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Switch costs when reading aloud words and nonwords: Evidence for shifting route emphasis?

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Reynolds and Besner (2005) examined contextual control over the use of lexical and nonlexical routes by requiring participants to alternate between reading pairs of low-frequency exception words and pairs of nonwords. Their main finding was that latencies for both words (e.g., *wad*) and nonwords (e.g., *flad*) were slower when the immediately preceding trial involved the opposite item type rather than the same item type (a *switch cost*). The authors interpreted this result as evidence that under certain circumstances, readers have the ability to shift emphasis between their lexical and nonlexical routes. The present research shows that these results can be replicated using Reynolds and Besner's items; however, the switch cost for words, but not for nonwords, disappears when more easily named nonwords are used. This result suggests that Reynolds and Besner's results were likely due to something other than shifting route emphasis.

A question that has received considerable research interest recently concerns what type of strategic control readers have over the processes involved in reading letter strings aloud (Baluch & Besner, 1991; Chateau & Lupker, 2003; Kinoshita & Lupker, 2002, 2003; Lupker, Brown, & Colombo, 1997; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Zevin & Balota, 2000). More specifically, the framework for this research has been dual-route models—typically, the models of Coltheart and colleagues (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001)—and the question has normally been whether readers have the ability to strategically alter the relative emphasis that the two routes are given when participating in speeded naming (i.e., reading aloud) tasks.

According to these types of models, there are two ways of converting print to sound without semantic involvement. One relies on sublexical spelling-to-sound correspondence rules (the nonlexical route). The other relies on looking up the pronunciation stored in a phonological output lexicon after finding the word's lexical entry in the orthographic input lexicon (the lexical route). Nonwords, which are not represented in the orthographic input lexicon (e.g., *flad*, *vip*), must be read via the nonlexical route. Words that do not follow the regular spelling-to-sound correspondence rules (exception words; e.g., *wad*, *bowl*) must be read via the lexical route. Regular words can be read by either route (or a combination of the two).

Typically, research on this topic involves a manipulation of list composition. The basic idea is that if subjects strategically adjust route emphasis, they should do so in a way that best suits the nature of the stimuli being named. Specifically, a context consisting mainly of exception words should cause subjects to give relatively more emphasis to the lexical route, whereas a context consisting mainly of nonwords should cause subjects to give relatively more emphasis to the nonlexical route. This shift in emphasis is typically modeled by assuming that readers strategically change the values of the processing parameters on one or both of the routes.

The basic expectation from a route-emphasis position is that when subjects are reading only one stimulus type (a "pure" block), they can set their parameters in a way that maximizes performance for that stimulus type. In a "mixed" block, in which two or more stimulus types are presented, they cannot. Thus, the basic prediction from this position is that naming latencies should always be shorter in pure blocks. As Lupker and colleagues (Chateau & Lupker, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) have shown, however, this is not what happens. Rather, although easily named stimuli show a pure block advantage, harder-to-name stimuli are actually read aloud faster when they are mixed with easy stimuli than when presented by themselves in pure blocks.

Lupker and colleagues (Chateau & Lupker, 2003; Kinoshita & Lupker, 2002, 2003; Lupker et al., 1997; Taylor & Lupker, 2001) interpreted these results in terms of the activity of a time criterion. That is, on the basis of the difficulty of the stimuli in the trial block, subjects

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determine a point in time at which they try to respond to all stimuli in the block (i.e., their time-criterion placement). When easy and hard stimuli are mixed, the placement is intermediate in comparison with the placements in pure blocks of easy and hard stimuli. Thus, responses to easy stimuli slow down, whereas responses to hard stimuli speed up, in contrast to their respective pure block situations. Results that were reported by Taylor and Lupker showed that this effect appears to happen on a trial-by-trial basis, since the latency to a stimulus was faster following an easy stimulus than following a hard stimulus.

