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Contextual Effects on Reading Aloud: Evidence for Pathway Control

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Recent evidence suggests that the processes responsible for generating a phonological code from print are flexible in skilled readers. An important goal, therefore, is to identify the conditions that lead to changes in how a phonological code is computed. Five experiments are reported that examine whether phonological processes change as predicted by the pathway control hypothesis when reading aloud words and nonwords. Changes in reading processes were assessed by measuring the effect of predictable switches between stimulus categories across trials. The results of the present experiments are argued to be consistent with the pathway control hypothesis.

Keywords: pathway control hypothesis, reading aloud, exogenous control, executive control, phonology

Accounts of skilled reading often describe the process of translating print into sound as the flow of activation through a series of distinct process-specific modules (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Morton, 1969; Perry, Ziegler, & Zorzi, 2007; Plaut, McClelland, Seidenberg, & Patterson, 1996; Zorzi, Houghton, & Butterworth, 1998). The role of each process-specific module is context independent. That is, currently implemented computational models simulate skilled reading with little consideration of how these process-specific modules may vary in response to context. Processing in these accounts is structurally determined in the sense that the same computations are always performed in the same way on a stimulus (Underwood, 1978). For this reason, it is sometimes argued that computational models of reading meet all of the requirements for automatic processing (e.g., McCann, Remington, & Van Selst, 2000).

Although computational models of reading are often structurally determined, this assumption is not without controversy. Indeed, a number of researchers have also proposed dynamic accounts of word and nonword reading (e.g., Balota & Yap, 2006; Baluch & Besner, 1991; Coltheart & Rastle, 1994; Havelka & Rastle, 2005; Kello & Plaut, 2003; Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Rastle & Coltheart, 1999; Reynolds & Besner, 2005a; 2005b; Tabossi & Laghi, 1992; Zevin & Balota, 2000). Much of this research has been couched in terms of localist dual-route models of reading (e.g., Coltheart et al., 2001). We therefore begin by considering the characteristics of Coltheart et al.'s (2001) dual-route cascaded (DRC) model.[1]

The DRC Model

The DRC model of visual word recognition and reading aloud generates a phonological code from print using two different pathways (see Figure 1). The nonlexical pathway (Pathway B in Figure 1) assembles a phonological code using sublexical grapheme to phoneme correspondences. This pathway generates a correct pronunciation for regular words (e.g., *hint*) and nonwords (e.g., *zint*) but regularizes exception words (e.g., *pint* is read so as to rhyme with *hint*). The lexical pathway (Pathway A in Figure 1) addresses a lexical-phonological code from a lexical-orthographic code. This pathway generates a correct pronunciation for regular words (e.g., *hint*) and exception words (e.g., *pint*). The lexical pathway does not generate a correct pronunciation for nonwords (e.g., *zint*) because their spellings are not represented in the orthographic input lexicon. Thus, although both routes are always active, the correct pronunciation of a nonword requires the nonlexical pathway, and the correct pronunciation of an exception word requires the lexical pathway.

Although DRC currently simulates reading aloud with a static processing architecture, processing can be rendered dynamic by changing parameters so as to be responsive to the context in which the items are being read. However, without a theory to guide such parameter changes, this would be an incredibly laborious process. This is because although DRC has a transparent structural architecture (e.g., lexical and nonlexical pathways for translating print into sound, separate orthographic and phonological lexicons), its functional architecture is surprisingly opaque (see Reynolds & Besner, 2002, for one such illustration). DRC not only has more than 30 parameters, but it also has serial and parallel processing components (the nonlexical and lexical pathways, respectively),

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[1] Perry et al.'s (2007) connectionist dual-process (CDP+) model is similar to Coltheart et al.'s (2001) DRC model in that it contains lexical and nonlexical pathways for generating a phonological code. Indeed, the lexical route is taken from the DRC model. The nonlexical pathway differs in some respects. The most notable difference is that that the grapheme to phoneme rules used in DRC were replaced by an orthography to phonology network that is sensitive to the consistency of the spelling–sound correspondences in the CDP+ model.

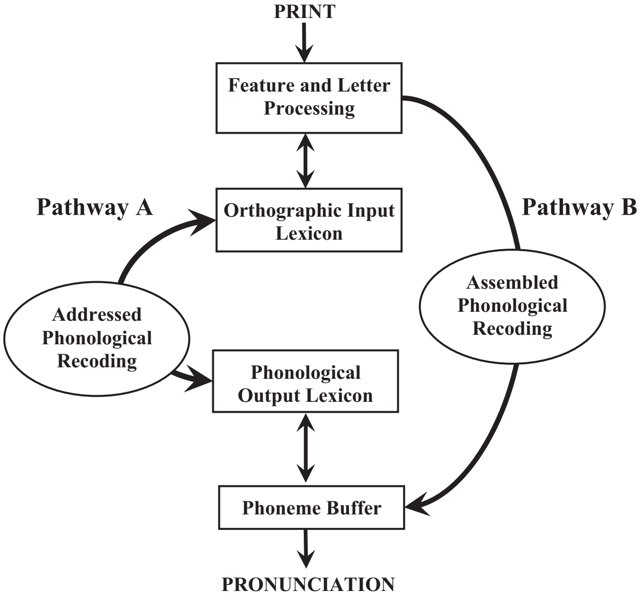

Figure 1. The structural architecture of Coltheart, Rastle, Perry, Langdon, and Ziegler's (2001) dual-route model of reading.

facilitatory and inhibitory connections, and interactive activation between four levels of representation. Transforming DRC into a dynamic account of reading aloud therefore requires specification of when processing changes, what processes are affected, and what types of processing changes occur. We do not claim to provide all the relevant information on the basis of the results of the present experiments. However, these results are relevant to such modeling.

The Pathway Control Hypothesis

One dynamic account of reading aloud that has been proposed on the basis of the localist dual-route framework is the pathway control hypothesis (Baluch & Besner, 1991; Coltheart & Rastle, 1994; Havelka & Rastle, 2005; Monsell et al., 1992; Rastle & Coltheart, 1999; Reynolds & Besner, 2005b; Tabossi & Laghi, 1992; Zevin & Balota, 2000). This account postulates that the relative contribution of a particular pathway for translating print into sound will be emphasized or deemphasized in response to the type of stimuli being read aloud. In particular, the relative contribution of a pathway will be increased when it is required to read a class of stimuli correctly and decreased when it cannot generate a correct pronunciation for that class of stimuli.

The pathway control hypothesis makes a number of straightforward predictions in the context of DRC. Namely, the nonlexical pathway will be emphasized when nonwords are read aloud because it is required to generate a correct pronunciation for items not represented in the orthographic and phonological lexicons. Similarly, the lexical pathway will be emphasized when exception words are read aloud because it is required to generate a correct pronunciation for words that do not follow the model's grapheme–phoneme conversion rules.

The hypothesis that control over reading aloud is intimately associated with the distinction between lexical and nonlexical procedures for translating print into sound has been the focus of a number of studies (e.g., Baluch & Besner 1991; Monsell et al., 1992; Reynolds & Besner, 2005b; Tabossi & Laghi, 1992; Zevin & Balota, 2000). For instance, Monsell et al. (1992) examined whether skilled readers would change how they generate a phonological code by changing the context in which words were read. They had participants read aloud either a pure list of exception words or these same exception words intermixed with nonwords. They hypothesized that the nonlexical route would be deemphasized when the pure list of exception words was read aloud but not when the exception words were mixed with nonwords. Consistent with the pathway control hypothesis, they reported that high-frequency exception words were read aloud faster in the pure list context than in the mixed list context.

