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OBSERVATION

# Nonword Repetition Priming in Lexical Decision Reverses as a Function of Study Task and Speed Stress

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The authors argue that nonword repetition priming in lexical decision is the net result of 2 opposing processes. First, repeating nonwords in the lexical decision task results in the storage of a memory trace containing the interpretation that the letter string is a nonword; retrieval of this trace leads to an increase in performance for repeated nonwords. Second, nonword repetition results in increased familiarity, making the nonword more "wordlike," leading to a decrease in performance. Consistent with this dual-process account, Experiment 1 showed a facilitatory effect for nonwords studied in a lexical decision task but an inhibitory effect for nonwords studied in a letter-height task. Experiment 2 showed inhibitory nonword repetition priming for participants tested under speed-stress instructions.

Research has shown that performance is better for stimuli that have been recently encountered in the context of an experiment than for stimuli that have not been encountered in such a context. These so-called *repetition priming* effects have been obtained in a large number of paradigms and across a wide variety of stimuli (e.g., Jacoby & Dallas, 1981; Masson & MacLeod, 2002; Scarborough, Cortese, & Scarborough, 1977; Vriezen, Moscovitch, & Bellos, 1995; Zeelenberg, Wagenmakers, & Raaijmakers, 2002). A task that has often been used to study long-term repetition priming[1] is the lexical decision task. In the lexical decision task, a letter string (e.g., *trovel, hour*) is presented, and participants have to decide whether the string is a word. The results for word stimuli have been consistently obtained in a large number of studies: Responses to repeated words are faster and more accurate than responses to words that have not been repeated (e.g., Ratcliff, Hockley, & McKoon, 1985; Scarborough et al., 1977). The picture is different, however, for nonwords. Only a few studies have investigated nonword repetition priming in lexical decision and, in contrast with the consistent finding of a facilitatory word repetition priming effect, the results for nonwords have been remarkably inconsistent. Some studies have reported facilitatory nonword repetition priming effects (e.g., Dannenbring & Briand, 1982; Kirsner & Smith, 1974; Logan, 1990; McKone, 1995; Scarborough et al., 1977), some studies have reported no effect of prior study for nonwords (e.g., Brown & Carr, 1993; Forbach, Stanners, & Hochhaus, 1974), and yet other studies have reported inhibitory[2] nonword repetition priming effects (e.g., Bowers, 1994; McKoon & Ratcliff, 1979).

Although previous studies have produced inconsistent results, a number of theories make clear predictions about nonword repetition priming. The instance theory of automaticity (Logan, 1988, 1990) predicts a facilitatory nonword repetition priming effect. A central assumption of Logan's instance theory is that for each item or event a separate trace is stored in memory. More specifically, repetition priming is attributed to the storage of associations between stimuli and their interpretation. Thus, for repeated nonwords instances are stored that contain the interpretation that this particular letter string is a nonword. Retrieval of such a trace speeds up

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[1] Researchers often distinguish between short-term priming and long-term priming (Bowers, 2000; see Wagenmakers et al., 2003, for a discussion of recent quantitative models of short-term and long-term priming). Short-term priming refers to a paradigm in which the prime stimulus is presented immediately prior to the target stimulus (e.g., Forster & Davis, 1984; Huber, Shiffrin, Lyle, & Ruys, 2001). Long-term priming refers to a paradigm in which the prime and target are separated by multiple stimuli (and often several minutes or even hours). The present study is concerned with long-term priming. Hence, when we discuss repetition priming we refer to the long-term repetition priming paradigm (unless otherwise stated).

[2] The terms *inhibitory* and *inhibition* are used in the present article to denote a negative (i.e., performance decreasing) effect of prior study. We do not argue that these effects arise from inhibitory processes. For discussions of inhibitory effects and processes we refer to Anderson and Bjork (1994) and Anderson and Spellman (1995). For a different view see MacLeod, Dodd, Sheard, Wilson, and Bibi (2003).

processing and results in a facilitatory nonword repetition priming effect. In support of this framework, Logan (1990) found considerable improvement for nonwords repeated up to 16 times in a lexical decision task.

In contrast to the instance theory, familiarity-based theories of lexical decision predict an inhibitory nonword repetition effect. A number of such familiarity-based theories of lexical decision have been proposed (e.g., Balota & Chumbley, 1984; Balota & Spieler, 1999; Wagenmakers, Steyvers et al., in press). Although these theories differ in several important aspects, they all assume that a lexical decision is (at least partially) based on the strength of the match between the stimulus and information stored in memory; this strength is usually referred to as *familiarity, resonance, intensity,* or *global activation.* Words are more familiar (i.e., they produce more global activation in memory) than nonwords, and hence familiarity can be used to make a word–nonword decision. Typically, familiarity-based theories assume that a *word* response is made if the familiarity is higher than some set criterion and that a *nonword* response is made if the familiarity is lower than some set criterion.[3] Familiarity-based theories often assume that the speed of responding depends on the distance between the familiarity of a stimulus and the criterion (cf. Hockley & Murdock, 1987). For example, these theories would suggest that a faster *nonword* response would be made for a very unfamiliar stimulus than for a stimulus with a familiarity just below the *nonword* response criterion. Under the assumption that the recent presentation of a nonword increases its familiarity, responses should be slower and less accurate to repeated nonwords than to nonrepeated nonwords.