The only exception to Lupker et al.'s (1997) general pattern arose when nonwords and low frequency exception words were mixed (Experiment 1). In that situation, although the latencies in pure blocks were approximately equal (suggesting that similar time criteria were used in the two blocks), in the mixed block, nonword latencies increased, whereas exception word latencies decreased. This result, which cannot be explained by a time-criterion account, was explained in terms of the concept of *lexical checking* (see also Kinoshita & Lupker, 2003). The idea is that prior to emitting a response, readers have the option of consulting their phonological output lexicon in order to determine whether the generated code matches a code in that lexicon. This lexical checking process is more likely to be used when the list contains only low-frequency exception words (i.e., the pure block) than when those words are mixed with nonwords. It will not be used, however, when the list contains only nonwords. Note that—as was described in Kinoshita and Lupker (2003)—this process is not one that alters the parameter settings on either route. It takes place after the routes have activated a candidate as a means of maintaining a reasonably low rate of mispronunciations.

The notions of time criterion, along with lexical checking, can explain most of the data considered as support for a route-emphasis account, as was recently noted by Reynolds and Besner (2005). That fact, however, does not rule out the possibility that readers can shift route emphasis under the right circumstances, and indeed, these authors have produced data which—they suggest—provide such evidence.

Reynolds and Besner (2005) used the alternating-runs (AABB) procedure that was developed by Rogers and Monsell (1995). Subjects read aloud two low-frequency exception words and two nonwords in succession in an alternating fashion. The main finding was that both exception words and nonwords were read more slowly following an item of the opposite type (*switch* trials) in comparison with when they followed an item of the same type (*stay* trials) (a "switch cost").

Such a result would follow from a route-emphasis account if one adopted the following analysis. On the switch trial, subjects are slow to read the stimulus because although they may know a switch is coming, they aren't able to adjust their parameter settings optimally prior to the trial. They then do adjust those settings prior to the next trial, making their latencies on that subsequent (stay) trial more rapid. When the trial after that involves a switch to the other stimulus type, however, the settings are again nonoptimal, requiring another adjustment prior to the next (stay) trial. In essence, subjects shift back and forth between settings that are better for nonwords or better for low-frequency exception words after each switch trial.

Reynolds and Besner (2005) noted that in the alternating runs paradigm, there is "no uncertainty with respect to the target's lexicality on critical trials" (p. 114), implying that this paradigm is more conducive to observing support for the route-emphasis account than the list composition (blocking or filler type) manipulations used previously. Such a claim, however, seems odd for a couple of reasons. First, pure blocks—that is, blocks in which all the stimuli are either words or nonwords—would actually provide less uncertainty than a paradigm in which there is a (predictable) shift every second trial. As was noted, these types of experiments produce little evidence for a route-emphasis account. Second, if readers do reconfigure parameters in the way that was described by Reynolds and Besner, nonoptimal parameter settings are used on half the trials. A more sensible strategy would be to simply use parameter settings that are reasonable for both low-frequency exception words and nonwords throughout.

Reynolds and Besner (2005) correctly argued that their full pattern of results cannot be explained by a time-criterion account. What can be explained by a time-criterion account, however, is the switch cost for the exception words. The naming latencies for the nonwords used by Reynolds and Besner were very slow (about 70 msec longer than for the words), probably because they had inconsistent bodies that were shared by the exception words (e.g., *flad*/*wad*). Therefore, on the basis of Taylor and Lupker's (2001) data showing that time-criterion effects occur on a trial-by-trial basis, one would expect that the word latencies would be slower on trials following a slow nonword (i.e., the switch trials) than on trials following a fast word (i.e., the stay trials).

What the time-criterion account cannot explain is why nonword latencies were longer following a more rapidly named word (switch trials) than following a more slowly named nonword (stay trials). This fact is not surprising, however, because, as was noted earlier, mixing nonwords with low-frequency exception words is the one situation that can produce effects that cannot be explained by the time-criterion account. In particular, the responses to nonwords slow down when the nonwords are mixed with low-frequency exception words, regardless of the latencies of the two stimulus types. We have explained this pattern in terms of the notion of lexical checking. Extending this idea to the present circumstance, lexical checking would be more likely when the previous trial involved a low-frequency exception word than a nonword.

The purpose of the present research was to reexamine Reynolds and Besner's (2005) route-emphasis explanation again using Rogers and Monsell's (1995) alternating-runs procedure. The simultaneous switch costs for both nonwords and low-frequency exception words observed by Reynolds and Besner is novel. Thus, initially, we felt it necessary to replicate Reynolds and Besner's results using their stimuli. Our first condition was the attempted replication.

