Dissociating Word Reading and Lexical Decision in Neglect Dyslexia: A Connectionist Account

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Abstract

Neglect dyslexia is a reading impairment acquired as a consequence of brain injury characterized by failures to read verbal material on the left side of a text or at the beginning of words. Neglect dyslexia patients make many errors when naming isolated words, whereas they perform nearly normally when required to make a lexical decision judgment. This behavior has been interpreted in terms of a dual route model where a preserved lexical route is used to perform the lexical decision task, and an impaired non-lexical phonological route is used for naming. We trained a connectionist model to read single words and then lesioned it in order to simulate neglect dyslexia. We show that the damage to the model contributes to the same naming/lexical decision dissociation in a model with a single route for reading.

Introduction

Neglect dyslexia is a reading impairment usually associated with right brain damage and unilateral visuospatial neglect. Patients with neglect dyslexia may fail to read verbal material on the left side of an open book, or the beginning words of a line of text, or more often the beginning letters of a single word (Bisiach & Vallar, 1988; Hillis & Caramazza, 1995).

Neglect dyslexia has been traditionally described according to a general framework of word representation proposed by Caramazza and Hillis (1990). In this model the process of word recognition has been hypothesized to be hierarchically organized through three stages (referred to as "retinocentric", "stimulus-centered" and "word-centered"), and neglect dyslexia has been shown to arise independently at each of these levels with different patterns of reading errors. With reference to the retinocentric level of representation, neglect dyslexia has been interpreted as an impairment of selective attention to the visual hemifield contralateral to the lesion in reference to a spatial coordinate system centred on the eye fixation point. Damage at this level results in the classic failure to correctly report the initial letters of a centrally presented word.

In the last few years a mounting body of evidence has suggested that partial information from the contralesional side is accessible at many levels of processing in these patients. Vallar, Guariglia, Nico, & Tabossi (1996) documented a patient with severe neglect dyslexia who was impaired when asked to read aloud compound words such as girasole (*sunflower*), made up of two words: gira (*turn*) and sole (*sun*), but was able to produce appropriate associations to the compound as a whole (e.g. *rose*). This relative sparing of the associative task suggests that information from the neglected side of the space is still accessible to the lexical processing system to some degree. Relatedly, some patients with mild neglect dyslexia impairments make less errors in reading words than nonwords (Ladavas, Shallice, & Zanella, 1997a). This lexical effect also suggests that the lexical representation of a word might be partially accessed.

Further evidence for preserved processing of some aspect of lexical processing from the contralesional portion of the word comes from a series of investigations by Ladavas, Umilta' and Mapelli (1997b). The authors found that Italian patients who could not read words or nonwords aloud were nevertheless able to perform correctly on a lexical decision task and a semantic categorization task (living-nonliving)[1]. This dissociation was found for the same stimuli.

Furthermore, Arduino, Burani and Vallar (2003) showed that, for neglect patients, lexical decision was influenced by the same morpho-lexical variables that influence lexical decision in control participants. The authors asked 6 Italian neglect dyslexic patients to perform a reading task on a list of words and nonwords and then tested them on the same stimuli on a lexical decision task. Patients made fewer errors in lexical decision for a written stimulus than in reading the word aloud. Arduino et al. (2003) also showed that lexical decision was influenced by the frequency of the word (high frequency words more likely to be accepted as lexical entries than low frequency words) and by the presence of a high frequency neighbor for the nonwords (a nonword with a high frequency neighbor was less likely to be rejected).

Neglect dyslexia therefore provides insight into the interaction and relative sparing of levels of lexical processing in the brain. In the next section we review models of reading that have been posited to account for the fine-grained behavioral data in neglect dyslexics.

