gaskell, and Marslen-Wilson (2002) argued that what pseudohomophones do is to increase reliance on semantic processing. If this claim was correct, the results of Experiment 1 could not necessarily be seen to provide support for the single-mechanism models.

In Experiment 2, therefore, nonword difficulty was manipulated in a somewhat different way. One fairly straightforward way of increasing nonword difficulty that does not appear to be related in any obvious way to semantic processing is to use nonwords created by transposing two letters in a word (i.e., JUDGE–JUGDE). As demonstrated by Perea and Lupker (2004), transposed-letter nonwords noticeably increase both word and nonword latencies in a lexical decision task. The reason, according to the types of models under discussion, would be that these nonwords are more wordlike than standard nonwords (e.g., JUPTE). Thus, if those models are correct, the expectation would be that transposed-letter nonwords should have the same impact on lexical processing that pseudohomophones do, that is, in addition to increasing both word and nonword latencies, they should produce an interaction with word frequency.

Method

Participants. There were 36 participants in Experiment 2.

Stimuli. The words were the same 80 words used in Experiment 1. The transposed-letter nonwords were created by selecting 40 five-letter words and transposing either the second and third letters (14 words), the third and fourth letters (22 words), or the fourth and fifth letters (four words). None of the transposed-letter nonwords had neighbors. A set of 40 standard nonwords was selected from the ARC database (Rastle, Harrington, & Coltheart, 2002) on the basis of having an equivalent *N* (0.10). (The mean total bigram frequencies were 766 and 455, respectively.)

Equipment and procedure. These were the same as in Experiment 1 except that only a single set of each type of nonword was used. Therefore, there were only four counterbalancing groups with nine participants assigned to each group.

Results

The exclusion criteria and the ANOVA designs were the same as in Experiment 1 (2.9% of the word trials and 9.0% of the nonword trials had latencies longer than 1,500 ms). The results from the subject analyses are presented in Table 1.

Word latencies. Both main effects and the interaction were significant: Frequency, $F_s(1, 34) = 94.35$, $MSE = 1{,}915.9$, $p < .001$; $F_i(1, 76) = 33.36$, $MSE = 5{,}088.4$, $p < .001$; Nonword

Type, $F_s(1, 34) = 91.21$, $MSE = 2{,}912.6$, $p < .001$; $F_i(1, 76) = 159.13$, $MSE = 1{,}632.6$, $p < .001$; Frequency × Nonword Type, $F_s(1, 34) = 7.45$, $MSE = 2{,}231.7$, $p < .01$; $F_i(1, 76) = 7.12$, $MSE = 1{,}632.6$, $p < .01$. High-frequency words were responded to faster than low-frequency words, latencies were longer when the nonwords were transposed-letter nonwords, and, most importantly, the word frequency effect was 48 ms larger when transposed-letter nonwords were used.

Word errors. The main effect of Frequency was significant in both analyses, $F_s(1, 34) = 9.55$, $MSE = 0.001$, $p < .01$; $F_i(1, 76) = 5.77$, $MSE = 0.002$, $p < .05$. Neither the Nonword Type effect—$F_s(1, 34) = 0.01$, $MSE = 0.001$, *ns*; $F_i(1, 76) = 0.02$, $MSE = .001$, *ns*—nor the interaction—$F_s(1, 34) = 1.77$, $MSE = 0.001$, $p > .15$; $F_i(1, 76) = 2.56$, $MSE = 0.001$, $p > .15$—were significant.

Nonword latencies. Latencies were longer for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 34) = 124.40$, $MSE = 3{,}104.5$, $p < .001$; $F_i(1, 78) = 113.86$, $MSE = 6{,}879.9$, $p < .001$.

Nonword errors. Error rates were higher for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 34) = 42.43$, $MSE = 0.005$, $p < .001$; $F_i(1, 78) = 28.85$, $MSE = 0.015$, $p < .001$.

Discussion

The results of Experiment 2 parallel those of Experiment 1. Most importantly, the frequency effect was substantially larger with the more wordlike, transposed-letter nonwords than with standard nonwords. As noted previously, virtually all of the models under discussion have no trouble accommodating these results because they all incorporate mechanisms for explaining nonword difficulty effects (created by pseudohomophones or transposed-letter nonwords) as well as the fact that nonword difficulty increases the size of lexically based effects. Before proceeding, however, an alternative account of these types of results needs to be examined. The present argument is that these results are due to increasing the difficulty of the word–nonword discrimination. One could argue, however, that whenever word latencies are increased, for whatever reason, effect sizes increase. If so, similar patterns would emerge whenever a lexical decision task takes longer even if the increase in latencies is not due to an increase in the difficulty of the word–nonword discrimination. Experiment 3 was an effort to examine and, potentially, rule out this type of explanation.

Experiment 3

As demonstrated by Lupker et al. (2003), one way to increase latencies in a lexical decision experiment without affecting the difficulty of the word–nonword discrimination is to use a task alternation procedure. That is, lexical decision trials are alternated with trials involving a different type of task. In the present situation, the task used was sum verification. On a strictly alternating trial basis, either a letter string would be presented, calling for a lexical decision response, or a numerical equation would be presented (e.g., 15 + 18 = 33), calling for a true or false response. This situation is contrasted with a situation in which all trials involved the presentation of letter strings for a lexical decision response. The expectation is that although both word and nonword latencies will be longer in the task alternation situation, there will not be a corresponding increase in the size of the frequency effect because the difficulty of the word–nonword discrimination has not been affected.

Method

Participants. There were 32 participants in Experiment 3.

Stimuli. The words were the same 80 words used in Experiments 1 and 2. The nonwords were the 80 standard nonwords from Experiment 1.

To create the proper counterbalancing, we divided the words and nonwords into two sets. Each word set had 20 high-frequency and 20 low-frequency words. Each word set was paired with each nonword set for half the participants.

The 80 sum verification stimuli consisted of expressions of the sort a + b = c. The addendums were mainly two-digit numbers, and half of the expressions were incorrect. The 40 incorrect expressions involved a sum that was typically quite close to the correct answer (e.g., 44 + 29 = 75).

Equipment and procedure. The equipment was the same as used in the previous experiments. Each participant received a short practice block of eight trials prior to each block, mimicking the trials in the block. Each block contained one set of words and one set of nonwords. The assignment of word sets to nonword sets was counterbalanced over participants as was the order of the blocks. In addition, in one of the blocks, the sum verification stimuli were presented alternating with the letter string stimuli. (On sum verification trials, participants were instructed to press the right button if the sum was correct and to press the left button if it was not.) There were, therefore, eight counterbalancing conditions with four participants assigned to each condition.

Results

The exclusion criteria were the same as in Experiments 1 and 2 (2.2% of the word trials and 5.1% of the nonword trials had latencies longer than 1,500 ms). The word trial analysis involved a 2 (Frequency) × 2 (Alternation) ANOVA. Both variables were within-subject variables. Alternation was a within-item variable, and Frequency was a between-item variable. The nonword trial analyses involved a two-level, within-subject and within-item contrast (i.e., Alternation). The results from the subject analyses are presented in Table 1.

Word latencies. Both main effects were significant: Frequency, $F_s(1, 30) = 104.69$, $MSE = 2{,}285.3$, $p < .001$; $F_i(1, 76) = 59.06$, $MSE = 4{,}993.0$, $p < .001$; and Alternation, $F_s(1, 30) = 74.38$, $MSE = 6{,}423.3$, $p < .001$; $F_i(1, 76) = 429.13$, $MSE = 1{,}340.1$, $p < .001$. High-frequency words were responded to faster than low-frequency words, and latencies were shorter when there were no alternating trials involving sum verification. In contrast to the two previous experiments, however, there was no hint of an interaction between Frequency and Alternation, $F_s(1, 30) = 0.75$, $MSE = 1{,}278.0$, *ns*; $F_i(1, 76) = 1.07$, $MSE = 1{,}340.1$, $p > .30$.

Word errors. The Frequency main effect—$F_s(1, 30) = 11.55$, $MSE = 0.002$, $p < .005$; $F_i(1, 76) = 10.52$, $MSE = 0.03$, $p < .005$—and the Alternation main effect—$F_s(1, 30) = 20.09$, $MSE = 0.002$, $p < .001$; $F_i(1, 76) = 25.17$, $MSE = 0.02$, $p < .10$—were significant. The interaction was not, $F_s(1, 30) = 0.32$, $MSE = 0.002$, *ns*; $F_i(1, 76) = 0.37$, $MSE = 0.002$, *ns*.

Nonword latencies. Nonword latencies were longer in the alternating condition than in the nonalternating condition, $F_s(1, 30) = 30.86$, $MSE = 5{,}790.3$, $p < .001$; $F_i(1, 78) = 221.58$, $MSE = 1{,}744.7$, $p < .001$.

