When Benefits Outweigh Costs: Reconsidering "Automatic" Phonological Recoding When Reading Aloud

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Abstract

Skilled readers are slower to read aloud exception words (e.g., PINT) than regular words (e.g., MINT). In the case of exception words sublexical knowledge competes with the correct pronunciation driven by lexical knowledge whereas no such competition occurs for regular words. The dominant view is that the *cost* of this "regularity" effect is evidence that sublexical spelling-sound conversion is impossible to prevent (i.e., is "automatic"). This view has become so reified that the field rarely questions it. However, the results of simulations from the most successful computational models on the table suggest that the claim of "automatic" sublexical phonological recoding is premature given that there is also a *benefit* conferred by sublexical processing. Taken together with evidence from skilled readers that sublexical phonological recoding *can* be stopped, we suggest that the field is too narrowly focused when it asserts that sublexical phonological recoding is "automatic" and that a broader, more nuanced and contextually driven approach provides a more useful framework.

The Regularity Effect When Reading Aloud

Words with irregular or exceptional spelling-sound correspondences are read aloud more slowly than words with regular spelling-sound correspondences (e.g., PINT versus MINT), provided that the words are lower frequency, and that the position of irregularity is early in the word (e.g., Roberts, Rastle, Coltheart & Besner, 2003). The best account of this "regularity" effect is provided by dual route theory (see Roberts et al., 2003 for evidence that PDP models do not simulate this effect).[1] This theory, implemented in two related computational models, The Dual Route Cascaded model (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001), hereafter DRC 1.2, and the Connectionist Dual Process model (Perry, Ziegler & Zorzi, 2007), hereafter CDP+[2], are able to simulate a wide variety of phenomena and hold that print is converted to sound via lexical and sublexical routes.[3]

The Lexical Route

The lexical route consists of an *orthographic input lexicon* (OIL) that has a single lexical entry for the spelling of each word known to the model. Feature processing activates letter processing which activates this lexicon. Activation of lexical entries also feeds activation to a *phonological output lexicon* (POL) that contains the sound of whole-word lexical entries for all words known to the model. Activation also feeds forward to the phonemic buffer where phonemes are held in preparation for speech. The letter level, OIL, POL, and phonemic buffer are all engaged in interactive activation.

The Sublexical Route

Each model also implements a second route based on sublexical spelling-sound correspondences. In the DRC model, letters are converted sequentially into phonology according to a set of rules explicitly specified by the modeler. In the CDP+ model, sublexical translation is accomplished by a two-layer assembly (TLA) network that has learned these correspondences through exposure to print. The two models differ in other ways, but we dispense with a more thorough discussion as it has no bearing here. In both models, the pronunciation produced by the sublexical route activates the phoneme buffer.

A Competition Account of the Regularity Effect

The regularity effect in these models arises because the sublexical route assigns the ”regular” pronunciation to items like PINT (rhymes with MINT), whereas the correct pronunciation is generated by the lexical route. These alternate pronunciations *compete* in the phoneme buffer. For regular words like MINT there is no conflict between routes because they activate the same set of phonemes.

Why do subjects allow competition to occur? If only words appear in the experiment the sublexical route is not needed; the lexical route alone will always provide the correct pronunciation provided that the word has a lexical entry in both lexicons. Reading researchers' standard answer to this question is that subjects are *unable to suppress the sublexical route* (i.e., it is automatic). Nonetheless, there are demonstrations that sublexical phonological recoding *can* be prevented when processing nonwords in a case decision task followed by an assessment of learning in a reading aloud task (e.g., Maloney, Risko, O'Malley & Besner, 2008). Given this result our perspective is that the field is better served by considering instead why subjects might allow both lexical and nonlexical processes to operate when reading *words* aloud.[4]

Discussion of the regularity effect invariably emphasizes competition, and hence *costs*. However, when the two processes do not compete, they *cooperate* (e.g., when reading regular words). When the two routes cooperate, responses should be faster than if only one process is operational. If there are such *benefits*, then it makes sense that subjects leave both processes operational. Why turn off the sublexical route if it makes for faster responses?

