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Pathway control in visual word processing: Converging evidence from recognition memory

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The extent to which readers can exert strategic control over oral reading processes is a matter of debate. According to the pathway control hypothesis, the relative contributions of the lexical and nonlexical pathways can be modulated by the characteristics of the context stimuli being read, but an alternative time criterion model is also a viable explanation of past results. In Experiment 1, subjects named high- and low-frequency regular words in the context of either low-frequency exception words (e.g., PINT) or nonwords (e.g., FLIRP). Frequency effects (faster pronunciation latencies for high-frequency words) were attenuated in the nonword context, consistent with the notion that nonwords emphasize the characteristics of the frequency-insensitive nonlexical pathway. Importantly, we also assessed memory for targets, and a similar attenuation of the frequency effect in recognition memory was observed in the nonword condition. Converging evidence was obtained in a second experiment in which a variable that was more sensitive to the nonlexical pathway (orthographic neighborhood size) was manipulated. The results indicated that both speeded pronunciation performance and memory performance were relatively attenuated in the low-frequency exception word context in comparision with the nonword context. The opposing influences of list context type for word frequency and orthographic neighborhood size effects in speeded pronunciation and memory performance provide strong support for the pathway control model, as opposed to the time criterion model.

Whether readers have strategic control over the processes that are engaged when reading letter strings aloud is a matter of debate in visual word-recognition research (see, e.g., Kinoshita & Lupker, 2003; Lupker, Brown, & Colombo, 1997; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Reynolds & Besner, 2005; Zevin & Balota, 2000). The issue has usually been framed in terms of dual-route models of reading (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), which postulate two pathways that mediate print and phonology: (1) a nonlexical route, in which phonology is assembled using spelling-to-sound correspondence rules, and (2) a lexical route, in which a letter string is matched to a lexical entry and the corresponding pronunciation is retrieved.[1] The question addressed in the present article is whether participants can modulate reliance on these pathways.

Pathway Control Hypothesis

In dual-route models of reading (Coltheart et al., 2001), exception words (e.g., PINT) can only be read correctly via the lexical route, since they violate spelling-to-sound correspondence rules; using the nonlexical route would result in regularization errors (i.e., reading PINT so that it rhymes with HINT). Nonwords (e.g., FLIRP), in contrast, are not represented in the lexicon and hence must be processed by the nonlexical route. Regular words (e.g., MINT) can be read correctly via either route. A priori, it would seem adaptive for readers to adjust the extent to which pronunciation performance relies on these functionally distinct processes. For instance, when to-be-pronounced words are primarily exception words, one might expect an attenuation of the output of the nonlexical route (since the output will be erroneous), and increased reliance on the lexical route. Conversely, in the context of nonwords, one might expect more emphasis on the nonlexical route, and an attenuation of the lexical route.

Support for the pathway control account was provided by Zevin and Balota (2000), who found that the presence of low-frequency exception (LFE) words or nonwords appeared to modulate the reliance on the two pathways. In their study, prior to pronouncing each target word, subjects had to pronounce five primes that were either LFE words or nonwords. Reading aloud five exception words should direct attention to the lexical route, whereas reading aloud five nonwords should emphasize the nonlexical route. Across four experiments, they demonstrated that target pronunciation performance was affected by prime type, and that the well-established effects of lexicality, regularity,

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frequency, and imageability were modulated in predictable ways by the processing pathway being emphasized. For example, in the case of word frequency, the time taken by the lexical pathway to retrieve a pronunciation depends on the reader's familiarity with a particular orthographic pattern; hence, high-frequency words are typically pronounced faster than low-frequency words. The nonlexical pathway, in contrast, is insensitive to the frequency of the whole letter string, since it is concerned with the translation of graphemes (letter units) to phonemes (sounds). Consistent with the pathway control view, Zevin and Balota (Experiment 3) showed smaller word-frequency effects in the condition that directed attention to the nonlexical pathway (i.e., the nonword prime condition) than in the condition that emphasized the lexical pathway (i.e., the exception word prime condition). These and other findings (see, e.g., Monsell et al., 1992; Reynolds & Besner, 2005) are consistent with the idea that the reading system can be tuned to rely more on stimulus-appropriate processing.