Response Time (RT) Homogenization

Although the results from Monsell et al. (1992) and other studies are consistent with the claim that the process of generating a phonological code changes across contexts, such data have also been argued to be consistent with a very different interpretation. Lupker and colleagues (Chateau & Lupker, 2003; Kinoshita & Lupker, 2002; 2003; Lupker, Brown, & Colombo, 1997; Taylor & Lupker, 2001) have proposed that these same data are better understood in terms of changes outside the reading system. According to their RT homogenization account, skilled readers use a time criterion to determine when they will make an overt response. This time criterion for responding is adjusted on a trial-by-trial basis in response to the relative speed of the previous trial and is influenced by how long it takes, on average, to respond in a particular context (e.g., over a block of trials). Thus, the time criterion is set earlier following a fast trial and later following a slow trial. The consequence of these adjustments is that mixing fast and slow stimuli in a single block results in slower responses to the fast stimuli and faster responses to the slow stimuli. Critically, RT homogenization is not influenced by the nature of the stimuli (e.g., whether the stimulus is a word or a nonword).

Compelling support for the claim that participants do homogenize their responses has been reported in a number of studies (e.g., Chateau & Lupker, 2003; Kinoshita & Lupker, 2002; 2003; Lupker et al., 1997; Raman, Baluch, & Besner, 2004; Taylor & Lupker, 2001). The results of these and other studies led Kinoshita and Lupker (2003, p. 414) to conclude that, "there is still no compelling evidence that target naming latency is affected by the qualitative nature of the context stimuli in the way proposed by the pathway control hypothesis."

It is important to note that the RT homogenization account and the pathway control hypothesis need not be mutually exclusive. It may well be that contextual changes in reading aloud performance are a consequence of both RT homogenization and changes in pathway emphasis. At present, it seems clear that reading performance is affected by RT homogenization; it is less clear whether there is also strong evidence for contextual changes in how a phonological code is generated as predicted by the pathway control hypothesis (but see Balota & Yap, 2006; Reynolds & Besner, 2005b; Zevin & Balota, 2000).

Reynolds and Besner (2005b) suggested that the probability of observing changes in how a phonological code is generated may be influenced by the predictability of events in a given context. If there is substantial uncertainty about the nature of an upcoming item (as is the case in mixed list contexts, where the probability that the next item could be a word or a nonword is often equal), then it is unlikely that skilled readers will change how they generate a phonological code. Thus, even if a correct pronunciation for an exception word is dependent on the lexical pathway and a correct pronunciation for a nonword is dependent on the nonlexical pathway, there is little point in emphasizing one pathway over the other on a trial-by-trial basis if the reader cannot predict what type of stimulus appears on the next trial. Skilled reading performance therefore needs to be examined as a function of stimulus characteristics in a predictable context to assess whether the process of generating phonological code is static or dynamic.

Reynolds and Besner (2005b) proposed that Rogers and Monsell's (1995) alternating runs paradigm could be used to create such context. In this procedure, participants perform two tasks in a predictable AABB sequence. The alternating runs paradigm has traditionally been used to examine how processing is affected when switching between different tasks by comparing RTs on switch (A→B, B→A) and stay trials (A→A, B→B). According to Rogers and Monsell's logic, if (a) the mental processes used to complete each task change on a trial-by-trial basis, (b) adjusting these processes takes time, and (c) at least part of this reconfiguration cost is driven by the presence of the stimulus, then it should take longer to respond on switch trials (A→B or B→A) than on stay trials (A→A, B→B). Thus, an increase in RT on switch trials relative to stay trials (a switch cost) is evidence that switching from one task to another requires reconfiguring the mental processes used to complete a task.

Switch Costs

It is important to note that there is considerable debate concerning whether the increase in RT on switch trials compared with stay trials indexes a reconfiguration cost (e.g., Rogers & Monsell, 1995; see also Monsell, 2003), carryover from the previous trial (proactive interference; see Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000; Waszak, Hommel, & Allport, 2003; 2004), or both. The important point here is that both of these accounts are consistent with the interpretation that mental processing is changing in response to changes in task demands (see Pashler, 2000, for a review).

The alternating runs procedure has also been used to examine whether processing changes even when the task is held constant. For instance, von Studnitz and Green (1997) adapted Rogers and Monsell's (1995) procedure to examine the control processes operating when bilingual participants perform lexical decision to letter strings from different languages. Consistent with different parameter settings being used to recognize words displayed in English and German, performance was slower on switch trials (A→B, B→A) compared with stay trials (A→A, B→B). Similarly, Shafiullah and Monsell (1999) adapted Rogers and Monsell's (1995) procedure to examine whether different mechanisms were involved when words from the different Japanese orthographies were read aloud. Consistent with different scripts using different processing mechanisms, Shafiullah and Monsell (1999) found slower performance on switch trials (A→B, B→A) compared with stay trials (A→A, B→B) when participants switched between reading aloud items written in Kana (the Japanese syllabic script) and Kanji (the Japanese ideographic script).

Reynolds and Besner (2005b) used the alternating runs procedure to examine whether contextual changes within a script (English) lead to changes in how a phonological code is computed as predicted by the pathway control hypothesis. Participants read aloud low-frequency exception words and nonwords in an AABB sequence. If the process(es) used to generate a phonological code change as a function of stimulus characteristics as predicted by the pathway control hypothesis and if (a) adjusting the relative contribution from the lexical and the nonlexical pathways takes time and (b) at least part of this reconfiguration is driven by the presence of a letter string, then it should take longer to respond on switch trials (A→B or B→A) than on stay trials (A→A, B→B). Consistent with the relative contributions from lexical and nonlexical pathways changing when skilled readers generated a phonological code, Reynolds and Besner (2005b) reported switch costs both for the low-frequency exception words and for nonwords.

Here, we report five new experiments that use Reynolds and Besner's (2005b) procedure to further examine whether the process of generating a phonological code is dynamic in the way predicted by the pathway control hypothesis. These experiments are organized into two sections. The first three experiments examine whether trial-by-trial control is observed. The remaining two experiments examine whether there are circumstances in which skilled readers use a single experiment-wide set. Overall, the results of these experiments are consistent with the pathway control hypothesis.

Part 1: Trial-by-Trial Changes in Pathway Emphasis

We first report three experiments that explore the conditions that result in skilled readers changing their reading style within a block of trials as predicted by the pathway control hypothesis. Following Reynolds and Besner's (2005b) procedures, participants read aloud two classes of stimuli in an alternating AABB sequence. Whether participants are adapting their reading style on a trial-by-trial basis in response to the type of stimuli is inferred from the presence or absence of a switch cost.

Experiment 1

Experiment 1 examined a simple prediction of the pathway control hypothesis by having participants read aloud high-frequency exception words and nonwords in a predictable AABB sequence. If exception words are read aloud by emphasizing the lexical route and nonwords are read aloud by emphasizing the nonlexical route, then switch costs should be observed when switching between lexical categories.[2]

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[2] There are, of course, alternative accounts of visual word recognition and reading aloud, most notably the parallel distributed processing framework (e.g., Plaut et al., 1996). In these accounts, it is possible for high-frequency exception words and nonwords to be read aloud by recourse to a single process (orthography−hidden units−phonology). In the context of such an account, the pathway control hypothesis would not, a priori, predict trial-by-trial control over how a phonological code is being generated. In contrast, it would predict the switch costs observed by Reynolds and Besner when low-frequency exception words and nonwords were read aloud (see Reynolds and Besner, 2005b).

Method

Participants. Sixteen undergraduate students from the University of Waterloo, Waterloo, Ontario, Canada were each paid $4.00 to participate in the present experiment. All individuals had normal or corrected-to-normal vision and were native English speakers.

Stimuli. Experiment 1 used 50 high-frequency exception words (as defined by DRC; mean frequency = 311 according the Celex database; Baayen, Piepenbrock, & van Rijn, 1993) and 50 nonwords (see Appendix A). The nonwords were generated by rotating the onsets and bodies in the exception words where possible. Therefore, 97% of the unique orthographic bodies from the exception words were repeated in the nonwords.