The benefits of the sublexical route: Can they be seen?

That *benefits* should be observed in the context of processing regular and exception words via the sublexical route is obvious once noted, but to our knowledge it has never been explicitly considered. From an empirical standpoint this may be due to the difficulty of choosing a suitable baseline in order to demonstrate it. One could present exception and regular words in separate blocks; for the exception words, there would no longer be any benefit to allowing the sublexical route to operate, leaving only costs. Thus, this condition would provide a strong incentive to disable the sublexical route if that were possible. However, even if subjects disabled the sublexical route when reading the exception words, there is no reason for subjects to also disable that route when reading only regular words. Why should they, given that it will only improve performance on regular words? We would therefore expect a regularity effect to persist if one compared regular and exception words under blocked conditions *even if subjects completely suppressed the sublexical route when reading the exception words.*

An additional problem with comparing blocked and mixed designs is that the time to read aloud in each word type is affected by the relative speed of the other word types present when the conditions are randomly intermixed (e.g., Lupker, Brown, & Colombo, 1997). These data can be summarized as follows: mixing slow and fast items slows the fast items and speeds the slow ones. Relative to the mixed condition, exception words when blocked would be expected to slow down because the faster regular words are now absent. Similarly, the regular words that are slowed down by the presence of the exception words in the mixed condition would be expected to speed up in the blocked condition. Thus, blocking versus mixing has effects over and above the regularity manipulation. Disentangling all of these effects to address the issue raised here would likely tax even the most sophisticated experimentalists.

A computational approach

Given the difficulty of demonstrating processing benefits for regular words in skilled readers, we turn to the dominant computational models of reading aloud to help us examine the question. A virtue of these models is that we can eliminate the sublexical contribution by having the phoneme buffer ignore its output. If the regularity effect arises from the interaction of the two routes, there should be no regularity effect when the sublexical route is prevented from contributing to reading aloud. More importantly, we expect the sublexical route to *benefit* regular words, producing faster responses than when this route is disabled. To preview the result, our simulations do indeed show that there are *benefits* to allowing the two routes to operate simultaneously and further, *these overall benefits sometimes outweigh the local costs.*

A comment on the simulation approach

Some may object that the present approach does not prove anything because the data come from computational models rather than from skilled readers. In reply, simulations constitute an existence proof of how the word recognition system *could* work. The gap between "could work" and "does work" is a limitation common to all computational simulations of any phenomenon. Our view is that these demonstrations are important in formulating alternative hypotheses that can inform future research.

Simulations

We presented the CDP+ and DRC 1.2 models with 100 words that are regular and 100 words that are irregular in terms of their spelling-sound correspondences (these items are taken from Besner, O'Malley, & Robidoux, 2010)[5] once with the sublexical route intact, and once with the sublexical route disabled. The sublexical route was disabled by setting the connections from sublexical processing to the phonemic buffer to zero.[6] All other parameters were left unchanged from their defaults. The results appear in Figure 1.

Figure 1 about here

Results

Of the 200 words, all of the regular words and 96 of the irregular words appeared in CDP+'s lexicons. All of the regular words, and 97 of the irregular words appear in DRC's lexicons. Words not in the model's lexicons were removed from analysis for that model. Items were included for analysis if the model provided the correct response under both "sublexical status" conditions. The cycle times for items that were correctly read aloud by each model both with and without the sublexical route intact were submitted to a 2 (Regularity) x 2 (Sublexical route status: functional vs. disabled) ANOVA. Regularity was a between item factor, while sublexical status was within items. CDP+ responded correctly to all 100 regular words and 89 of 96 irregular words, while DRC made one error to an irregular word. Both models produced a significant interaction between regularity and sublexical status, (DRC 1.2: $F(1,194) = 1{,}353.9$, $MSE = 18.6$, $p < .001$; CDP+: $F(1,187) = 56.05$, $MSE = 75.2$, $p < .001$).