As the results of previous studies investigating nonword repetition priming have been largely inconsistent, neither instance theory nor familiarity-based theories are strongly supported by the existing data. However, one possible interpretation of the inconsistent results is that repetition priming for nonwords is the net effect of two opposing processes: (a) a process causing facilitatory nonword repetition priming on the basis of the retrieval of a specific trace containing information that the letter string is a nonword (as is proposed by Logan's instance theory; Logan, 1988, 1990) and (b) a process causing inhibitory nonword repetition on the basis of the increased familiarity of repeated nonwords (as is predicted by familiarity-based theories of lexical decision). Whether inhibitory or facilitatory nonword repetition priming is obtained depends on the balance (i.e., the relative influence) of these two processes.

The proposal that two different processes underlie nonword repetition priming might not seem very attractive, if only for reasons of parsimony. Certainly, the fact that past results have been inconsistent provides no strong evidence to back up such a dual-process account. However, the idea that two opposing processes underlie nonword repetition priming is not entirely unreasonable either. As we mentioned above, different processes for nonword repetition priming have already been proposed. In addition, some other researchers (e.g., Feustel, Shiffrin, & Salasoo, 1983) have also proposed two opposing forces to account for the fact that on some occasions nonword repetition leads to worse performance, whereas on other occasions it leads to better performance. Finally, as we discuss in more detail in the General Discussion, some existing theories have explicitly assumed that more than one process might be responsible for performance in the lexical decision task (e.g., Balota & Chumbley, 1984; Balota & Spieler, 1999).

Additionally, it is worth noting that several researchers (e.g., Atkinson & Juola, 1973; Jacoby & Dallas, 1981; Mandler, 1980; Yonelinas, 1994) have proposed dual-process accounts of recognition memory, a task that some have argued bears many similarities to lexical decision (cf. Ratcliff & McKoon, 1988). According to dual-process accounts of recognition memory, recognition can be based on the assessment of the familiarity of an item or on the recollection of specific details of the earlier presentation of an item (for a recent review of dual-process accounts of recognition memory see Yonelinas, 2002). In a similar vein, repetition priming in lexical decision might be driven by two processes. Participants may give a *word* (or *nonword*) response because the letter string seems familiar (or not familiar) or they may make a *word* (or *nonword*) response because they retrieve specific information about a previous encounter with the same letter string (e.g., participants may retrieve the fact that on a previous presentation they gave a *nonword* response to the letter string *trovel*). Unfortunately, no published studies have made a deliberate attempt to manipulate the influence of these two processes, and consequently there is hardly any evidence supporting a dual-process account of nonword repetition priming in lexical decision. Therefore, in the present study we aimed at obtaining evidence for the hypothesis that nonword repetition priming is the net result of two opposing processes.

## Experiment 1

The most straightforward prediction of the dual-process hypothesis is that inhibition for repeated nonwords should be obtained if nonwords are studied in a task other than lexical decision because under these circumstances information concerning the word–nonword status of the stimuli will probably not be stored in memory. Hence, priming effects will be due almost uniquely to the familiarity-based process. Consistent with the hypothesis that study task is an important factor, some researchers (e.g., Dorfman, 1994; Duchek & Neely, 1989; Tenpenny, 1995) have noted that facilitatory nonword repetition priming in lexical decision tends to be found only when nonwords have also been presented in the lexical decision task during study. For example, Scarborough et al. (1977) and Logan (1990) obtained facilitatory nonword repetition priming effects when nonwords (and words) were presented in a lexical decision task during study. Other studies (e.g., Bowers, 1994) in which nonwords were presented in a task other than lexical decision during study have obtained inhibitory nonword repetition priming effects. However, these observations are based on comparisons between studies involving different stimulus materials, different participant populations, and different procedures. Moreover, not all studies that repeated nonwords in the lexical decision task have found facilitatory nonword repetition priming. Brown and Carr (1993; see also Scarborough et al., 1977, Experiment 4), for example, failed to find nonword repetition priming even though the nonwords had been presented in a lexical decision

[3] Some models (e.g., multiple read-out model; Grainger & Jacobs, 1996) assume a different mechanism for *nonword* responses. These models assume a time-out deadline: A *nonword* response is made if the activation criterion is not reached before the deadline.

task during study (and even though a repetition priming effect was found for words). Also, some of the studies that did find facilitatory nonword "repetition priming" confounded repetition effects with time-on-task effects. These studies investigated repetition effects by comparing performance on trial (or block) $n$ with performance on a previous trial (or block) $n - x$ involving the same stimulus. The problem in such a comparison is that any improvement can be due to a true repetition priming effect, a nonspecific practice effect, or both. Because of these problems no firm conclusion can be drawn from existing data.