Apparatus. Stimulus presentation was controlled by a Pentium IV 1.8 GHz computer running Eprime 1.1 software (Schneider, Eschman, & Zuccolotto, 2001). Vocal responses were collected using a Plantronics LS1 microphone headset (Santa Cruz, CA) and a voice-key assembly. Stimuli were displayed on a 17-inch (43.18-cm) ADI Microscan monitor (Taipei, Taiwan).

Procedure. The type of stimulus used on the initial trial (e.g., exception word or nonword) and whether a particular item would occur in a switch or stay context were counterbalanced across participants. Participants were assigned to one of four counterbalance conditions on the basis of the order in which they arrived in the lab.

Participants were tested individually and were seated approximately 50 cm from the computer monitor. A practice block consisted of eight trials to familiarize participants with the procedure. At the end of the practice session, participants were given limited feedback about their performance. Feedback about accuracy was limited to the regularizations of the exception words, lexicalizations of the nonwords, hesitations, and the addition or subtraction of phonemes.

The experimental block consisted of 100 trials. Each trial began with a fixation marker ("+") displayed at the center of the screen. The fixation marker remained on the screen for 1,000 ms, followed by a blank screen for 250 ms, and then the target, which remained on the screen until a vocal response was made. Once the stimulus disappeared, the screen remained blank for 1,000 ms before the next trial began. Thus, the response–stimulus interval was 2,250 ms.

Responses were classified by the experimenter during the response–stimulus interval as correct, incorrect, or voice-key failure. A pronunciation error was defined as an utterance that represented a clear mispronunciation of the word or nonword (i.e., an extra or deleted phoneme, hesitation or pause, stutter, regularization of the exception words, or lexicalization of the nonwords).

Participants were asked to read the letter strings aloud quickly and accurately. Exception words were described as words that do not sound like they look. Nonwords were described as stimuli that could be words but were not. Participants were told that the type of stimulus followed a predictable AABB sequence but were not given any explicit instructions about how to read the nonwords.

Results

Participant data were analyzed using a repeated-measures analysis of variance (ANOVA) with stimulus type (e.g., words–nonwords) and switch condition (switch–stay) as factors. Item data were analyzed using a mixed-model ANOVA with stimulus type as a between factor and switch condition as a repeated factor. The RT data were converted into *z* scores for the item analysis to reduce the impact of participant variability. We computed *z* scores for each participant by collapsing across conditions.

Trials on which there was an incorrect pronunciation (6.2%) or a voice-key failure (4.1%) were removed prior to the RT analysis. RTs to correct responses were subjected to a recursive trimming procedure in which the criterion cutoff for outlier removal was established independently for each condition for each participant by reference to the sample size in that cell (Van Selst & Jolicoeur, 1994). This resulted in the removal of 2.0% of the correct RT data. Correct RT and percentage error (PE) can be seen in Table 1.

RT. The exception words were read aloud faster than were nonwords, $F_1(1, 15) = 39.3$, $p < .001$, $MSE = 1{,}045$, $\eta^2 = .724$; $F_2(1, 98) = 58.9$, $p < .001$, $MSE = 0.414$, $\eta^2 = .375$. The time to read aloud was longer on switch than on stay trials, $F_1(1, 15) = 10.7$, $p < .001$, $MSE = 163$, $\eta^2 = .417$; $F_2(1, 98) = 6.3$, $p < .05$, $MSE = 0.108$, $\eta^2 = .07$. There was no interaction between stimulus type and switch condition (Fs < 1.3).

PE. More errors were made to nonwords than to words, $F_1(1, 15) = 51.9$, $p < .001$, $MSE = 33.9$, $\eta^2 = .776$; $F_2(1, 98) = 33.2$, $p < .001$, $MSE = 160$, $\eta^2 = .253$. No other effects approached significance (Fs < 1).

Discussion

A switch cost was observed for both the high-frequency exception words and the nonwords, replicating the pattern of results reported by Reynolds and Besner (2005b) for low-frequency exception words and nonwords. This outcome is consistent with skilled readers emphasizing the lexical pathway when reading aloud exception words and the nonlexical pathway when reading aloud nonwords as predicted by the pathway control hypothesis.

Experiment 2

The vast majority of the exception word and nonword stimuli used in Experiment 1 shared orthographic bodies (e.g., "ave" in *have* and *bave*). As a consequence, the majority of the bodies read aloud in Experiment 1 were assigned both an irregular and a regular pronunciation. An alternative account of these data, therefore, is that participants changed how a phonological code was generated to minimize the impact of a previously assigned phono-

Table 1
Mean Response Time (RT) and Percentage Error (PE) for High-Frequency Exception Words and Nonwords as a Function of Switch and Stay Trials in Experiment 1

	High-frequency exception words		Nonwords	
Trial	RT	PE	RT	PE
Switch	491	2.0	539	12.2
Stay	478	0.5	531	11.3
Difference	13	1.5	8	1.0

Note. Ninety-seven percent of the unique orthographic bodies in the exception words are repeated in the nonwords. RTs are in milliseconds.

logical code that may not be appropriate in the present context (e.g., /æv/ from *have* when reading *bave*). This same confound exists in the experiment reported by Reynolds and Besner (2005b).

If the switch costs observed in Experiment 1 were entirely due to orthographic overlap at the level of rimes between the exception words and nonwords, then a switch cost should not be observed when this overlap is reduced. In contrast, if the switch costs are a consequence of the fact that the exception word and nonword stimuli require different procedures for generating a correct phonological code, then a switch cost should still be observed for both classes of items.

Method

Participants. Sixteen undergraduate students from the University of Waterloo were each paid $4.00 to participate in the present experiment. All individuals had normal or corrected-to-normal vision and were native English speakers.

Stimuli. Experiment 2 used the 50 high-frequency exception words from Experiment 1 and a new set of 50 nonwords (see Appendix B). Only 37% of the unique orthographic bodies from the exception words were repeated in the nonwords, as compared with 97% in Experiment 1.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 1.

Results

Trials on which there was an incorrect pronunciation (4.6%) or a voice-key failure (2.3%) were removed prior to the RT analysis; 2.3% of the correct RT data were removed due to the trimming procedure. Correct RT and PE can be seen in Table 2.

RT. The exception words were read aloud faster than were nonwords, $F_1(1, 15) = 86.1$, $p < .001$, $MSE = 729$, $\eta^2 = .85$; $F_2(1, 98) = 147.7$, $p < .001$, $MSE = .267$, $\eta^2 = .61$. There was also a significant switch cost, $F_1(1, 15) = 24.7$, $p < .001$, $MSE = 181$, $\eta^2 = .62$; $F_2(1, 98) = 22.6$, $p < .001$, $MSE = .114$, $\eta^2 = .19$. There was no interaction between stimulus type and switch condition ($F_1 < 1.5$, $\eta^2 = .08$; $F_2 = < 1$, $\eta^2 < .01$).

PE. More errors were made to nonwords than to words, $F_1(1, 15) = 18.3$, $p < .001$, $MSE = 34.1$, $\eta^2 = .55$; $F_2(1, 98) = 18.0$, $p < .001$, $MSE = 108$, $\eta^2 = .16$. There was no effect of switch condition ($F_1 < 1$, $\eta^2 < .01$; $F_2 < 1$, $\eta^2 < .01$), nor was there an interaction between stimulus type and switch condition, $F_1(1, 15) = 1.4$, $\eta^2 = .08$; $F_2 < 1$, $\eta^2 < .01$.

Table 2
Mean Response Time (RT) and Percentage Error (PE) for High-Frequency Exception Words and Nonwords as a Function of Switch and Stay Trials in Experiment 2

	High-frequency exception words		Nonwords	
Trial	RT	PE	RT	PE
Switch	504	1.0	563	8.0
Stay	484	2.0	550	7.5
Difference	20	−1.0	13	0.5

Note. Thirty-seven percent of the unique orthographic bodies in the exception words are repeated in the nonwords. RTs are in milliseconds.