Neglect dyslexia and the Reading System

The dissociation between reading and lexical decision has been interpreted by Ladavas et al. (1997a, 1997b) in terms of an interaction between the attentional system and the two main routes proposed by the dual route model of reading (Coltheart, 1978; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). According to this theory, there are two different procedures for producing a phonological code and

[1] Patient data comes from untimed responses. Performance under such circumstances is almost 100% correct for reading and lexical decision in matched controls.

so converting a printed word into speech: a lexical route, which involves accessing a stored lexical representation of the word, and a nonlexical route, which involves assembling a pronunciation by the application of grapheme-phoneme correspondence rules. Patients with neglect dyslexia might have a degraded visual representation of the letter string which did not support correct reading through the nonlexical route, a pathway that requires the scanning from left to right of all the letters in a word, but it might still be strong enough to activate the lexical route to perform a lexical decision and identify the word as a whole single unit.

There are two main problems with this interpretation. First, if the lexical route is spared, why do neglect dyslexic patients fail to use this route to read aloud? Second, why is only the nonlexical route affected by the attentional disturbance and not also the lexical route?

Ladavas at al. (1997a) proposed that the lexical route leads to a broadening of the attentional focus that encompasses the single letters, whereas the nonlexical route focuses on the single units (letters), the latter resulting in being more affected by the attentional disruption. Nevertheless, Arduino, Burani and Vallar (2002) reported morpho-lexical effects in the reading task for mild neglect patients, suggesting that when the attentional disruption is less severe patients might still benefit from lexical information in reading aloud as well as in lexical decision.

Another central issue for this debate is the nature of the reading process itself. Connectionist approaches to reading (e.g., Plaut, Seidenberg, McClelland & Patterson, 1996; Seidenberg and McClelland, 1989) have challenged the claim of the existence of two independent routes used to read developing models that could successfully pronounce monosyllabic words (regular and irregular) by use of a single mechanism, without the application of any conversion rule or “look up” procedure. Lexical knowledge in these models develops from general learning principles applied to the mappings among distributed representations of orthographic inputs and phonological outputs, without recourse to word-specific representations.

Lexical decision has also been explored in models employing distributed representations. Plaut (1997) showed that a feedforward network that maps orthography to semantics with a direct pathway and also via phonological representations can discriminate between words and nonwords on a measure of familiarity defined over semantics, with no need to consult any lexicon as suggested by the dual route model (Coltheart et al., 2001).

Lexical decision can also be performed at the phonological or at the orthographic level rather than in terms of processing semantic representations (Waters & Seidenberg, 1985). Connectionist models have also proven effective in distinguishing words from nonwords using only orthographic and phonological representations. The original PDP model developed by Seidenberg and McClelland (1989) could discriminate words from nonwords at the orthographic level, using the orthographic error score as a discriminator. In another type of architecture, Ans, Carbonnel and Valdois (1998) developed a connectionist model which incorporated an orthographic checking procedure and could perform lexical decision by comparing the activities of the patterns generated over two different orthographic layers, O1 and O2, corresponding to the orthographic input and to feedback from an episodic memory layer (EM), respectively. In this simulation, it was demonstrated that the lexical decision task does not require access to individualized word representations, because the echo from the EM to the O2 resulted from the contribution of a number of different word traces.

In this paper we describe a set of simulations using a feedforward neural network that learns to map orthographic onto phonological representations. We test the extent to which a simple model of reading can be extended to simulate neglect dyslexia performance in reading and show a dissociation between reading and lexical decision tasks. Semantics is not implemented in the model and we investigate the extent to which treating lexical decision as a process on the output of phonological processing can resemble the behavioral data. From a theoretical perspective, the results test whether a connectionist model implementing a single mechanism (and not two independent routes) and with no explicit word-level representation or semantic support can offer a more parsimonious interpretation of the neglect dyslexia dissociation than the dual route account.

Simulating neglect dyslexia

Method

Architecture The network is comprised of an orthographic layer with 208 units, a hidden layer with 100 units, and a phonological layer with 88 units. The orthographic units were fully connected to the hidden units, which in turn were fully connected to the phonological output units. All the connections were monodirectional. The orthographic representations for words were slot based, with one of 26 units active in each slot for each letter. There were 8 letter slots. Words were inputted to the model with the first vowel of the word in the fourth letter slot. So, the word “help” was inputted as “- - h e l p - -”, where “-” indicates an empty slot.

