Regularity and Length Effects in Word Naming: A Test of the Dual Route Cascaded Model

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Abstract

According to some dual-route theories of word naming, an inhibitory effect of length is caused by assembled phonology. Exception words are read via addressed phonology, and so should be immune from length effects. Analyses reported here show, however, that there is an inhibitory length effect for both regular and exception words, and this effect is no smaller for exception than regular words. The DRC, a computational implementation of dual-route theory, does not produce this pattern, instead showing a facilitatory length effect for exception words. This is partially due to the correlation between length and position of irregularity, but length effects are predicted to be smaller for exception words than regular words at all positions of irregularity by the DRC, contrary to the data. This suggests that length effects occur at the letter identification stage and a smaller length effect for words than nonwords may be due to length-sensitivity of word superiority effects.

The dual-route theory of reading (e.g., Monsell, Patterson, Graham, Hughes, & Milroy, 1992) proposes that there are two mechanisms for converting print to sound: a lexical route that retrieves known pronunciations (addressed phonology), and a non-lexical route that assembles pronunciations from grapheme-phoneme correspondences (assembled phonology). These mechanisms compete to produce the pronunciation of a written word. Regular words are read equally well by both routes; exception words are only read correctly by the lexical route; and nonwords are read by the non-lexical route.

The dual-route cascaded (DRC) model of reading aloud (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) is a computational instantiation of the dual-route theory. Its lexical route is an extension of the interactive-activation model of McClelland and Rumelhart (1981; Rumelhart & McClelland, 1982), which processes letters in letter strings in parallel, and its non-lexical route processes letter strings sequentially left-to-right with a set of grapheme-phoneme rules. According to Coltheart et al. (2001), the slowing of exception words relative to regular words is due to the conflict between the pronunciations generated by the rule-based and lexical routes. That is, exception words are read primarily by the lexical route, but regular words are read with a contribution from the non-lexical route. Moreover, in the DRC, length effects are the signature of the non-lexical route, as later letters influence the production of pronunciation by the non-lexical route slower due its seriality: the phonemes that they generate lag behind the other phonemes in activation, and are hence slower to reach threshold, delaying the pronunciation of the entire word. Since pseudowords are read entirely by the non-lexical route, length effects are predicted to be greater for pseudowords than words, as is indeed the case (Weekes, 1997).

Given the balance between the two routes in this dual route model, one could (possibly simplistically) predict that whilst the influence of the sequential, non-lexical route will cause an effect of orthographic length for regular words, these effects will be absent or reduced for exception words, as their pronunciation is largely driven by the lexical route. Here, regression analyses were used to examine the predictions of the DRC for such an effect, and a comparison was made with the same effect in the Spieler and Balota (1997; Balota & Spieler, 1998) word naming databases.

Method

Empirical Data

Empirical data were the mean item naming latencies for young and old adults reported by Spieler and Balota (1997; Balota & Spieler, 1998)[1]. These are reaction times, for a set of monosyllables that has been used in the testing of computational models, in a standard word naming task using 31 young adults (mean age 22.6 years) and 29 older adults (mean age 73.4 years).

DRC

The predictions from the DRC analysed here are the number of cycles needed by the model to produce the correct pronunciation with the standard parameters examined by Coltheart et al. (2001)[2,3].

Variables

Covariates were obtained from the CELEX database. These were log frequency, orthographic neighborhood

[1]These are made available by Spieler and Balota at `http://www.artsci.wustl.edu/~dbalota/naming.html` .

[2]These are made available by Coltheart and colleagues at `http://www.maccs.mq.edu.au/~max/DRC/words.html` .

[3]An alternative set of parameters was also examined. Its predictions for the Spieler and Balota (1997) response times were improved: $R^2 = 9.71\%$ for these parameters compared with $R^2 = 4.24\%$ for the standard parameters on the words examined here. The broad pattern of results was nonetheless similar.