Discussion

Statistically symmetric switch costs were again observed for both classes of items. The persistence of a switch cost despite reduced orthographic overlap between the exception word and nonword rimes is consistent with phonological processing changing as predicted by the pathway control hypothesis. It should also be noted that reducing orthographic overlap did not lead to a reduction in the size of the switch cost as compared with Experiment 1. As such, the present data suggest that phonological discordance due to ubiquitous orthographic overlap at the level of rimes is not a necessary condition for changes in phonological processing to be observed. That said, this outcome does not rule out the possibility that skilled readers can exploit orthographic overlap at the level of rimes across conditions to generate a phonological code.

Experiment 3

In Experiment 1, and, to a lesser degree, Experiment 2, the nonwords were inconsistent (e.g., Glushko, 1979; Jared, 1997). Inconsistent nonwords are those for which there are alternative pronunciations for the rime (e.g., the rime in *zint* can be assigned the pronunciation /aɪnt/ as in *pint* or the pronunciation /Int/ as in *hint*). It is therefore possible that participants are adapting how they generate a phonological code on a trial-by-trial basis in response to ambiguity in the pronunciations of these nonwords. According to such an account, it is not that a particular pathway is required to read an item correctly that leads skilled readers to adapt how they generate a phonological code, but rather it is the ambiguous lexical contribution to phonology.

If the changes in phonological processing observed in Experiments 1 and 2 were due to nonword consistency, then the switch costs should be eliminated if the nonwords are consistent (as well as not sharing rimes with the exception words). In contrast, if the changes in how a phonological code is computed arise as predicted by the pathway control hypothesis, then switch costs will still be observed.

Method

Participants. Sixteen undergraduate students from the University of Waterloo were each paid $4.00 to participate in the present experiment. All individuals had normal or corrected-to-normal vision and were native English speakers.

Stimuli. Experiment 3 used the 50 exception words from Experiments 1 and 2 and a new set of 50 consistent nonwords (see Appendix C). None of the unique orthographic bodies from the exception words were repeated in the nonwords.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiments 1 and 2.

Results

Trials on which there was an incorrect pronunciation (3.3%) or a voice-key failure (2.6%) were removed prior to the RT analysis;

1.9% of the correct RT data were removed due to the trimming procedure. Correct RT and PE can be seen in Table 3.

RT. The exception words were read aloud faster than were the nonwords, $F_1(1, 15) = 18.9$, $p < .001$, $MSE = 6{,}055$, $\eta^2 = .55$; $F_2(1, 98) = 106.2$, $p < .001$, $MSE = 0.273$, $\eta^2 = .52$, and there was a significant switch cost, $F_1(1, 15) = 7.6$, $p < .001$, $MSE = 469$, $\eta^2 = .35$; $F_2(1, 98) = 10.9$, $p < .001$, $MSE = .128$, $\eta^2 = .10$. There was no interaction between stimulus type and switch condition ($F_1 < 1$, $\eta^2 < .01$; $F_2 < 1$, $\eta^2 < .01$).

PE. More errors were made to nonwords than to words, $F_1(1, 15) = 17.3$, $p < .001$, $MSE = 10.5$, $\eta^2 = .54$; $F_2(1, 98) = 14.5$, $p < .001$, $MSE = 51$, $\eta^2 = .12$. There was no switch cost ($F_1 < 1$, $\eta^2 < .01$; $F_2 < 1$, $\eta^2 < .01$), nor was there an interaction between stimulus type and switch condition, $F_1(1, 15) = 1.2$, $\eta^2 = .08$; $F_2(1, 98) = 2.2$, $p > .10$, $MSE = 46.1$, $\eta^2 = .02$.

Discussion

Once again, statistically symmetric switch costs were observed despite the use of consistent nonwords that did not share rimes with the exception words. This outcome is consistent with skilled readers changing how they generate a phonological code as predicted by the pathway control hypothesis. The observation of switch costs in the present experiment also reinforces the conclusion that orthographic overlap or phonological discordance between the exception words and nonwords was not the cause of the switch costs observed in Experiment 1, nor in Reynolds and Besner's (2005b) work. It also suggests that ambiguity in the pronunciation of the nonwords (as defined by consistency at the level of the nonword body) is not a necessary condition for trial-by-trial control to be observed.

Summary: Experiments 1–3

Experiments 1–3 examined whether skilled readers change how they read as predicted by the pathway control hypothesis. According to this account, skilled readers will emphasize the lexical pathway when reading exception words aloud because it is required to generate a correct pronunciation and will emphasize the nonlexical pathway when reading nonwords aloud because it is required to generate a correct pronunciation.

There are now four demonstrations (Experiments 1–3 reported here and the experiment reported by Reynolds & Besner, 2005b) that skilled readers do change how they generate a phonological code from print when reading aloud exception words and nonwords in a predictable sequence. Pathway emphasis (defined here by the presence of a switch cost) occurs (a) regardless of how frequently the exception words are encountered in print, (b) regardless of the orthographic overlap between the exception words and nonwords, and (c) regardless of the consistency of the nonwords. The pathway control hypothesis therefore provides a good account of these data.

Table 3
Mean Response Time (RT) and Percentage Error (PE) for High-Frequency Exception Words and Nonwords as a Function of Switch and Stay Trials in Experiment 3

	High-frequency exception words		Nonwords	
Trial	RT	PE	RT	PE
Switch	531	2.3	613	4.8
Stay	516	1.0	599	5.3
Difference	15	1.3	14	−0.5

Note. None of the unique orthographic bodies in the exception words are repeated in the nonwords. RTs are in milliseconds.

Part 2: Experiment-wide Control

The data from Experiments 1–3 and those reported by Reynolds and Benser (2005b) can be accounted for by a straightforward version of the pathway control hypothesis in which a pathway will only be emphasized if it is required to generate a correct pronunciation. This simple version of the pathway control hypothesis predicts that a trial-by-trial control over how a phonological code is generated will only be observed if the stimuli being read aloud require different pathways for correct pronunciation (e.g., exception words and nonwords). In contrast, if one set of stimuli requires the use of a particular pathway and the other set of stimuli does not require the use of a different pathway, then no switch cost need be observed.

According to the DRC model, regular words differ from exception words and nonwords in that a correct phonological code can be generated by both the lexical pathway and the nonlexical pathway. Therefore, if participants read aloud regular words and exception words in a predictable sequence, then the presence of exception words should result in the regular words being read aloud with the lexical pathway emphasized. If participants read aloud regular words and nonwords in a predictable sequence, then the presence of nonwords should result in the regular words being read aloud with the nonlexical pathway emphasized. A switch cost would therefore not be expected in either of these cases.

Experiment 4

Exception words and regular words were read aloud together in Experiment 4. If the lexical pathway can be emphasized throughout the experiment, then an effect of switching between stimuli need not be observed.

Method

Participants. Sixteen undergraduate students from the University of Waterloo were each paid $4.00 to participate in the present experiment. All individuals had normal or corrected-to-normal vision and were native English speakers.

Stimuli. Experiment 4 used 48 exception words and 48 regular words (see Appendix D). Approximately 75% of the exception words were used in Experiments 1–3. The stimuli for both types of words were selected from the entire frequency spectrum. However, the mean frequency of the exception words ($M = 268$ counts per million) was significantly higher than that of the regular words ($M = 47$ counts per million), $t(94) = 3.7$, $p < .001$. An advantage of this difference in word frequency is that it is possible to produce a main effect of word type in the context of an experiment in which a null switch cost is expected, rather than report an experiment in which there are no significant effects at all. Similar to Experiment

1, 85% of the unique orthographic bodies from the exception words were repeated in the regular words.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiments 1–3.