At the output layer, there were eight phoneme slots for each word. Three representing the onset, two for the nucleus, and three for the coda of each word, and so “help” was represented at the output as “- - h E - l p -”. This kind of representation has the advantage of capturing the fact that different phonemes in different positions sometimes differ phonetically (Harm & Seidenberg, 1999). Each phoneme was represented in terms of 11 phonemic features, as employed by Harm and Seidenberg (1999). The units were standard sigmoidal units with real-valued output ranging between 0 and 1 for the input and hidden layer, and –1 and 1 for the output layer.

Training and testing As a training set for the model, we selected 2153 monosyllabic words from the CELEX English database (Baayen, Pipenbrock, & Gulikers, 1995), a dictionary based on a corpus of 17.7 million words. We selected words with frequency greater than 68 per million in the database. Each word was 1 to 8 letters long and was assigned a log-transformed frequency according to its frequency in the CELEX database (see Plaut et al., 1996, for a discussion of log frequency compression). Words with more than three phonemes in the coda were omitted from the input set. The model was trained using the backpropagation learning algorithm (Rumelhart, Hinton & Williams, 1986), with the weight of the connections initialized to small random values (mean 0, variance 0.5) and learning rate μ=0.01.

In addition to the word set, two sets of nonwords were used for testing, making a total of 205 nonwords. The first set was Glushko's (1979) nonwords derived from regular and irregular words; the second set consisted of 119 nonwords created by taking existing words from the training corpus and replacing the first letter.

Words were selected randomly according to their frequency. We stopped training after one million words had been presented. For testing, we assessed the model's performance for a reading task and a lexical decision task on all words in the training set, and for the nonwords.

For the reading task, the model's production for each phoneme slot at the output was compared to all the possible phonemes in the training set, and to the empty phoneme slot. For word presentations, if the model's performance matched that of the target phoneme representation for the presented word, then the model was judged to have read the word correctly. For the nonwords, more than one pronunciation is possible for some words (e.g., *bint* can be read to rhyme with *mint* or with *pint*). Accordingly, we used the criterion of Harm and Seidenberg (1999) where the nonword is judged to have been read correctly if the rime (the *int* in the above examples) was consistent with at least one of the rimes in the corpus of words (Harm & Seidenberg, 1999).

For the lexical decision task we used a measure of familiarity assessed at the phonological output. The production of the model was compared against the targets for all the words in training set to find the one that matched the closest. The distance between the actual output activation and the closest word in the corpus was computed as a measure of Euclidean distance across all the phonemes in the word. The lower this distance value, the closer the output was to the target. This distance measure was taken to reflect familiarity of the system to the presented word.

The naming task and the lexical decision task can therefore be distinguished in terms of whether the model can correctly read each letter *individually* in the word or whether the model can produce an output representation close to the target word when considered across *all* phoneme positions.

Lesioning Unilateral neglect following damage to the right hemisphere of the brain has been widely interpreted as a selective attentional impairment to stimuli presented in the left visual field. This general picture also applies for neglect dyslexia. Theories of neglect have typically suggested that each hemisphere of the brain prioritizes attention to the contralateral visual field, with a gradient of attention (Kinsbourne, 1993) or neuronal gradient, where more neurons respond to stimuli in the contralateral visual field (Monaghan & Shillcock, 2004; Pouget & Driver, 2000).

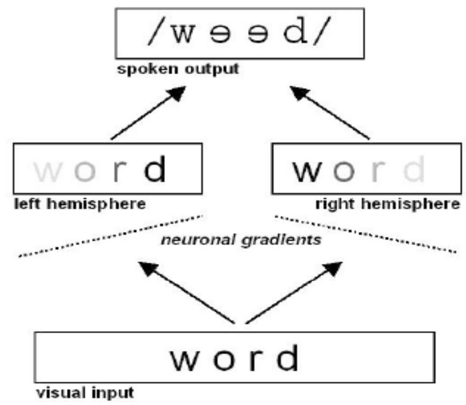

Figure 1: Neuronal gradients in the left and right hemisphere applied to a model of orthography to phonology.