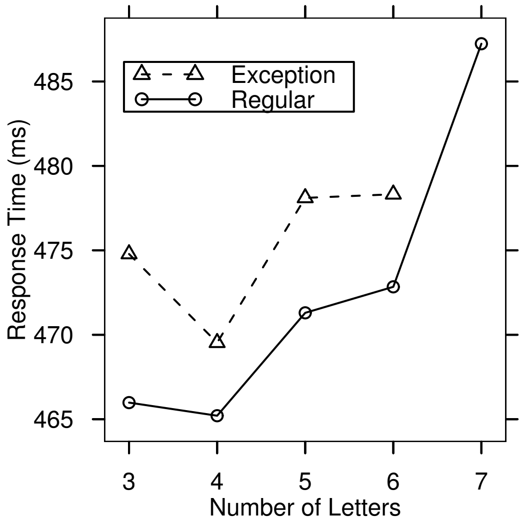

Figure 1: Young adult word naming response times from Spieler and Balota (1997) as a function of length and regularity (covariate adjusted).

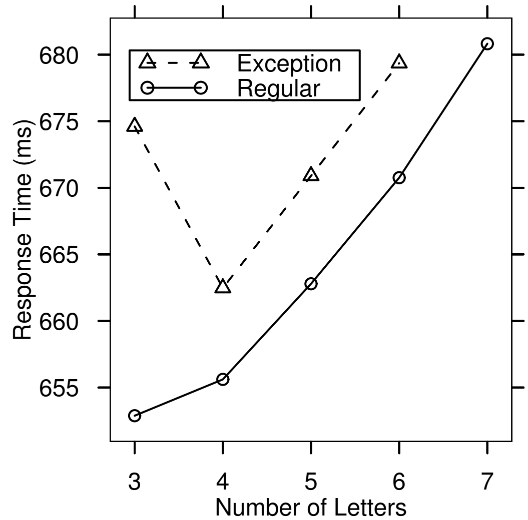

Figure 2: Older adult word naming response times from Balota and Spieler (1998) as a function of length and regularity (covariate adjusted).

size (N), rime consistency (by types) and first phoneme. In all analyses, the multiplicative interaction between log frequency and N was included, following Balota, Cortese, Sergent-Marshall, Spieler, and Yap (2004), and first phoneme was used as a factor with 33 levels without any attempt to code phonetic features. Position of irregularity was defined in the manner of Rastle and Coltheart (1999) as the position of the first phoneme not corresponding to the output of the Coltheart et al. (2001) rules.

Stimuli

Once heterophonic homographs, words not listed as first variants in CELEX, and words not modeled by Coltheart et al. (2001) were excluded, 2728 monosyllabic words were available for analysis.

Results

First, length effects were sought for regular and exception words in the word naming response times after the covariates (log frequency, N, consistency, first phoneme) had been partialled out. In the young adult data, there was a 3.27 ms/letter effect for regular words ($p < .0001$), and a 4.40 ms/letter effect for exception words ($p < .0001$). This ordinal interaction between length and regularity was not significant ($p > .2$). This pattern may be seen in Figure 1. In the older adult data, the length effect for regular words was 5.70 ms/letter ($p < .0001$), and for exception words 5.42 ms/letter ($p < .01$), and there was no interaction between length and regularity ($p > .8$). This pattern may be seen in Figure 2.

The relevant predictions of the DRC may be seen in Figure 3: for regular words, increases in length lead to an increase in cycles to pronunciation 2.02 cycles/letter ($p < .0001$), but a reversed -3.66 cycles/letter effect was found for exception words ($p < .0001$). Long regular words were read slower than short regular words, but long exception words were read faster than short exception words; the disordinal interaction was significant ($p < .0001$).

Position of Irregularity

This effect may obtain in the DRC's predictions because of the inherent confound between length and position of irregularity. Longer words are more likely to have their first irregularity at a later position in the word. When the irregularity is later in the word, the exception effect will be smaller (Rastle & Coltheart, 1999). This means that the DRC would predict that short exception words are slowed relative to long exception words because they are more penalised for their earlier irregularities. If such an effect is too strong in the DRC with the standard parameters, this would counteract a effect of length occurring within each position of irregularity. This suggests that the data should be analysed separately for each position of irregularity.

The length effect in the young data is broken down for the first three positions of irregularity in Figure 4. The corresponding regression coefficients are shown in Table 1. There are significant length effects for regular words, and for exceptions with irregularities at positions 2 and 3, and these effects for exceptions are greater than those for regular words. In all but the fourth position of irregularity, which shows a non-significant reverse length effect, the length effect is at least numerically greater for exception words than regular words.