Assuming that Reynolds and Besner's (2005) results replicate, the key condition then becomes the second condition. As was described previously, what is notable about Reynolds and Besner's stimuli is that the responses to their nonwords were extremely slow, most likely because they contained bodies that were contained in the exception words used. Thus, in the second condition, the nonwords were designed to make responses to them much faster: Specifically, they were slightly shorter and had consistent bodies that did not occur in the exception words.[1] The basic prediction that Reynolds and Besner's account makes is that because nonwords can be named only via the nonlexical route and low-frequency exception words can only be named accurately via the lexical route, the same motivation to shift route emphasis every second trial should arise here. Hence, the results in this condition will mirror those in the other condition. In particular, Reynolds and Besner regard the switch cost as evidence that processing parameters for the lexical and nonlexical routes are altered prior to the stay trials. Thus, if the switch cost emerges for one stimulus type (low-frequency exception words or nonwords), it has to be there for both.

In contrast, if Reynolds and Besner's (2005) switch cost pattern that was observed with their stimuli was not due to altering route emphasis, but was instead due to a time-criterion effect for low-frequency exception words and lexical checking for nonwords, a different pattern would be expected in the second condition. Specifically, because the nonwords should be read rapidly, there would now be no reason to expect the low-frequency exception words to be slower following a nonword trial (i.e., no switch cost would be observed for words). Nonwords, on the other hand, would be expected to be disadvantaged following the low-frequency exception words, because of lexical checking. Thus, for nonwords, the pattern would be expected to be similar in the two nonword conditions.

METHOD

Subjects

Thirty-two Macquarie University undergraduate students participated in this experiment as part of a course requirement. All subjects were native speakers of Australian English.

Materials

Eighty low-frequency (range 0–23 per million, $M = 6.7$, based on Kučera & Francis, 1967) exception words and 80 nonwords were selected from the list of items used by Reynolds and Besner (2005). All stimuli were monosyllabic, and 3–5 letters in length. These "R&B nonwords" contained the same bodies as the exception words (e.g., *wad*/*flad*). In addition, 40 monosyllabic nonwords (length 3–4 letters) were selected using the ARC nonword database (Rastle, Harrington, & Coltheart, 2002, available at www.maccs.mq.edu.au/~nwdb). These nonwords, which will be referred to as *K&L nonwords*, did not contain the same bodies as the exception words (e.g., *vip*, *lat*). The stimuli may be accessed through the Psychonomic Society archive of norms, stimuli, and data, www.psychonomic.org/archive.

The exception words were each divided into four sets (A, B, C, and D), with each set containing 20 items. The assignment of the four sets of exception words to the four experimental conditions arising from a factorial combination of switch type (stay vs. switch) and block type (whether they were mixed with the R&B nonwords or the K&L nonwords) was fully counterbalanced across subjects so that each subject saw a target word once and every word occurred in each of the four experimental conditions once for every four subjects. (The 40 R&B nonwords mixed with the 40 exception words were always the ones sharing bodies with those words.)

Apparatus and Procedure

Subjects were tested individually and seated approximately 40 cm in front of an NEC Multisync 4FG monitor upon which the stimuli were presented. Subjects were instructed (both verbally and on the monitor) that a list of letter strings—words and nonwords—would be presented on the screen, one at a time. Subjects were asked to read aloud each letter string as quickly as possible. Subjects were also told that the item presentation would involve a sequence of two words followed by two nonwords. In each block, the critical stimuli were presented following 16 practice trials that were selected according to the same criteria as the experimental trials.

Instructions and stimuli were presented, and reaction time (RT) data were recorded to the nearest millisecond using the DMDX display system (Forster & Forster, 2003) on a Dell Optiplex GX240 that ran on an Intel Pentium III chip at 650 MHz. The RT was recorded by a Bayerdynamic microphone (MEM 194/TG-X45) that was fitted to each subject and held at a constant distance from the subject's mouth throughout the experiment by means of a headset. Naming errors and possible measurement errors that were due to inappropriate voice key activation (e.g., coughing) were recorded manually by the experimenter.