Results

Trials on which there was an incorrect pronunciation (4.7%) or a voice-key failure (4.9%) were removed prior to the RT analysis; 2.4% of the correct RT data were removed due to the trimming procedure. Correct RT and PE can be seen in Table 4.

RT. As expected, the higher frequency exception words were read aloud faster than were the lower frequency regular words, $F_1(1, 15) = 40.9$, $p < .001$, $MSE = 619$, $\eta^2 = .732$; $F_2(1, 94) = 19.7$, $p < .001$, $MSE = .432$, $\eta^2 = .174$. There was no cost of switching between regular and exception words ($F_1 < 1$, $\eta^2 = .001$; $F_2 < 1$, $\eta^2 = .002$), nor was there an interaction between stimulus type and switch condition ($F_1 < 1$, $\eta^2 = .027$; $F_2 = 1.1$, $\eta^2 = .012$).

PE. No effects approached significance in the error data (*F*s < 1.4).

Discussion

A switch cost was not observed in Experiment 4, consistent with the claim that both the exception words and the regular words were read aloud by emphasizing the lexical pathway throughout the experiment.

Experiment 5

The regular words from Experiment 4 were read together with a set of nonwords. If the nonlexical pathway can be emphasized throughout the experiment, then a switch cost need not be observed here.

Method

Participants. Sixteen undergraduate students from the University of Waterloo were each paid $4.00 to participate in the present experiment. All individuals had normal or corrected-to-normal vision and were native English speakers.

Stimuli. Experiment 5 used the 48 regular words (from Experiment 4) and 48 nonwords (see Appendix E). Similar to Experiments 1 and 4, 82% of the unique orthographic bodies from the exception words were repeated in the nonwords.

Table 4
Mean Response Time (RT) and Percentage Error (PE) for High-Frequency Exception Words and Regular Words as a Function of Switch and Stay Trials in Experiment 4

Trial	High-frequency exception words RT	PE	Regular words RT	PE
Switch	517	5.6	553	5.4
Stay	512	3.2	557	6.0
Difference	5	2.4	−4	−0.6

Note. Eighty-five percent of the unique orthographic bodies in the exception words are repeated in the regular words. RTs are in milliseconds.

Table 5
Mean Response Time (RT) and Percentage Error (PE) for Regular Words and Nonwords as a Function of Switch and Stay Trials in Experiment 5

Trial	Regular words RT	PE	Nonwords RT	PE
Switch	543	2.2	614	10.8
Stay	536	3.6	618	9.4
Difference	7	−1.4	−5	1.4

Note. Eighty-two percent of the unique orthographic bodies in the regular words are repeated in the nonwords. RTs are in milliseconds.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiments 1–4.

Results

Trials on which there was an incorrect pronunciation (6.1%) or a voice-key failure (5.5%) were removed prior to the RT analysis; 1.8% of the correct RT data were removed due to the data trimming procedure. Correct RT and PE can be seen in Table 5.

RT. The regular words were read aloud faster than were the nonwords, $F_1(1, 15) = 30.5$, $p < .001$, $MSE = 3{,}070$, $\eta^2 = .670$; $F_2(1, 94) = 58.0$, $p < .001$, $MSE = 6{,}191$, $\eta^2 = .400$. There was no significant switch cost ($F_1 < 1$, $\eta^2 = .002$; $F_2 < 1$, $\eta^2 < .001$), nor was there an interaction between stimulus type and switch condition, $F_1 < 1$, $\eta^2 = .015$; $F_2(1, 94) = 1.9$, $p > .10$, $MSE = 2{,}115$, $\eta^2 = .02$.

PE. More errors were made to nonwords than to words, $F_1(1, 15) = 16.9$, $p < .001$, $MSE = 49.1$, $\eta^2 = .529$; $F_2(1, 94) = 11.5$, $p < .001$, $MSE = 200$, $\eta^2 = .111$. There was no switch cost ($F_1 < 1$, $\eta^2 < .001$; $F_2 < 1$, $\eta^2 < .001$), nor was there an interaction between stimulus type and switch condition, $F_1(1, 15) = 1.2$, $p > .15$, $MSE = 23.7$, $\eta^2 = .077$; $F_2(1, 94) = 2.5$, $p > .10$, $MSE = 45.9$, $\eta^2 = .026$.

Discussion

No significant main effect of switching stimulus categories was observed in Experiment 5 (1 ms), consistent with participants using a single experiment-wide set for generating a phonological code. Although there was a nonsignificant 7-ms switch cost for the regular words, this coincided with a decrease in errors on the switch trials. Thus, despite a switch cost when exception words and nonwords were intermixed in Experiments 1–3, no switch cost was observed when exception words and regular words were mixed together (Experiment 4) or when nonwords and regular words were mixed together (Experiment 5). This suggests that the regular words in Experiment 4 were read with an experiment-wide emphasis on the lexical pathway, whereas the same set of words in Experiment 5 was read with an experiment-wide emphasis on the nonlexical pathway.

The Effect of Word Frequency

To further assess whether the regular words were being read with the lexical pathway emphasized in Experiment 4 and with the nonlexical pathway emphasized in Experiment 5, we also examined whether the effect of word frequency changed size for the regular words between experiments. The expectation is that the effect of word frequency should be larger for the regular words in Experiment 4 than in Experiment 5 because in the former case, the lexical pathway is emphasized, whereas in the latter case, the nonlexical pathway is emphasized.

As noted above, the regular words were selected from the entire frequency spectrum. The effect of word frequency was therefore examined by calculating the slope relating log10[(word frequency / million) $+1$] and RT separately for each participant. These slopes were then analyzed using a mixed-model ANOVA with switch condition as the repeated factor and experiment as the independent factor. An average slope of zero would imply that there is no effect of word frequency. As can be seen Table 6, there was a significant frequency effect in both Experiment 4, $F(1, 15) = 40.0$, $p < .001$, $MSE = 1{,}041$, and Experiment 5, $F(1, 15) = 7.0$, $p < .05$, $MSE = 493$. However, further analysis revealed a significant effect of experiment, $F(1, 30) = 13.3$, $p < .001$, $MSE = 767$, indicating that the effect of word frequency was larger in Experiment 4 (-36 ms / log10[frequency]) compared with Experiment 5 (-10 ms / log10[frequency]). No other effects approached significance (Fs $<$ 1). Consistent with the pathway control hypothesis, this outcome implies that there was a larger contribution from the lexical route when the regular words were read with exception words compared with when they were read with nonwords.

Part 3: Exogenous and/or Endogenous Control

The switch costs observed in the present studies indicate that the processes responsible for generating a phonological code from print are dynamic, but they do not inform us about the control processes responsible for implementing these changes. Fortunately, some insight into these control processes can be gained by considering accounts of residual switch costs in the task-switching literature. A common finding in such experiments is that a residual switch cost is observed despite sufficient time to prepare for the new task (e.g., 2,250 ms, as in the present studies). One account of this cost is that it reflects exogenous control driven by the presentation of the task-relevant stimulus. For instance, Rogers and Monsell (1995; see also Monsell, 2003) have suggested that residual switch costs index the time taken for an exogenous component of the task-set reconfiguration process, and Allport et al. (1994) have suggested that the residual switch cost is due to passive carryover from the inappropriate task set. Critically, both of these accounts of the residual switch costs suggest that processing changes are not finalized until after the stimulus is presented. An alternative account is that the residual switch cost is due to endogenous control. For instance, De Jong (2000) suggested that on a subset of trials participants wait until the stimulus appears to implement the necessary changes. According to this account, the residual switch cost arises not because reconfiguration requires an external stimulus for completion, but rather because people sometimes fail to engage the new task set prior to the stimulus.

