Proceedings of the Annual Meeting of the Cognitive Science Society

Title

Routes, Races, and Attentional Demands in Reading: Insights from Computational Models

Permalink

https://escholarship.org/uc/item/48w715wg

Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 21(0)

Author

Zorzi, Marco

Publication Date

1999

Routes, Races, and Attentional Demands in Reading: Insights from Computational Models

Marco Zorzi (mzorzi@psico.unipd.it)
Dipartimento di Psicologia Generale, Universita` di Padova
via Venezia 8, 35131 Padova, Italy
Institute of Cognitive Neuroscience, University College London
17, Queen Square, London WC1N 3AR, UK

Abstract

One influential view about the attentional demands of the reading processes maintains that phonological assembly is less automatic and more attention-demanding than phonological retrieval. The strongest evidence is this respect is the release-from-competition (RFC) effect (Paap & Noel, 1991), in which the pronunciation of low frequency exception words is speeded when participants have to perform a concurrent memory task. However, the results of follow-up investigations have led to a sharp controversy regarding whether the phenomenon is real and whether it can be replicated or not. The debate has reached stalemate, partly because the discussion about architectural and processing assumptions has been carried out only in verbal terms. This paper investigates the RFC phenomenon through simulations with two computational models of reading, the Connectionist Dual-Process model (Zorzi et al., 1998) and the DRC model (Coltheart et al., 1993). Both models failed to reproduce the RFC effect, even when the specific assumptions made by Paap and Noel were accurately implemented in the simulations. This finding casts further doubts about the reality of the phenomenon.

Introduction

Models of reading aloud distinguish between at least two different ways to derive the phonological form of written words. One route, usually referred to as lexical route, is thought to operate by retrieving the phonology of known words (*addressed or retrieved phonology*) from the visual word form through a word-specific association mechanism. The second route, named the assembly or phonological route, is conceptualized as a spelling to sound mapping process which allows the computation of the phonology (*assembled phonology*) for any (legal) string of letters (Carr & Pollatsek, 1985; Patterson & V. Coltheart, 1987, for reviews). This fairly general "two-process" architecture is supported by a large body of empirical data, and by converging evidence coming from the neuropsychological studies of reading disorders (acquired dyslexia; Denes, Cipolotti, & Zorzi, 1998; Shallice, 1980, for reviews).

Although most of the researchers would probably agree with the broad definition provided above, the details of the models in the literature vary widely, and the different claims about the nature of the computations underlying the reading system have sparked a vigorous debate (see, e.g., Besner, Twilley, McCann, & Seergobin, 1990; Coltheart, Curtis, Atkins, & Haller, 1993; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McCelland, 1989; Van Orden, Pennington, & Stone, 1990; Zorzi, in press; Zorzi, Houghton, & Butterworth, 1998a, 1998b).

A disputed issue regards the nature of the assembly mechanism and the role of phonology in lexical access from print. One view is that phonological assembly consists of grapheme to phoneme correspondence (GPC) rules, that is, a system based upon explicit rules specifying the dominant (e.g., most frequent) relationships between letters and sounds (Coltheart, 1978; Coltheart et al., 1993, for a computational version of the GPC system). Furthermore, the GPC route is held to be slow and serial (i.e., it delivers one phoneme at a time), and is therefore regarded as a controlled process, which is resource-demanding and subject to strategic control (e.g., Monsell, Patterson, Graham, Hughes, & Milroy, 1992; Paap & Noel, 1991). More generally, the dual-route model (Baron, 1973; Coltheart, 1978; Meyer, Schvaneveldt, & Ruddy, 1974) gives a predominant role to the visual route, because the assembly of phonology is believed to be too slow to affect lexical access. A sublexical (or prelexical) activation of phonology (coming from the assembly route) can make some contribution to word recognition only for very low frequency words, that is, those that are too slowly dealt with by the lexical route (e.g., Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Furthermore, because the GPC route delivers the regular pronunciation of a letter string, the assembled phonology is beneficial only in the case of regular words, while it is detrimental in the case of words with irregular spelling-sound correspondences (Coltheart et al., 1993; Coltheart & Rastle, 1994). On this account, written word recognition in real circumstances is largely a matter of direct visual access from print.