The stimuli were presented in lowercase letters in the center of the screen, and they remained on the screen for 2,000 msec or until the subject made a verbal response that triggered the voice key. Subjects were not given feedback during the course of the experiment on either naming latency or error rates.

Each subject completed two blocks of trials, one block containing 40 exception words and 40 R&B nonwords, and a second block containing the other 40 exception words and 40 K&L nonwords. The order of the blocks was counterbalanced so that half the subjects began with the block containing the R&B nonwords and the other half began with the block containing the K&L nonwords. Within each order, half of the subjects started with exception words and the other half started with nonwords. Thus, combined with the four different versions of the lists, 16 subjects comprised a fully counterbalanced set.

RESULTS

Any trial involving a subject or voice key error was excluded from the latency analyses. (Only the regular pronunciation for nonwords was accepted as correct.) To minimize the effects of outliers, spuriously long or short latencies were trimmed to the cutoff value of 3 *SD*s above or below the mean for each subject (1.62% of all trials). Analyses treating both subjects (F_s) and items (F_i) as random factors are reported. An α value of .05 was used unless an alternative value is specified.

Mean correct naming latencies and error rates are presented in Table 1. The initial question is whether Reynolds and Besner's (2005) results can be replicated using their stimuli. We report an ANOVA with stimulus type (exception word vs. nonword) and switch type (stay vs. switch) as factors. In the by-subjects analysis, all were within-subjects factors; in the by-items analysis, stimulus type was a between-items factor and switch type was a within-items factor.

For latency, the results closely paralleled those of Reynolds and Besner (2005). Both main effects, stimulus type

Table 1
Mean Naming Latency (RT, in Milliseconds) and Percent Errors (%E)

	Switch Type					
	Stay		Switch		Switch Cost	
Stimulus Type	RT	%E	RT	%E	RT	%E
R&B nonword block						
Exception words	619	11.72	644	10.16	25	−1.56
R&B nonwords	714	17.50	724	15.63	10	−1.87
K&L nonword block						
Exception words	586	10.63	581	9.69	−5	−0.94
K&L nonwords	576	5.93	591	6.09	15	0.16

Note—R&B, Reynolds and Besner (2005); K&L, Rastle, Harrington, and Coltheart (2002).

[$F_s(1,31) = 42.91$, $MS_e = 5{,}624.73$; $F_i(1,158) = 41.41$, $MS_e = 13{,}632.22$] and switch type [$F_s(1,31) = 6.12$, $MS_e = 1{,}597.79$; $F_i(1,158) = 6.35$, $MS_e = 5{,}115.50$] were significant. There was no interaction [$F_s(1,31) < 1.0$; $F_i(1,158) = 1.17$, $p > .28$]. For error rates,[2] the main effect of stimulus type was significant [$F_s(1,31) = 21.28$, $MS_e = 47.58$; $F_i(1,158) = 8.99$, $MS_e = 281.45$]. The main effect of switch type was nonsignificant [$F_s(1,31) = 1.61$, $MS_e = 58.64$; $F_i(1,158) = 1.78$, $MS_e = 132.99$]. These factors did not interact (both Fs < 1.0).

The second question is whether the same pattern emerged with the easy-to-name (K&L) nonwords. The identical ANOVA performed on those data showed a different pattern. For latency, neither stimulus type nor switch type was significant (all Fs < 1.0). The interaction was significant, however, although only by subjects [$F_s(1,31) = 4.83$, $MS_e = 658.93$; $F_i(1,158) = 2.25$, $MS_e = 3{,}152.91$, $p = .14$]. As can be seen in Table 1, the interaction reflected virtually no effect for exception words and a switch cost for nonwords. For error rates, the main effect of stimulus type was significant [$F_s(1,31) = 18.48$, $MS_e = 29.68$; $F_i(1,158) = 7.19$, $MS_e = 190.68$]. The main effect of switch type and the interaction were not significant (all Fs < 1.0).

