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Lexical decision with pseudohomophones and reading in the semantic variant of primary progressive aphasia: A double dissociation

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ABSTRACT

The co-occurrence of semantic impairment and surface dyslexia in the semantic variant of primary progressive aphasia (svPPA) has often been taken as supporting evidence for the central role of semantics in visual word processing. According to connectionist models, semantic access is needed to accurately read irregular words. They also postulate that reliance on semantics is necessary to perform the lexical decision task under certain circumstances (for example, when the stimulus list comprises pseudohomophones). In the present study, we report two svPPA cases: M.F. who presented with surface dyslexia but performed accurately on the lexical decision task with pseudohomophones, and R.L. who showed no surface dyslexia but performed below the normal range on the lexical decision task with pseudohomophones. This double dissociation between reading and lexical decision with pseudohomophones is in line with the dual-route cascaded (DRC) model of reading. According to this model, impairments in visual word processing in svPPA are not necessarily associated with the semantic deficits characterizing this disease. Our findings also call into question the central role given to semantics in visual word processing within the connectionist account.

1. Introduction

The semantic variant of primary progressive aphasia (svPPA) is a neurodegenerative disease characterized by atrophy, usually more extensive in the left hemisphere (Gorno-Tempini et al., 2004; Noppeney et al., 2007; M. Wilson et al., 2012; S. Wilson et al., 2009), of the anterior temporal lobes (ATLs). This atrophy is manifested at the behavioral level in the progressive loss of semantic knowledge. In line with this semantic impairment, the ATLs are considered as a semantic "hub" that serves to create transmodal semantic representations (Lambon Ralph, 2014).

Patients with svPPA also often exhibit a reading impairment known as surface dyslexia (Funnell, 1996; Marshall and Newcombe, 1973). This language impairment is characterized by difficulty in reading irregular words (i.e., words that have exceptional grapheme-to-phoneme correspondences, like *pint*), leading to regularization errors (e.g. reading *pint* to rhyme with *mint*). The extent of ATL atrophy has been found to correlate with the degree of impairment of irregular-word reading (Brambati et al., 2009). This relationship between svPPA (and its neural correlate) and the impairment of irregular-word reading has been for decades at the heart of a debate over the role of semantics in visual word processing.

Connectionist models of visual word processing, the most influential of which is the Parallel Distributed Processing (PDP) framework, have taken the association between surface dyslexia and semantic impairment in svPPA as supporting evidence for the necessity of semantics to the correct reading of irregular words (Harm and Seidenberg, 2004; Plaut et al., 1996; Plaut, 1997). In the PDP framework, orthographic, phonological, and semantic information is represented by patterns of activation distributed over groups or layers of units (Plaut et al., 1996). Visual word processing is carried out by the interaction of units in the network via weighted connections (Harm and Seidenberg, 2004; Plaut et al., 1996; Seidenberg and McClelland, 1989). There are two pathways for visual word processing in the PDP model: a direct pathway, from orthography to phonology (O→P), also known as the phonological pathway, and a semantic pathway (O→S→P). The model

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postulates that there is a division of labor between the two pathways whereby processing of consistent and/or high-frequency words can be achieved effectively by the phonological pathway, while processing of low-frequency inconsistent words depends on the contribution of the semantic pathway (Harm and Seidenberg, 2004; Plaut et al., 1996; Woollams et al., 2007). This is because the phonological pathway computes mostly consistent O→P correspondences and, in the course of learning, it comes to rely on the semantic pathway to read low-frequency words with inconsistent O→P correspondences (Plaut et al., 1996). It follows then that damage to the semantic system, such as the one witnessed in svPPA, would inevitably result in impaired reading of irregular words, namely surface dyslexia, since the phonological pathway alone cannot read them. According to Plaut et al. (1996), this division of labor is graded and varies from one individual to another (depending on a number of factors, such as the extent of the reader's experience). Thus, patients who premorbidly relied less on the semantic pathway will show reduced impaired irregular-word reading than those who relied on the semantic pathway for irregular-word reading to a great extent. This hypothesis draws support from a few computational simulations that showed that individual differences can account for the association of or dissociation between irregular-word reading and semantic impairment (Dilkina et al., 2008; Plaut, 1997).

Another theoretical account of reading aloud, the dual route cascaded (DRC) model (Coltheart et al., 2001), supports a completely different view and claims that while surface dyslexia and semantic impairment may co-occur in svPPA, they are unrelated deficits. In other words, the co-occurrence or association of these two deficits does not entail a causal relationship. In this view, the degradation of semantics arises from ATL atrophy, while surface dyslexia results from additional lesions to other brain regions supporting the reading system (Coltheart, 2004; Coltheart et al., 2010a; Patterson et al., 2006).