Table 6
Mean Slope Relating RT (in Milliseconds) to log10 (Word Frequency) for Regular Words as a Function of Switch and Stay for Experiments 4 and 5

Experiment	Switch	Stay
4	−34	−37
5	−10	−11
Difference	−24	−26

Although a switch cost, by itself, does not discriminate between exogenous and endogenous control, the pattern of switch costs across experiments is instructive. For instance, switch costs are observed when exception words and nonwords are read aloud in alternating sequence, irrespective of the words' printed word frequency and across a number of different nonword contexts. If it is the case that the parameter settings are always adjusted when alternating between exception words and nonwords, then endogenous control operating on a trial-by-trial basis is not necessary to explain these findings; exogenous control driven by the stimulus itself would be sufficient to engage the appropriate parameter changes.

A more formal approach to distinguishing between exogenous and endogenous accounts of control in the task-switching literature consists of examining the cumulative RT distributions for switch and stay trials (De Jong, 2000; Nieuwenhuis & Monsell, 2002). According to De Jong (2000), if the difference between switch and stay trials is due to exogenous control linked to the presentation of the stimulus, then the cumulative RT distributions for switch trials will be shifted along the abscissas relative to the stay distribution but both distributions should be identical in shape; in other words, additive effects of switch condition across the cumulative RT distribution. In contrast, if the difference between switch and stay trials is due to endogenous control that is linked to the stimulus on a subset of trials, then the response distribution for switch trials will be composed of trials on which there was no change in processing associated with the presentation of the stimulus and trials on which the change in processing is tied to the presentation of the stimulus. When the change in processing on switch trials is linked to the presentation of the stimulus, RTs will be longer as compared with when the change occurs prior to the stimulus presentation. As a consequence, the fastest RTs will mostly consist of switch trials on which there is no change in processing associated with the presentation of the stimulus, and the slowest RTs mostly consist of trials on which the change is associated with the presentation of the stimulus. As noted by De Jong, this predicts that the switch and stay distributions should converge at fast RTs and diverge at slow RTs. Thus, endogenous control predicts that the cumulative RT distributions for switch and stay trials will differ in shape; as RT increases, the difference between the distributions will increase. We use these predictions here to assess whether the switch costs observed in the present experiments are due to exogenous control, endogenous control, or both, depending on the experiment.

The cumulative RT distributions for switch and stay trials were calculated individually for each participant in Experiments 1–5, collapsing across lexicality. The distributions were created by rank ordering the correct RT in the switch and stay conditions and then splitting the data into deciles (see De Jong, 2000). An average RT was calculated for each decile for each participant.

The analysis of switch costs reported earlier suggests that (a) the trial-by-trial control observed in Experiments 1–3 is due to exogenous control and (b) the trial-by-trial control is not occurring in

Experiments 4 and 5. The data from these experiments were therefore analyzed separately. However, to improve power, Experiments 1–3 were analyzed together, as were Experiments 4 and 5. The data were analyzed using a repeated-measures ANOVA with switch and decile as factors. Given that endogenous control predicts that the difference between the switch and stay distributions will increase with RT, only the linear component of the interaction will be examined to increase power. The data can be seen in Figure 2.

Experiments 1–3

The observation that switch costs are found across a range of contexts is sufficiently explained by exogenous control. This account predicts that the cumulative response distributions for switch and stay should be separated by a constant. Thus, exogenous control predicts a main effect of switch condition and no interaction. As can be seen in the left panel of Figure 2, when exception words and nonwords were read aloud in an alternating sequence in Experiments 1–3, a 14-ms main effect of switch condition was observed, $F(1, 47) = 30.7$, $p < .001$, $MSE = 1{,}571$. However, there was no evidence of an interaction with decile, $F(1, 47) < 1$. A sufficient account, therefore, is that the switch costs observed when alternating between exception words and nonwords are due to exogenous control.

Experiments 4 and 5

In Experiments 4 and 5, it was possible for a single experiment-wide parameter set to be used. It was therefore hypothesized that trial-by-trial control would not be observed. Consistent with this prediction, a main effect of switch condition was not observed. If trial by-trial control does not occur, then the cumulative RT distributions for switch and stay trials should not differ. Such an outcome would provide converging evidence for the claim that trial-by-trial control was not occurring in these experiments. As can be seen in the right panel of Figure 2, there was no effect of switch condition and no interaction between switch condition and decile (Fs < 1).

Summary

The RT distribution data are consistent with the central premise of dual-route theory, namely that (a) the lexical pathway must dominate performance for exception words to be read aloud correctly, (b) the nonlexical pathway must dominate performance for nonwords to be read aloud correctly, and (c) regular words can be read correctly with either the lexical pathway or the nonlexical pathway dominating performance. The data are also compatible with the pathway control hypothesis; when the stimuli require different pathways to dominate, as is the case when alternating between exception words (that require the lexical route) and nonwords (that require the nonlexical route), the appropriate pathway is emphasized.

The RT distribution data are also consistent with the dynamics of the reading system being controlled exogenously, linked to the presentation of the target stimulus. At first blush, it may appear as though it is necessary to invoke endogenous control to explain why trial-by-trial control was observed in Experiments 1–3 but not in

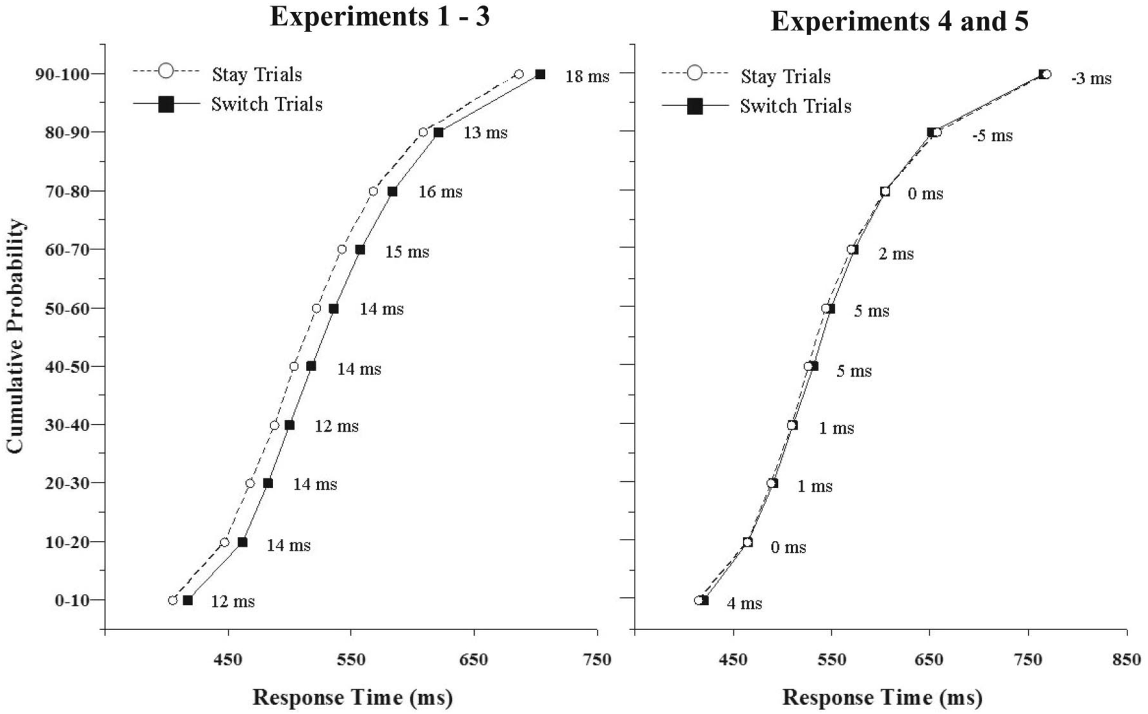

Figure 2. Cumulative response time distributions (in milliseconds) for switch and stay trials for Experiments 1–3 (left) and Experiments 4 and 5 (right).