In choosing a suitable study task we aimed at using a task that would divert attention from the word–nonword status of the stimuli. For example, we did not present nonwords and words simply for reading during study (as is often done in repetition priming studies) because reading is such an automated process that we feared participants might start paying attention to the word–nonword status of the stimuli. Instead, we chose to present nonwords and words in a modified version of the letter-height task recently developed by Masson and MacLeod (2002). In the present study, nonwords and words were presented visually in uppercase letters (e.g., *TROVEL, HOUR*). Participants had to decide whether the stimuli would have contained more ascending letters or more descending letters if the letter string had been presented in lowercase (e.g., the nonword *trovel* contains more ascending letters than descending letters). In several experiments, Masson and MacLeod showed that presenting words in a letter-height task during study produced repetition priming effects comparable to those obtained when words were presented for reading at study. Therefore, the letter-height task seemed a suitable study task for the purposes of the present experiment. The dual-process account of repetition priming in lexical decision predicts inhibitory nonword repetition priming for nonwords studied in the letter-height task. A second group of participants studied nonwords in the lexical decision task. For this group, facilitatory nonword repetition priming might be obtained, provided that the positive influence of studying nonwords in the lexical decision task is larger than the negative influence that results from the increased familiarity for repeated nonwords.

## Method

*Participants.* Forty-four Indiana University students participated for course credit. All participants were native speakers of English. Twenty-two students were randomly assigned to the letter-height condition, and the other twenty-two students were assigned to the lexical decision condition. The data from 2 participants were discarded because of excessive error rates (i.e., more than 2.5 standard deviations above the average error rate for all participants). We replaced these participants while keeping the counterbalanced design intact.

*Stimulus materials and design.* The design consisted of two between-subjects conditions. During the study phase, nonwords and words were presented either in the letter-height task or in the lexical decision task. To boost the size of the repetition priming effects, we presented stimuli four times during the study phase. For both groups, nonwords and words were presented in a lexical decision task during test.

The experimental stimuli consisted of 32 words and 32 pronounceable nonwords. Nonwords were created by changing one or two letters from an existing English word. Nonwords were derived from words that were not presented in the experiment. Frequency counts for words were obtained from the CELEX norms (Baayen, Piepenbrock, & van Rijn, 1993). The median frequency per million of the words was 77 (range: 23–541). Thus, the words were of relatively high frequency. Half of the nonwords and half of the words contained more ascending letters than descending letters (e.g., *trovel, hour*). The other half of the stimuli contained more descending letters than ascending letters (e.g., *wappy, appear*). Two different lists were generated for counterbalancing purposes. Across the two lists each nonword and each word appeared once in the studied condition and once in the nonstudied condition.

*Procedure.* Participants were tested in individual participant booths and received written instructions. Each study block consisted of 32 trials in which 16 nonwords and 16 words were presented. The same 16 nonwords and 16 words were presented in each of the four study blocks. Eight of the 16 nonwords and 8 of the 16 words contained more ascending letters than descending letters. The remaining 8 nonwords and 8 words contained more descending letters than ascending letters. The test block consisted of 16 old nonwords (i.e., nonwords presented during study), 16 new nonwords (i.e., nonwords not presented during study), 16 old words, and 16 new words. Thus, the average number of items intervening between the presentation of an item in the last block of the study phase and the presentation of that item in the test phase was 47. In each block, the stimuli were presented in a different random order. A different random order was used for each participant. Participants were not informed about the relation between the study blocks and the test block.

In both conditions, nonwords and words were presented one at a time in uppercase during the entire experiment. Participants were instructed to respond as quickly and accurately as possible. Each trial started with the presentation of a fixation mark (* * * * *) for 500 ms. The fixation mark was followed immediately by the target stimulus that remained on the screen until the participant made a response. In the letter-height task, participants responded by pressing the *?/* key (for more ascending letters) or the *Z* key (for more descending letters). In the lexical decision task, participants responded by pressing the *?/* key for a *word* response and the *Z* key for a *nonword* response. If the participant made an error, the word *ERROR* was presented for 1,000 ms. If the response was correct, but slower than 2,000 ms, the words *TOO SLOW* were presented for 1,000 ms. The next trial started 1,000 ms after the response or feedback.