Figure 1 shows how the neuronal gradients account applies to the reading system. The figure indicates the orthography of the word as visual input producing graded activations across the word in the left and right hemispheres, which combine to produce the phonology of the word at the output.

In order to simulate damage to the right hemisphere of the brain, we reduced the activation from input letter slots along a gradient from left to right, such that the largest reduction in activation was from the leftmost letter slots (see Figure 1). The reduction decreased monotonically from left to right letter slots. We used two severities of lesioning. The severe lesion was implemented by reducing the weights of the connections to the leftmost (first) letter slot by 75%, the connections to the second letter slot by 64%, reduction of 53% to the third letter slot, and so on across the input units. Hence, the gradient was linear, ending with a 0% reduction of connections to the rightmost unit. We refer to this as the 75% lesion. A milder lesion reduced connections from the first letter slot by 50%; the second slot was reduced by 43%, the third letter slot by 36%, and so on, to zero reduction for the rightmost letter slot. We term this the 50% lesion.

Results

Unlesioned performance

Naming task. After 1 million patterns had been presented the model correctly reproduced 95.4% of the words in the corpus, which was a level comparable to the accuracy achieved by Seidenberg and McClelland's (1989) feedforward model of reading. On the nonword reading, overall the model scored 71.3% correct (73% on Glushko's regular nonwords, 71.1% on the irregular ones, and 69.5% on the remaining words created from the corpus of words). The model generalizes to novel items to the same extent as other feedforward connectionist models of reading (Harm & Seidenberg, 1999; Seidenberg and McClelland, 1989). In the remainder of the analyses, we report assessments of the model's reading of just those words and nonwords that the model initially read correctly.

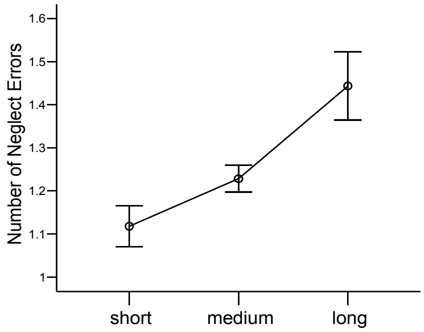

Figure 2: Mean of errors per word as a function of length in the severe lesion model.

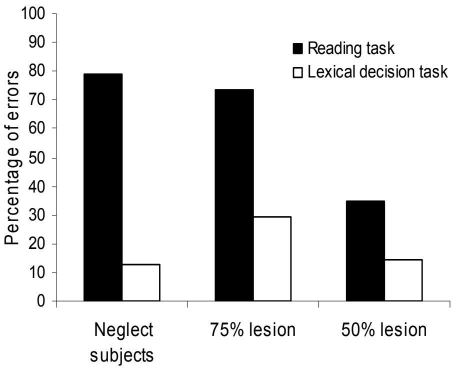

Figure 3: Percentage of errors in the reading task and the lexical decision task in neglect patients and the two lesioned models. Neglect data are adapted from Ladavas et al. (1997a). Words and nonwords are collapsed together.

Lexical decision. We performed a discriminant analysis with word/nonword as a grouping variable and the familiarity measure described in the previous section as a discriminating variable. The model correctly classified 97.7% of the stimuli: 98.2% of the words and 90.3% of the nonwords. The familiarity measure can accurately discriminate words from nonwords, χ^2 (1) = 1873.88, p < .001. Most of the few nonwords incorrectly classified as words were phonologically similar to the words ("beed" similar to "bead", "dore" similar to "door", "fite" similar to "fight"). Overall, the model was very accurate at discriminating words from nonwords in the lexical decision task.