Nonword errors. There were more errors in the alternating condition than in the nonalternating condition, $F_s(1, 30) = 7.48$, $MSE = 0.05$, $p < .01$; $F_i(1, 78) = 38.61$, $MSE = 0.002$, $p < .001$.

Discussion

Although the alternation manipulation produced a large increase in overall lexical decision latencies, there was no corresponding increase in the size of the frequency effect—a result that is consistent with the models under discussion. The increase in latency in the alternating condition in Experiment 3 cannot be attributed to making the word–nonword discrimination more difficult because the same words and nonwords were used in the alternating and nonalternating conditions. Thus, the fact that the alternation manipulation did not create a corresponding increase in the size of the frequency effect points to the conclusion that it is the difficulty of the word–nonword discrimination (and not longer word latencies per se) that altered the size of the frequency effect in Experiments 1 and 2.

Experiment 4

The results of Experiments 1, 2, and 3 are quite consistent with the conclusion that nonword difficulty affects lexical processing, as is claimed by many models of lexical decision making, including the three single-mechanism models discussed above. The implication is that parallel nonword difficulty manipulations should affect other lexically based effects in the same way that the frequency effect was affected. That is, the size of the effect should increase as the word–nonword discrimination becomes more difficult. The focus of the next four experiments is the semantic priming effect.

As shown originally by Meyer and Schvaneveldt (1971), target words preceded by related primes (e.g., DOCTOR preceded by the prime NURSE) are responded to more rapidly than when they are preceded by unrelated primes (e.g., BUTTER). This phenomenon has been extensively replicated (see Neely, 1991, for a review), and, therefore, any successful model of lexical decision making will need to provide an account of this effect. At present, there are a number of explanations of semantic priming in the literature. Some of these explanations are based on the idea that semantic priming effects are due to the use of a special mechanism that is invoked only in priming situations—for example, Neely and Keefe's (1989) retrospective semantic-matching account or Ratcliff and McKoon's (1988) compound-cue theory. However, many explanations are lexically based, with the most common account invoking the idea of automatic spreading activation (Neely, 1977). Specifically, activation spreads between lexical and semantic units, leading to heightened activation in lexical units (e.g., Borowsky & Besner, 1993; Stolz & Neely, 1995; see also Pexman & Lupker, 1999; Pexman, Lupker, & Hino, 2002). As a result, lexical units that are semantically primed allow more rapid lexical processing.

At present, none of the models discussed above have specifically attempted to incorporate a mechanism for explaining either semantic priming effects or, in fact, any other semantic effects (e.g., Borowsky & Masson, 1996; Grondin, Lupker, & McRae, 2009; Hino & Lupker, 1996; Jastrzembski, 1981; Rodd et al., 2002; Rubenstein et al., 1970). Thus, the architects of those models would be free to postulate an additional mechanism, such as Neely and Keefe's (1989) retrospective semantic-matching mechanism, to explain such effects. Presumably, however, the creators of the models would prefer to explain these types of effects within the framework of the single mechanism on which their models are based. Fortunately, doing so would be a reasonably straightforward task for any of the models being discussed.

The MROM, for example, could essentially adopt the basic spreading activation assumption. That is, the lexical units in that model could be assumed to be directly linked to semantic units, as in Collins and Loftus's (1975) original model. Activation spreading among those units and back to the lexical units would produce heightened activation levels, leading to more rapid responding. The diffusion model makes no claims about the exact nature of lexical processing (only about the results of that processing and the implications for the decision-making process), and, therefore, it would also have no problem assuming something like a spreading activation type process that affects the nature of lexical processing. The impact would be to cause semantically primed words to have a larger drift rate than words preceded by unrelated primes. The account offered by the Bayesian reader model, as noted, is based on a calculation of the probability of the input being a word versus a nonword. These calculations are partially based on a priori probabilities for the various words in a reader's lexicon, probabilities that take into account the frequencies of the words. There would be no reason that these a priori probabilities could not also reflect the influence of a prime. That is, one could assume that semantic priming is due to the fact that the prime CAT would increase the a priori probabilities for semantically related targets, such as DOG, FOOD, HOUSE, CLAW, and so forth, allowing $P(w|i)$ to reach threshold more rapidly following a semantically related prime. In fact, an assumption of this sort was incorporated into Norris's (1986) previous model of word recognition.

If this analysis is correct, all the models should be able to explain the semantic priming effect without adding a second mechanism. Most importantly for present purposes, however, doing so would then lead those models to predict that semantic priming effects would behave like frequency effects, that is, they should increase as nonword difficulty increases. At present, the relevant literature concerning semantic priming and nonword difficulty, specifically the type of nonword difficulty manipulations used here, is sparse. In support of the prediction of an interaction, Joordens and Becker (1997) did demonstrate that semantic priming effects in a lexical decision task are larger when pseudohomophones are used. Their task was a continuous lexical decision task, that is, a task in which participants must respond to every letter string. Priming effects involve faster responding to a target when one of the previous stimuli had been a semantically related word in comparison with when there had been no previous semantically related word (up to eight trials back). In contrast, Milota, Widau, McMickell, Joula, and Simpson (1997) reported that semantic priming effects were actually larger when using standard nonwords than when using pseudohomophones. More recently, Yap, Tse, and Balota (2009) reported virtually identical size priming effects when using standard nonwords and pseudohomophones in two different contrasts (involving two different participant samples). Perea and Lupker (2003) reported similar results when using masked semantic primes. Finally, Stone and Van Orden (1992) reported no difference in the sizes of the priming effects in pseudohomophone versus standard nonword conditions with a long (2,000-ms) prime-target interval, an interval that should encourage the generation of expectations, but they reported an interaction (a larger effect with pseudohomophones) using a prime-target interval of approximately the same size as that used in the present experiments (200 ms).

Given the mixed findings in the previous literature, the answer to the question of whether a nonword difficulty manipulation involving pseudohomophones (or transposed-letter nonwords) increases the size of the semantic priming effect is not clear. Experiments 4–7 were an attempt to answer that question. The manipulation in Experiments 4 and 5 was a pseudohomophone versus standard nonword manipulation, whereas the manipulation in Experiments 6 and 7 was a transposed-letter versus standard nonword manipulation. The related word pairs in Experiments 4 and 6 were selected to be as strongly related as possible, requiring selection of new sets of standard nonwords and pseudohomophones. In Experiments 5 and 7, the nonword stimuli from Experiments 1 and 2 were used, requiring selection of a new set of word pairs, involving targets that were, like the nonword stimuli, five letters in length.

Method

Participants. There were 32 participants in Experiment 4.

Stimuli. Ninety-six pairs of strongly semantically associated words were selected from Nelson, McEvoy, and Schreiber's (1998) association norms (mean association strength of .62). The mean target length was 4.57 letters, and the CELEX median frequency was 75.0 per million (mean frequency = 170.8). Forty-eight pseudohomophones and 48 standard nonwords were selected having equivalent mean lengths (4.4 letters) and *N*s (4.9). (The mean total bigram frequencies were 1556 and 1122, respectively.) The word pairs were divided into two sets, one for presentation with one type of nonword and one for presentation with the other type of nonword. This mapping was counterbalanced over participants. Each of these sets was arbitrarily divided into two subsets, one to be presented with related primes and the other to be presented with unrelated primes. This mapping was also counterbalanced over participants. The unrelated prime-word target pairs were created by re-pairing the primes and targets within a subset. The primes for the nonwords were words, selected so that each had a reasonably strong associate (e.g., "never," having the strong associate "always," was a prime for one nonword target), because each of the primes for the word targets also had a strong associate. Each nonword target had its own prime.

Equipment and procedure. The equipment was the same as used in the previous experiments. The primes were all presented for 250 ms with the target following immediately. In all other ways, the procedure was the same as in Experiment 2 except for the extra counterbalancing factor of which targets were primed by related primes and which were primed by unrelated primes. Thus, in this experiment there were eight counterbalancing groups, each consisting of four participants.

Results

The exclusion criteria were the same as in the previous experiments (0.5% of the word trials and 1.6% of the nonword trials had latencies longer than 1,500 ms). As in previous experiments, a Groups/Lists factor was included as a dummy factor. The essential word trial analysis involved a 2 (Relatedness) × 2 (Nonword Type) ANOVA. Both variables were within-subject variables. Nonword Type and Relatedness were within-item variables. The essential nonword trial analyses involved a two-level, within-subject but between-item contrast (i.e., Nonword Type). The results from the subject analyses are presented in Table 2.