Given the significant interaction, we proceeded with several planned comparisons. The regularity effect is significant in both models when the two routes are intact, (DRC: $t(194) = 34.1$, $p < .001$; CDP+: $t(187) = 7.85$, $p < .001$), and eliminated when the sublexical route is disabled (DRC 1.2: $t < 1$; CDP+: $t(187) = 1.03$, *ns*). Our major interest, however, concerns whether regular words benefit from the operation of the sublexical routine. In both models, responses to regular words were *faster* when the sublexical route was intact than when it was disabled, (DRC: $t(99) = 141.8$, $p < .001$; CDP+: $t(99) = 33.7$, $p < .001$).

Discussion

As expected, both of the intact models produce a regularity effect and this effect is eliminated when the sublexical route is disabled. The novel and most important finding is that when the sublexical route is disabled, responses to *regular words are slower than when both routes are intact*. In other words, when the sublexical route is operational it provides a *benefit* to regular words. This benefit is considerably larger than the cost of regularity produced by the intact CDP+ model. Importantly, when the sublexical route in the CDP+ model is operative it even provides a *benefit for exception words* relative to when the sublexical route is disabled, ($t(88) = 5.98$, $p < .001$). M. Zorzi (personal communication, November 20, 2009) offered two hypotheses (either or both of which may play a role here): first, that the sublexical route plays a larger role in reading aloud in CDP+ than it does in DRC, and second, that although CDP+'s sublexical (TLA) network most strongly activates the incorrect (regular) pronunciation, it also activates, to a lesser extent, the correct (irregular) pronunciation (see Zorzi, Houghton, & Butterworth, 1998). It is thus the case that the costs/benefits story is more complicated in CDP+ than in DRC. In CDP+ there is a general *benefit* from sublexical processing that dwarfs the potential "cooperative vs. competitive" benefits and costs related to regularity, though there is still clearly an "irregularity-cost/regularity-benefit" (because the net benefit to irregular words is smaller than the net benefit to regular words). This result strikes us as important. It remains to be seen which of the DRC or CDP+ approaches better approximates human performance.[7]

In summary, these results suggest that there is an incentive for skilled readers to allow the sublexical route to operate. In CDP+, there are benefits to *all* words, but less so for exception words. In DRC, though it comes at a cost to low-frequency irregular words, the sublexical route provides benefits to regular words. Accepting the performance cost to low-frequency exception words makes even more sense in the context of reading text. By definition, subjects are exposed to low-frequency words infrequently (high-frequency words typically do not show a regularity effect, presumably because the lexical route operates quickly enough to outrun the sublexical competition), and only a small subset of those will have exceptional pronunciations early in the word (only early irregularities produce a regularity effect; see Roberts et al., 2003). Consequently, the vast majority of words that readers encounter in text can only benefit from sublexical processing.

When these simulations are considered along with evidence that sublexical processing requires resources (Besner, Reynolds & O'Malley, 2009), and can be stopped in at least one context (Maloney et al., 2008), thus providing evidence against two widely held hallmarks of automatic processes, we see little value in appealing to automatic sublexical processing to explain the regularity effect. It is equally well accommodated by assuming that, in this context, readers allow sublexical processes to operate in order to accrue benefits on many trials.

Last words

The debate about automaticity in the context of reading aloud (and visual word recognition more generally) is unlikely to be settled in the near future. Nonetheless, a substantive point is that the field's pre-occupation with the notion of automaticity has resulted in the neglect of questions concerning how context can modulate processing. The fact is that context modulates processing, and some of these context effects are subtle and counter-intuitive (e.g., Besner et al., 2010 for a report that stimulus quality and regularity when reading aloud are additive when nonwords are present and underadditive when they aren't; Ferguson, Robidoux, & Besner, 2009 who report that stimulus quality and semantic priming are additive when the proportion of related trials is .25, but overadditive when the proportion is .50). The theorizing needed to accommodate these facts will likely take the form of module(s) responsible for evaluating the context and taking the appropriate action to optimize processing. We suspect that the coming years will see a profound shift in that more research will be devoted to issues surrounding *control* of processing than to *automaticity* of processing. In the long run the former approach is likely to be more fruitful than the latter.