75% lesion performance

Naming task. In order to assess the extent to which the lesioned model resembled neglect dyslexic behavior, we examined the model's naming performance according to the same criteria used by Ladavas et al. (1997a). An error was considered a neglect dyslexia error only when the rightmost 50% of the phonemes of the words and nonwords were correctly reported in the correct position and at least one of the leftmost phonemes in the phonological representation was omitted, misplaced or reported in a wrong position (e.g., *drank* read as "rank", *ink* read as "onk").

When the lesioned model made a reading error, it was usually an omission or substitution of the first phoneme. The model made errors on reading 79.2% of the words and 77.0% of the nonwords. Of these, 73.5% of the word-reading errors were classified as neglect errors, and 73.0% of the nonword errors were neglect errors.

A further hallmark of neglect reading errors is that longer words tend to be read less accurately than short words (Tegnér and Levander, 1993). We tested this prediction in the model to verify whether the severe lesioning procedure succeeded in reproducing this feature. Words were grouped according to their length in number of letters (short words group: 1 to 3 letters long; medium length words group: 4 to 5 letters long; long words group: 6 to 8 letters long). The errors for each word length group are shown in Figure 3. An ANOVA was performed on the errors for the words in the three length groups, and there was a significant effect of length, $F(2, 1193) = 27.2$, $p < .001$, indicating greater rate of errors for longer words. Thus, combined with the neglect errors produced in reading, the model matches two of the standard features usually found in neglect dyslexia patients.

Lexical Decision. All the words and nonwords were tested for the familiarity measure to reflect lexical decision. This was regardless of the type of error (neglect/non-neglect) produced in the reading task. A discriminant analysis of words/nonwords for the familiarity measure was performed to assess the extent to which this measure could be used to guide lexical decision performance. The lesioned model classified correctly a total of 70.8% of the stimuli. 72.4% of the words were classified correctly and 47.9% of the nonwords, $\chi^2(1) = 32.01$, $p < .001$. Even after lesioning, the familiarity measure could discriminate effectively between words and nonwords.

The percentage of neglect errors produced in reading was then compared to the percentage of errors in the classification task. The results are shown in the left side of Figure 3. Errors were more numerous in the reading task than in the lexical decision task: 29.2% errors in lexical decision *versus* 73.5% errors in reading, $\chi^2(1) = 763.6$, $p <$ .001. The model produced the behavioral dissociation shown by neglect dyslexia patients.

A possible confound in the dissociation may be due to a difference in task complexity, with chance level performance of correct lexical decision being 50% and chance level for the naming task being considerably lower. This point was addressed by Ladavas at al. (1997b), where they gave patients' responses to the reading task to normal control subjects in order to make a lexical decision. It was assumed that, if indeed the lexical decision task was easier than reading, then controls subjects would have guessed correctly the status of the stimulus. This prediction was not confirmed. Control subjects could not produce correct responses on the basis of patients' response. It was concluded that guessing strategies on the patients' part were unlikely to be the cause of increased accuracy for lexical decision.

50% lesion performance

Naming task. The model with a mild lesion made errors on 40.5% of the words and 44.5% of the nonwords. Neglect errors accounted for 73.3% of the word errors and 65.6% of the nonword errors. The length effect for the mild lesioned model was not significant, $F(2, 607)$, $p < 1$. This less severe impairment to the strength of connection weights in the model also resulted in reading errors reflecting those of mildly impaired neglect dyslexic patients.

Lexical decision. We generated the familiarity measure for all the words and nonwords that the model read correctly before lesioning. The familiarity measure was entered into a discriminant analysis as before. The results are shown in the right side of Figure 3. The model correctly classified a total of 85.6% of the stimuli: 87.8% of the words and 54.2% of the nonwords, $\chi^2(1) = 305.22$, $p < .001$.