Experiments 4 and 5. However, the data from all of the present experiments can be explained by two simple context insensitive rules: (a) If a stimulus (e.g., an exception word) is incompatible with the nonlexical pathway (leaving aside the issue of how this is computed), then emphasize the lexical route, and (b) if a stimulus (e.g., a nonword) is incompatible with the lexical route (again leaving aside the issue of how this is computed), then emphasize the nonlexical route. Neither of these rules applies to regular words, so these stimuli will not elicit a change in pathway emphasis. Consequently, when both rules are used in an experiment, trial-by-trial control will be observed (e.g., Experiments 1–3). If only one rule is used, then trial-by-trial control will not be observed (e.g., Experiments 4 and 5) because a single pathway will be emphasized for both classes of stimuli (i.e., the lexical pathway in Experiment 4 and the nonlexical pathway in Experiment 5). If the rules that govern the dynamics of the reading system are context insensitive, then the most efficient implementation is to have the stimulus itself engage the appropriate parameter set (i.e., under exogenous control). This raises an important question for future research: Is there a role for endogenous control over the process of generating a phonological code?

Switch Costs: Reconfiguration or Interference?

The effect of predictable changes in lexicality as reported here and by Reynolds and Besner (2005b) can be attributed to either the time it takes to reconfigure the processing system online (reconfiguration cost) or to proactive interference from attempting to read using a nonoptimal configuration from the previous trial. According to the reconfiguration account, slower RTs are observed on switch trials because reconfiguration of the reading system finishes after the stimulus appears but before a response is made. Here, the RT difference between switch and stay trials is a measure of the time necessary to reconfigure the system to optimally read a stimulus (e.g., Rogers & Monsell, 1995). One problem with this account in the present context is that it is unclear what analysis of the stimulus takes place online that would result in online reconfiguration and does not interact with the online computation of a phonological code.

According to the proactive interference account, slower RTs are observed on switch trials because the system parameters from the previous trial are used (e.g., Allport et al., 1994). According to this interpretation of a switch cost, the processing system is reconfigured *after* a stimulus is read using the inappropriate parameter settings (e.g., because of the magnitude of the discrepancy between the outputs of the two routes). Thus, on switch trials, an exception word would be read using the parameters optimized for the previous nonword and vice versa. (Note that this does not imply that the exception words will be regularized, only that the nonlexical route will have a larger impact on switch trials compared with stay trials.) Here, faster RTs for stay trials (A→A, B→B) reflect a benefit from having successfully reconfigured the processing system.

Although the present studies do not address whether differences in RT between switch and stay trials are a consequence of reconfiguration time or proactive interference, one can imagine an experiment that does. For instance, a powerful test of the proactive interference account would come from a within-subjects comparison of the effect of a psycholinguistic variable (e.g., word frequency) across switch and stay trials. Consider an experiment in which participants read aloud exception words that vary on word frequency and nonwords in an AABB sequence. If the switch cost arises because the system parameters from the previous trial are being used, then this implies that the exception words are being read with the nonlexical pathway emphasized on switch trials and with the lexical pathway emphasized on stay trials. This suggests that the effect of word frequency should be smaller for exception words on switch trials as compared with stay trials in the context of an experiment that produces a main effect of switch condition. In contrast, we see no reason for the online reconfiguration account to predict any change in the size of the word frequency effect across switch and stay trials.

Additional insight may come from comparing the pronunciations made with items on switch and stay trials. Variability in the pronunciations assigned to nonwords has been used to make inferences about the underlying structure of the reading system (e.g., Andrews & Scarrett, 1998). Similarly, some of the earliest evidence for the pathway control hypothesis comes from errors made during reading aloud (Midgley-West, 1979; Monsell et al., 1992). In the present context, such an analysis could provide important insight into the dynamic structure of the reading system while simultaneously providing evidence for the interference account. For example, if an irregular pronunciation of a nonword (e.g., *zint* read so as to rhyme with *pint*) is more likely on a switch trial compared with a stay trial, then this would provide compelling evidence that the contribution from the lexical pathway is changing across switch and stay trials. Unfortunately, such an analysis is impossible with the present studies because we did not record participants' pronunciations.

Control and Optimization

A core assumption of the pathway control hypothesis is that changes are made to the reading system to optimize the reading process. An important question, then, is how to assess whether the reading system is being optimized under conditions where trial-by-trial control is observed, such as Experiments 1–3. If one considers the stay trials to be an appropriate baseline for optimized performance, then slower responses on switch trials represent a failure of the system to optimize performance. Similarly, if the switch trial is viewed as an appropriate baseline, then the benefit from the optimization process is quite small (14 ms, on average, in Experiments 1–3), implying that the optimization process is inefficient. Although both baselines suggest that the reading system is attempting to optimize performance, their validity remains to be verified. Indeed, there are at least two other baselines that will likely provide more appropriate insight into the optimization of the reading process and the true costs of control.

To assess whether trial-by-trial changes in parameter values optimize performance when two intermixed classes of stimuli (e.g., exception words and nonwords) appear in a predictable alternating sequence (as in the present studies), performance should to be compared with a baseline in which the same stimuli are randomly intermixed. Faster overall RTs in the alternating runs condition would suggest that performance is being optimized. This is clearly a useful direction for future research.

Additional insight into the nature of the control processes and their costs can be gained by comparing performance in an alternating runs context with a baseline condition in which participants read aloud a single class of items. Evidence from the task-switching literature suggests that task performance is substantially slower on stay trials in an alternating runs context compared with when only a single task is performed. This cost is often attributed to having to maintain two task sets in memory (see Monsell, 2003; Pashler, 2000). Switching between tasks, however, requires a greater number of parameter changes than switching between stimuli when the task and script remain the same. It remains to be seen whether similar performance differences will be observed when alternating between different stimulus categories, as in the present studies.

General Discussion

According to the basic version of the pathway control hypothesis considered here, (a) there are two pathways for generating a phonological code from print and (b) changes to the relative emphasis of these pathways arise when a specific pathway is required to generate a correct pronunciation. In this account, exception words require the lexical pathway to generate a correct pronunciation, nonwords require the nonlexical pathway to generate a correct pronunciation, and a correct pronunciation can be generated by either pathway for regular words.

The results of the present experiments are consistent with this simple version of the pathway control hypothesis. In Experiments 1–3, the process of generating a phonological code changed as a function of stimulus category (exception words vs. nonwords) when the stimuli required different pathways. Furthermore, these changes in pathway emphasis appear to be initiated by an exogenous control process time linked to the onset of the stimulus. Within Experiments 4 and 5, the process of generating a phonological code did not change as a function of stimulus category but it did change across experiments. This result suggests that both classes of items were read using a single parameter set in which a particular pathway is emphasized.

RT Homogenization

The results of the present experiments also suggest that contextual changes in reading performance are not solely a consequence of RT homogenization, in contrast to the conclusion offered by Lupker et al. (1997; Kinoshita & Lupker, 2003; Taylor & Lupker, 2001). According to RT homogenization, the point in time for responding is adjusted on a trial-by-trial basis based on the relative speed of the previous trial. This account therefore predicts that there should be a cost when switching from a slow item to a fast item but a benefit when switching from a fast item to a slow item because the time criterion is set earlier following a fast trial and later following a slow trial. This pattern was not reliably observed in any of the experiments reported here.

Although the pattern predicted by RT homogenization was not reliably observed in any single experiment, there was a nonsignificant trend for the switch costs to be smaller when switching from a fast item to a slow item compared with when switching from a slow item to a fast item in each of the experiments. This is consistent with RT homogenization having a small but consistent effect on overall performance in addition to the changes in pathway emphasis.