## Results and Discussion

Mean reaction times for correct responses were calculated for each condition. Responses more than 2.5 standard deviations above or below each participant's mean reaction time were excluded from the analyses (trimming was done separately for nonwords and words). Trimming resulted in removal of 3.0% of the reaction times for words and 2.3% of the reaction times for nonwords. The mean reaction times and percentage errors are shown in Table 1. As can be seen, we obtained a facilitatory repetition priming effect for nonwords studied in the lexical deci-

Table 1
*Mean Lexical Decision Times (in ms) and Percentage Errors (PEs) to Words and Nonwords in Experiment 1*

| | Word | | Nonword | |
|---|---|---|---|---|
| Study condition | RT | PE | RT | PE |
| Lexical decision | | | | |
| Studied | 582 | 0.9 | 671 | 8.2 |
| Nonstudied | 655 | 10.2 | 726 | 8.2 |
| Priming | 73 | 9.3 | 55 | 0.0 |
| Letter height | | | | |
| Studied | 605 | 0.5 | 805 | 22.7 |
| Nonstudied | 662 | 6.3 | 756 | 9.9 |
| Priming | 57 | 5.8 | −49 | −12.8 |

*Note.* RT = reaction time.

sion task but an inhibitory repetition priming effect for nonwords studied in the letter-height task. For repeated words, facilitatory repetition priming effects were obtained regardless of the study task in which they were presented.

These conclusions were supported by separate analyses of variance (ANOVAs) on the nonword and word results with repetition condition (studied vs. nonstudied) as a within-subjects condition and study task (lexical decision vs. letter height) as a between-subjects condition. The ANOVA on the nonword reaction time data showed a main effect of study task, $F(1, 42) = 7.36$, $p < .01$, $MSE = 20{,}061.06$. The main effect of repetition was not significant, $F(1, 42) < 1$, $MSE = 1{,}784.56$. More important, the Study Task × Repetition interaction was significant, $F(1, 42) = 33.48$, $p < .0001$, $MSE = 1{,}784.56$. Simple main effects showed that in the lexical decision condition, responses were faster to studied nonwords than to nonstudied nonwords, $F(1, 42) = 18.59$, $p < .001$, $MSE = 1{,}784.56$. In the letter-height condition, in contrast, responses were slower to studied nonwords than to nonstudied nonwords, $F(1, 42) = 15.00$, $p < .001$, $MSE = 1{,}784.56$. Thus, nonword repetition priming reversed as a function of study task.

The ANOVA on the percentage errors for nonwords showed significant main effects of study task and repetition, $F(1, 42) = 14.16$, $p < .001$, $MSE = 101.82$, and $F(1, 42) = 16.53$, $p < .001$, $MSE = 54.39$, respectively. Finally, the Study Task × Repetition interaction was also significant, $F(1, 42) = 16.53$, $p < .001$, $MSE = 54.39$. Simple main effects showed no repetition priming in the lexical decision condition, $F(1, 42) < 1$, $MSE = 54.39$. In the letter-height condition, however, *more* errors were made to studied nonwords than to nonstudied nonwords, $F(1, 42) = 33.06$, $p < .001$, $MSE = 54.39$.

The ANOVA on the word reaction time data showed that the main effect of study task was not significant, $F(1, 42) < 1$, $MSE = 10{,}054.16$. The main effect of repetition, however, was significant, $F(1, 42) = 74.55$, $p < .0001$, $MSE = 1{,}256.42$. Although there seemed to be a trend toward a more pronounced repetition priming effect in the lexical decision condition, the Study Task × Repetition interaction was not significant, $F(1, 42) = 1.05$, $MSE = 1{,}256.42$. Simple main effects showed significant facilitation for repeated words in both the lexical decision condition and the letter-height condition, $F(1, 42) = 46.66$, $p < .001$, $MSE = 1{,}256.42$, and $F(1, 42) = 28.95$, $p < .001$, $MSE = 1{,}256.42$, respectively.

The ANOVA on the percentage errors for words showed no significant main effect of study task, $F(1, 42) = 2.63$, $MSE = 37.98$. The main effect of repetition, however, was significant, $F(1, 42) = 41.05$, $p < .0001$, $MSE = 30.38$. The Study Task × Repetition interaction was not significant, $F(1, 42) = 2.47$, $MSE = 30.38$. Simple main effects showed that the repetition priming effect was significant in both the lexical decision condition and the letter-height condition, $F(1, 42) = 31.83$, $p < .001$, $MSE = 30.38$, and $F(1, 42) = 11.69$, $p < .001$, $MSE = 30.38$, respectively.

To summarize, nonword repetition priming changed dramatically as a function of the task in which the nonwords were presented during study. For nonwords studied and tested in lexical decision a facilitatory repetition priming effect was obtained. For nonwords studied in the letter-height task and tested in lexical decision, in contrast, a robust inhibitory repetition priming effect was obtained. These results are consistent with the hypothesis that two opposing processes underlie repetition priming for nonwords in lexical decision.