Time-Criterion Hypothesis

An alternative account of these list context effects is that readers do not always initiate articulation as soon as possible; instead, readers set a flexible time criterion or deadline, which serves as a signal to initiate the response (Kinoshita & Lupker, 2003). The placement of the criterion is adjusted on a trial-by-trial basis, so that the criterion is set higher after a trial with a slowly pronounced item than after a trial with a rapidly pronounced item. Accordingly, the criterion is primarily modulated by the average pronunciation difficulty of items in a block.

Kinoshita and Lupker (2003), using a priming paradigm similar to that of Zevin and Balota (2000), demonstrated that lexicality and word-frequency effects were modulated by the pronunciation speed of the primes. When nonword primes were pronounced faster than exception word primes (which was the case in Zevin & Balota, 2000), then lexicality and word-frequency effects were indeed reduced in the nonword prime condition. But when slower, more difficult nonword primes were used (such that nonword and exception word primes were pronounced at equivalent speeds), lexicality and frequency effects were similar across the nonword and exception word prime conditions. Proponents of the time-criterion account have also challenged other evidence that has been taken to support pathway control (see, e.g., Kinoshita & Lupker, 2007; Lupker et al., 1997), arguing that the evidence is actually more consistent with a flexible time criterion.

Although there is still some controversy regarding how well the time criterion account can handle the results of Zevin and Balota (2000; see Balota & Yap, 2006), it is clear that relying only on pronunciation performance to adjudicate between the two positions has not yielded conclusive results. To further test the pathway control hypothesis, we sought to look beyond pronunciation at the memorial aftereffects of the list context manipulation. Specifically, biasing attention toward the lexical pathway should cause variables such as word frequency to have larger effects on subsequent recognition memory for target items. Conversely, if the list context emphasizes the nonlexical pathway, frequency effects on recognition memory should be attenuated. Importantly, it is unclear what predictions the time-criterion account can make about memory performance, since it is concerned solely with pronunciation latencies. Hence, in Experiment 1, we manipulated a variable that is primarily sensitive to the lexical pathway—word frequency. In contrast, in Experiment 2, we manipulated orthographic neighborhood size (*N*; i.e., the number of words that can be produced by changing one letter in a word; e.g., DOG is a neighbor of LOG)—a variable that should be primarily influenced by the nonlexical pathway in naming. Although *N* effects are not exclusively nonlexical (see Reynolds & Besner, 2002), there is clear evidence for a large nonlexical component (see Andrews, 1997, for more discussion). For example, *N* strongly influences word pronunciation and nonword lexical decision, but has little effect on word lexical decision (Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004). Importantly, both *N* and word-frequency effects have been studied in recognition memory and produce the mirror pattern in hits and false alarms. Specifically, low-frequency and low-*N* words produce both higher hits and lower false alarms than do high-frequency words and high-*N* words, respectively (see, e.g., Glanzer & Adams, 1985, for word-frequency mirror effects; Glanc & Greene, 2007; Heathcote, Ditton, & Mitchell, 2006, for *N* mirror effects).

In our present experiments, we used a route priming paradigm adapted from Zevin and Balota (2000). Subjects read aloud high- and low-frequency target words (Experiment 1) or high- and low-*N* target words (Experiment 2) that were preceded, on average, by five primes (also read aloud). Crucially, the primes were either LFE words, which should emphasize lexical processes, or nonwords, which should emphasize nonlexical processes. If readers are able to strategically alter their reliance on these reading pathways, then we would expect the word-frequency mirror effect in recognition memory to be smaller in the nonword prime condition, because the nonlexical route is insensitive to word frequency. Importantly, one might also expect the difference in discrimination (for old and new items in the recognition test) between high- and low-frequency targets to be greater in the LFE word condition than in the nonword prime condition. Turning to the manipulation of *N*, in contrast with the influence of word frequency, one might expect relatively larger *N* effects for the nonword prime condition in pronunciation, and likewise the difference in later memory discrimination between high- and low-*N* words to be greater for the nonword prime condition.