A comparison between the lexical decision performance and the reading one revealed again that the lexical decision task was less impaired by the lesioning than the reading task: 14.4% errors in lexical decision *vs*. 34.8% errors in reading, $\chi 2(1) = 232.4$, $p < .001$.

Discussion

The dissociation between word reading and lexical decision shown by neglect dyslexic patients and what it reveals about the reading system has been the topic of this computational investigation. Patients with neglect dyslexia perform very poorly while reading words but show an almost preserved performance when making a lexical decision on the same stimuli. This dissociation has been traditionally interpreted in terms of the dual route model of reading as resulting from the interaction between the impaired attentional mechanism and the routes used to read a string of letters (Ladavas et al., 1997a, 1997b). According to Ladavas et al. (1997a) the visual representation of the word, although degraded by the attentional disruption, is still strong enough to support the use of the lexical route and correctly perform a lexical judgment. However, if the route is intact, this cannot explain why neglect patients fail to use the lexical route to read aloud words.

One possibility is that the presence of both words and nonwords in the same list might have supported the preferential use of just the non-lexical route (Coltheart et al., 2001). Yet, Ladavas at al. (1997a) reported no effect of list manipulation on the errors made by patients in reading. Performance of patients when reading pure lists (words only) and when reading mixed lists (words combined with nonwords) did not differ.

Connectionist models of reading provide an alternative interpretation of the naming/lexical decision dissociation. Proponents of the connectionist approach showed that a model implementing a single mechanism (Seidenberg and McClelland, 1989:, Plaut et al., 1996) can successfully read regular and irregular words and perform a lexical decision with no recourse to any lexicon or set of pronunciation rules, and without making additional architectural assumptions about multiple routes in processing.

In line with this approach, we demonstrated first that a standard connectionist model of reading could successfully perform a reading task and a lexical decision task on a phonological similarity basis. The unlesioned model could adequately read and distinguish between words and nonwords without using feedback to an orthographic representation and without using semantic representations.

We also demonstrated that a standard model of reading in the connectionist tradition could be impaired according to theories of neuronal gradients of activity responding to different points across the visual field (Pouget & Driver, 2000). When lesioned according to this neuronal gradient, the model simulated neglect dyslexia reading behavior in terms of producing omissions and replacements to letters only on the left side of the word, and, for the severe lesioning, reflecting the length effect in naming responses.

The lesioned model also replicated the dissociation between reading tasks and lexical decision tasks in terms of accuracy of performance for both severities of lesioning. The model replicates this finding without any recourse to a dual route or a distinct lexical representation. The dissociation emerges in the model from the difference between a measure of global phonological similarity for the lexical decision task and a measure of similarity at a componential level – activation of single phonemes – for the reading task. In the model, the activation of individual phonemes is not sufficient to reach threshold for reproducing the phoneme, particularly at the left portion of the word, yet the subthreshold activity of the individual phonemes are still contributing to the global similarity used for the lexical decision task.

However, the model is not exhaustive in its coverage of neglect data, and the points at which the model requires attenuation highlight additional mechanisms in the normal and the impaired reading system. One critical finding that the model cannot replicate is the lexicality effect found in the reading performance of patients, where words are read better than nonwords. Models with semantic representations, such as by Plaut (1997) and Mozer and Berhmann (1990) produce this effect. In the latter model – MORSEL – a stored lexical/semantic representation of the word boosts the processing of degraded information from the visual perception and results in words being more resistant to impairment than nonwords (which by definition lack any lexical representation).

Another important difference between our model and human performance is the quality of the dissociation between the reading task and the lexical decision task. While our model displays relatively greater impairment on the reading task, human subjects show more or less total sparing on the lexical decision task. The trend shown by the model is still a major point and reflects the dissociation between the two tasks, nevertheless we believe the lack of semantic support in the model might have resulted in words being less strongly represented and more prone to misclassification. We believe a model with such level of representation integrated with the orthographic and phonological ones, such as the one developed by Harm & Seidenberg (2004), could in principle reflect the same total sparing shown by humans.