## Experiment 2

In Experiment 2 we wanted to obtain additional evidence for the hypothesis that two opposing processes underlie nonword repetition priming in lexical decision. Experiment 1 showed that the nature of the task performed during study determined whether a facilitatory or an inhibitory nonword repetition priming effect was obtained. In Experiment 2 we investigated whether nonword repetition priming effects can be reversed by manipulating retrieval processes instead of encoding processes. More specifically, we manipulated speed stress at test.[4] The hypothesis was that the familiarity of an item can be assessed very quickly whereas more time is needed to retrieve specific details about a previous encounter with a certain item. Many dual-process models of recognition memory make similar assumptions (e.g., Atkinson & Juola, 1973; see Yonelinas, 2002, for a review). The study phase of Experiment 2 was similar to that of the lexical decision condition of Experiment 1: Nonwords and words were repeated in a lexical decision task under standard accuracy-stress instructions (we refer to the standard instructions as *accuracy-stress instructions,* because under these instructions participants typically make few errors). At test, participants performed a lexical decision task under one of two conditions: accuracy stress or speed stress. The hypothesis was that if participants respond very fast, often there would not be enough time to complete retrieval of specific details about the previous encounter with that stimulus. For participants in the speed-stress group, therefore, we hypothesized that the familiarity-based process would dominate the lexical decision. Hence, the dual-process account of repetition priming predicts an inhibitory nonword repetition priming effect for the speed-stress group (even though nonwords had been presented in a lexical decision task during study). For the accuracy-stress group we expected to replicate the results of Experiment 1 in which a facilitatory nonword repetition priming effect was obtained for nonwords presented in a lexical decision task during both study and test.

It should perhaps be noted that in the speed-stress condition, we expected the effects of prior study to show up mainly in the error rates instead of reaction times. In this condition, processing of the stimulus often will not be completed when a response is made. Consequently, response time distributions will be "artificially" truncated and effects that show up in reaction times under standard instructions will now show up in error rates.

### Method

*Participants.* Sixty-eight Indiana University students participated for course credit. All participants were native speakers of English. Thirty-four

[4] Wagenmakers, Zeelenberg, et al. (in press) observed a facilitatory nonword repetition priming effect under standard conditions but an inhibitory effect under speed-stress conditions (i.e., in a signal-to-respond procedure). However, these results were obtained across different experiments using different participant populations (Dutch vs. American students) and stimulus materials from different languages. Also, this study confounded accuracy versus speed-stress conditions at study and test. Thus, one possibility is that under speeded conditions stimulus-to-interpretation associations were not stored in memory; another possibility is that the associations were stored but could not be retrieved. Therefore, one cannot infer with certainty that the effect of the speed-stress manipulation observed by Wagenmakers, Zeelenberg, et al. was mediated by retrieval processes rather than storage processes.

students were randomly assigned to the speed-stress condition, and the other 34 students were assigned to the accuracy-stress condition. The data from 7 participants in the speed-stress condition were discarded because of excessive error rates (i.e., 50% or more) or failure to follow the instructions.[5] We replaced these participants while keeping the counterbalanced design intact.

*Materials, design, and procedure.* For both participants in the speed-stress condition and participants in the accuracy-stress condition, the study phase was identical to that of the lexical decision condition of Experiment 1 with one exception: To shorten the experiment, we presented all nonwords and words twice during the study phase (instead of four times). In the speed-stress condition, participants were informed immediately prior to the test phase that there was a change in procedure and that it was important that they respond very fast. The instruction further stated "Because this task is difficult you will make more errors than in the first part. Try to limit the number of errors, but make sure you respond in time." As further motivation for participants to respond very fast the message *TOO SLOW* was presented for 2,000 ms if they did not respond within 500 ms. No feedback about errors was provided. The test phase started with the presentation of 24 filler items (12 words and 12 nonwords) to help participants adjust to the required speed of responding. For participants in the accuracy-stress condition, the test phase was identical to that of Experiment 1, except that for these participants too the test block started with the presentation of 24 filler items. Thus for both conditions, the average number of items intervening between the presentation of an item in the last block of the study phase and the presentation of that item in the test phase was 71.

### Results and Discussion

As in Experiment 1, responses more than 2.5 standard deviations above or below each participant's mean reaction time were excluded from the analyses.[6] Trimming resulted in removal of 2.1% of the reaction times for words and 2.3% of the reaction times for nonwords. The mean reaction times for correct responses and the percentage errors are shown in Table 2. As can be seen, facilitation was obtained for repeated nonwords under standard accuracy-stress instructions, but inhibition was obtained for repeated nonwords under speed-stress instructions. For repeated words, we obtained facilitation regardless of speed stress. Note that, as we expected, priming effects in the speed-stress group tended to show up mainly in error rates rather than in reaction times.