METHOD

Subjects

Thirty-two undergraduates from the Washington University Psychology Subject Pool participated in each experiment (subjects participated in either Experiment 1 or Experiment 2).

Stimuli

For both experiments, 100 LFE words and 100 nonwords (taken from Zevin & Balota, 2000) served as primes. The LFE words had a mean frequency of 19.1 occurrences per million (Lund & Burgess, 1996), and they were all irregular and inconsistent. The nonwords and LFE words were matched on *N* ($M = 2.1$), initial phoneme, and letter length (see Zevin & Balota, 2000, for more details). A subset of the primes (20 of each type) were selected to be targets in a subsequent recognition test (of primes), so an additional 20 LFE words and 20 nonwords served as distractors on that test. These distractors matched the primes on length, *N*, bigram frequency, and word frequency (for the exception words), and were based on the ELP database (Balota et al., 2007).

Experiment 1. The targets in the speeded pronunciation task came from a pool of 40 high-frequency ($M = 1{,}832.9$) and 40 low-frequency ($M = 26.6$) regular words that were divided into four equal sets (10 high frequency and 10 low frequency) and were matched on *N* ($M = 10.6$), letter length ($M = 4.0$), and bigram frequency. In addition, high- and low-frequency targets in each set were matched on initial phoneme. Each set was yoked to one other set, so that if that set served as targets in the pronunciation task, its yoked set served as distractors on the subsequent recognition test. The four sets were rotated among subjects, and each set served equally often as targets and distractors.

Experiment 2. The targets in the speeded pronunciation task came from a pool of 20 regular words with high *N* ($M = 11.4$) and 20 regular words with low *N* ($M = 2.0$), based on the English Lexicon Project (see Balota et al., 2007). The high- and low-*N* words were matched on length ($M = 4.2$), frequency ($M = 24.7$), imageability, and initial phoneme, and were divided into two equal sets (10 high *N* and 10 low *N*). Each set served equally often as targets and distractors.

Design

Prime type (LFE words vs. nonwords) was manipulated between subjects, whereas word frequency (Experiment 1) and the *N* (Experiment 2) of targets were manipulated within subjects.

Procedure

Subjects were seated at a computer terminal and were instructed to read aloud each letter string that would appear in a central location on the computer screen. They were told that the letter strings could comprise real words as well as made-up nonwords, and that their task was to pronounce each item aloud as quickly and as accurately as possible. They were also informed that there would be a memory test later. Each subject read aloud 100 primes and 20 targets, and each target was preceded by 3 to 7 primes (average of 5; we decided to modify the fixed sequence of 5 primes followed by a target used by Zevin & Balota, 2000, to avoid subjects detecting a regular pattern in the sequence). The sequence of primes vis-à-vis targets was fixed across subjects (i.e., one pseudorandom order was used for all subjects), whereas the actual primes and targets that appeared in that fixed sequence were randomly ordered. For each trial of the pronunciation task, an item was presented for 1,500 msec (Experiment 1) or 1,000 msec (Experiment 2), followed by a blank screen for 500 msec. Items remained on the screen even after subjects pronounced them, in order to equate exposure duration. Subjects' pronunciation output was recorded on tape, and a microphone connected to a voice key measured response latencies.

After the pronunciation task, subjects performed a math distractor task for 90 sec (Experiment 1) or 240 sec (Experiment 2). They were then administered an old–new recognition test for the targets in the previous pronunciation task (20 targets and 20 distractors), followed by an old–new recognition test for the primes in the pronunciation task (20 primes and 20 distractors). The recognition test for the targets and primes were administered in two separate blocks on the computer, and subjects indicated their responses by pressing the appropriate key.

RESULTS

Pronunciation Latencies

Before analyzing the pronunciation latencies, we screened the data by disregarding observations that were <200 msec or that were >2.5 *SD*s below or above each subject's overall mean. The α level for all analyses was set at .05. Mean pronunciation latencies are listed in Table 1.