Word latencies. The main effect of Relatedness was significant, $F_s(1, 28) = 49.66$, $MSE = 858.8$, $p < .001$; $F_i(1, 92) = 44.77$, $MSE = 3{,}111.2$, $p < .001$, as targets following related primes were responded to more rapidly than targets following unrelated primes. The main effect of Nonword Type was significant in the items analysis and was marginally significant in the subjects analysis, $F_s(1, 28) = 2.93$, $MSE = 3{,}068.7$, $p < .10$; $F_i(1, 92) = 15.50$, $MSE = 1{,}794.0$, $p < .001$, with word latencies being 17 ms faster in the standard nonword condition. More importantly,

Table 2
Mean Latencies (in Milliseonds) and Error Percentages (in Parentheses) for the Words and Nonwords in Experiments 4–7

Experiment 4

Prime	With standard nonwords	With pseudohomophones
Related	572 (2.9)	586 (2.0)
Unrelated	606 (2.3)	625 (3.1)
Effect	34 (−0.6)	39 (1.1)
Nonwords	681 (4.5)	719 (7.4)

Experiment 5

Prime	With standard nonwords	With pseudohomophones
Related	579 (5.2)	610 (3.7)
Unrelated	613 (3.8)	649 (7.0)
Effect	34 (−1.4)	39 (3.3)
Nonwords	701 (4.0)	746 (11.2)

Experiment 6

Prime	With standard nonwords	With TL nonwords
Related	579 (1.8)	630 (1.4)
Unrelated	607 (3.7)	642 (3.0)
Effect	28 (1.9)	12 (1.6)
Nonwords	639 (2.4)	792 (11.1)

Experiment 7

Prime	With standard nonwords	With TL nonwords
Related	571 (2.2)	628 (3.7)
Unrelated	595 (5.0)	664 (6.7)
Effect	24 (2.8)	36 (3.0)
Nonwords	646 (2.7)	766 (13.5)

Note. TL = transposed-letter.

there was no hint of an interaction between Relatedness and Nonword Type, $F_s(1, 28) = 0.33$, $MSE = 820.2$, *ns*; $F_i(1, 92) = 0.48$, $MSE = 2{,}509.1$, *ns*.[2]

Word errors. Neither main effect nor the interaction was significant (all *p*s $> .11$).

Nonword latencies. Latencies were significantly longer for the pseudohomophones than for the standard nonwords, $F_s(1, 28) = 16.52$, $MSE = 1{,}405.8$, $p < .001$; $F_i(1, 93) = 14.66$, $MSE = 7{,}896.3$, $p < .001$.[3]

Nonword errors. Error rates were significantly higher for the pseudohomophones than for the standard nonwords, $F_s(1, 28) = 8.17$, $MSE = 0.002$, $p < .001$; $F_i(1, 93) = 5.36$, $MSE = 0.015$, $p < .05$.

Discussion

Although there was a robust semantic priming effect in Experiment 4, there was little evidence that this effect was larger when pseudohomophones were used. This result does not appear to be readily explainable in terms of the single-mechanism models discussed above. Specifically, it does not appear to be consistent with the idea that frequency effects, nonword type effects, and semantic priming effects can all be explained in terms of a single lexical decision-making mechanism. Before accepting the null hypothesis, however, a couple of points need to be considered. First, numerically, the priming effect was slightly larger with pseudohomophones (by 5 ms). Second, the nonword type manipulation does not appear to have been quite as potent as that in Experiment 1. That is, in the subject analysis, the nonword type effect was only marginally significant in the word latency data, and the nonword type effect size in the nonword latency data (38 ms) was a bit smaller than that in Experiment 1 (i.e., 54 ms). Thus, it is possible that a stronger manipulation of nonword type might produce the expected interaction between semantic relatedness and nonword type.

Experiment 5

Experiment 5 was an attempt to again examine the question of whether the semantic priming effect will increase when the nonword type manipulation involves the contrast between standard nonwords and pseudohomophones. Because the pseudohomophones and standards nonwords used in Experiment 1 produced large nonword type effects in both the word and the nonword data, as well as the predicted interaction with frequency, the nonword stimuli used in Experiment 5 were selected from that set of nonwords. As all those nonwords were five letters long, it was necessary to select a new set of semantically associated pairs in which the target was also five letters long.

Method

Participants. There were 32 participants in Experiment 5.

Stimuli. Eighty pairs of semantically associated words were selected from the semantic priming literature (mean association value from Nelson et al.'s, 1998, norms = 0.60). The main constraint was that the length of the target had to be five letters. The CELEX median target frequency was 59.0 per million (mean frequency = 158.4). The 40 pseudohomophones and 40 standard nonwords from Set 1 from Experiment 1 were selected to be the nonword stimuli (mean *N* for the pseudohomophones = 3.35; mean *N* for the standard nonwords = 3.45). The division of word pairs into sets for counterbalancing, the counterbalancing procedures, and the prime assignments for the unrelated pairs and the nonword targets were the same as in Experiment 4.

Equipment and procedure. The equipment was the same as used in the previous experiments. The procedure was the same as in Experiment 4. Thus, there were eight counterbalancing groups, each consisting of four participants.

Results

The exclusion criteria were the same as in the previous experiments (0.7% of the word trials and 1.6% of the nonword trials had latencies longer than 1,500 ms). The analyses were the same as in Experiment 4. The results from the subject analyses are presented in Table 2.

Word latencies. The main effect of Relatedness was significant, $F_s(1, 28) = 32.99$, $MSE = 1{,}270.4$, $p < .001$; $F_i(1, 76) = 41.60$, $MSE = 2{,}873.0$, $p < .001$, as targets following related primes were responded to more rapidly than targets following unrelated primes. In addition, the main effect of Nonword Type was significant, $F_s(1, 28) = 12.94$, $MSE = 2{,}506.1$, $p < .005$; $F_i(1, 76) = 30.77$, $MSE = 3{,}299.0$, $p < .001$. Once again, however, there was no hint of an interaction, $F_s(1, 28) = 0.17$, $MSE = 912.8$, *ns*; $F_i(1, 76) = 0.18$, $MSE = 4{,}423.2$, *ns*.

Word errors. Neither the main effect of Relatedness—$F_s(1, 28) = 2.05$, $MSE = 0.001$, $p > .15$; $F_i(1, 76) = 1.41$, $MSE = 0.10$, $p > .20$—nor the main effect of Nonword Type—$F_s(1, 28) = 0.86$, $MSE = 0.003$, *ns*; $F_i(1, 76) = 0.58$, $MSE = 0.06$, *ns*—was significant. There was, however, a significant interaction at least partially because of the fact that there was a small reverse relatedness effect in the standard nonword condition, $F_s(1, 28) = 9.68$, $MSE = 0.002$, $p < .01$; $F_i(1, 76) = 10.04$, $MSE = 0.04$, $p < .005$.

Nonword latencies. Latencies were significantly longer for the pseudohomophones than for the standard nonwords, $F_s(1, 28) = 10.00$, $MSE = 3{,}181.4$, $p < .005$; $F_i(1, 78) = 8.75$, $MSE = 10{,}255.9$, $p < .01$.

Nonword errors. Error rates were significantly higher for the pseudohomophones than for the standard nonwords, $F_s(1, 28) = 7.94$, $MSE = 0.010$, $p < .01$; $F_i(1, 78) = 17.66$, $MSE = 0.022$, $p < .001$.

Discussion

Once again, there were significant semantic priming effects in both nonword type conditions. In addition, there was now a highly significant nonword type effect in the word data, as there was when these nonwords were used in Experiment 1. Nonetheless, unlike in Experiment 1, there was still very little evidence that the

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[2] Power analyses were conducted for Experiments 4–7. If the true size of the interaction (i.e., the increase in the size of the priming effect) was 20 ms, the power to detect that interaction would have been more than .80 in all four experiments.

[3] The standard nonword "boit" was typed into the stimulus list as "boil" in Experiment 4. Hence, data from this stimulus were not analyzed in the nonword analyses.

effect of interest (i.e., the semantic priming effect) was larger when using pseudohomophones.

What should be noted, of course, is that there was an interaction in the error data. That interaction arose because there were a few more errors in the related condition than in the unrelated condition with standard nonwords (i.e., a small reverse priming effect), whereas with pseudohomophones, there were 25 more errors (over the 32 participants) in the unrelated condition than in the related condition. Error metrics are, of course, slightly different than latency metrics (Sternberg, 1969), and, hence, it is not clear what to make of this interaction. However, this result at least supports the possibility that, with an even stronger manipulation of nonword difficulty, we may yet find an interaction in the latency data.