A radically different view is that phonological assembly is a fast and automatic process (e.g., Perfetti, Bell, & Delaney, 1988; Perfetti & Bell, 1991), that plays an important role in written word recognition (for reviews see Berent & Perfetti, 1995; Van Orden et al., 1990). Phonological properties of printed words can affect performance in a variety of reading tasks (see Frost, 1998, for review) and the results of several studies suggest a fast and automatic assembly process, preceding word identification. A fast and parallel process of phonological assembly is implemented in the recent connectionist "dual-process" model developed by Zorzi and colleagues (1998a, 1998b; Zorzi, in press).

The Release-From-Competition Effect

In 1991 Paap and Noel reported a new experimental phenomenon which seemed to provide strong evidence in favor of a "classic" dual-route model of reading. The participants in Paap and Noel experiments had to maintain in memory a number of digits while reading words aloud. The surprising finding was that a memory load of five digits speeded the pronunciation of low frequency exception words in the reading task compared to a memory load of one digit. By contrast, high frequency exceptions and both high and low frequency regular words slowed down in the same comparison. The speeding of low frequency exception was in fact predicted by Paap and Noel (although a concurrent task usually has a detrimental effect on performance of the primary task). They made specific assumptions (within the dual-route framework) about the attentional demands of the two reading routes. Paap and Noel proposed that phonological assembly is less automatic and more attention-demanding than phonological retrieval; therefore, the former would be more susceptible to interference in the case of a concurrent task. In the case of substantial slowing of the assembly route (as in the case of the five digits load), the lexical retrieval process would not be affected by the competing candidate that are usually assembled in reading exception words. Thus, low frequency exception words would not suffer from the competition derived from the existence of conflicting pronunciations. Bernstein and Carr (1996) named this effect "release from competition" (or RFC). The effect of the load manipulation on the four types of words can be seen in Figure 1.

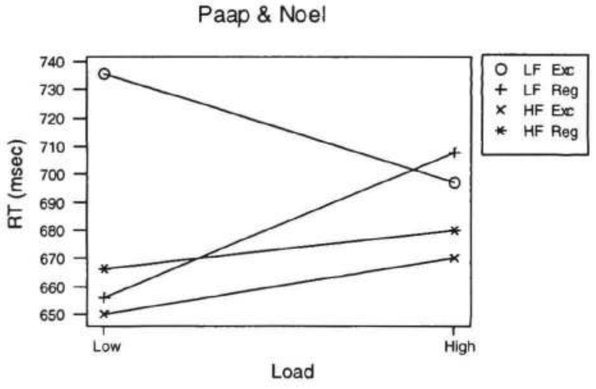

Figure 1: Data from Paap and Noel's (1991) study. The graph shows the effect of a digit memory load (low = one digit; high = five digits) on the naming latencies in the reading task.

The striking results of Paap and Noel (1991) prompted some researcher to carry out follow-up investigations. The results of these studies have led to a sharp controversy regarding whether the phenomenon reported by Paap and Noel is real and whether it can be replicated or not. Only one study by Herdman and Beckett (1996) replicated the RFC effect. Pexman and Lupker (1995) reported a complete failure to replicate the RFC effect in a series of five experiments. In their experiments, all word types slowed down under the high load condition (see Figure 2). Bernstein and Carr (1996) succeeded in replicating the RFC effect, but only in a subset of readers, suggesting individual differences in the architecture of the reading system. However, Pexman and Lupker (1998) criticized Bernstein and Carr's finding as artifactual and failed to replicate it with a different way of selecting readers. In a follow-up study of the individual differences account, Bernstein, DeShon, and Carr (1998) found little evidence of systematic individual differences in the occurrence of the RFC effect. Thus, Bernstein et al. concluded that the effect cannot be replicated (but see Paap and Herdman, 1998, for opposing views).