Experiment 1. High-frequency targets were pronounced faster than were low-frequency targets [$F(1,30) = 22.52$, $MS_e = 22{,}926.481$]. Furthermore, word frequency interacted marginally with prime type [$F(1,30) = 4.07$, $MS_e = 4{,}141.772$, $p = .053$]. As can be seen in Figure 1, the word-frequency effect was larger in the LFE word than in the nonword prime condition, replicating the result of Zevin and Balota (2000). Also, LFE word primes were pronounced slower than were nonword primes [$t(30) = 2.27$]. This nonequivalence makes it possible that the modulation in the word-frequency effect was due to changes in the positioning of the time criterion, and not because reading pathways were selectively attended to. Primes, on average, were named slower than were targets in both prime conditions, and target pronunciation may have been slowed down because of a higher time criterion. However, it is unclear how this slowing of target pronunciation could account for the modulation of the frequency effect, since the slow prime items should have slowed down the faster high-frequency words more than the slower low-frequency words, thereby—if anything—reducing the word-frequency effect.

Experiment 2. The effect of *N* on pronunciation also appeared to depend on prime type, as is shown in Figure 2. As was predicted, there was a larger effect of *N* for the nonword prime condition [$t(15) = 1.61$, $p = .06$, one-tailed] than for the LFE word condition ($t < 1$), although the $N \times$ prime type interaction failed to reach significance ($F = 1.23$). Also, the pronunciation latencies for LFE and

Table 1
Mean Pronunciation Latencies and Standard Deviations As a Function of Prime Type and Target Type

	Experiment 1							Experiment 2						
	Target							Target						
Prime	LF		HF		Frequency	Prime		Low *N*		High *N*		*N*	Prime	
Condition	*M*	*SD*	*M*	*SD*	Effect	*M*	*SD*	*M*	*SD*	*M*	*SD*	Effect	*M*	*SD*
LFE words	616	80	562	62	55	660	85	539	51	543	56	−4	585	57
Nonwords	549	70	527	68	22	589	92	534	62	522	60	12	561	66

Note—Latencies are in milliseconds. LF, low frequency; HF, high frequency; LFE, low-frequency exception; *N*, orthographic neighborhood density.