Footnotes

[1] We do not consider this question in the context of the PDP class of models because we have been unable to obtain versions of them that would allow us to test them by preventing a particular route from operating It should be noted, however, that Perry et al. (2007) compared intact forms of CDP+ and PDP models, and found that CDP+ outperformed the PDP models in terms of variance accounted for by more than an order of magnitude when reading aloud.

[2] Both models are available on the Internet (CDP+: http://ccnl.psy.unipd.it/CDP.html; DRC 1.2: http://www.maccs.mq.edu.au/~ssaunder/DRC/). The DRC 1.2 model (which replaces the 2001 model published in Psychological Review) is a beta version; a final parameter set had not been settled on at the time these simulations were run.

[3]The theoretical models both allow for a third route via the semantic system. Neither of these computational models has an implemented semantic system. For the present purposes we consider this third method of phonological recoding to be subsumed into the lexical route approach.

[4] One problem with attributing effects to automaticity is that researchers make little or no effort to explain *why* the processes might have developed to be automatic. The benefits described here could be taken as an answer to this “why” question (though we do not believe in automatic phonological recoding for reasons discussed later).

[5]These items along with the simulation data and parameter settings can be found at (http://artsweb.uwaterloo.ca/~dbesner2/publications.html). The Besner et al. (2010) regular and

exception items were selected to ensure that they did not have hidden lexical confounds in the computational models. They are also matched on letter length, orthographic frequency, neighbourhood density, and letter confusability. One additional piece of evidence that they are not confounded on some subtle lexical factor is evident in the fact that both models produce no regularity effect when the sublexical route does not contribute to performance here.

[6] In DRC 1.2 this is the GPCPhonemeExcitation parameter; in CDP+ this is the Network to Phoneme Buffer Output Activation parameter.

[7] Though this debate may be premature since DRC 1.2 is no longer being developed and is soon to be superceded by DRC 2.0 (M. Coltheart, personal communication, July 27, 2010).