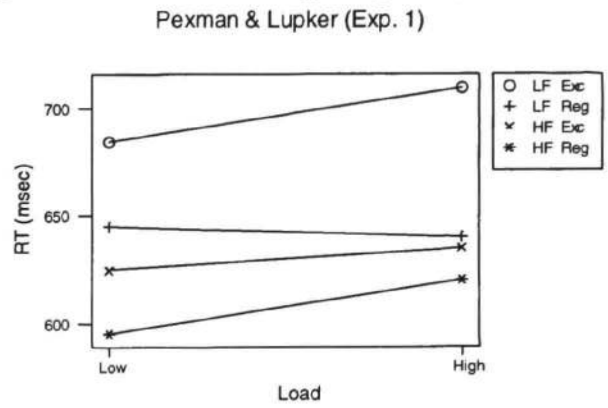

Figure 2: Data from Pexman and Lupker's (1995) experiment 1. Note that the increasing digit memory load (low = one digit; high = five digits) slowed down all word types in the same way

Simulations of the RFC Effect

It is clear that the debate concerning the Paap and Noel (1991) phenomenon has reached stalemate. The investigators involved in this debate have discussed at length why the effect should or should not exist, focusing on the predictions derived from different models and/or different architectural assumption. However, these detailed analyses and discussions have been carried out only in verbal terms, that is without actually testing any of the available computational models. Pexman and Lupker (1995) have even hypothesized how memory load might affect a single route connectionist model. In the limit, this enterprise might be misleading, because the behavior of a complex computational model can be neither predicted nor inferred without actually running the simulations.

In this article, I investigate the Paap and Noel (1991) phenomenon through simulations with the Connectionist Dual-Process model (Zorzi et al., 1998a) and with Coltheart et al.'s (1993) DRC (Dual-Route Cascade) model. Starting with simple computational assumptions regarding the effect of memory load (which follow directly the assumptions made by Paap and Noel), I assess whether the RFC effect can be observed in the models in any of a range of tested conditions.

Simulations with the Dual-Process Model

Zorzi et al. (1998a) developed a connectionist model of reading where a dual-route processing system emerges from the interaction of task demands and initial network architecture in the course of reading acquisition. In this model, the distinction between phonological assembly and lexical retrieval is realized in the form of connectivity (either direct of mediated) between orthographic input and phonological output patterns (see Houghton & Zorzi, 1998, for similar treatment of the problem of learning the sound-spelling mapping in writing). The model thus maintains the uniform computational style of the PDP models, but makes a clear distinction between lexical and sublexical processes in reading. The model has been shown to account for a number of empirical results, including the interaction between frequency and regularity, the effects of consistency, the effect of the position of irregularity, the interaction between word length and lexicality, and the impaired performance of patients with neuropsychological disorders (Zorzi et al., 1998a; 1998b; Zorzi, in press).

The two processing pathways of the Dual-Process model are activated in parallel and their phonological output builds up over time in a cascaded fashion. However, in contrast to a classic dual-route horserace model, the processing rates of the two routes are very similar (the assembly route is actually faster than the lexical route). Following Paap and Noel's (1991) assumption that a digit memory load slows down processing in the assembled route, the effect of memory load was simulated in the Dual-Process model by manipulating the ramp parameter of the phonological assembly route. This parameter dictates the number of processing cycles that are necessary for the assembly route to reach its asymptotic (i.e., maximum) output value. Therefore, an increase in the value of ramp corresponds to a slower production of the assembled phonology in the model.

Method The low load condition was simulated by holding the ramp parameter unchanged (8 cycles). That is to say, the low load condition was a no-load condition in the model. For the high load condition, the model was tested with two different values of the ramp parameter, that is 15 and 20 cycles. The word lists used by Paap and Noel (1991) were submitted to the model. Of the 40 words used in the Paap and Noel study, 8 were not in the model's lexicon (two of these were bisyllabic, and four other were inflected words) and were therefore excluded. Because the words are matched in quadruplets, the three corresponding words for each of the excluded word were removed from the analyses. This left with 14 words in each list.