The speed-stress manipulation resulted in large overall differences in reaction times and error rates between the accuracy-stress group and the speed-stress group (indicating that the speed-stress vs. accuracy-stress manipulation was effective). Hence, instead of performing ANOVAs including both speed-accuracy groups, we performed separate *t* tests for each group. Analyses of the percentage errors for nonwords showed a facilitatory nonword repetition priming effect for the accuracy-stress condition, $t(33) = 3.05$, $p < .01$, $SEM = 1.27$, but an inhibitory nonword repetition priming effect for the speed-stress condition, $t(33) = 2.18$, $p < .05$, $SEM = 2.70$. Thus, for error rates nonword repetition priming reversed as a function of speed stress. The reaction time data showed a significant repetition priming effect for the accuracy-stress condition, $t(33) = 3.16$, $p < .01$, $SEM = 8.29$; responses were faster to studied nonwords than to nonstudied nonwords. For the speed-stress condition, however, the trend toward slower reaction times to studied nonwords than to nonstudied nonwords was not significant, $t(33) = .73$, $p > .10$, $SEM = 12.21$.

For word targets, error rates showed significant facilitatory repetition priming effects for both the accuracy-stress condition, $t(33) = 4.03$, $p < .001$, $SEM = 1.28$, and the speed-stress condition, $t(33) = 3.78$, $p < .001$, $SEM = 2.83$. The reaction time data showed a significant repetition priming effect in the accuracy-stress condition, $t(33) = 8.48$, $p < .0001$, $SEM = 5.15$, with faster responses to studied words than to nonstudied words. In the speed-stress condition, the repetition priming effect for reaction times was marginally significant, $t(33) = 1.70$, $p < .10$, $SEM = 7.08$.

To summarize, nonword repetition priming changed dramatically as a function of the speed-stress versus accuracy-stress manipulation at test. For nonwords tested under accuracy-stress instructions a facilitatory repetition priming effect was obtained. For nonwords tested under speed-stress instructions an inhibitory repetition priming effect was obtained. These results provide further support for the hypothesis that two opposing processes underlie repetition priming for nonwords in lexical decision.

Table 2
*Mean Lexical Decision Times (in ms) and Percentage Errors (PEs) to Words and Nonwords in Experiment 2*

| | Word | | Nonword | |
|---|---|---|---|---|
| Test condition | RT | PE | RT | PE |
| Accuracy stress | | | | |
| Studied | 587 | 2.2 | 673 | 2.6 |
| Nonstudied | 631 | 7.4 | 699 | 6.4 |
| Priming | 44 | 5.2 | 26 | 3.8 |
| Speed stress | | | | |
| Studied | 392 | 20.8 | 462 | 45.8 |
| Nonstudied | 404 | 31.4 | 454 | 39.9 |
| Priming | 12 | 10.6 | −8 | −5.9 |

*Note.* During study, stimuli were always presented under accuracy-stress instructions. RT = reaction time.

## General Discussion

The present study tested the hypothesis that nonword repetition priming in lexical decision results from two opposing processes. The main idea is that for repeated nonwords and words participants can base their decision on two different kinds of information. A lexical decision can be based on the assessment of the global familiarity of a stimulus: If the stimulus is familiar, a *word* response will be given; if the stimulus is relatively unfamiliar, a *nonword* response will be given. A lexical decision also can be based on the retrieval of specific details of a previous encounter with that stimulus. In particular, if information about the word–nonword status of the stimulus was stored on a previous encounter, this information can be retrieved and used to make a lexical

[5] All effects remained significant even when these participants were included in the analyses.

[6] Note that although participants were instructed to respond before the 500-ms deadline, responses slower than 500 ms were included in the reaction time data. Also, when calculating error rates these responses were still scored according to the given response. Thus, we did not treat all responses slower than 500 ms as errors.

decision.[7] The familiarity-based process will result in a decrease in performance for repeated nonwords (relative to nonstudied nonwords), because an increase in familiarity will slow down the decision process. In some cases the increase in familiarity may even result in an increase in the number of erroneous *word* responses to repeated nonwords. The retrieval-based process, in contrast, will act to increase performance for repeated nonwords. If information about the nonword status can be retrieved, this will facilitate making a *nonword* response.

