Nonverbal Semantic Processing Disrupts Visual Word Recognition in Healthy Adults

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Abstract

Two experiments examined the effect of semantic interference on visual lexical decision (vLD) in normal skilled readers. Experiment 1 employed a dual-task paradigm to test whether nonverbal semantic processing disrupts visual word recognition when the orthographic structure of words and non-words is controlled. Experiment 2 employed the same paradigm to test whether participants strategically shifted their reliance onto orthographic information when orthographic structure provided a cue to lexicality. The results showed (1) significant semantic interference in the vLD task in normal skilled readers when words and non-words were matched for orthographic well-formedness and (2) no semantic interference when words and non-words differed reliably in their orthographic well-formedness. The results are consistent with the view that accurate lexical decisions depend upon semantic activation, especially when judgments cannot be made on the basis of orthographic structure alone.

Keywords: semantics; lexical decision; dual-task; dual-route models.

Introduction

What is the relationship between semantic and lexical knowledge in the mind and brain? Neuropsychological investigations of this question have led to two contradictory conclusions. One long-standing tradition has emphasized neuropsychological dissociations to support the argument that knowledge of word forms and meanings are supported by functionally independent cognitive systems. For instance, patient EM performed poorly on semantic tasks such as picture naming but perfectly when reading or recognizing even irregular, low-frequency, and orthographically strange words (Blazely, Coltheart, & Casey, 2005; for similar cases, also see Cipolotti & Warrington, 1995; Schwarz, Saffran, & Marin, 1980). For some theorists, such evidence suggests that successful performance in lexical tasks like reading aloud or recognizing words does not depend on intact input from the word-meaning system (Coltheart, 2004).

A different tradition has emphasized that such classical dissociations are observed in only a tiny fraction of patients with semantic impairment, and that, in the vast majority of cases, lexical and semantic impairments go hand-in-hand (Woollams, Ralph, Plaut, & Patterson, 2007). For instance, Patterson et al. (2006) examined performance on four lexical tasks—including reading aloud, lexical decision, spelling, and past-tense inflection—in fourteen patients with semantic dementia (SD), a progressive degenerative syndrome that produces a remarkably pure semantic impairment. Results revealed that, in all four tasks, all fourteen patients were seriously impaired at processing low-frequency items with atypical phonological, orthographic, or syntactic structure. Similarly Woollams and colleagues (2007) reported reading performance in a cohort of 51 patients with semantic impairment and found that only a vanishingly small proportion—3 out of 51—showed spared performance comparable to EM's (and see Graham, Patterson, & Hodges, 2000; Patterson & Hodges, 1992; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; for similar accounts of association between semantic and lexical impairment). For these theorists, the strong association between semantic and lexical impairment suggests that, in most individuals, performance on lexical tasks depends importantly on intact input from the semantic system (Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989).

Differentiating these views on the basis of neuropsychological evidence has proven challenging because both views can account for the major findings, that is, the strong association of lexical and semantic impairment in the majority of reported cases and the occasional dissociation in a small minority. For those who believe semantic and lexical processes are functionally independent, the strong association arises because the disease process in these individuals has affected both systems. Patterson et al. (2006) refer to this as the "Associated but unrelated deficits" (ABUD) view. Under ABUD, only dissociations provide useful information about the functional architecture of the language system, because they straight-forwardly disprove causal necessity: reading, word recognition, spelling, etc, cannot of necessity depend upon intact semantic input, because it is possible for these abilities to be completely spared in the face of degraded semantic knowledge.

The alternative view—that lexical processes depend importantly upon semantic input—was dubbed "It's All Semantics" (IAS) by Patterson et al. (2006). For proponents of IAS, the few cases that show strong lexical-semantic

dissociations are the exceptions that prove the rule. Such cases may deviate somewhat from the more typical pattern of associated deficits because they are exceptional in other ways. For instance, they may have had unusually good lexical skills in their premorbid state, so that, with mild semantic impairment, they remain capable of performing within the established norms for their age group, even if they have declined significantly from their premorbid peak. From this point of view, the fact that EM was a secretary for much of her life is potentially important—she presumably took dictation and as a result may have developed unusually robust orthographic and phonological representations.