The final issue is whether it was the word results or the nonword results that changed as a function of changing the nonwords. For latency, the three-way interaction between nonword type (R&B nonwords vs. K&L nonwords), stimulus type (exception words vs. nonwords), and switch type (switch vs. stay) approached significance [$F_s(1,31) = 3.90$, $MS_e = 1{,}233.02$, $p = .057$; $F_i(1,158) = 3.33$, $MS_e = 3{,}917.40$, $p = .07$]. For words, switch type × nonword type interaction was significant [$F_s(1,31) = 6.69$, $MS_e = 1{,}093.94$; $F_i(1,79) = 6.66$, $MS_e = 3{,}983.61$], indicating that the switch pattern for the words changed as a function of nonword type. For nonwords, there was no hint of an interaction [$F_s(1,31) = 0.14$, $MS_e = 1{,}169.74$; $F_i(1,79) = .004$, $MS_e = 3{,}851.19$], indicating that the switch patterns for the two sets of nonwords were the same.

For errors, the three-way interaction was nonsignificant [$F_s(1,31) < 1.0$; $F_i(1,158) < 1.0$]. For words, none of the main effect or interaction effects were significant [$F_s(1,31) < 1.0$; $F_i(1,79) < 1.0$]. For nonwords, only the main effect of nonword type was significant [$F_s(1,31) = 37.93$, $MS_e = 93.84$; $F_i(1,79) = 43.35$, $MS_e = 205.29$]. There were more errors to the R&B nonwords than the K&L nonwords. Other main and interaction effects were nonsignificant [$F_s(1,31) < 1.0$; $F_i(1,79) < 1.0$].

Table 2
Error Types (in Percentages)

	R&B Nonword Block		K&L Nonword Block	
	Stay	Switch	Stay	Switch
	Exception Words			
Regularization	3.4	3.0	3.3	3.6
Dysfluencies	2.3	3.1	3.6	2.8
Others (voice key)	5.9	4.1	3.8	3.3
Total	11.7	10.2	10.6	9.7
	Nonwords			
Analogy	1.9	1.6	0	0
Lexicalization	3.6	3.4	0.6	1.6
Dysfluencies	7.3	5.8	1.6	1.1
Others (voice key)	4.7	4.8	3.8	3.4
Total	17.5	15.6	5.9	6.1

DISCUSSION

The pattern that was observed by Reynolds and Besner (2005)—a switch cost for both low-frequency exception words and nonwords—was replicated using their stimuli. In contrast, when using nonwords that were easier to read aloud, the pattern was different. Specifically, the low-frequency exception words showed no switch cost following these nonwords. In contrast, the switch cost pattern for nonwords did not change as a function of nonword type.

The fact that the switch cost for exception words was observed only following Reynolds and Besner's (2005) slow nonwords and not following the easy-to-name nonwords is entirely consistent with the time-criterion account. In contrast, Reynolds and Besner's route-emphasis proposal could only explain the change in the word data, as a function of changing nonword type, if there were also a parallel change in the nonword data. Specifically, from the route-shifting position, the absence of an interaction between nonword type and switch type for nonwords implies that the same shifting of relative route emphasis (between switch and stay trials) must have been occurring for both nonword types. If so, a switch cost should also have been observed for the exception words in the two nonword type blocks. In essence, if there is switching—and, hence, a switch cost—for one stimulus type (exception words or nonwords), there should have been a switch cost for the other stimulus type.

The apparent switch cost observed for both types of nonwords is typical of the pattern we have observed using list composition/filler type manipulations (see, e.g., Kinoshita & Lupker, 2003, Experiment 3; Lupker et al., 1997, Experiment 1). We noted in these articles that this cost for nonwords following exception words does not fit the RT homogenization pattern, because the slowdown occurred even when the exception words and nonwords had similar latencies. The notion of lexical checking that we proposed to explain the slowdown is not based on the idea of switching emphasis between lexical and nonlexical routes. The lexical checking process does not change the way in which phonology is computed from orthography. What changes is what happens to the phonology after it is computed.