Consistent with the dual-process account, we obtained a reversal of nonword repetition priming effects in two lexical decision experiments. In Experiment 1, a facilitatory nonword repetition priming effect was obtained when stimuli were presented in a lexical decision task during study, but an inhibitory nonword repetition priming effect was obtained when stimuli were presented in a letter-height task during study. In the latter condition, no (or little) information about the word–nonword status of the nonword will be stored in memory. Hence, nonword repetition priming will be based primarily on the familiarity-based process, resulting in an inhibitory nonword repetition priming effect. The facilitatory repetition priming effect for nonwords presented in the lexical decision task during study showed that under these conditions the outcome of the lexical decision process was dominated by the retrieval-based process. In Experiment 2, an inhibitory nonword repetition priming effect was obtained for participants tested under speeded conditions (i.e., when they were instructed to respond within 500 ms of the onset of the stimulus) even though stimuli had been presented in a lexical decision task during study. This result was predicted under the assumption that the familiarity of an item can be assessed very quickly, whereas more time is needed to retrieve specific details about a previous encounter with a certain stimulus (cf. Yonelinas, 2002). Thus, even though information about the word–nonword status of the stimuli was stored in memory this information often could not be retrieved under speeded conditions and hence the lexical decision was dominated by the familiarity-based process.

In the last 2 decades, hundreds of studies have investigated repetition priming effects, and the lexical decision task is one of the tasks that has been used extensively toward this purpose. However, surprisingly few studies have investigated nonword repetition priming in lexical decision, even though a number of theories make clear predictions about the effect of prior study on performance for nonwords. We believe that one reason why so few researchers have bothered to systematically study nonword repetition priming in lexical decision is that the few studies that have been performed have yielded inconsistent results. We argue that one important reason for these inconsistent results is that nonword repetition priming in lexical decision is the net result of two opposing processes. Dependent on the relative influence of these two processes, an inhibitory or a facilitatory nonword repetition priming effect may be obtained. The present study provides clear evidence supporting this view.

In the present study, the relative influence of familiarity-based and retrieval-based processes responsible for nonword repetition priming was manipulated by varying study task and speed stress. We emphasize, though, that we do not think that these variables are the only ones that may affect the relative influence of these two processes. Another potentially important factor is the type of nonwords and words used in the experiment. In the present study we used words of fairly high frequency. As a result the familiarity distributions for nonwords and words were probably relatively well separated, which affords making relatively fast responses on the basis of familiarity. We know from other studies (e.g., Glanzer & Ehrenreich, 1979) that responses to nonwords are slower when only low-frequency words are used compared with when only high-frequency words are used. Had we used low-frequency words in our experiments responses probably would have been slower, and consequently there would have been more time for retrieval-based processes to affect performance. Under such conditions facilitatory nonword repetition priming effects may be more pronounced than when high-frequency words are used. The important point is that the pattern of nonword repetition priming may be affected by a number of factors and, therefore, comparisons between studies that vary on a number of such factors are problematic. In the present study we held all such factors under control by manipulating one variable within a single experiment while keeping all other factors (e.g., stimulus characteristics, participant population) constant.

To the best of our knowledge, only one other study (Smith & Oscar-Berman, 1990) reported both facilitatory and inhibitory nonword repetition priming effects for the same set of stimuli. Smith and Oscar-Berman examined repetition priming in lexical decision with Korsakoff patients and alcoholic controls. The stimuli were presented in a lexical decision task during both study and test. For words, a facilitatory repetition priming effect was obtained for both the control participants and the Korsakoff patients. For nonwords, however, a facilitatory repetition priming effect was obtained for control participants, but an inhibitory nonword repetition priming effect was obtained for Korsakoff patients. These results can be explained by assuming that for Korsakoff patients the storage and/or retrieval of specific traces containing information about the word–nonword status of the nonwords is greatly impaired, whereas the familiarity-based process is relatively unaffected.

Another relevant study was performed by Bodner and Masson (1997). In contrast to the studies discussed thus far, Bodner and Masson examined nonword repetition priming in a masked short-term priming paradigm. They reasoned that previous failures (e.g., Forster & Davis, 1984) to find nonword repetition priming in this paradigm were due to two opposing processes. On the one hand, masked repetition priming for nonwords (and words) facilitates orthographic encoding resulting in an increase in performance. On the other hand, repetition of nonwords causes an increase in the sense of familiarity resulting in a decrease in performance. When these effects cancel, a null effect of nonword repetition priming is obtained. In their study, Bodner and Masson reasoned that participants would rely less on familiarity when target processing was made more difficult by presenting the target in an unfamiliar form. The repetition prime would, however, still facilitate orthographic

[7] Logan's instance theory attributes priming to the storage of stimulus-to-interpretation associations. An alternative possibility would be that participants store stimulus-to-response associations. This possibility was dismissed by Logan (1990) because repetition priming did not vary as a function of stimulus-to-response mapping. Equal amounts of priming were found when stimulus-to-response mapping was consistent (e.g., on every trial participants responded *word* with the right key and *nonword* with the left key) as when stimulus-to-response mapping was varied (participants responded *word* with the right key in one block and with the left key in another block).

encoding of the target stimulus. Consistent with this idea, a facilitatory nonword repetition priming effect was obtained when targets were presented in alternating case (e.g., *TrOvEl*). In another experiment, Bodner and Masson reasoned that participants would tend to rely more on familiarity when word–nonword discrimination was made easier by using very high frequency words and nonwords that consisted of consonant strings (e.g., *rgprt*). Under these conditions, they obtained an inhibitory nonword repetition priming effect. Thus although the exact mechanisms underlying masked short-term repetition priming and long-term repetition priming are probably different, the Bodner and Masson study, like the present one, provides evidence for the view that in the lexical decision task an increase in familiarity for repeated nonwords may cancel the effect of another facilitatory process.