Further complicating the picture is the fact noted by Plaut (1997) and others that some patterns of apparent dissociation in the literature may be attributable to poorly controlled stimulus materials. It is now well established that, when semantic knowledge degrades, patients can retain good knowledge of the "surface" structure of different domains. For instance, even when unable to retrieve the meanings of words, patients with semantic impairments can retain knowledge about orthographic structure, that is, which letter sequences are common and which unusual in the language. In tests of word-recognition, such patients can appear completely normal if the target words are all orthographically well-formed and the distractor words are all orthographically strange (Rogers, Ralph, Hodges, & Patterson, 2004). The same patients show serious impairments, however, if the orthographic structure of words and non-words is matched—indeed, some patients judge well-formed non-words to be real words at rates exceeding chance, showing a strong over-reliance on orthographic structure in making their decisions.

Taken together, the evidence from neuropsychological studies is arguably compatible with both ABUD and IAS and it is not clear that further neuropsychological evidence can adjudicate the different positions. Because the status of semantic knowledge cannot be manipulated experimentally in such studies the causal links between semantic and lexical processing are difficult to establish.

Experiment 1 of the present study tests the hypothesis that semantic processing contributes to one kind of lexical process—word recognition—using a dual-task paradigm. Healthy participants performed a visual lexical decision task while simultaneously performing a secondary nonverbal task (sound judgment) that either did or did not tap semantic memory. The key question is whether word-recognition is significantly more disrupted by the semantic than the non-semantic secondary task. According to ABUD, word recognition does not depend upon input from semantics, so there should be no effect of secondary task type as long as the two tasks are equally demanding. According to IAS, word recognition does depend upon semantics, so word recognition should be worse when participants simultaneously perform the nonverbal semantic task. Experiment 2 uses the same methods to test the hypothesis that people show less or even no reliance on input from semantics when lexicality is confounded with orthographic structure—that is, when words and non-words differ reliably in their orthographic well-formedness.

Experiment 1

Method

Participants Fifty-one undergraduate students from UW-Madison participated in Experiment 1 for course credit or monetary compensation. All were native English speakers with normal or corrected-to-normal vision.

Materials and Design Participants were asked to perform two tasks simultaneously: a visual lexical-decision (vLD) task and a sound judgment task. The experimental manipulation concerned whether the sound judgment task did or did not draw upon semantic knowledge. In the non-semantic "Tones" condition, participants listened to a complex tone and judged whether it was ascending in pitch or not. The task is non-semantic because it does not require the participant to consult or draw upon stored knowledge about the sound. In the semantic "Birds" condition, participants listened to an animal sound and judged whether it was produced by a bird or not—hence this task required participants to draw on stored knowledge about the sounds produced by birds and animals.

The stimuli for the vLD task were adapted from a previous study (Hauk, et al., 2006) and consisted of 50 orthographically typical words (TW; e.g., "rot"), 50 orthographically strange words (SW; "yacht"), 50 orthographically typical non-words (TNW; "yot") and 50 orthographically strange non-words (SNW; "racht"). Words and non-words were matched for the goodness of their orthographic structure as measured by summed bigram and trigram frequencies (for details, see Rogers, et al., 2004). This manipulation ensured that participants could not rely on the well-formedness of the letter string to decide whether the item was a word (Blazely, et al., 2005; Plaut, 1997). In all word items, only 11% of them referred to animal names. Since little is known about the semantic interference with non-word stimuli, we will examine the effect of sound-judgment tasks on word and non-word stimuli separately.

The sound judgment task included 50 items in each condition. The tones were complex sounds similar to a dial tone, half ascending in pitch and half descending, and varying in initial pitch and rate of change. The animal sounds included the vocalizations of 25 different birds and 25 non-bird animals. Items from the two conditions were matched on total duration. A pilot study with 28 participants who did not engage in Experiment 1 showed that the two tasks did not differ significantly by items or subjects in

mean accuracy and response time (all *ps* > 0.10). Thus the two sound-judgment tasks were closely matched for overall difficulty.