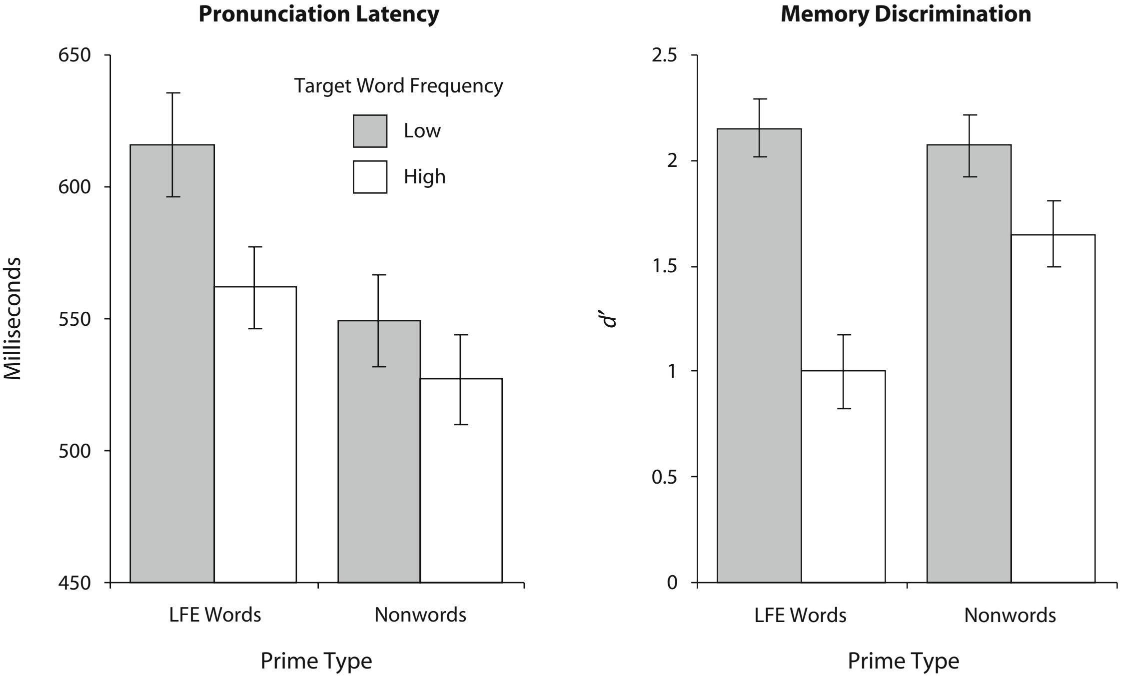

Figure 1. Performance in Experiment 1 as a function of target word frequency and prime type. Error bars indicate standard errors.

nonword primes were not significantly different ($t = 1.10$) in this experiment. There was also a marginally stronger correlation between *N* and pronunciation latencies for nonword primes ($r = -.47$) than for LFE word primes ($r = -.28$) ($p = .06$, one-tailed), which is consistent with the idea that the nonlexical pathway is more sensitive to *N* than is the lexical pathway.

Recognition Performance for Targets

Experiment 1. As can be seen in the top half of Table 2, the word-frequency mirror pattern was clearly observed for target recognition in the LFE prime condition: Low-frequency targets had a higher hit rate (HR; i.e., proportion correctly recognized as "old") than did high-frequency targets, whereas low-frequency distractors had a lower false alarm rate (FAR; i.e., proportion incorrectly recognized as "old") than did high-frequency distractors. For the nonword prime condition, however, the mirror pattern was not obtained, as would have been expected if attention was directed to the nonlexical pathway (which is insensitive to word frequency). This was confirmed by a 2 (HR vs. FAR) × 2 (target frequency) × 2 (prime type) mixed ANOVA. Target frequency interacted with HR−FAR [$F(1,30) = 34.55$, $MS_e = .538$], basically indicating the word-frequency mirror effect. But this was qualified by a three-way interaction between target frequency, HR−FAR, and prime type [$F(1,30) = 6.87$, $MS_e = .107$], which revealed that the mirror effect was indeed modulated by prime type. Although there were fewer false alarms to low-frequency than to high-frequency distractors in the LFE word prime condition [$t(15) = 2.26$], the FAR values in the nonword prime condition were equivalent for low- and high-frequency distractors ($t < 1$). Thus, the frequency effect on false alarms was eliminated in the nonword prime condition. The frequency effect on hits was also reduced in the nonword prime condition relative to the LFE word prime condition, but this difference was not significant ($t = 1.11$).

A complementary way to assess the effect of target frequency is to examine differences in discrimination (or sensitivity) between high- and low-frequency targets. Discrimination was computed both in terms of the two-high-threshold model (i.e., HR−FAR) and signal detection theory (d'; Snodgrass & Corwin, 1988). There was better discrimination for low- than for high-frequency words [HR−FAR, $F(1,30) = 34.55$, $MS_e = 1.076$; d', $F(1,30) = 32.21$, $MS_e = 9.875$]. Importantly, target frequency interacted with prime type [HR−FAR, $F(1,30) = 6.87$, $MS_e = .214$; d', $F(1,30) = 7.05$, $MS_e = 2.161$], indicating that the effect of frequency on discrimination was reduced in the nonword prime condition, as is shown in Figure 1. Neither target frequency nor prime type had an effect on response bias (C was close to 0 for all conditions).