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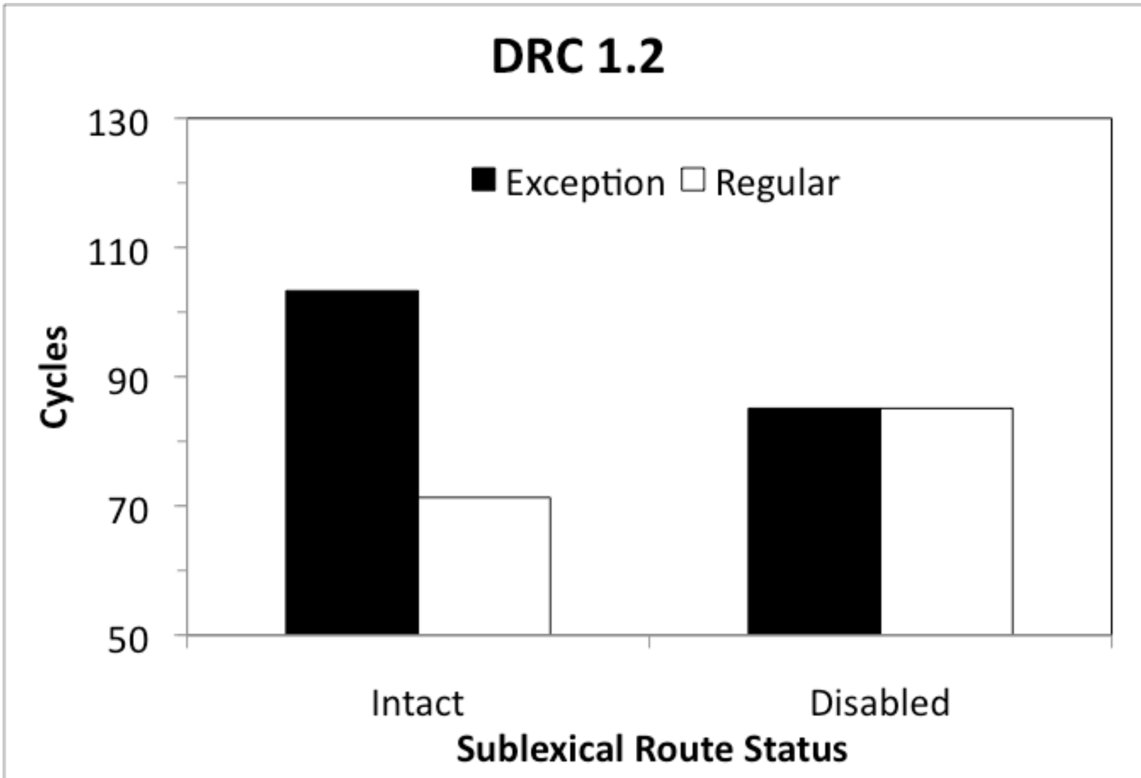
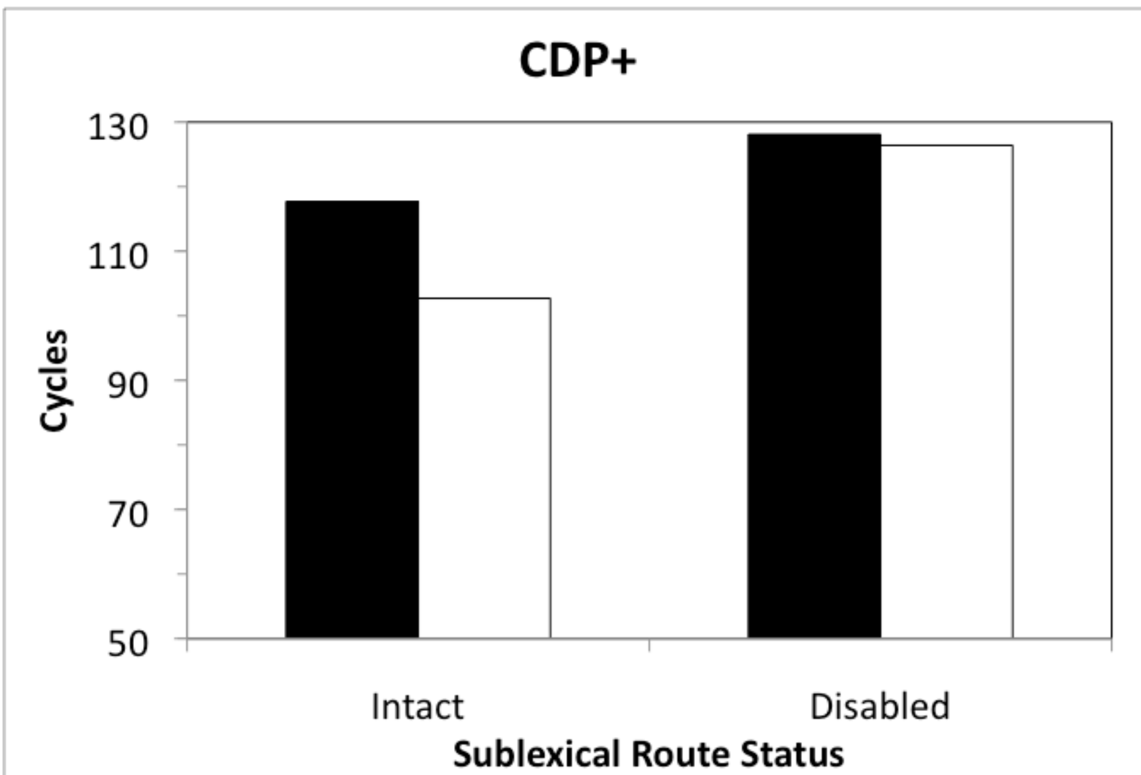
Figure Captions

Figure 1: Simulation results from the DRC 1.2 and CDP+ models when the models are intact, and when there is no contribution from the sublexical route.


DRC 1.2
130
110
90
70
50
Cycles
Exception
Regular
Intact
Disabled
Sublexical Route Status


CDP+
130
110
90
70
50
Cycles
Intact
Disabled
Sublexical Route Status