Experiment 6

The lack of an interaction between nonword type and semantic relatedness when contrasting pseudohomophones and standard nonwords in the latency data (which is a replication of Yap et al., 2009) would seem to be problematic for single-mechanism models. If the locus of the frequency effect, the semantic priming effect, and the pseudohomophone effect is a single mechanism based on lexical processing, an interaction between semantic relatedness and nonword type would be expected.

In the final two experiments, we wished to further evaluate the possibility that an interaction between semantic relatedness and nonword type can be found by using an alternative manipulation of nonword difficulty. As demonstrated in Experiment 2, there is an interaction between nonword type and frequency when the nonword type manipulation is based on the contrast between transposed-letter nonwords and standard nonwords. Further, the impact of a transposed-letter manipulation did appear to be somewhat stronger than the impact of a pseudohomophone manipulation in terms of increasing both word and nonword latencies, presumably creating more opportunity to observe an interaction between semantic relatedness and nonword type. If it is the case that a nonword type manipulation of the sort being used here truly does not affect the size of the semantic priming effect, a transposed-letter nonword manipulation should also produce a null interaction. If, however, the lack of an interaction in Experiments 4 and 5 is due to the fact that the nonword type manipulation was based on using pseudohomophones (which may have their impact outside the lexicon; Azuma & Van Orden, 1997; Rodd et al., 2002) and/or was not sufficiently strong, then a nonword type manipulation based on using transposed-letter nonwords may produce the expected interaction.

Experiments 6 and 7 were attempts to evaluate these possibilities. The semantically related word pairs used in Experiment 6 were those used in Experiment 4, and the semantically related word pairs used in Experiment 7 were those used in Experiment 5.

Method

Participants. There were 32 participants in Experiment 6.

Stimuli. The 96 pairs of strongly associated word used in Experiment 4 were used again in Experiment 6. Forty-eight transposed letter nonwords and 48 standard nonwords were selected on the basis of having equivalent mean lengths (4.46 letters) and mean *N*s (0.83 for the transposed letter nonwords, 0.60 for the standard nonwords). (The mean total bigram frequencies were 856 and 501, respectively.) The division of word pairs into sets for counterbalancing, the counterbalancing procedures, and the prime assignments for the unrelated pairs and the nonword targets were the same as in Experiment 4.

Equipment and procedure. The equipment and procedure were the same as in Experiment 4.

Results

The exclusion criteria were the same as in the previous experiments (0.6% of the word trials and 0.2% of the nonword trials had latencies longer than 1,500 ms). The analyses were the same as in Experiment 4. The results from the subject analyses are presented in Table 2.

Word latencies. The main effect of Relatedness was significant, $F_s(1, 28) = 15.63$, $MSE = 820.0$, $p < .001$; $F_i(1, 92) = 16.00$, $MSE = 2{,}704.8$, $p < .001$, as targets following related primes were responded to more rapidly than targets following unrelated primes. The main effect of Nonword Type was also significant, $F_s(1, 28) = 32.66$, $MSE = 1{,}786.0$, $p < .001$; $F_i(1, 92) = 70.39$, $MSE = 2{,}480.6$, $p < .001$, as latencies were longer in the transposed-letter nonword condition. The pattern of the means suggests the possibility of an interaction, albeit in the opposite direction from that predicted; however, the interaction was again nonsignificant, $F_s(1, 28) = 2.01$, $MSE = 1{,}022.5$, $p > .16$; $F_i(1, 92) = 2.31$, $MSE = 2{,}138.5$, $p > .13$.

Word errors. The main effect of Relatedness was significant, $F_s(1, 28) = 8.69$, $MSE = 0.001$, $p < .01$; $F_i(1, 92) = 8.70$, $MSE = 0.003$, $p < .01$, as targets following related primes were responded to more accurately than targets following unrelated primes. Neither the Nonword Type effect nor the interaction was significant (all *p*s $> .25$).

Nonword latencies. Latencies were significantly longer for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 28) = 162.35$, $MSE = 2{,}298.9$, $p < .001$; $F_i(1, 94) = 127.80$, $MSE = 1{,}5337.0$, $p < .001$.

Nonword errors. Error rates were significantly higher for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 28) = 60.41$, $MSE = 0.002$, $p < .001$; $F_i(1, 94) = 22.95$, $MSE = 0.035$, $p < .001$.

Experiment 7

Method

Participants. There were 32 participants in Experiment 7.

Stimuli. The 80 pairs of semantically associated words used in Experiment 5 were used here. The 40 transposed-letter nonwords and the 40 standard nonwords from Experiment 2 were selected to be the nonword stimuli. The division of word pairs into sets for counterbalancing, the counterbalancing procedures, and the prime assignments for the unrelated pairs and the nonword targets were the same as in Experiment 4.

Equipment and procedure. The equipment was the same as used in the previous experiments. The procedure was the same as in Experiment 5. Thus, there were eight counterbalancing groups, each consisting of four participants.

Results

The exclusion criteria were the same as in the previous experiments (1.6% of the word trials and 3.0% of the nonword trials had latencies longer than 1,500 ms). The analyses were the same as in Experiment 5. The results from the subject analyses are presented in Table 2.

Word latencies. The main effect of Relatedness was significant, $F_s(1, 28) = 25.09$, $MSE = 1{,}136.1$, $p < .001$; $F_i(1, 76) = 18.28$, $MSE = 3{,}519.7$, $p < .001$, as targets following related primes were responded to more rapidly than targets following unrelated primes. In addition, the main effect of Nonword Type was significant, $F_s(1, 28) = 20.88$, $MSE = 6{,}109.7$, $p < .001$; $F_i(1, 76) = 83.98$, $MSE = 3{,}420.7$, $p < .001$, as word latencies were longer in the transposed-letter nonword condition. Once again, however, there was no real evidence of an interaction, $F_s(1, 28) = 0.53$, $MSE = 2{,}085.2$, *ns*; $F_i(1, 79) = 0.07$, $MSE = 3{,}749.2$, *ns*.

Word errors. The main effect of Relatedness was significant, $F_s(1, 28) = 9.68$, $MSE = 0.003$, $p < .01$; $F_i(1, 76) = 9.09$, $MSE = 0.007$, $p < .005$, as targets following related primes were responded to more accurately than targets following unrelated primes. The Nonword Type effect was marginal, although it was significant in the item analysis, $F_s(1, 28) = 3.38$, $MSE = 0.003$, $p < .08$; $F_i(1, 76) = 5.46$, $MSE = 0.004$, $p < .05$, as participants were slightly less accurate in the transposed-letter nonword condition. There was no hint of an interaction, $F_s(1, 28) = 0.80$, $MSE = 0.001$, *ns*; $F_i(1, 76) = 0.04$, $MSE = 0.005$, *ns*.

Nonword latencies. Latencies were significantly longer for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 28) = 40.88$, $MSE = 5{,}648.4$, $p < .001$; $F_i(1, 78) = 128.03$, $MSE = 7{,}670.9$, $p < .001$.

Nonword errors. Error rates were significantly higher for the transposed-letter nonwords than for the standard nonwords, $F_s(1, 28) = 49.50$, $MSE = 0.004$, $p < .001$; $F_i(1, 78) = 39.53$, $MSE = 0.023$, $p < .001$.

Discussion

The results from Experiments 6 and 7 show strong semantic priming effects and strong nonword type effects. The transposed-letter nonwords used here increased word latencies by 30–60 ms and produced large differences between the transposed-letter and standard nonword conditions in the nonword data. Nonetheless, there was very little evidence that these manipulations increased the size of the semantic priming effect. Therefore, on the basis of the data from all four experiments involving a semantic priming manipulation, the empirical conclusion seems to be that the semantic priming effect is not influenced by nonword difficulty manipulations of the sort used here (paralleling the effects reported by Yap et al., 2009), in stark contrast to the influence of these nonword difficulty manipulations on the size of the frequency effect.[4]

General Discussion

In recent years, a number of models have been proposed that attempt to account for lexical decision making in terms of a single, lexically driven mechanism (e.g., Grainger & Jacobs, 1996; Norris, 2006; Ratcliff et al., 2004). Many of these models have had good success explaining a number of lexical-decision phenomena, including the effect of nonword difficulty and its impact on the size of frequency effects. The effects reported here—involving replication of the interaction between frequency and nonword difficultly when the nonword difficulty manipulation is a pseudohomophone manipulation and the demonstration that the same interaction occurs when the nonword difficulty manipulation is a transposed-letter manipulation—are quite consistent with these models.