Experiment 2. Recognition performance for Experiment 2 is shown in the bottom half of Table 2. Although the HRs and FARs did not display a mirror pattern for *N*, low-*N* words were better discriminated than were high-*N* words, but only in the nonword prime condition. These observations were supported by a significant three-way interaction between target *N*, HR−FAR, and prime type [$F(1,30) = 6.76$, $MS_e = .070$], as well as by an interaction between *N* and prime type on discrimination [HR−FAR, $F(1,30) = 6.76$, $MS_e = .141$; d', $F(1,30) = 4.04$, $MS_e = .247$, $p = .054$]. In contrast with word frequency, which

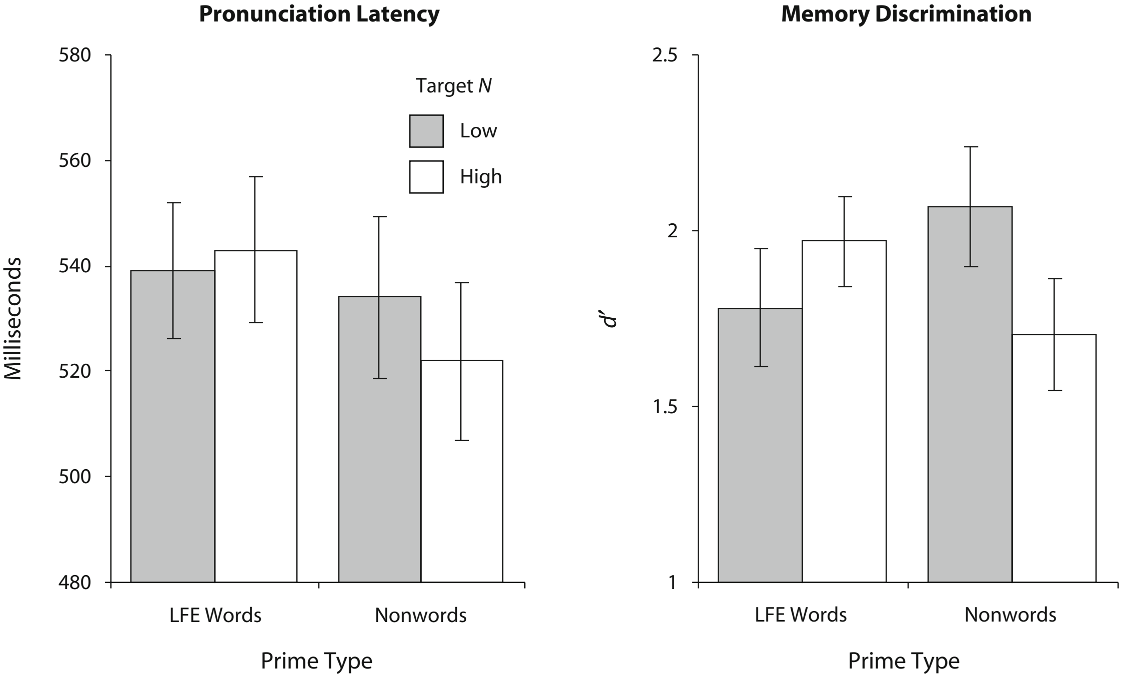

Figure 2. Performance in Experiment 2 as a function of target *N* and prime type. Error bars indicate standard errors.

had a larger effect in the LFE word context, the results from Experiment 2 showed better discrimination of low-*N* than of high-*N* words for the nonword prime condition [HR−FAR, $t(15) = 2.83$; d', $t(15) = 2.39$], but this was not so for the LFE word prime condition (ts < 1.10), as is shown in Figure 2.

Recognition Performance for Primes

Although not of primary interest, recognition memory for primes was also assessed, and mean performance is displayed in Table 3. In Experiment 1, there was no difference in the recognition of LFE words and nonwords. The HRs, FARs, and discrimination were equivalent for both prime types (all ps $> .13$). The equivalence of memory performance for the primes is important, because it suggests that there is no evidence of a trade-off in the memorability of the context items that somehow modulated the word-frequency effect. In Experiment 2, the FAR was marginally higher for nonword than for LFE word distractors [$t(30) = 1.92$, $p = .064$], yielding better discrimination for LFE words than for nonwords [HR−FAR, $t(30) = 1.86$, $p = .073$; d', $t(30) = 2.11$]. When the results from both experiments are considered together, it is unlikely that this difference was responsible for the modulation of the *N* effect.