The absence of a reliable pattern of RT homogenization in any one particular experiment may be due to the predictive nature of the present context. The predictable alternating pattern contained reliable information about the difficulty of the current item being read. The presence of this information may have allowed skilled readers to use one of two approaches. They may have simply reduced their reliance on a time criterion for responding. Alternatively, the time criterion may have been predominantly based on the time it took to read aloud a previous item at that position of the alternating sequence.

Lexical Checking

Lexical checking refers to the process of consulting the phonological output lexicon for a lexical entry that matches a phonological code (Kinoshita & Lupker, 2003; Lupker et al., 1997). According to Kinoshita and Lupker (2003), lexical checking is an extra process that occurs after a phonological code has been computed. It is argued to be beneficial when reading words—it may yield a small time cost, but responses will be more accurate. In contrast, lexical checking is argued to be counterproductive in the case of nonwords because of how long it takes to conduct an unsuccessful check of the lexicon (Kinoshita & Lupker, 2003).[3]

It is possible to explain the observation of a switch cost when fast words and slow nonwords are read aloud together, as in Experiments 1–3, by combining RT homogenization and lexical checking. According to this account, the switch cost for fast words following slow nonwords is a consequence of RT homogenization. The switch cost for slow items can be attributed to lexical checking if it is assumed that participants are likely to accidentally conduct a lexical check on the first nonword trial (Reynolds & Besner, 2005b).

One problem with this account is that lexical checking has only been invoked to account for an increase in the time to read aloud nonwords when intermixed with low-frequency exception words compared with the time it takes to read aloud nonwords in a pure block of trials. This increase in the time to read aloud nonwords is typically not seen when nonwords are mixed with high-frequency exception words (e.g., Kinoshita & Lupker, 2003, Experiments 1 and 2). Thus, it is unclear why lexical checking would be invoked in the present experiments, given that they do not contain any low-frequency exception words.

To provide a viable account of the present data then, the RT homogenization–lexical checking account needs to further articulate the contextual factors that determine when these processes will occur. This account will need to explain why there was no reliable effect of RT homogenization in any of the present experiments, why lexical checking did not occur in Experiment 5, and why it would have occurred when high-frequency exception words were used in contrast with previous findings.

Future Directions

Although the present studies suggest that the process of generating a phonological code can change across contexts, more re-

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[3] Initially, Lupker et al. (1997) postulated that lexical checking can take place while a phonological code is being generated. According to this account, lexical checking slows responses to nonwords because it interferes with the process of generating a phonological code to such items.

search is needed to understand the range of conditions that can lead to such changes. For instance, the primary focus of the present studies was changes that arise because of the compatibility of stimuli with the lexical and nonlexical pathways as predicted by the pathway control hypothesis operating in the context of a localist dual-route model with a nonlexical route that uses grapheme to phoneme correspondences. This raises two areas for future research. First, do the reading system parameters change in response to other factors, such as orthographic overlap or consistency? The data from Experiments 2 and 3 suggest that these are not necessary conditions for control, but this does not rule out the possibility that they are sufficient for processing changes to take place. Second, examining the conditions in which control is observed may allow us to discriminate between different models. For instance, the nonlexical pathway in Perry et al.'s (2007) CDP+ can read exception words with consistent bodies nonlexically. As a consequence, the pathway control hypothesis operating in the context of this model predicts that consistent exception words and nonwords can be read by using a single experiment-wide set in which the nonlexical route is emphasized.

Conclusions

The results of the present experiments are inconsistent with models of reading aloud that explain performance as automatic in Underwood's (1978) sense of being structurally determined. Instead, the present results suggest that how a phonological code is generated changes across contexts in response to the changing demands placed on it by different stimuli (here, exception words and nonwords). Most generally, the present results (a) broaden the empirical support for the claim that skilled readers are able to exert at least some control over how they generate a phonological code, (b) delineate some of the conditions that lead to changes in reading style on a trial-by-trial basis or use a single experiment-wide set, and (c) provide evidence for the operation of exogenous control processes.

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Appendix A

Stimuli From Experiment 1

Exception words			Nonwords		
blood	none	head	tood	wone	tead
break	said	heard	heak	chaid	meard
change	some	hold	gange	wome	knold
cold	stood	know	brold	knood	fow
dead	told	learn	kead	lold	dearn
doubt	want	lose	soubt	gant	bose
give	were	meant	mive	cere	greant
good	wild	mind	dood	hild	lind
have	both	move	mave	hoth	bove
health	built	passed	healt	truilt	hassed
heart	child	show	deart	dild	yow
kind	come	spread	sind	chome	shead
known	death	talk	lown	geath	malk
lived	done	truth	blived	whone	muth
love	find	where	nove	lind	pere
month	gone	young	stonth	sprone	coung
most	growth		wost	howth	

Appendix B

Stimuli From Experiment 2

Exception words

blood
both
break
built
calf
child
cold
come
death
done
doubt
dread
find
give
gone
good
growth
have
head
health
heard
heart
hold
kind
know
known
learn
lived
lose
love
meant
mind
month
most
move
none
said
shoe
show
some
spread
stood
talk
told
truth
want
war
were
where
wild

Nonwords

dall
vound
feath
keaf
jind
pive
tave
mouch
nove
keard
pome
pone
sull
tand
tood
sild
lut
yaze
zool
bint
bove
bross
daste
dreak
peaf
bieve
tive
dush
fash
hild
famp
jead
lutch
mant
neak
pook
pouth
plood
parp
tarm
tuss
doot
paunt
boof
zeat
beath
yose
breat
doot
gome

Appendix C

Stimuli From Experiment 3

Exception words

blood
both
break
built
calf
child
cold
come
death
done
doubt
dread
find
give
gone
good
growth
have
head
health
heard
heart
hold
kind
know
known
learn
lived
lose
love
meant
mind
month
most
move
none
said
shoe
show
some
spread
stood
talk
told
truth
want
war
were
where
wild

Nonwords

beal
dilt
doke
fice
jank
kag
gobe
moust
nuff
parl
pung
roud
sape
teap
titch
vack
wote
yeech
zoon
bink
broff
darge
dreap
peam
pilt
binch
deach
dobe
fust
hing
jark
lang
moop
nake
pern
pount
simp
tope
tunk
vout
warch
yean
zill
bope
beash
brean
gomp
peem
tife
drait

(*Appendixes continue*)

Appendix D

Stimuli From Experiment 4

Exception words			Regular words		
blood	head	none	bead	fonts	mean
both	heard	pint	beard	food	paid
bowl	heart	plaid	bleak	gild	plead
break	kind	said	bone	golf	rant
broad	know	shoe	bonk	goop	save
child	known	show	brow	hear	sheath
come	learn	some	care	here	sneak
cough	lived	spread	chow	hilt	sought
dead	lose	steak	cloth	hint	sphere
death	love	stood	clown	home	tar
dove	meant	want	cove	hove	tint
give	mind	war	dive	laid	toe
gone	monk	were	dived	lead	tome
good	month	where	dome	lint	tone
grind	most	wild	dose	load	wind
have	move	wolf	fears	lost	yowl

Appendix E

Stimuli From Experiment 5

Regular words			Nonwords		
goop	dome	fears	trood	wome	meart
bleak	sneak	chow	kneak	treak	trow
tome	rant	hear	bome	gant	dearn
lead	here	dose	gead	kere	mose
dive	hilt	mean	mive	hild	feant
food	hint	tint	tood	bint	lind
save	yowl	hove	mave	powl	bove
beard	bonk	home	healt	sonk	bome
lint	cloth	brow	nind	hoth	srow
clown	load	plead	lown	doad	chead
dived	gild	golf	bived	trild	bolf
cove	sheath	sphere	sove	leath	grere
fonts	cove	tar	conth	tove	yar
lost	bone	paid	wost	pone	kaid
tone	wind	sought	wone	shind	mought
laid	bead	toe	haid	tead	scoe

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