Also reported in the present article, however, is the fact that nonword difficulty does not affect the size of the semantic priming effect. Semantic relatedness is, obviously, a potent factor in the lexical decision-making process, and, hence, any model of the process will need to explain its impact. Further, many models of semantic priming assume that at least part of the basis of semantic priming effects is lexical, most often that the effect is due to spreading activation raising the activation level of lexical units, although other lexically based conceptualizations are possible as well (e.g., Norris, 1986). Thus, in theory, it would appear to be possible for any of the present models to explain semantic priming effects within the framework of their proposed mechanisms. The expectation derived from this analysis of single-mechanism models, however, would be that nonword difficulty should then affect the size of the semantic priming effect in the same way that nonword difficulty affects the size of the frequency effect. Clearly, therefore, the present results represent a challenge for any model of lexical decision making that attempts to explain semantic priming effects, frequency effects, and nonword type effects in terms of a single, lexically driven mechanism.

Plaut and Booth's (2000) Single-Mechanism Model

The single-mechanism models discussed to this point have been based on the idea that lexical decision making is driven by the nature/results of lexical processing. The goal, as noted, was to attempt to extend those models to allow them to account for the effects of semantic priming without abandoning the single-mechanism assumption. An alternative to these types of models, which, nonetheless, maintains the single-mechanism assumption, can be found in the parallel distributed processing (PDP) model proposed by Plaut and Booth (2000), a model that assumes that

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[4] One might note that the targets used in the semantic priming experiments were somewhat higher in frequency than the low-frequency words in Experiments 1–3, the words most affected by the nonword difficulty manipulation. Therefore, a reasonable question might be whether we would have observed an interaction of semantic relatedness and nonword type if we had used less frequent targets. To investigate this issue, we examined responses to the subset of targets with CELEX frequencies less than 35 (32 of the 96 targets in Experiments 4 and 6; 30 of the 80 targets in Experiments 5 and 7). Across the four experiments, these targets produced average priming effects of 47 ms in the standard nonword conditions and 44 ms in the more difficult nonword conditions. (For the entire set of targets, the respective effects were 30 ms and 32 ms.) This analysis is, of course, entirely post hoc, and, therefore, the low-frequency targets were not matched to the other targets on any factors (e.g., association strength). Nonetheless, this result suggests that there is no reason to expect an interaction of relatedness and nonword type if only low-frequency targets had been used.

lexical decision performance is driven by semantic, rather than lexical, processing.

According to Plaut and Booth's (2000) model, word–nonword decisions are based on the calculation of a uni-dimensional measure termed "semantic stress." Words generate higher levels of stress because their orthographic structures activate semantic units much more strongly than nonwords do. Therefore, a criterion on the semantic stress dimension is assumed to allow words to be successfully discriminated from nonwords. The model further assumes that nonwords that look more like words would generate higher levels of semantic stress, causing the criterion to become more conservative and, hence, prolonging both word and nonword processing (i.e., latencies). As Plaut and Booth demonstrated, the model can readily explain the impact of nonword difficulty when the manipulation is a manipulation of orthographic regularity.

What Plaut and Booth (2000) also demonstrated is that their model can explain a number of other important empirical results: the typically reported interaction of semantic relatedness and frequency (e.g., Becker, 1979; Borowsky & Besner, 1993; Stone & Van Orden, 1992; Yap et al., 2009, Experiments 3 and 4; although see Plaut & Booth, 2000; Yap et al., 2009, Experiments 1 and 2), how the specific nature of that interaction varies as a function of prime-target interval, why the interaction does not emerge in certain situations (e.g., with their "low perceptual ability" participants), the interaction of stimulus clarity with semantic relatedness (Balota, Yap, Cortese, & Watson, 2008; Becker & Killion, 1977; Borowsky & Besner, 1993; Meyer, Schvaneveldt, & Ruddy, 1975), and the lack of an interaction between stimulus clarity and frequency (Becker & Killion, 1977; Plaut & Booth, 2006).

The more central question for our purposes, of course, would be whether this model could account for the interactions between nonword type and frequency and the lack of an interaction between nonword type and semantic relatedness reported here. At present, the general answer to that question appears to be no because what the model does not have is a mechanism for explaining the impact of nonword difficulty when the manipulation involves pseudohomophones ("pseudohomophone effects in lexical decision are outside the scope of the more general theoretical framework of distributed network models"; Plaut & Booth, 2000, p. 812).

Given that, as Plaut (1997) has demonstrated, it is possible to implement the necessary assumptions within a model of this sort to allow pseudohomophones (and, potentially, transposed-letter nonwords) to produce semantic stress levels above those of standard nonwords (hence, explaining pseudohomophone and, potentially, transposed-letter effects), it is not entirely clear why Plaut and Booth (2000) have not done so in their model. The most likely reason appears to be that if these special types of nonwords were assumed to have higher semantic stress scores than standard nonwords, those scores would then overlap considerably with the distributions of semantic stress scores for words. Thus, the model would have difficulty distinguishing between words and these types of nonwords at anywhere near the same level people are able to (e.g., Borowsky & Besner, 2006). Therefore, like the other single-mechanism models discussed above, at this point it appears that this type of model also would not be able to successfully explain the pattern of data reported in the present experiments.

Interactions Involving Semantic Relatedness and Frequency

The lack of an interaction between semantic relatedness and nonword type is not only a problem for the single-mechanism models but it is also somewhat of a surprise from a more general theoretical perspective. As demonstrated here and elsewhere, frequency and nonword type interact, suggesting that they affect a common process. In addition, there is evidence that frequency often interacts with semantic relatedness (Becker, 1979; Borowsky & Besner, 1993; Stone & Van Orden, 1992; Yap et al., 2009, Experiments 3 and 4; although see Plaut & Booth, 2000; Yap et al., 2009, Experiments 1 and 2), suggesting that those factors also affect a common process. An obvious assumption to make initially would be that the relevant process in the two situations is the same process. Therefore, the general expectation would be that semantic relatedness would also interact with nonword type, a result that, as discussed, could be fairly easily explained by the single-mechanism models.

The fact that semantic relatedness and nonword type do not interact means that the situation created by the present results is not unlike that described by Besner and Smith (1992) when considering the interactions among frequency, semantic relatedness, and stimulus clarity. Besner and Smith noted that (a) frequency and semantic relatedness typically interact, (b) stimulus clarity and semantic relatedness interact (Becker & Killion, 1977; Besner & Smith, 1992; Meyer et al., 1975), but (c) frequency and stimulus clarity typically do not interact (Balota & Abrams, 1995; Becker & Killion, 1977; Yap & Balota, 2007). To explain such a pattern, Besner and Smith suggested that one needs to hypothesize two separate processes, one affected by stimulus clarity and semantic relatedness and one affected by frequency and semantic relatedness. A similar argument would seem to apply in the present situation. That is, to explain the present patterns, in the end, one does need to hypothesize two separate processes, one affected by frequency and nonword difficulty and one affected by frequency and semantic relatedness.

Additional Processes/Mechanisms

From the perspective of any of the models under discussion, one reasonably simple way of dealing with this problem would be to argue that the basic structure of the model is correct and that the second mechanism that is required is a more peripheral one, one having little to do with the more central processes those models are trying to describe. For example, one could argue that semantic priming effects are either late effects or due to special processes invoked only in semantic priming experiments. With respect to the first of these possibilities, research by Balota and Abrams (1995; see also Abrams & Balota, 1991) demonstrated that word frequency affects measures such as response force, response duration, and the speed to initiate a response to a response cue that is presented well after lexical processing has finished. These results imply that frequency affects at least one process fairly late in the processing stream (i.e., a more response-based process). If it were the case that semantic relatedness also affected this process, it would be possible to explain the lack of an interaction between nonword difficulty and semantic relatedness as well as the typical interaction between frequency and semantic relatedness without making any large changes to most of the assumptions of the single-mechanism models.

Alternatively, the second possibility would be to argue that contextual manipulations, such as presenting a prime prior to the target, actually cause participants to invoke an additional process. For example, consider the proposal contained in Neely and Keefe's (1989) retrospective semantic-matching model. According to this idea, in semantic priming experiments, participants engage in a post-lexical process in which they evaluate the semantic relatedness of the prime and target prior to responding. Such a strategy is a reasonable one because the presence of a relationship is an almost perfect predictor that the target is a word. The only time such would not necessarily be the case would be if the nonwords were pseudohomophones and the primes for the pseudohomophones were, at least some proportion of the time, semantically related to those nonwords (e.g., dog–KAT). The result of finding a semantic relationship between the prime and target is that it creates a bias toward a "word" response, producing an advantage on related trials. What would also need to be worked into this type of account would be an explanation of why frequency also affected this process, allowing an explanation of the Frequency × Semantic Relatedness interaction while at the same time not requiring any large changes to most of the assumptions of the single-mechanism models.