DISCUSSION

Current computational models of reading assume that the process of deriving phonology from print involves the operation of separate process-specific modules. This modular approach presupposes that such processing is context independent. However, there has been growing evidence that the process of converting print into sound is sensitive to context, leading some researchers to propose that our reading systems are flexible and dynamic (e.g., Balota & Yap, 2006). According to the pathway control hypothesis, the relative contribution of the lexical and nonlexical pathways for the derivation of phonology depends on the type of stimuli being read aloud (see, e.g., Zevin & Balota, 2000).

Existing evidence in favor of this hypothesis is based exclusively on pronunciation performance. The interpretation of this evidence is not unanimous (see, e.g., Kinoshita & Lupker, 2003), and a competing view is that the effects of list context can be better explained by a flexible time criterion for responding. The purpose of the present study was to extend this area of investigation by examining memory performance of target items read aloud in two different list contexts. If manipulating list context modulates the relative reliance on the lexical and nonlexical routes during reading, any effects should be seen not just in pronunciation performance, but also in subsequent recognition memory.

This prediction was confirmed by the results of two experiments. In Experiment 1, the effect of word frequency on pronunciation latencies was smaller in the condition that encouraged reliance on the nonlexical pathway (i.e., the nonword prime condition), thus replicating the results of Zevin and Balota (2000, Experiment 3). This influence extended to later recognition memory performance; that is, there was better discrimination for low- than for high-frequency words, but this effect was reduced when targets were read aloud along with nonword primes (cf. LFE word primes). The modulation of the frequency effect on discrimination was primarily—but not exclusively—due to

Table 2
Recognition Performance for Targets As a Function of Prime Type and Target Type

Experiment 1

	Low Frequency				High Frequency				Frequency Effect	
Prime Type	HR	FAR	HR−FAR	*d′*	HR	FAR	HR−FAR	*d′*	HR−FAR	*d′*
LFE words	.84	.14	.70	2.15	.58	.25	.33	1.00	.37	1.15
Nonwords	.79	.13	.67	2.07	.63	.10	.53	1.65	.14	0.42

Experiment 2

	Low *N*				High *N*				*N* Effect	
Prime Type	HR	FAR	HR−FAR	*d′*	HR	FAR	HR−FAR	*d′*	HR−FAR	*d′*
LFE words	.82	.25	.57	1.78	.74	.11	.63	1.91	−.06	−0.13
Nonwords	.85	.17	.68	2.07	.70	.14	.56	1.71	.12	0.36

Note—HR, hit rate; FAR, false alarm rate; LFE, low-frequency exception; *N*, orthographic neighborhood density.

the modulation of the frequency effect on false alarms. Although the typical higher FAR for high- than for low-frequency distractors was observed in the LFE prime condition, this frequency effect was abolished in the nonword prime condition (i.e., equivalent FARs were obtained for both high- and low-frequency distractors). It is worth noting that the FAR portion of the word-frequency effect, as compared with the HR portion, is very rarely disrupted (see, e.g., Balota, Burgess, Cortese, & Adams, 2002; Criss & Shiffrin, 2004; Joordens & Hockley, 2000).

A possible explanation for why high- and low-frequency distractors produced similar levels of false alarms in the nonword prime condition is source-constrained retrieval (Jacoby, Shimizu, Daniels, & Rhodes, 2005). That is, at retrieval, the processes engaged during study are recapitulated by the rememberer to constrain what comes to mind during retrieval. Therefore, if the nonlexical pathway was emphasized during study (i.e., reading words aloud with nonword primes), it is conceivable that this relative emphasis on nonlexical processing was reimplemented during the recognition test. Indeed, this is precisely the pattern we found when we manipulated a variable that was more sensitive to the nonlexical pathway—that is, *N*, in Experiment 2.

One might suggest that embedding words among nonwords during the pronunciation task made the target words more salient, and hence the reduction in the word-frequency effect in the nonword prime condition was due to a greater increase in the distinctiveness of the high-frequency (relative to low-frequency) target words at encoding. However, changes in distinctiveness at encoding ought to primarily influence HRs; false alarms to distractors should remain relatively unaffected. Our results showed that the modulation of recognition performance by prime condition was mainly reflected in the FARs, making an enhanced distinctiveness explanation untenable.