RT data were collected from the model by first running the word lists with the original model's parameter (low load condition). The same lists were presented to the model two other times with the assembly ramp parameter changed to 15 and then to 20 cycles.

Results - Ramp 15 The RT data obtained from the model were analyzed in a 2 (Frequency: high vs. low) X 2 (Regularity: regular vs. exception) X 2 (Load: low vs. high) repeated measures analysis of variance. The effects of frequency ($F_{1,13}$=64.72, Mse=91.08, p<.001), regularity ($F_{1,13}$=39.45, Mse=23.22, p<.001), as well as their interaction ($F_{2,13}$= 17.67, Mse= 9.72, p=.001) were significant. Naming latencies for high frequency words (2.62 cycles) were faster compared to low frequency words (4.43 cycles), and regular words (3.07) were faster compared to exception words (3.98). The effect of load was significant ($F_{1,13}$=162.87, Mse=33.22, p<.001), showing that naming latencies under high load (4.07) were longer than under low load (2.98). However, load interacted with both regularity ($F_{2,13}$=36.38, Mse=3.22, p<.001) and frequency ($F_{2,13}$=33.85, Mse=8.58, p<.001). That is, load was more affecting low frequency words (3.6 vs. 5.24) than high frequency words (2.35 vs. 2.89), and regular words (2.35 vs. 3.78) more than exception words (3.60 vs. 4.35). The three-way interaction was not significant. The results are shown in Figure 3, panel A.

Results - Ramp 20 The RT data obtained from the model were analyzed in a 2 (Frequency: high vs. low) X 2 (Regularity: regular vs. exception) X 2 (Load: low vs. high) repeated measures analysis of variance. The effects of frequency ($F_{1,13}$=114.49, Mse=106.08, p<.001), regularity ($F_{1,13}$=38.21, Mse=16.51, p<.001), as well as their interaction ($F_{2,13}$= 13.72, Mse= 7.51, p<.01) were significant. The effect of load was significant ($F_{1,13}$=250.13, Mse=58.58, p<.001), showing that naming latencies under high load (4.43) were longer than under low load (2.98). However, load interacted with both regularity ($F_{2,13}$=52.36, Mse=6.51, p<.001) and frequency ($F_{2,13}$=49.81, Mse=13.58, p<.001). The three-way interaction was significant ($F_{3,13}$=4.94, Mse=.72, p<.05. The results are shown in Figure 3, panel B.

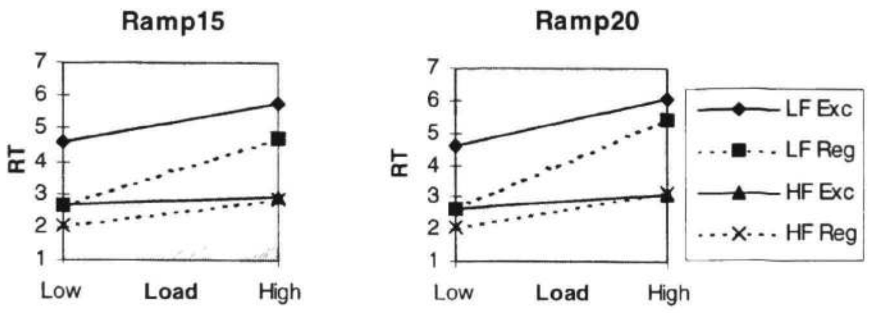

Figure 3: Results of the load manipulation with the Dual-Process model. Panel A: ramp parameter was set to 15 cycles (Ramp15). Panel B: ramp parameter was set to 20 cycles (Ramp20).