Procedure The 51 participants were randomly assigned to either condition, resulting in 25 in Tones and 26 in Birds. Every participant was tested individually and began with three short practice sessions. First, participants practiced the vLD task: on each trial they viewed a letter string on the computer monitor and pressed a button with their dominant hand to indicate whether it was a word or not. Next, they practiced the sound-judgment task alone: participants listened to a series of sounds presented over headphones and orally reported their response by saying "Yes" (for ascending tones in the Tones condition or for birds in the Birds condition) or "No" (for descending tones / non-birds). The oral responses were recorded by the experimenter. If any lexical processing was involved in the oral response, it should be equivalent across two conditions. In the third practice phase, participants performed both tasks simultaneously with a small number of stimuli. In this practice phase and in the experiment proper, the onsets of stimuli in vLD and sound tasks were asynchronous so participants could not get into a "rhythm" of doing one task then the other. After participants were familiarized with the dual-task procedure, they continued to the experiment proper, performing both tasks simultaneously until they had responded to all 200 items in the vLD task (presented in random order). In the sound task, sounds were selected randomly with replacement until participants had finished the vLD task. The study took about 40 minutes.

Results

The mean accuracy in the sound judgment tasks was generally high and did not differ significantly between groups: 0.90 (SD = 0.07) for Tones and 0.93 (SD = 0.03) for Birds, $F(1,49) = 2.329$, MSE = 0.003, $p = 0.133$.

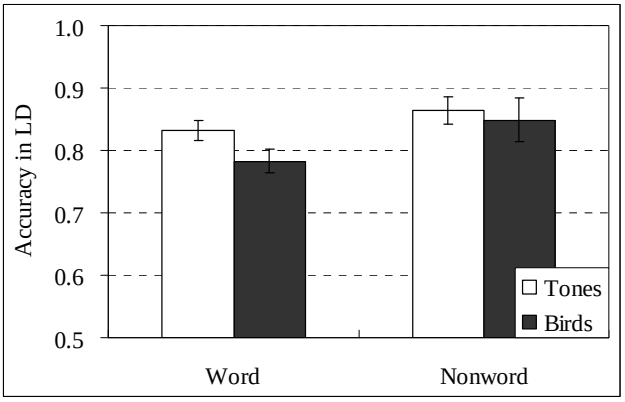

Fig. 1: Mean accuracy of the vLD task in Experiment 1.

Figure 1 shows mean accuracy and standard errors for words and non-words in each condition. A one-way ANOVA revealed that, for word items, accuracy was significantly lower in the Birds than in the Tones condition both by subject and by item (Tones, mean = 0.83, SD = 0.08; Birds, mean = 0.77, SD = 0.10), $F_1(1,49) = 5.410$, MSE = 0.008, $p = 0.024$, $F_2(1,99) = 50.996$, MSE = 0.003, $p < .001$) with no difference in response time (Tones, mean = 1079.36, SD = 358.67; Birds, mean = 1066.43, SD = 439.40, all *ps* > 0.10). For non-words neither accuracy (Tones, mean = 0.86, SD = 0.11; Birds, mean = 0.85, SD = 0.18) nor RT (Tones, mean = 1112.12, SD = 317.14; Birds, mean = 1108.26, SD = 451.54) differed reliably between conditions, all *ps* > .05. Thus, the participants made more errors recognizing words, but not rejecting non-words, when their semantic system was occupied with a secondary nonverbal categorization task compared to an equally-demanding but non-semantic task.

To further test the hypothesis that semantic processing interferes with vLD, we investigated the correlation in overall accuracy between the vLD and the sound judgment task across subjects in each group. If the two tasks do not share a critical resource, we expect a strong positive correlation in accuracy: participants who generally cope well with dual-task situations will perform well on both, whereas those who generally cope poorly with dual tasks will perform poorly on both. If, however, the two tasks share an important resource, this relationship should be altered: allocation of the resource to one task should boost performance in one task but should hinder performance of the other task, attenuating or eliminating the expected positive correlation between the two tasks.

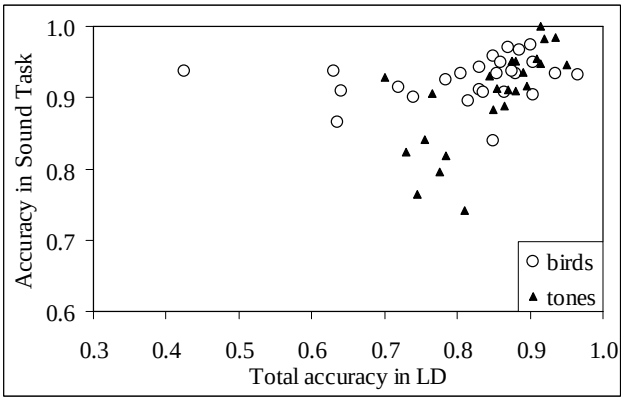

Fig. 2: Correlation between mean accuracy in the vLD task and sound judgment tasks in Experiment 1.