The problem with either of these possibilities, however, is that any account based on the idea that the sole impact of semantic relatedness is later in the processing sequence would have considerable difficulty explaining the interaction between semantic relatedness and stimulus clarity (Balota et al., 2008; Becker & Killion, 1977; Borowsky & Besner, 1993; Meyer et al., 1975). Presumably, stimulus clarity is a factor that has an early locus. Therefore, its interaction with semantic relatedness implies that semantic relatedness must also have a reasonably early locus (even if it also has a later locus).

An alternative way of adding a special second process in certain experimental contexts would be to focus not on what might be done in response to a semantic priming manipulation but rather on the impact of the type of nonwords used. Specifically, one could argue that although some types of nonword difficulty manipulations (e.g., the contrast between standard and orthographically illegal nonwords or any manipulation involving nonword *N*) affect lexical processing in the way described by the models, when the nonwords become too wordlike (e.g., when using pseudohomophones or transposed-letter nonwords), a spell-checking/verification process is added. The addition of a process of this sort would certainly explain the longer latencies for both words and nonwords when nonword difficulty is increased in this fashion. It would also explain the lack of an interaction between semantic relatedness and the present nonword type manipulations under the assumption that semantic relatedness affects only an early process. Further, if one was to assume that frequency in some way affected this spell-checking process, the data from Experiments 1 and 2 could also be explained.[5]

The idea that lexical decision making can require a spell-checking/verification process is certainly not new (Balota & Chumbley, 1984; Balota & Spieler, 1999; Becker, 1976; Paap, Newsome, MacDonald, & Schvaneveldt, 1982; Ziegler, Jacobs, & Klüppel, 2001), although in most of these proposals, the argument is that this process is one that is used more generally, not merely when special nonwords are used. Ziegler et al. (2001) have, however, suggested that such a verification process may be invoked specifically in response to the use of pseudohomophones. That is, the claim is that because pseudohomophones specifically activate (through a phonologically based process) a single word, participants must check the spelling of that word against the spelling of the presented letter string.

Ziegler et al.'s (2001) claim is based on their finding that pseudohomophones having high-frequency base words are easier to reject than ones having low-frequency base words. As they show, models trying to explain pseudohomophone effects in the same way that, for example, they explain nonword *N* effects (Coltheart et al., 1977) would make the opposite prediction. Therefore, a different account for pseudohomophone effects is required. Although, at present, there are no data looking at base word frequency effects with transposed-letter nonwords, it would seem to be possible to extend Ziegler et al.'s notion to transposed-letter nonwords because, like pseudohomophones, they also specifically resemble a single word. Therefore, participants would need to verify the spelling of that specific word against the letter string being presented.

Recently, Yap et al. (2006) have attempted to test a specific version of a two-process model in which the second process could be thought of as a spell-check process. In their first experiment, pseudohomophones and standard nonwords were examined, whereas in their second experiment, standard nonwords and illegal letter strings were examined. Yap et al. did not assume that the spell-check process was only used in the presence of pseudohomophones but rather that its use declined monotonically from the pseudohomophone condition to the standard nonword condition to the illegal nonword condition. Their results suggested that the contrast between the standard and illegal nonword conditions was not well modeled by having a second spell-checking process. In considering the contrast between the standard nonword condition and the pseudohomophone condition, however, the model fared much better, providing further support for the possibility that the impact of pseudohomophones (and, potentially, transposed-letter nonwords) could be to cause participants to engage a frequency-based, spell-check process following normal lexical processing.

One piece of evidence that argues against the idea that what pseudohomophones (and, potentially, transposed-letter nonwords) do is to invoke such a process is the fact that pseudohomophones seem to increase the size of certain semantic effects. For example, Pexman and Lupker (1999) reported that pseudohomophones increased the size of the ambiguity advantage, Pexman et al. (2002) reported that pseudohomophones increased the size of the number of features advantage, and Rodd et al. (2002) reported that pseudohomophones increased the size of their number of meanings inhibition effect. The assumption that there is a spell-checking process that is frequency based, but not semantically based, an assumption presumably required on the basis of the results of

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[5] Balota et al. (2008) have recently demonstrated that semantic relatedness and frequency affect the distribution of response latencies in slightly different ways. Whereas a frequency manipulation shifts and skews the distribution, a semantic relatedness manipulation typically only shifts the distribution. Although this fact does not allow us to discriminate among the various theoretical possibilities offered here, it seems to be quite consistent with the argument that frequency has a broad-based impact (i.e., it affects at least two processes), whereas the impact of semantic relatedness is somewhat narrower.

Experiments 4–7, leads to the expectation that semantic effects should not be affected by nonword manipulations of the sort used by these researchers.

Conclusions

Everything considered, the main conclusion appears to be, as also argued by Yap et al. (2009), that different experimental contexts cause participants to make qualitative changes in the nature of their lexical decision-making process—changes designed to best suit the demands of the situation (see also some of the discussion in Borowsky & Besner, 2006; Plaut & Booth, 2000). Therefore, lexically based, single-mechanism models of the sort discussed here are, ultimately, not likely to be successful models of lexical decision making. For example, as Yap et al. discussed, the main problem created by using pseudohomophones is that their phonological codes activate semantics. Therefore, if there were a way to diminish the impact of phonologically generated semantics, participants would be expected to do so. This could involve a weakening of the weights between these two levels of representation (if such were possible) or invoking a decision process based heavily on orthographic information (i.e., one that requires a higher level of orthographic clarity than when standard nonwords were used). Alternatively, as argued here, these types of nonwords may be handled best by invoking a spell-checking process. Future research should help to clarify which of these assumptions is the most reasonable.

One additional point to note is that a fuller understanding of how the lexical/semantic processes change as a function of the experimental context could allow the development of a complete model of the lexical decision-making process that does incorporate some of the components of the single-mechanism models discussed here. For example, consider the decision-making mechanism contained in Ratcliff et al.'s (2004) diffusion model. As noted, according to this model, a wordlikeness measure is derived from lexical processing that then drives the random walk. At present, the processes that generate this measure are quite underspecified. However, in theory at least, that measure could be generated in any number of ways, ways that could vary quite dramatically as a function of the specific context of the task. Whether this type of idea would then be able to successfully deal with the impact of semantics demonstrated here and elsewhere (e.g., Pexman et al., 2002) is, of course, an empirical question. However, also as noted, the random walk process incorporated into the diffusion model has proven to be remarkably successful in accounting for many aspects of lexical decision data.

The more central point here, however, is that it seems unlikely that lexical decision making can be explained without assuming that the process is altered in qualitative ways in response to changes in the decision-making context. Whether that fact will necessitate the addition of subprocesses within the lexical system or the addition of processes outside of the lexical system is an issue for future research.

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(*Appendices follow*)

Appendix A

Word Stimuli in Experiments 1, 2, and 3; Nonword Targets in Experiments 1, 3, and 5

HF words	LF words	Pseudohomophones-1	Standards-1	Pseudohomophones-2	Standards-2
ABOVE	APRON	AMBUR	BIAST	BEEST	AMTER
CHILD	CARVE	BLAIM	BROIN	BRANE	BLIME
CLOSE	CHESS	CHANE	CHEIR	CHARE	CHAIM
DRIVE	COMIC	CHEAK	CHIAT	CHEET	CHIEK
FINAL	CROOK	CLAME	CIRSE	CLEEN	CLAIN
HOUSE	CRUSH	CRAIN	CLEAM	CREEM	CRUNE
LARGE	DIARY	DANSE	CREAN	DRANE	DONCE
LIGHT	FLOAT	DREEM	DLAIN	DRINC	DROAM
MONEY	GRAPE	ELBOE	DRONK	FAWLT	ELHOW
NIGHT	MUNCH	FEEST	FOULT	FORSE	FIAST
PAPER	PLUMP	FRALE	FRIAK	FREEK	FRANT
PLACE	POLAR	FRUNT	FURCE	GRAIT	FREIL
RADIO	QUART	GRANE	GLOAN	GREAN	GLAIN
SMALL	RULER	GREEF	GRIEN	GRONE	GRAUP
START	SHOUT	GROOP	GRUTE	HOWND	GRUEF
STUDY	SNORT	IDEEL	HAUND	KURSE	IGEAL
THINK	SPICE	LEESH	LAMON	LEMUN	LOASH
TOTAL	THORN	LOGIK	MATAL	MAGIK	LOMIC
WATER	TROUT	MELUN	MAVIC	METUL	MALON
WOMAN	WRECK	NERSE	NAISE	NOIZE	NARVE
CAUSE	CANON	NURVE	PELCH	PANIK	NULSE
CLASS	CHEER	PANZY	PIACE	PEECE	PLOOF
DAILY	CLOWN	PERSE	PLUCE	PLASE	PORSE
EARLY	COBRA	PROZE	PONIC	POIZE	PRUSE
HOTEL	CRUMB	PRUFE	PUISE	PURCH	PUNSY
HUMAN	DENSE	RELIK	SARVE	SCAIL	RESIC
LATER	DUMMY	SHAIR	SCILE	SHURT	SCAIN
MAJOR	HOBBY	SKARE	SCOLP	SKALP	SKEAK
MUSIC	MARSH	SKORE	SLAIL	SLEAP	SLARE
OFTEN	OLIVE	SLEAT	SLALE	SNALE	SLEAR
PARTY	PEARL	SNEEK	SLUEP	SPASE	SLORE
RIGHT	PUNCH	SPEEK	SNIRT	STAIL	SMARE
SHORT	ROAST	STANE	SPEAM	STEEM	SMEAK
SOUND	SKULL	STOAR	SPOCE	SURVE	SMEET
STATE	SLASH	SWARE	TANIC	TEATH	STIRE
TABLE	SPOIL	TEAZE	TEOTH	TEECH	TEOSE
TODAY	STINK	THURD	TLEAT	TONIK	THORD
VOICE	TORCH	TOPIK	TOACH	TRALE	TOGIC
WHITE	VALVE	TRATE	TROIL	TREET	TRUIT
WORLD	WAVER	VURSE	WREAT	WHEET	VORSE

Note. HF = high-frequency; LF = low-frequency.