Discussion Inspecting the graphs in Figure 3, it can be noted that the results are quite similar for both values of ramp. More important, however, is that in both cases the model does not show a RFC effect. That is, the significant interactions in the two anova qualify a pattern that is very different from that found by Paap and Noel (1991). The load manipulation does not speed up any of the word types. Load has more impact on low frequency words; within low frequency words, the detrimental effect of load is maximal for the regular words. This pattern of results can be ascribed to the reduced contribution of phonological assembly in the model. Note, however, that load has some effect on the high frequency words as well. This is because the assembly procedure in the Dual- Process model is a fast process, interacting with the lexically-derived phonology even in the case of high frequency words.

The pattern produced by the Dual-Process model resembles rather closely that found by Pexman and Lupker (1995) in their Experiment 1, which attempted to replicate the Paap and Noel (1991) phenomenon using the same experimental material.

Simulations with the DRC model

The DRC model (Coltheart et al., 1993; Coltheart & Rastle, 1994) is a traditional dual-route model, where the assembly procedure is conceptualized (and implemented) as a slow, serial route, operating on grapheme-phoneme correspondences. Note that this characterization perfectly fits the dual-route horse-race model described by Paap and Noel (1991). Therefore, it might be anticipated that DRC is the model that would most likely show a pattern similar to the Paap and Noel phenomenon. In contrast to the Dual-Process model, the processing rates of the two routes are quite different. In this regard, the key feature of DRC is that the lexical route operates in parallel on the letter constituents of the input word, whereas the assembly (GPC) route operates serially on the individual letters. The letters are therefore submitted to the GPC route one at a time, with the speed of serial processing determined by a parameter specifying the time interval between submission of each letter. Such parameter is tied to the processing in the lexical route, and is therefore measured in processing cycles. The parameter is normally set to 17; that is, each letter is submitted to the GPC algorithm every 17 processing cycles in the lexical route. An increase of the interval would slow down the assembly procedure and as such is a good candidate for simulating a memory load manipulation. A second parameter of DRC which can be useful to simulate a memory load condition is the strength of the GPC procedure, that is, the excitation received by the phoneme system when a given phoneme is produced by the GPC rules.

Method A procedure similar to that used with the Dual-Process model was employed to investigate the effect of memory load in DRC (I am grateful to Kathy Rastle for running the simulations). The low load condition was simulated in DRC by holding all GPC parameters unchanged (inter-letter interval=17 cycles; GPC excitation=.055). Thus, similarly to the simulations with the Dual-Process model, the low load condition was actually a no-load condition. For the high load condition, the model was tested with two different values of the inter-letter interval parameter, which was increased to 25 and to 50 cycles. In addition, a third simulation of the high load condition was obtained by reducing the strength of GPC excitation from .055 to .03.

The word lists used by Paap and Noel (1991) were submitted to the model. Of the 40 words used in the Paap and Noel study, 4 were not in the model's lexicon (two of these were bisyllabic) and one was wrong in the database. These words were therefore excluded, and the corresponding matched words in the other three lists were removed from the analyses. This left with 15 words in each list.

RT data were collected from the model by first running the word lists with the original model's parameter (low load condition). The same lists were presented to the model three other times with the GPC parameters altered as to simulate the high load condition.

Results - Inter-letter interval 25 The RT data obtained from the model were analyzed in a 2 (Frequency: high vs. low) X 2 (Regularity: regular vs. exception) X 2 (Load: low vs. high) repeated measures analysis of variance. The effects of frequency ($F_{1,14}$=42.58, Mse=1209.68, p<.001) and regularity ($F_{1,14}$=21.17, Mse=880.21, p<.001) were significant. Their interaction, however, was not significant ($F_{2,14}$= .46, Mse= 20.01, p>.5). Naming latencies for high frequency words (76.9 cycles) were faster compared to low frequency words (83.2 cycles), and regular words (77.3 cycles) were faster compared to exception words (82.7 cycles). The effect of load was not significant ($F_{1,14}$=1.16, Mse=8.01, p>.1). However, load interacted with regularity ($F_{2,14}$=14.91, Mse=81.68, p=.002). That is, regular words slowed down under high load (76.8 vs. 77.9 cycles), whereas exception words sped up (83.8 vs. 81.7 cycles). The load by frequency and the three-way interactions were not significant. The results are shown in Figure 5, panel A.