Our model showed that judgments about the phonological representation itself can mimic lexical decision behavior without requiring top-down feedback from semantic representations. We have shown that these bottom-up effects can make a substantial contribution to higher level effects in neglect dyslexia behavior.

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References

Ans, B., Carbonnel, S., Valdois, S. (1998). A connectionist multiple-trace memory model for polysyllabic word reading. *Psychological Review, 105* (4), 678-723.

Arduino, L.S., Burani, C., Vallar, G. (2002). Lexical effects in left neglect dyslexia: a study in italian patients. *Cognitive Neuropsychology*, *19*, 421-444.

Arduino, L.S., Burani, C., Vallar, G. (2003). Reading aloud and lexical decision in neglect dyslexia performance: a dissociation. *Neuropsychologia*, *41*, 877-885.

Baayen, R.H., Pipenbrock, R., & Gulikers, L. (1995). *The CELEX Lexical Database* (CD-ROM). Linguistic Data Consortium, University of Pennsylvania, Philadelphia, PA.

Bisiach, E., Rusconi, M.L. (1990). Break-down of perceptual awareness in unilateral neglect. *Cortex, 26,* 643-649.

Caramazza, A., & Hillis, A.E. (1990). Levels of representation, coordinate frames and unilateral neglect. *Cognitive Neuropsychology, 7*, 391-445.

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

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204-256.

Glushko, R.J. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimantal Psychology: Human Perception and Performance, 5*, 674-691.

Harm, M.W., & Seidenberg, M.S (1999). Phonology, reading and dyslexia: insights from connectionist models. *Psychological Review, 163*, 491-528.

Harm, M.W., & Seidenberg, M.S. (2004). Computing the meaning of words in reading: cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*, 662-720.

Hillis, A.E., & Caramazza, A. (1995). A framework for interpreting distinct patterns of hemispatial neglect. *Neurocase, 1*, 189-207.

Kinsbourne, M. (1993). Orientational bias model of unilateral neglect: Evidence from attentional gradients within hemispace. In I.H. Robertson & J.C. Marshall (Eds), *Unilateral neglect: clinical and experimental studies*. LEA: Hove, UK.

Ladavas, E., Umilta', & C., Mapelli, D. (1997a). Lexical and semantic processing in the absence of word reading: evidence from neglect dyslexia. *Neuropsychologia, 35*, 1075-1085.

Ladavas, E., Shallice, T., & Zanella, M.T. (1997b). Preserved semantic access in neglect dyslexia. *Neuropsychologia, 35*, 257-270.

Monaghan, P., & Shillcock, R. (2004). Hemispheric asymmetries in cognitive modelling: Connectionist modelling of unilateral visual neglect. *Psychological Review, 111*, 283-308.

Mozer, M.C., & Berhmann, M. (1990). On the interaction of selective attention and lexical knowledge: a connectionist account of neglect dyslexia. *Journal of Cognitive Neuroscience, 2*, 96-123.

Plaut, D.C. (1997). Structure and function in the lexical system: Insights from distributed models of word reading and lexical decision. *Language and Cognitive Precesses, 12*, 765-805.

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

Pouget, A., & Driver, J. (2000). Relating unilateral neglect to the neural coding of space. *Current opinion in neurobiology, 10*, 242-249.

Rumelhart, D.E., Hinton, G.E., & Williams, R.J. (1986). Learning representations by back–propagating errors. *Nature, 323*, 533-536.

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

Tegnér, R., & Levander, M. (1993). Word length coding in neglect dyslexia. *Neuropsychologia, 31*, 1217-1223.

Vallar, G., Guariglia, C., Nico, D., Tabossi, P. (1996). Left neglect dyslexia and the processing of neglected information. *Journal of Clinical and Experimental Neuropsychology, 18*, 1-14.

Waters, G.S., & Seidenberg, M.S. (1985). Spelling-sound effects in reading: Time course and decision criteria. *Memory and Cognition, 13*, 557-572.