Appendix B

Nonword Targets in Experiments 2 and 7

TL nonwords	Standard nonwords
AILSE	AIVVS
ALEIN	BLUMN
AMROR	CWELB
BAGDE	DWAGN
CAGRO	DWYLM
CRAEM	FELMB
CRPYT	FEWVE

(*Appendices continue*)

Appendix B (*continued*)

TL nonwords	Standard nonwords
CRUBM	FRIRN
CUOCH	GHLIK
DETLA	GNAWG
FLAOT	GWAKT
GRION	GWARZ
LACTH	HEIPH
LOGDE	JAPCE
LUGNE	JORFE
OGRAN	KLAUC
ONUCE	KNYZZ
OPUIM	KWORG
PLUBM	MOOBE
PUSRE	NANZE
QAURT	NOPCE
QIULL	PHURV
RIGDE	PHYKE
SPAER	PHYLT
SRHUG	PRETH
SRPAY	PYDDS
STIAN	RURMB
STIAR	SAWCH
UCLER	SMULV
WALZT	SPOLV
ADUTL	SWYDE
AGNER	TOWDE
AGNRY	TWYSK
BAERD	TYXTE
BECNH	VARND
CUVRE	VOOGN
FRIUT	WELPH
GIUDE	WRYLD
OCAEN	YOPCE
UCNLE	ZOATE

Note. TL = transposed-letter.

Appendix C

Sum Verification Stimuli in Experiment 3

15 + 18 = 33
26 + 17 = 43
17 + 24 = 41
16 + 26 = 42
28 + 15 = 43
16 + 15 = 31
17 + 19 = 36
37 + 17 = 54
26 + 13 = 39
10 + 19 = 29
18 + 19 = 37
13 + 12 = 25
21 + 13 = 34
13 + 14 = 27
13 + 15 = 28
19 + 16 = 35
13 + 17 = 30
13 + 18 = 31

(*Appendices continue*)

Appendix C (*continued*)

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17 + 19 = 36
14 + 9 = 23
14 + 12 = 26
17 + 15 = 32
9 + 16 = 25
14 + 17 = 31
15 + 19 = 34
28 + 34 = 62
23 + 18 = 41
35 + 46 = 81
45 + 29 = 74
22 + 38 = 60
29 + 13 = 42
54 + 37 = 91
48 + 56 = 104
39 + 25 = 64
55 + 67 = 122
37 + 15 = 52
27 + 38 = 65
59 + 46 = 105
47 + 24 = 71
76 + 15 = 91
16 + 18 = 23
23 + 39 = 59
57 + 44 = 91
34 + 47 = 85
25 + 18 = 32
44 + 28 = 67
56 + 66 = 123
17 + 28 = 41
15 + 7 = 23
19 + 38 = 54
26 + 18 = 44
37 + 13 = 40
17 + 48 = 54
44 + 29 = 75
28 + 27 = 56
39 + 54 = 98
9 + 17 = 25
10 + 14 = 34
32 + 18 = 48
27 + 33 = 61
46 + 28 = 72
23 + 38 = 59
28 + 14 = 39
36 + 19 = 53
29 + 56 = 78
58 + 45 = 99
46 + 25 = 67
37 + 16 = 51
45 + 62 = 109
22 + 59 = 79
38 + 55 = 83
34 + 18 = 55
20 + 13 = 43
24 + 56 = 82
63 + 45 = 98
47 + 54 = 106
16 + 17 = 34
16 + 8 = 23
88 + 14 = 104
26 + 67 = 83

(*Appendices continue*)

Appendix D

Word Stimuli and Nonword Primes in Experiments 4 and 6; Nonword Targets in Experiment 4

Targets	Related primes	Unrelated primes	Nonword primes	Pseudohomophones	Standards
APART	TOGETHER	HAMMER	NEVER	BEAF	BIRF
AWAKE	ASLEEP	HEAVEN	SWEET	BERCH	BOIT
BALL	BAT	KEG	FLOWER	BERD	BLOME
BEER	KEG	LOW	SISTER	BLAK	BLIK
BOOK	TEXT	FORK	BREAD	BLAIM	DEAB
BREAD	RYE	BAT	RUG	BLIS	FEAP
CHURCH	PRIEST	NICKEL	ORDER	BOTE	GLOKE
DEER	DOE	BOY	TAKE	BOAL	GLIEF
DIME	NICKEL	TOGETHER	NAIL	BRANE	HOCH
DRAW	SKETCH	ASLEEP	HAIR	CAIK	HOBE
DUCK	QUACK	FOUND	TRUTH	KAMP	HOCE
FINGER	THUMB	BLAZE	FOOD	CAIR	CUMP
FIRE	BLAZE	QUACK	DREAM	KECH	GECH
FISH	TROUT	THUMB	BUG	CLEEN	SCOGE
GIRL	BOY	KEY	SALAD	COAD	SEWK
GOLD	SILVER	PRIEST	MOUTH	COTTUN	SOIRCE
HELL	HEAVEN	SILVER	DIE	DEEL	SPO
HIGH	LOW	RYE	YOURS	DOWT	TOACH
KNIFE	FORK	MORE	STAR	FEER	TRAUSE
LESS	MORE	BANK	KETCHUP	FYNE	WHIAT
LOCK	KEY	DOE	LETTER	GURL	MUTH
LOST	FOUND	TROUT	BUY	GLOAB	WARTH
MONEY	BANK	TEXT	FAST	GLOO	WOAND
NAIL	HAMMER	SKETCH	TUNE	GREEF	WAPE
PLANE	JET	NAP	ROUND	HEET	BLOS
POOR	RICH	EAST	ADD	HOAM	BOWB
PUSH	SHOVE	FALSE	MEAT	HOAP	COFE
QUEEN	KING	HALT	CHAIR	HOURSE	DOYT
RIGHT	LEFT	HERB	SMELL	HUCH	FIPE
SALT	PEPPER	HEIGHT	GUMS	KEAP	GLIE
SHORT	TALL	KING	STEAL	LERN	KEET
SLEEP	NAP	JET	CAR	MAJIC	CABE
SOUTH	NORTH	DRYER	DRINK	MITH	RAFE
SPICE	HERB	LEFT	ARM	RAYK	SULE
STEAL	ROB	NEW	KNIT	SAIN	TUPE
STRONG	WEAK	LION	OLD	SCOAR	GARL
STOP	HALT	TALL	HILL	SOAN	BORCH
STREET	ROAD	RICH	UGLY	SHO	CAZE
TEST	QUIZ	WEAK	MOTH	SOURSE	LERT
TIGER	LION	QUIZ	LOOK	TAIP	MAVIC
TOILET	FLUSH	SHOVE	STAND	TUTCH	BROIN
TREE	OAK	RIP	TAXI	TRAISE	CLEUN
TRUE	FALSE	NORTH	BULL	WAIK	BEEG
WASHER	DRYER	FLUSH	WOMAN	WHEET	CITTON
WEIGHT	HEIGHT	PEPPER	FUEL	WIRTH	HEAK
WEST	EAST	ROAD	PISTOL	WOOND	HOURLE
TEAR	RIP	OAK	CAT	DED	NEP
OLD	NEW	ROB	ONE	NOO	AIF
ABOVE	BELOW	TABLE	MAD		
BACK	FRONT	THERE	CHILD		
BEACH	SAND	SOFT	GOD		
BLADE	RAZOR	FRONT	TOWN		
CHAIR	TABLE	BRIDE	KITCHEN		
CHEESE	SWISS	BRAWL	LIGHT		
CLOCK	TIME	LEAP	PLATE		
CLOSE	OPEN	LATE	GROUND		
COLD	HOT	UP	HARD		