Results - Inter-letter interval 50 The RT data obtained from the model were analyzed in a 2 (Frequency: high vs. low) X 2 (Regularity: regular vs. exception) X 2 (Load: low vs. high) repeated measures analysis of variance. The effects of frequency ($F_{1,14}$=46.56, Mse=974.70, p<.001) and regularity ($F_{1,14}$=12.76, Mse=410.70, p<.01) were significant. Their interaction, however, was not significant ($F_{2,14}$= .09, Mse= 2.13, p>.7). Naming latencies for high frequency words (75.2 cycles) were faster compared to low frequency words (80.2 cycles), and regular words (76.2 cycles) were faster compared to exception words (79.9 cycles). The effect of load was significant ($F_{1,14}$=72.10, Mse=616.53, p<.001), showing that naming latencies under low load (80.3 cycles) were longer than under high load (75.8 cycles). Load interacted with regularity ($F_{2,14}$=50.80, Mse=340.03, p<.001). That is, both regular and exception words were faster under high load compared to low load, but exception words sped up (83.8 vs. 75.9 cycles) more than regular words (76.7 vs. 75.6 cycles). The load by frequency interaction was not significant, but the three-way interaction was reliable ($F_{3,14}$=5.86, Mse=38.53, p<.05. The results are shown in Figure 5, panel B.

Results - GPC Excitation .03 The RT data obtained from the model were analyzed in a 2 (Frequency: high vs. low) X 2 (Regularity: regular vs. exception) X 2 (Load: low vs. high) repeated measures analysis of variance. The effects of frequency ($F_{1,14}$=47.19, Mse=1098.08, p<.001) and regularity ($F_{1,14}$=20.48, Mse=658.01, p<.001) were significant. Their interaction, however, was not significant ($F_{2,14}$= .94, Mse= 20.01, p>.3). Naming latencies for high frequency words (75.7 cycles) were faster compared to low frequency words (81.8 cycles), and regular words (76.4) were faster compared to exception words (81.1). The effect of load was significant ($F_{1,14}$=45.55, Mse=285.21, p<.001), showing that naming latencies under low load (80.3 cycles) were longer than under high load (77.2 cycles). Load interacted with regularity ($F_{2,14}$=32.92, Mse=170.41, p<.001). That is, exception words were faster under high load compared to low load (83.8 vs. 78.4 cycles), whereas the effect of load for the regular words was quite small (76.8 vs. 76.1 cycles). The load by frequency interaction was not reliable, but there was a trend towards a three-way interaction ($F_{3,14}$=3.27, Mse=10.21, p=.09. The results are shown in Figure 5, panel C.

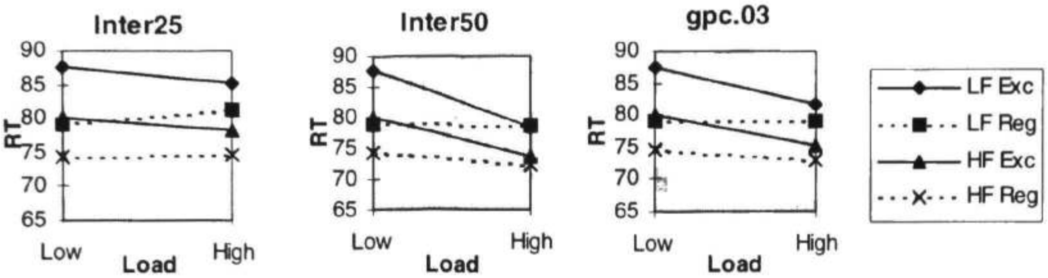

Figure 5: Results of the load manipulation with the DRC model. Panel A: the inter-letter interval was set to 25 cycles (Inter25). Panel B: the inter-letter interval was set to 50 cycles (Inter50). Panel C: GPC excitation was set to 0.03 (gpc.03).