Figure 2 plots the mean accuracy in vLD and the sound-judgment task for the two groups. Performance on vLD and the Tones task was positively correlated (r = 0.700, $p < .001$), while this relationship in the Birds condition was not reliable (r = 0.201, $p = .325$) and was significantly lower than that in Tones condition, $Z = 2.225$, $p = 0.026$. Thus some participants traded off accuracy on vLD for an acceptable level of accuracy on the semantic but not the

non-semantic sound judgment task.

Experiment 2

Experiment 1 found that healthy participants showed worse performance on the vLD task when their semantic knowledge was engaged in a concurrent task. Experiment 2 assessed whether this semantic interference is attenuated when orthographic structure provides a valid cue to lexicality. We hypothesized that, if words and non-words differed reliably in their orthographic well-formedness, participants could rely on this surface cue to guide their decisions, so that reliance on the semantic system would be reduced or eliminated.

Method

Participants Sixty undergraduate students who did not participate in Experiment 1 participated in return for course credit.

Materials and Designs We used identical materials but with two important differences in design. First, stimuli were grouped into two sets in such a way that, within each set, words and non-words differed systematically in their orthographic structure. Thus Set 1 (TW-SNW) included typical words (e.g., rot) and strange non-words (e.g., racht); while Set 2 (SW-TNW) included strange words (e.g., yacht) and typical non-words (yot). Participants completed either Set 1 or Set 2. Second, to maximize our power to detect an influence of semantic interference on word recognition, the secondary task condition (Tones vs. Birds) was manipulated within every subject. Each set was divided into two subsets closely matched for accuracy and response time (all the *p*s > 0.05) in a pilot study with 23 participants who did not participate in Experiment 2. Participants in each group then completed one subset paired with the Tones task and the other subset paired with the Birds task. The order of subsets and their combinations with Tones or Birds condition were counterbalanced across participants.

Procedure Participants were randomly assigned to one of the set conditions resulting in 30 participants in each. The dual-task procedure was identical to that in Experiment 1 except that the participants were exposed to both Tones and Birds conditions in a block design.

Results

Set 1 (TW-SNW) Unexpectedly, the mean accuracy in the sound judgment tasks differed reliably for this group (0.86, SD = 0.10 for Tones and 0.91, SD = 0.04 for Birds), $F(1,29) = 6.447$, MSE = 0.006, $p = 0.017$. Some participants performed especially badly in the Tones task, as implied by the larger SD in this condition. We will return to this issue later in this section.

Neither mean accuracy nor RT in the vLD task differed significantly in the Tones versus Birds conditions—F values ranged between 0.005 and 2.04, all *p*s > 0.16 for all comparisons except response time to reject non-words for tones versus birds. In this contrast there was a trend toward an effect, but with somewhat *faster* response times in the Birds than the Tones condition (Tones, mean = 1026.45, SD = 340.14; Birds, mean = 956.34, SD = 364.01), $F_1(1,29) = 3.424$, MSE = 21558.907, $p = 0.073$, $F_2(1,49) = 2.400$, MSE = 61468.119, $p = 0.128$). Thus there is no evidence that performance of the nonverbal semantic task disrupted word recognition in this condition.

Could this difference from Experiment 1 somehow be attributable to the participants who performed poorly at Tone judgment? To address this question we identified 8 participants with accuracy lower than 0.80 in the Tones task and excluded them from all analyses to see whether the results would differ. With these participants excluded, mean accuracy in Tones condition was 0.91 (SD = 0.07) which was not significantly difference from the Birds condition (mean = 0.91, SD = 0.04), $F(1,21) = 0.242$, MSE = 0.004, $p = 0.628$). In the remaining 22 participants we still observed no reliable effect of sound-judgment task on either accuracy or response time in the vLD task (all the *p*s > 0.05). Thus when words are well-formed and non-words are ill-formed, there is no evidence that participants rely on semantic processing to make lexical decisions.

Set 2 (SW-TNW) For participants who completed Set 2, where words were orthographically ill-formed and non-words were orthographically typical, there was no significant difference in the sound judgment accuracy for Tones versus Birds (Mean accuracy = 0.91, SD = 0.08 for Tones and 0.93, SD = 0.04 for Birds, $F(1,29) = 0.781$, MSE = 0.003, $p = 0.384$).