A similar pattern may been seen for the same comparisons in the data from older participants shown in Fig-

Table 1: Length effects by position of irregularity in young and older adult word naming response times from Spieler and Balota (1997) and Balota and Spieler (1998) (after covariates and main effect of position of irregularity) in ms/letter, and in DRC predictions (after other variables) in cycles/letter.

		Position of Irregularity			
	Regular	1	2	3	4
Young	3.23*	4.37	8.59*†	8.06*†	-6.22 †
Old	5.57*	13.09*	8.04*	13.15*†	-8.06
DRC	1.89*	-.07 †	-2.26*†	-.23 †	-.18 †
Number of Words	2282	50	250	116	24

* indicates different from 0 at $p < .05$. † indicates different from effect for regular words at $p < .05$.

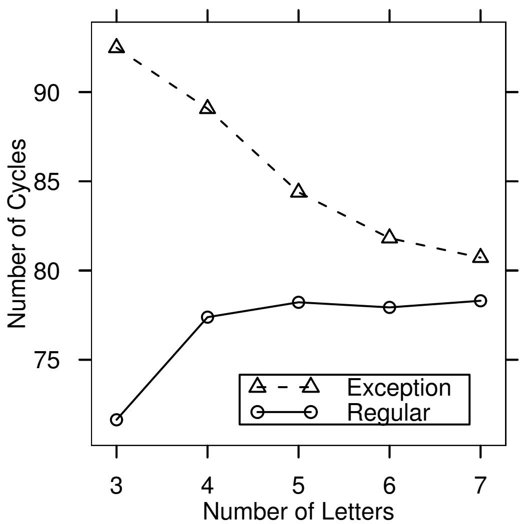

Figure 3: DRC predictions for response times as a function of length and regularity (covariate adjusted).

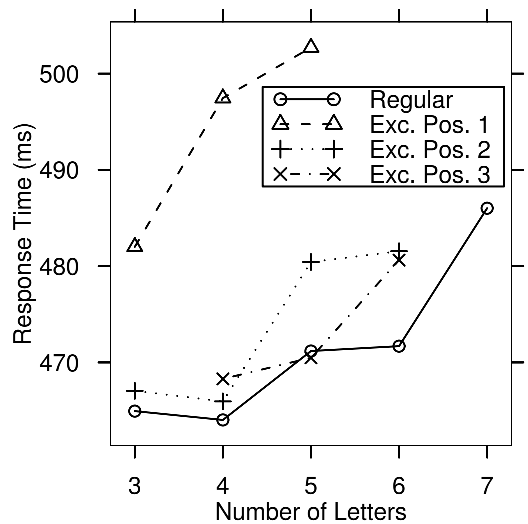

Figure 4: Young adult word naming response times from Spieler and Balota (1997) by length and position of irregularity (covariate adjusted). (Points with fewer than ten words are omitted.)

ure 5, with the regression coefficients in Table 1. There are significant length effects for regular words, and those with irregularities at positions 1, 2, and 3. At all except the fourth position of irregularity, the length effect is at least numerically greater for exception words than regular words.

The pattern that the DRC predicts, which is shown in Figure 6, differs markedly from the data. The coefficients in Table 1 show a length effect for regular words, but reversed length effects for exception words, except at position 4; the effect was significant at position 2. Critically, at the first three positions of irregularity, the length effect for exception words was significantly different from that for regular words.

Discussion

As expected, the DRC predicted that the length effect was reduced for exception words compared to regular words. Overall, the predicted length effect was reversed for exception words, although this was partially due to position of irregularity. Nonetheless, length effects for exception words were absent or reversed after this factor had been controlled. This ran counter to the effect found in the data, which showed no tendency for the length effect to differ between regular and exception words.

The non-lexical route of the DRC produces a length effect for regular words because it generally provides a boost in activation for the last (rightmost) phoneme later for longer words, as it processes the letters in serial, and the stopping rule is that all phonemes must exceed a threshold. This means that pronunciation of the entire word must wait for this last phoneme. By contrast, an exception effect is produced because the irregular phoneme receives no boost at all from the non-lexical route, and the regular phoneme incorrectly activated in that position inhibits the correct phoneme, and so it is often this irregular phoneme for which pronunciation must wait, rather than the last phoneme. Thus, exceptions are relatively immune from the effect of length.