(*Appendices continue*)

Appendix D (*continued*)

COUCH	SOFA	SOIL	VOTE
CRAZY	INSANE	SUPPER	SPRING
DINNER	SUPPER	MURDER	POLE
DIRT	SOIL	OPEN	HAND
DOWN	UP	BAD	GREEN
EARLY	LATE	SOFA	JOY
FIGHT	BRAWL	EMPTY	MIGHT
FROG	TOAD	TIME	BIZARRE
FULL	EMPTY	RAZOR	DOCTOR
GOOD	BAD	HOT	APPLE
GROOM	BRIDE	BELOW	SHIRT
HARD	SOFT	TOAD	PAPER
HERE	THERE	SWISS	CROWD
JUMP	LEAP	SAND	SALT
KILL	MURDER	INSANE	CHURCH
LIME	LEMON	BLACK	LOUD
LOSE	WIN	BOW	WAGE
LOUD	NOISE	THICK	AFRAID
MOVIE	FILM	AUNT	ITCH
NEPHEW	NIECE	SATIN	DEEP
NIGHT	DAY	ILL	HEALTH
OVER	UNDER	NOISE	ROUGH
SHINE	POLISH	QUENCH	TALK
SHOE	SOCK	FILM	SMOKE
SICK	ILL	DAY	DRINK
SILK	SATIN	NIECE	DOOR
STEEL	IRON	TAME	LITTLE
TAIL	WAG	WIN	PEACE
THIN	THICK	SPOOL	COFFEE
THIRST	QUENCH	POLISH	PLEAD
THREAD	SPOOL	UNDER	THEN
TWICE	ONCE	SOCK	BLUE
UNCLE	AUNT	ONCE	CUT
VERB	NOUN	IRON	LOBE
WALK	RUN	INK	YOLK
WHITE	BLACK	LEMON	WEEP
WILD	TAME	NOUN	HIVE
ARROW	BOW	RUN	POT
PEN	INK	WAG	DAD

Appendix E

Nonword Targets in Experiment 6

TL nonwords	Standard nonwords
AILSE	AIVVS
ALEIN	BLUMN
AMROR	CWELB
BAGDE	DWAGN
CAGRO	DWYLM
CRAEM	FELMB
CRPYT	FEWVE
CRUBM	FRIRN
DETLA	GHLIK
FLAOT	GNAWG
GRION	GWAKT
LACTH	GWARZ
LOGDE	HEIPH
LUGNE	JAPCE

(*Appendices continue*)

Appendix E (*continued*)

TL nonwords	Standard nonwords
OGRAN	JORFE
ONUCE	KLAUC
OPUIM	KNYZZ
PLUBM	KWORG
PUSRE	MOOBE
QAURT	NANZE
QIULL	NOPCE
RIGDE	PHURV
SPAER	PHYKE
SRHUG	PHYLT
SRPAY	PRETH
STIAN	PYDDS
STIAR	RURMB
UCLER	SAWCH
WALZT	SMULV
ADUTL	SPOLV
AGNER	SWYDE
AGNRY	TOWDE
BAERD	TWYSK
BECNH	TYXTE
CUVRE	VARND
FRIUT	VOOGN
GIUDE	WELPH
OCAEN	WRYLD
CALN	YOPCE
BLAD	ZOATE
FILP	CILN
INO	BLID
CALP	FELP
MAON	INI
BAOR	CULP
GALD	MION
PIAR	BUOR
FELD	GULD

Note. TL = transposed-letter.

Appendix F

Word Stimuli and Nonword Primes in Experiments 5 and 7

Targets	Related primes	Unrelated primes	Nonword primes
ALBUM	RECORD	ORANGE	SUBTRACT
APPLE	ORANGE	RECORD	BOMB
BASIC	NORMAL	ABOVE	BAT
BELOW	ABOVE	NORMAL	HIVE
BLAZE	FIRE	COMB	KEG
BRUSH	COMB	FIRE	LITTLE
CHAIR	TABLE	FLOWER	NEST
PLANT	FLOWER	TABLE	OAR
CLOCK	TIME	SOFA	TEXT
COUCH	SOFA	TIME	SISTER
DRYER	WASHER	GROUND	TAXI
EARTH	GROUND	WASHER	PRIEST
EMPTY	FULL	TOILET	HOT
FLUSH	TOILET	FULL	KITCHEN
FRONT	BACK	BRIDE	BULL

(*Appendices continue*)

Appendix F (*continued*)

Targets	Related primes	Unrelated primes	Nonword primes
GROOM	BRIDE	BACK	WEEP
JELLY	JAM	TEACH	DOE
LEARN	TEACH	JAM	NICKEL
MONEY	BANK	FILM	SUPPER
MOVIE	FILM	BANK	SOIL
NIGHT	DAY	SHIRT	CAT
PANTS	SHIRT	DAY	KNOB
PEACE	WAR	DISH	UP
PLATE	DISH	WAR	SKETCH
QUACK	DUCK	LEFT	DAWN
RIGHT	LEFT	DUCK	LOBE
SATIN	SILK	PUSH	YOLK
SHOVE	PUSH	SILK	SPRING
SOUTH	NORTH	HERB	TOAD
SPICE	HERB	NORTH	FUEL
STAND	SIT	ROB	BOY
STEAL	ROB	SIT	SILVER
TASTE	SMELL	HERE	BAD
THERE	HERE	SMELL	SOFT
THUMB	FINGER	FEEL	HEAVEN
TOUCH	FEEL	FINGER	HIM
TRUTH	HONEST	AUNT	LOW
UNCLE	AUNT	HONEST	BUG
WATER	DRINK	MAN	LEAP
WOMAN	MAN	DRINK	MURDER
APART	TOGETHER	ASLEEP	ARM
AWAKE	ASLEEP	TOGETHER	MORE
BEACH	SAND	RAZOR	FIB
BLADE	RAZOR	SAND	KEY
BREAD	RYE	THROW	WIN
CATCH	THROW	RYE	DAD
CHILD	BABY	DIRTY	KETCHUP
CLEAN	DIRTY	BABY	HAMMER
CLOSE	OPEN	INSANE	NEW
CRAZY	INSANE	OPEN	CHOICE
EARLY	LATE	VOTE	POT
ELECT	VOTE	LATE	INK
FALSE	TRUE	LOST	HOG
FOUND	LOST	TRUE	RICH
GRIEF	SORROW	HOME	WAGE
HOUSE	HOME	SORROW	PEPPER
KNIFE	FORK	LIME	ITCH
MOUTH	LIPS	NEPHEW	DEEP
NIECE	NEPHEW	LIPS	HE
NOISE	LOUD	PENCIL	SOCK
PAPER	PENCIL	LOUD	ILL
PLANE	JET	BEG	PAVEMENT
PLEAD	BEG	JET	TUNE
QUEEN	KING	LETTUCE	HALT
SALAD	LETTUCE	KING	BIZARRE
SHORT	TALL	NAP	ROAD
SLEEP	NAP	TALL	WEAK
SPEAK	TALK	THREAD	WAG
LEMON	LIME	FORK	LOOK
SPOOL	THREAD	TALK	COFFEE
STEAK	MEAT	IRON	RIP
STEEL	IRON	MEAT	QUIZ
TEETH	GUMS	THIN	QUENCH
THICK	THIN	GUMS	OAK
TIGER	LION	FISH	NOUN
TROUT	FISH	LION	RUN

(*Appendices continue*)

Appendix F (*continued*)

TWICE	ONCE	OVER	HEIGHT
UNDER	OVER	ONCE	EAST
WHITE	BLACK	MINE	TAME
YOURS	MINE	BLACK	KNIT

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Call for Nominations

The Publications and Communications (P&C) Board of the American Psychological Association has opened nominations for the editorships of **Experimental and Clinical Psychopharmacology, Journal of Abnormal Psychology, Journal of Comparative Psychology, Journal of Counseling Psychology, Journal of Experimental Psychology: General, Journal of Experimental Psychology: Human Perception and Performance, Journal of Personality and Social Psychology: Attitudes and Social Cognition, PsycCRITIQUES, and Rehabilitation Psychology** for the years 2012–2017. Nancy K. Mello, PhD, David Watson, PhD, Gordon M. Burghardt, PhD, Brent S. Mallinckrodt, PhD, Fernanda Ferreira, PhD, Glyn W. Humphreys, PhD, Charles M. Judd, PhD, Danny Wedding, PhD, and Timothy R. Elliott, PhD, respectively, are the incumbent editors.

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