Just as in Set 1, the mean accuracy and response time for the vLD task did not differ significantly in the Tones versus Birds conditions—all F ratios were between 0.001 and 1.17, all *p*s > 0.28. Thus even when words were orthographically strange and non-words were regular, participants showed no evidence of worse performance when simultaneously performing a semantic relative to a non-semantic task. Experiment 2 thus suggests that, when orthographic structure can serve as a reliable cue to lexicality, participants do not substantially rely upon semantic processing to recognize words.

Discussion

In a dual-task interference paradigm we found that nonverbal semantic processing disrupted word recognition in healthy adults (Experiment 1), especially when orthographic structure did not provide a useful cue to

lexicality (Experiment 2). These results are consistent with the view that word recognition depends upon semantic processing (Patterson, et al., 2006; Rogers, et al., 2004; Woollams, et al., 2007), and they also suggest, in accordance with other work (Plaut, 1997), that such effects can be attenuated in tasks that confound lexicality with orthographic structure.

Our results complement patient studies documenting a strong association between impaired semantic knowledge and disturbed performance on lexical tasks including word recognition (Patterson, et al., 2006; Rogers, et al., 2004; Woollams, et al., 2007). A natural interpretation of this patient work has been that semantic, orthographic and phonological representations of words are all represented within the same interactive system (Dilkina, McClelland, & Plaut, 2008; Plaut, et al., 1996) so that, when semantic representations degrade, so too does the stability of unusual phonological and orthographic forms. This hypothesis has proven difficult to test through patient studies alone, however, because it has been difficult to rule out the alternative hypothesis that lexical and semantic impairments occur as a consequence of a disease process that jointly affects two independent systems. The current study provides a stronger test of the hypothesis because there is no disease process—instead, the contribution of semantic processing to word recognition was functionally disrupted by engaging the semantic system in a secondary task. Moreover, the secondary task was a nonverbal sound-recognition judgment that arguably makes no demands upon lexical processes. Nevertheless, it led to poorer word-recognition when performed simultaneously with vLD.

Our results challenge the view that there exists "an orthographic lexicon that is distinct from the semantic system" (pp1163, Coltheart, 2004). On this view, normal participants with intact orthographic lexicons should show equivalent performance in dual-task conditions, regardless of nature of the secondary task, because accurate word-recognition can be accomplished solely by consultation of the orthographic lexicon.

Others have previously argued that the orthographic structure of targets and distracters might influence the extent to which accurate lexical decisions depend upon semantic processing (Plaut, 1997; Seidenberg & McClelland, 1989), and this hypothesis was corroborated in Experiment 2: using the same materials and procedure as Experiment 1, the semantic interference effect was eliminated simply by blocking stimuli so that orthographic well-formedness provided a reliable cue to lexicality. If participants could perform accurately simply by accepting (for Set 1) or rejecting (for Set 2) all well-formed letter strings, then they relied less or not at all on semantic input.

It is worth noting that this latter result also poses a puzzle for the view that there exists an orthographic lexicon that is independent of semantics. If lexical decisions are "…done at the level of the orthographic lexicon" (pp701, Blazely, et al., 2005), it is not clear why one should observe different patterns of behavior for the exact same set of target words, depending upon how they are blocked with non-word distractors. Besides, the results from Experiment 2 eliminated the possibility that the semantic interference observed in Experiment 1 was due to difference in the extent of covert word reading across conditions. If so, some might expect to observe poorer performance on vLD in the Birds condition as well, since the same paradigm and sound stimuli were used in Experiment 2. However, this prediction is not supported by the result, suggesting that the covert articulation, if any, cannot be the alternative explanation for the observed semantic inference in Experiment 1.

The present study leaves at least one important question unanswered: How does one account for individual cases who, despite serious semantic impairment, can perform within the normal range on tests of word recognition or other lexical tasks? Recent computational modeling work has emphasized that individual differences in linguistic experience can influence the performance of lexical tasks and might account for the occasional lexical/semantic dissociations observed in neuropsychological studies (Dilkina, et al., 2008). For instance, Zevin and Seidenberg (2006) showed that variability in the model training regime can produce individual differences in non-word reading patterns similar to those observed in skilled readers. Dilkina et al. (2008) also demonstrated how differences in the frequency with which a model encounters orthographic versus visual inputs can produce dissociations between word reading and object naming in an interactive model of the lexico-semantic system.