Discussion Inspecting the graphs in Figure 5, it can be seen that the results produced by the three different high load conditions are similar, in particular for Inter50 and gpc.03. The crucial finding, however, is that in all cases the low frequency exception words speed up under high load. Thus, it would seem that the DRC model produces the RFC effect. However, other word types speed up under high load. For instance, high frequency exception words benefit of the high load as much as the low frequency exceptions. What is more striking, however, is that even high frequency regular words speed up under high load in two of the simulations, whereas low frequency regular words are virtually unaffected by the load manipulation. It should be clear that this pattern does not match that found by Paap and Noel (1991). This becomes more evident by visually comparing the original data from Paap and Noel in Figure 1 with the graphs of Figure 5.

General Discussion

Paap and Noel's (1991) RFC phenomenon is potentially very important because, if real, it poses a number of constraints on the architectural and processing assumptions of reading models. This is why the controversy about its replicability has been relatively sharp (e.g., Bernstein & Carr, 1996; Bernstein et al., 1998; Paap & Herdman, 1998; Pexman & Lupker, 1995, 1998). However, the theoretical debate has been carried out on purely verbal grounds. For example, Paap and Noel predicted that slowing down the nonlexical route (through a digit memory load) would facilitate processing of low frequency exception words. Pexman and Lupker (1995) argued that the same result could be explained within a single-route PDP account: they speculated that a memory load would hinder the ability of the competitors of the correct word pronunciation to compete during a phonological cleanup process. The debate has reached stalemate for two main reasons: first, several studies failed to replicate the RFC phenomenon (even when possible individual differences among readers where considered; Pexman & Lupker, 1995, 1998; Bernstein et al., 1998), but at least one study provided a complete replication of the effect (Herdman & Beckett, 1996); second, the various predictions and/or accounts have not been tested computationally.

The basic question addressed by the present study is not that of replicability of the effect, but rather that of whether a dual-route processing system does actually predict the Paap and Noel phenomenon. The RFC effect was investigated using two computational models of reading: the DRC model and the Dual-Process model. I assumed, following Paap and Noel (1991), that a memory load slows down the nonlexical route. However, the simulations with both models failed to produce the complete Paap and Noel phenomenon. The Dual-Process model showed a pattern of results that resembled the findings of Pexman and Lupker (1995). The simulations with the DRC model revealed a more complex pattern, but no simulation resembled the overall pattern observed by Paap and Noel (1991). This might be surprising, given that the architectural and processing assumptions of the DRC model appear to largely overlap with Paap and Noel's own characterization of the dual-route model.

In summary, the present study has important implications for the debate concerning the Paap and Noel (1991) phenomenon. Indeed, the predictions made by Paap and Noel were not confirmed in either of two different computational implementations of dual-route theories (the Dual-Process model and the DRC model). The models fail to produce the effect even when Paap and Noel's assumptions are accurately implemented in the simulations. This finding casts further doubts about the reality of the phenomenon.

References

Baron, J., & Strawson, C. (1976). Use of orthographic and word-specific knowledge in reading words aloud. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 386-392.

Berent, I., & Perfetti. C.A. (1995). A rose is a reez: The two-cycles model of phonology asssembly in reading English. *Psychological Review, 102,* 146-184.

Bernstein, S.E., & Carr, T.H (1996). Dual-route theories of pronouncing printed words: What can be learned from concurrent task performance? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 86-116.

Bernstein, S.E., DeShon, R.P., & Carr, T.H (1998). Concurrent task demands and individual differences in reading: How to discriminate artifacts from real McCoys. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 822-844.

Besner, D., Twilley, L., McCann, R.S., & Seergobin, K. (1990). On the connection between connectionism and data: Are a few words necessary? *Psychological Review, 97,* 432-446.