In any case, the results from Experiment 2 conclusively rule out a distinctiveness account. To recapitulate, the nonword prime condition, but not the LFE word prime condition, was associated with *N* effects on both pronunciation and subsequent episodic recognition. In fact, the route priming paradigm yielded a double dissociation between the effects of word frequency and *N* in both speeded pronunciation performance and memory performance: The former was amplified by the LFE word prime condition and was attenuated by the nonword prime condition, whereas the latter exhibited the opposite pattern. Cross-experiment ANOVAs supported these observations: Significant three-way interactions between prime type (nonwords vs. LFE words), target level (high vs. low), and experiment (1/word frequency vs. 2/*N*) were obtained for target pronunciation latency [$F(1,60) = 5.02$, $MS_e = 4{,}624.176$], HR−FAR [$F(1,60) = 13.50$, $MS_e = .351$], and *d′* [$F(1,60) = 11.01$, $MS_e = 3.046$]. Although the modulation of the *N* effect on pronunciation was not statistically significant in Experiment 2, it is worth noting that in the nonword prime condition, there was a reliable, positive correlation between the magnitudes of the *N* effect on pronunciation and on later episodic recognition ($r = .70$), again supporting a close relationship between the two. The correlation was not reliable ($r = .12$) in the LFE word prime condition, in which the *N* effect was eliminated. Indeed, the findings from Experiment 2 converge on the notion that *N* effects depend more on nonlexical than on lexical processing (although see Peereman & Content, 1995, for evidence of a lexical influence using French stimuli).

In closing, it is important to note that the pathway control and time-criterion hypotheses are not mutually exclusive. It could be that changes in the relative emphasis of particular reading pathways and changes in the placement of a time criterion jointly influence pronunciation performance. Our study demonstrated that in terms of recognition discrimination, the word-frequency effect was attenuated when targets were studied in the context of nonword primes and, conversely, the *N* effect was eliminated when targets were studied in the context

Table 3
Recognition Performance for Primes
As a Function of Prime Type

Prime Type	HR	FAR	HR−FAR	*d′*
Experiment 1				
LFE words	.84	.13	.72	2.27
Nonwords	.82	.17	.65	2.00
Experiment 2				
LFE words	.82	.09	.72	2.39
Nonwords	.79	.16	.63	1.95

Note—HR, hit rate; FAR, false alarm rate; LFE, low-frequency exception.

of LFE word primes. Importantly, the modulation of these effects by prime condition paralleled the pattern observed in pronunciation performance. These findings cannot be explained by the time-criterion hypothesis, but instead are most consistent with the notion that readers can flexibly adjust the relative contributions of the lexical and nonlexical pathways for generating phonology. Hence, the present study provides strong evidence for the pathway control hypothesis, with the implication that future models of skilled reading should incorporate control mechanisms that allow the modulation of reading processes by stimulus characteristics. We have also demonstrated that memory performance can provide converging evidence, nicely complementing the traditional measures (e.g., pronunciation performance) that are the mainstay of visual word-recognition research.

AUTHOR NOTE

This research was supported by NSF Grant BCS 0001801 and NIH Grant PO1 AGO3991. S.H.K.K. is now at the Department of Psychology, University of California, San Diego. This research was presented in a poster at the 49th Annual Meeting of the Psychonomic Society, Chicago, in November 2008. Correspondence concerning this article should be addressed to S. H. K. Kang, Department of Psychology, University of California, San Diego, 9500 Gilman Drive, #0109, La Jolla, CA 92093-0109 (e-mail: seankang@ucsd.edu).

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NOTE

1. Although pathway control has typically been framed within dual-route models, such control also can be incorporated within Plaut, McClelland, Seidenberg, and Patterson's (1996) parallel distributed connectionist models by assuming adjustments to the relative contributions of direct or semantically mediated spelling-to-sound translation. Zevin and Balota (2000) specifically considered how the Plaut et al. and other models of lexical processing (such as the dynamical systems model proposed by Van Orden and Goldinger, 1994) might account for pathway control effects.

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