In these earlier articles, we suggested that following a trial involving a low-frequency exception word, readers are more likely to consult the phonological output lexicon to determine whether the generated code matches a code in the lexicon. For nonwords, this results in a delay because no matching lexically based code can be found. The lexical checking mechanism construed this way is therefore specific to reading, in contrast to the mechanism driving the time-criterion effects, which is general across any type of stimuli. However, this doesn't mean the mechanisms are "intrinsically inconsistent" as was suggested by Reynolds and Besner (2005). In fact, it is possible to explain the slowdown for nonwords following exception words and RT homogenization within a single framework.

Specifically, in a more recent conceptualization, Mozer and colleagues (Kinoshita & Mozer, 2006; Mozer, Kinoshita, & Davis, 2004) put forward a mathematical formulation of the RT homogenization pattern, called the *adaptation to the statistics of the environment* (ASE) model. According to this idea, RT homogenization comes about because subjects average error curves (the subjective estimates of accuracy over time) for previous trials with the current trial. This averaged error curve is then combined with an RT cost function (which reflects the cost of waiting before responding, which increases linearly with time) to produce a utility measure (which reflects the combined cost of responding early at the risk of making an error and the cost of waiting). The optimal time to respond is estimated as the point in time at which utility is maximized. When the previous trial is fast, the averaged error curve is shifted to the left along the time axis. When the previous trial is slow, the averaged error curve is shifted to the right. Hence, the estimated optimal time to respond is also shifted to the left in the former case and to the right in the latter case. The effect of the latency of previous trials is thus explained in terms of this shift in the estimated optimal time to initiate responding as a result of averaging error curves.

The ASE model explains the RT homogenization pattern without assuming that the slope of the RT cost function (which reflects the cost of waiting) is changed as a function of latencies of previous trials. Increasing the slope of the RT cost function means that speed is emphasized (relatively) at the cost of accuracy; decreasing the slope means accuracy is valued more than speed. This assumption of no change to the RT function slope is justified by the fact that in the naming task, error rates are generally low and, for most items, responding early typically does not increase error rates (see, e.g., Colombo & Tabossi, 1992). The stimuli that are most likely to be an exception to this characterization, however, are low-frequency exception words. That is, they are exactly the type of stimuli that could lead to a wrong pronunciation (e.g., a "regularized" pronunciation, such as pronouncing *pint* to rhyme with *mint*) if the response is emitted too early. They stand in stark contrast to nonwords for which the constitution of a "correct" pronunciation is much more ambiguous. Thus, naming low-frequency exception words and nonwords may be the situation in which the relative emphasis on speed versus accuracy (i.e., the slope of the RT cost function) is most likely to be changed as a function of the previous trial: Following low-frequency exception words, more emphasis may be placed on accuracy (i.e., the slope of the RT cost function is flatter), whereas following nonwords, that emphasis on accuracy may be much less. Thus, within the ASE model, the notion of lexical checking could be viewed as a change in the relative emphasis on speed versus accuracy.

In sum, we suggest that it is possible to explain RT homogenization and the slowdown of nonwords following exception words within a single framework (although they do involve different mechanisms) in terms of attempts to optimize naming performance (optimizing RT and accuracy). Thus, there is no reason to prefer a "route-emphasis-shifting" account over the combined "time-criterion-plus-lexical-checking" account on the basis of parsimony. Most importantly, the empirical data reported here are inconsistent with a route-emphasis account, but not with the time-criterion-plus-lexical-checking account. We conclude, therefore, that there is still little evidence indicating that readers shift emphasis between lexical and nonlexical routes in speeded naming tasks.

AUTHOR NOTE

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NOTES

1. The new set of nonwords differed from Reynolds and Besner's (2005) nonwords on several dimensions, including length, whether they contained inconsistent bodies, and whether they contained the same inconsistent bodies as the exception words that were used as stimuli. It is therefore unknown which of these was the critical factor that led to the faster latencies. Note that from the time criterion perspective, this question is immaterial: What is relevant is simply that these nonwords were read aloud faster (see Lupker et al., 1997).

2. Error rates here refer to total errors—including voice key trigger failures that were due to responses being too quiet. We included these, because in some cases they represent the subject's uncertainty concerning how the item should be pronounced (e.g., *weau*, *muite*) and are distinct from dysfluency errors (which did trigger the voice key). The breakdown of error types is shown in Table 2.

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