The sharp contrast between the DRC's account of reading impairments in svPPA and that of the PDP stems from the fact that the two models' architectures and processing mechanisms are very different. One fundamental difference is that in the DRC, all word representations are local rather than distributed. Whole-word forms are thus represented as entries in orthographic and phonological lexicons (the existence of which is eschewed in the PDP framework). Another important point of difference between the two models is that in PDP the same processing mechanism supports both words and non-words, whereas in the DRC the two main routes for visual word processing (lexical for words and sublexical for non-words and regular words) operate according to two different mechanisms. The sublexical route, also known as the grapheme-to-phoneme conversion (GPC) route, operates according to a rule-based mechanism, as it converts graphemes into phonemes serially (i.e. letter by letter, from left to right) by applying spelling-to-sound correspondence rules. It processes non-words and regular words but cannot process irregular words, since their pronunciation does not follow spelling-to-sound correspondence rules. On the other hand, the lexical route operates with a lexical access mechanism and is subdivided in two routes. The first one is the lexical non-semantic route, which is basically a direct route from the orthographic input lexicon to the phonological output lexicon. When a word is presented, the visual features for the word's letters in each position spread activation to its corresponding letter units in each position. These then activate the word's lexical entry in the orthographic lexicon, which in turn activates its corresponding entry in the phonological lexicon. The second lexical route is the lexical semantic route which is supported by the same mechanism as the non-semantic route except that access to the phonological output lexicon is mediated by the semantic system. Both lexical routes (semantic and non-semantic) can process regular and irregular words. Consequently, in case of semantic impairment, and if the lexical non-semantic route is intact, reading of irregular words would remain unimpaired. Thus, in the DRC account, correct pronunciation of irregular words is possible without needing access to semantics. Case studies of svPPA patients who had a significant semantic impairment but had normal reading of irregular words (e.g., Blazely et al., 2005; Cipolotti and Warrington, 1995; Lambon Ralph et al., 1995; Schwartz et al., 1980; Wilson and Martínez-Cuitiño, 2012) have provided evidence for the DRC model and against the connectionist account.

The role played by semantics in lexical decision (LD), a visual word recognition task where participants are asked to decide whether a given letter string is a word or not, is also matter of debate. In the DRC model that, as mentioned before, posits local representations of words, LD is performed in quite a straightforward way. The visual stimulus' letter units activate a number of lexical entries in the orthographic lexicon. A real word is identified (i.e. a *yes* decision is made) when the activation level of one of those entries reaches some critical activation level that allows the *yes* decision to be made or when early in processing the activation of the orthographic lexicon as a whole reaches the critical activation level (Coltheart et al., 1977, 2001; Coltheart and Rastle, 1994). Thus, in this model, recognition of words relies on the retrieval of their orthographic form and does not necessitate access to their meaning (i.e. their semantic representations) (Coltheart, 2004; Rastle and Coltheart, 2006). Non-words are identified (i.e. a *no* decision is made) when no entry in the orthographic lexicon reaches the set critical activation level after a given amount of time (i.e. number of processing cycles; Coltheart and Rastle, 1994). The criterion for this 'deadline' varies depending on the activation level in the lexicon in the first processing cycles: if it is high, the deadline will be longer, if it is low, the deadline will be shorter (Coltheart et al., 1977; Jacobs and Grainger, 1992). Making decisions on word-like stimuli like pseudohomophones (i.e., non-words that sound like a word but do not look like one, such as *brane*) takes longer because the assembled phonological form of the pseudohomophone through the GPC route activates an existing entry in the phonological output lexicon. This phonological activation (/breɪn/) feed forwards to the orthographic lexicon where it excites the orthographic entry corresponding to the real word (*brain*) from which the pseudohomophone was derived. It also receives excitation from the visual stimulus' letter units which overlap with the real word's letter positions (for instance, both *brane* and *brain* have *b* in the first position, *r* in the second, and *a* in the third, making the phonological overlap also orthographic). At the same time, those letter units which do not overlap with the real word will send inhibition to that same entry. This results in higher global activation of the orthographic lexicon and as a result, the deadline for pseudohomophones will be extended as compared to words and simple non-words. Thus, the DRC account of LD predicts that if the lexical non-semantic route is intact, svPPA patients will perform accurately on LD with pseudohomophones, in spite of their semantic impairment.

LD has posed quite a challenge for connectionist models, mainly because they posit distributed representations of words. In contrast with the DRC model, in the PDP framework, semantic activation is essential to perform LD under special circumstances, for example in the presence of particular items in the stimulus list like pseudohomophones or inconsistent words. For such stimuli, orthographic and phonological information alone may not be sufficient to make an accurate decision (Dilkina et al., 2010; Evans et al., 2012; Harm and Seidenberg, 2004; Plaut and Booth, 2000). Plaut (1997) has developed a connectionist model in which accurate LD could be successfully simulated by relying on a measure of semantic familiarity called *semantic stress*, which represents the strength of activation of semantic units. Words have much higher