Additional, albeit indirect, support for the dual-process account comes from studies examining nonword repetition priming in tasks other than lexical decision. These studies have obtained facilitatory nonword repetition priming effects in a number of tasks, including perceptual identification (e.g., Feustel et al., 1983; Rueckl, 1990) and naming (e.g., Brown & Carr, 1993). Note that although not each and every study has obtained nonword repetition priming there are, to the best of our knowledge, no studies reporting inhibitory nonword repetition priming effects in these tasks. In tasks such as perceptual identification and naming, inhibitory nonword repetition priming effects are not predicted by the dual-process account because there is no conflict in the generation of responses. Thus, it seems that, in accordance with the dual-process account, inhibitory repetition priming is obtained only in tasks such as lexical decision in which an increase in familiarity may interfere with correctly classifying the stimulus.

In the present article we argue that long-term nonword repetition priming is the net result of two opposing processes. An interesting question is how familiarity-based and retrieval-based processes are combined to jointly determine performance. One possibility is that the slower retrieval-based process is initiated after the familiarity process fails to provide a satisfying result. The Balota and Chumbley (1984) theory, for example, assumes two familiarity-based criteria: Participants make a fast *word* response if the familiarity exceeds the upper criterion, and participants make a fast *nonword* response if the familiarity is below the lower criterion. If familiarity falls between the two criteria a slower more analytic process is assumed to take place. Just as in the Atkinson and Juola (1973) model, this slower analytic process is initiated only after the familiarity process fails to trigger a response. The retrieval of details about previous encounters with the stimulus may be part of the analytic process and could account for the facilitatory nonword repetition priming effect observed under some conditions.

Another possibility is that the familiarity-based and retrieval-based processes run in a parallel fashion instead of a sequential one. Such a possibility would be consistent with Logan's (1990) instance theory. The instance theory assumes that performance in any task is based on some algorithmic computation and on the retrieval of specific instances (provided that such instances have been stored). The instance theory has little to say about the basic algorithm used for lexical decision, and in the discussion of his results Logan assumed that repetition priming was entirely due to the storage and retrieval of instances and not to a change in the algorithmic computation. Nevertheless, Logan did not completely exclude the possibility that the algorithm changes with practice. The present data indicate that a theory of repetition priming based on the retrieval of stimulus-to-interpretation associations alone does not fare well; it has no mechanism to explain inhibitory nonword repetition priming. Thus, the instance retrieval mechanism must be combined with another mechanism to give a more complete account of repetition priming. One such candidate is the interfacing of instance retrieval with a familiarity-based lexical decision process, a possibility that was briefly mentioned by Logan. The major change from previous conceptions of the instance theory would be that one would have to assume that the (familiarity-based) algorithmic process is affected by prior study. To conclude, both the Balota and Chumbley (1984) theory and Logan's instance theory could be extended to give a more complete account of nonword repetition priming. Without such an extension neither theory can explain the pattern of results obtained in the present study. A difference between these two theories would be whether the familiarity-based and retrieval-based processes run in parallel. The present study was not designed to deal with this issue and resolution of this point must await further research.

Finally, we mention that the influence of retrieval-based processes may not be limited to lexical decision. Logan (1990) used the same mechanism of instance retrieval to account for priming in pronunciation decision, a task in which participants must decide whether letter strings are pronounceable. Some findings in more conceptual tasks are also relevant. For example, Vriezen et al. (1995) studied repetition priming in a number of different semantic classification tasks. They obtained repetition priming in a size decision task (*Is it larger than a breadbox?*) for words that were previously also presented in a size decision task but not for words that were previously presented in a man-made decision task (*Is it man-made?*). According to the instance theory, the absence of transfer from man-made decision to size decision is expected because the stored stimulus-to-interpretation association (e.g., *house is man-made*) is irrelevant for the subsequent size decision. It should be noted, however, that a simple stimulus-to-interpretation association does not account for the entire pattern of repetition priming effects obtained in semantic classification tasks, as transfer can be found between two different tasks if those tasks rely on the same type of conceptual information (i.e., transfer is found from size decision to dimension decision). Nevertheless, the retrieval of specific instances may be partially responsible for repetition priming in a number of implicit memory tasks.

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