Carr, T.H., & Pollatsek, A. (1985). Recognizing printed words: A look at current models. In D. Besner, T.G. Waller, & G.E. MacKinnon (Eds.), *Reading research: Advances in theory and practice* (Vol. 5, pp. 1-82). San Diego, CA: Academic Press.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies of information processing* (pp. 151-216). London: Academic Press.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual-route and parallel-distributed-processing approaches. *Psychological Review, 100,* 589-608.

Coltheart, M., & Rastle, K. (1994). Serial processing in reading aloud: Evidence for dual-route models of reading. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1197-1211.

Denes, F., Cipolotti, L., & Zorzi, M. (1998). Acquired dyslexias and dysgraphias. In G. Denes & L. Pizzamiglio (Eds.), *Handbook of Clinical and Experimental Neuropsychology.* Hove: Psychology Press.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin, 123,* 71-99.

Herdman, C.M., & Beckett, B.L. (1996). Code specific processes in word naming: Evidence supporting a dual-route model of word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1149-1165.

Houghton, G., & Zorzi, M. (1998). A model of the sound-spelling mapping in English and its role in word and nonword spelling. In M.A. Gernsbacher & S.J. Derry (Eds.), *Proceedings of the Twentieth Annual Conference of the Cognitive Science Society* (p. 490-495). Mahwah (NJ): Erlbaum.

Meyer, D.E., Schvaneveldt, R.W., & Ruddy, M.G. (1974). Functions of graphemic and phonemic codes in visual-word recognition. *Memory & Cognition, 2,* 309-321.

Monsell, S., Patterson, K.E., Graham, A., Hughes, C.H., & Milroy, R. (1992). Lexical and sub-lexical translation of spelling to sound: Strategic anticipation of lexical status. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 452-467.

Paap, K.R., & Herdman, C.M. (1998). Highly skilled participants and failures to redirect attention: Two plausible reasons for failing to replicate Paap and Noel's effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 845-861.

Paap, K.R., & Noel, R.W. (1991). Dual route models of print to sound: Still a good horse race. *Psychological Research, 53,* 13-24.

Patterson, K.E., & Coltheart, V. (1987). Phonological processes in reading: A tutorial review. In M. Coltheart (Ed.), *Attention and Performance XII: The psychology of reading* (pp. 421-447). Hillsdale, NJ: Erlbaum.

Perfetti, C.A., & Bell, L.C. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and masked priming. *Journal of Memory and Language, 30,* 473-485.

Perfetti, C.A., & Bell, L.C.,& Delaney, S.M. (1988). Automatic (prelexical) phonemic activation in silent word reading: Evidence from backward masking. *Journal of Memory and Language, 27,* 59-70.

Pexman, P.M., & Lupker, S.J. (1995). Effects of memory load in a word naming task: Five failures to replicate. *Memory & Cognition, 23,* 581-595.

Pexman, P.M., & Lupker, S.J. (1988). Word naming and memory load: Still searching for an individual differences explanation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 803-821.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523-568.

Seidenberg, M.S., Waters, G.S., Barnes, M.A., & Tanenhaus, M.K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behaviour, 23,* 383-404.

Shallice, T. (1988). *From neuropsychology to mental structure.* Cambridge, England: Cambridge University Press.

Van Orden, G.C., Pennington, B.F., & Stone, G.O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488-522.

Zorzi, M. (in press). Serial processing in reading aloud: No challenge for a parallel model. *Journal of Experimental Psychology: Human Perception and Performance.*

Zorzi, M., Houghton, G., & Butterworth, B. (1998a). Two routes or one in reading aloud? A connectionist dual-process model. *Journal of Experimental Psychology: Human Perception and Performance, 24,* p. 1131-1161.

Zorzi, M., Houghton, G., & Butterworth, B. (1998b). The development of spelling-sound relationships in a model of phonological reading. *Language and Cognitive Processes, 13,* 337-371.