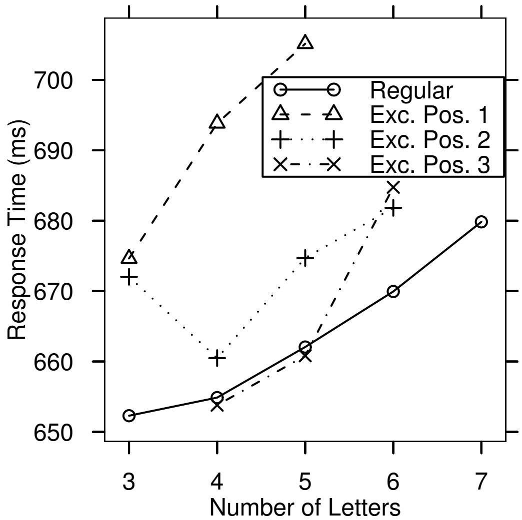

Figure 5: Older adult word naming response times from Balota and Spieler (1998) as a function of length and position of irregularity (covariate adjusted). (Points with fewer than ten words are omitted.)

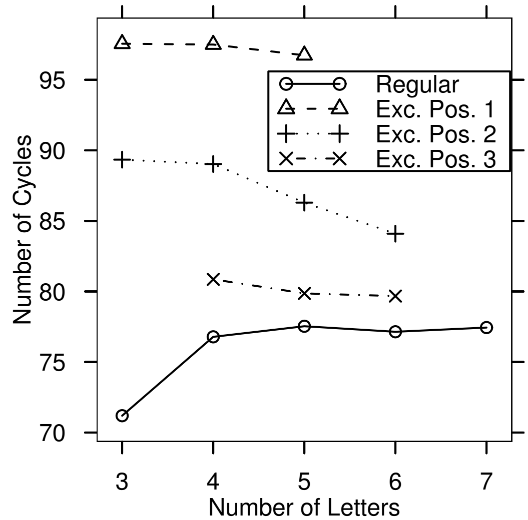

Figure 6: DRC predictions for response times as a function of length and position of irregularity (covariate adjusted). (Points with fewer than ten words are omitted.)

In principle it might seem possible that an alteration to the stopping procedure would allow a length effect for exception words. However, in the model, a delay occurs in the last phoneme, and another delay occurs in the irregular phoneme; if these phonemes are processed in parallel, their influence when both occur must be subadditive. Further, any stopping measure designed to equalise the influence of each phoneme must still show a reduced exception effect for longer words, as the weak activation of the irregular phoneme will tend to be eclipsed by the increasing number of other phonemes.

Instead, it would appear to be necessary, if there are two routes to pronunciation, that the lexical route is also sensitive the lengths of words. Were the lexical route as sensitive to length as is the non-lexical route, though, there would be no reason for there to be a greater length effect for pseudowords than words. However, such an interaction between lexicality and length is observed (Weekes, 1997).

Further, given that there are length effects in lexical decision (Balota et al., 2004) and other word identification tasks (Pelli, Farell, & Moore, 2003) that do not involve pronunciation, it is not parsimonious to attribute length effects to pronunciation mechanisms. If instead length effects arise from inefficient letter recognition, whose source may be seriality, limited-capacity parallel processing, or visual crowding, then effects for regular and exception words would be equivalent.

However, were this the case, the effect for nonwords would be equivalent to both effects for regular and exception words. The smaller length effect for words than nonwords could, though, have a different source in word superiority effects. Were word superiority effects greater for longer words, this tendency would counteract a general perceptual slowing effect of length, producing the observed lexicality by length interaction.

Even if the relationship between lexicality and length effects is due to the superiority of words over nonwords, the lack of a reduction in length effect for exception words requires that the effects of length on the two routes in a dual-route model are equivalent, either by chance or due to a common locus in perception. The finding that exception words show length effects that are no smaller than those of regular words is incompatible with dual-route models that have routes that are differentially sensitive to length, such as the DRC.

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