In addition to such differences in experience, our results suggest that individuals may differ in other important respects. In Experiment 1, we found that, whereas some individuals coped well with the dual task scenario—performing near ceiling on both tasks—others struggled considerably and, in the "semantic interference" condition, appeared to trade off the accuracy of one task for another. Previous work (Herdman & LeFevre, 1992) has shown that a dual-task paradigm increases resource demands and affects different aspects of word recognition process, such as speed and efficiency. Presumably, participants with superior cognitive control are better able to manage the resource demands for both tasks and so may show little semantic interference. Understanding how individual differences in linguistic experience and in cognitive control may contribute to differential reliance on the semantic system in the performance of lexical tasks remains a goal for future research.

In conclusion, the present study demonstrates that normal participants' performance on a visual lexical decision task is disrupted by a simultaneous sound judgment task that taxes semantic memory, suggesting that lexical processes draw upon semantic processes. Moreover, the semantic interference was affected by the orthographic structure of

the words and non-words, suggesting that reliance on semantic versus orthographic information in lexical decision is dynamic.

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References

Blazely, A. M., Coltheart, M., & Casey, B. J. (2005). Semantic impairment with and without surface dyslexia: Implications for models of reading. *Cognitive Neuropsychology, 22*(6), 695 - 717.

Cipolotti, L., & Warrington, E. K. (1995). Semantic memory and reading abilities: A case report. *Journal of the International Neuropsychological Society, 1*, 104-110.

Coltheart, M. (2004). Are there lexicons? *Quarterly Journal of Experimental Psychology: Section A, 57*, 1153-1171.

Dilkina, K., McClelland, J. L., & Plaut, D. C. (2008). A single-system account of semantic and lexical deficits in five semantic dementia patients. *Cognitive Neuropsychology, 25*(2), 136-164.

Graham, N. L., Patterson, K., & Hodges, J. R. (2000). The impact of semantic memory impairment on spelling: Evidence from semantic dementia. *Neuropsychologia, 38*(2), 143-163.

Hauk, O., Patterson, K., Woollams, A., Watling, L., Pulvermüller, F., & Rogers, T. T. (2006). [Q:] When would you prefer a SOSSAGE to a SAUSAGE? [A:] At about 100 msec. ERP correlates of orthographic typicality and lexicality in written word recognition. *Journal of Cognitive Neuroscience, 18*, 818-832.

Herdman, C. M., & LeFevre, J.-A. (1992). Individual differences in the efficiency of word recognition. *Journal of Educational Psychology, 84*(1), 95-102.

Patterson, K., & Hodges, J. R. (1992). Deterioration of word meaning: Implications for reading. *Neuropsychologia, 30*(12), 1025-1040.

Patterson, K., Lambon Ralph, M. A., Hodges, J. R., & McClelland, J. L. (2001). Deficits in irregular past-tense verb morphology associated with degraded semantic knowledge. *Neuropsychologia, 39*(7), 709-724.

Patterson, K., Ralph, M. A. L., Jefferies, E., Woollams, A., Jones, R., Hodges, J., et al. (2006). "Presemantic" cognition in semantic dementia: Six deficits in search of an explanation. *Journal of Cognitive Neuroscience, 18*(2), 169-183.

Plaut, D. C. (1997). Structure and function in the lexical system: Insights from distributed models of word reading and lexical decision. *Language & Cognitive Processes, 12*, 765-806.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.

Rogers, T. T., Ralph, M. A. L., Hodges, J. R., & Patterson, K. (2004). Natural selection: The impact of semantic impairment on lexical and object decision. *Cognitive Neuropsychology, 21*(2-4), 331-352.

Schwarz, M. F., Saffran, E. M., & Marin, O. S. M. (1980). Fractionating the reading process in dementia: Evidence for word-specific print-to-sound associations. In M. Coltheart, K. Patterson & J. C. Marshall (Eds.), *Deep dyslexia*. London: Routledge and Kegan Paul.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*(4), 523-568.

Woollams, A. M., Ralph, M. A. L., Plaut, D. C., & Patterson, K. (2007). SD-squared: On the association between semantic dementia and surface dyslexia. *Psychological Review, 114*(2), 316-339.

Zevin, J. D., & Seidenberg, M. S. (2006). Simulating consistency effects and individual differences in nonword naming: A comparison of current models. *Journal of Memory and Language, 54*(2), 145-160.