One Mechanism or Two: A Commentary on Reading Normal and Degraded Words

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Abstract

The SERIOL model of letter-position encoding (Whitney, 2001) led to a precise, verified prediction on how to abolish the length effect normally observed in lexical decision for left visual field presentation of words (Whitney & Lavidor, 2004). Here I present a commentary on an fMRI study on the length effect (Cohen *et al*., in press), in which the authors fail to consider the implications of this finding. I demonstrate that the SERIOL framework provides a better explanation of the authors' data than does their own account.

1.0 ***Introduction***

Following the publication of the SERIOL model of letter-position encoding (Whitney, 2001), interest in orthographic processing has exploded. Indeed, understanding how the brain encodes letter strings is potentially of great theoretical and practical significance. It may shed light on basic processes of visual analysis, and lead to insights into the etiology and remediation of developmental dyslexia (Helenius *et al*., 1999; Maurer *et al*., 2007; Whitney & Cornelissen, 2005).

Hence it is important to identify a detailed, accurate model of orthographic analysis. Therefore, this article discusses problems with the study of orthographic processing presented in *Neuroimage* by Cohen and colleagues (in press). I first briefly review the issues at stake, and then elaborate on the difficulties with the target article.

2.0 ***Serial versus parallel processing***

Cohen *et al.* (in press) espouse a model in which letter strings are normally processed in parallel, dubbed the Local Combination Detector (LCD) model (Dehaene, Cohen, Sigman, & Vinckier, 2005). They assume that strings presented in non-canonical formats invoke an entirely different, serial mechanism, driven by the parietal lobes. The target article seeks evidence for these assumptions. In particular, they assume that an absence of an effect of word length on reaction times indicates parallel processing, which should be associated occipitotemporal activity but not parietal activity. In contrast, they assume that the presence of a length effect indicates serial processing, which should be associated with parietal activity (and increased occipitotemporal activity).

In contrast, the SERIOL model (Whitney, 2001; 2004a) proposes that letters are *always* processed serially within occipitotemporal cortex, on the time scale of ~15 ms/letter. This serial encoding is driven by an activation gradient across a retinotopic representation. Under normal presentation to skilled readers, the activation gradient is formed in a bottom-up manner, as described in Whitney (2001). In other cases (beginning readers, non-canonical formats) formation of the activation gradient requires top-down allocation of an attention gradient by the parietal lobes (Whitney & Cornelissen, 2005; pers. comm. to Andrew Ellis, 2007).

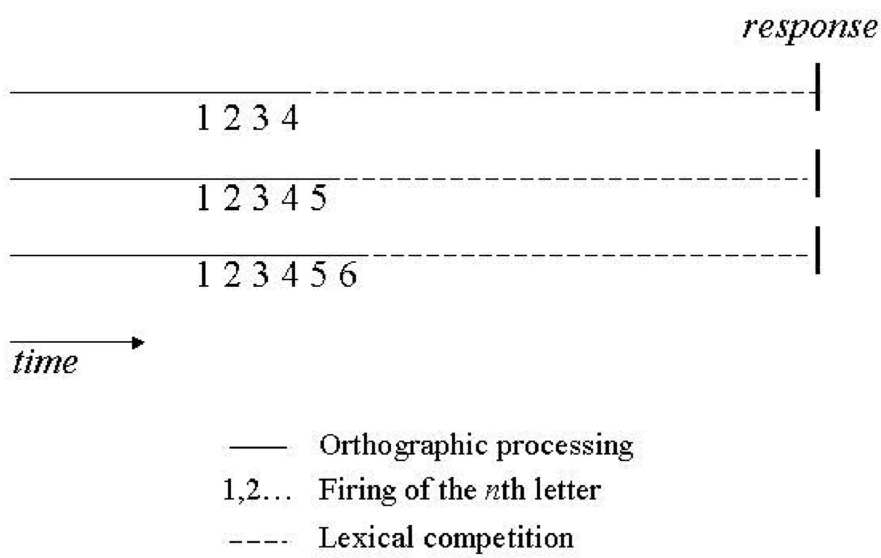

Figure 1: Diagram illustrating how a length effect could fail to emerge under a serial encoding, for four-, five- and six-letter words. If additional letters have a facilitative effect on the amount of time that it takes for the lexical network to settle after the final letter fires, this could cancel out the increased time that it takes to process the letters.

Under the SERIOL model, the presence or absence of a length effect depends on the balance of inhibitory and facilitative effects of additional letters. More letters provide more information, which could speed competition within the lexical level and allow the target word to dominate faster. For longer words, increased letter processing time may be followed by decreased lexical settling time; if these two factors cancel each other out, there will be no length effect, despite a serial encoding. Thus the absence of a length effect does not necessarily imply parallel processing. See Figure 1.

In fact, a recent ERP study of lexical decision provides support for this scenario (Hauk & Pulvermuller, 2004). Word length had no effect on reaction times, but yielded complementary effects on ERP amplitudes at different time periods. Relative to short words, long words yielded *increased* amplitudes from 100 to 125 ms post-stimulus, but yielded *decreased* amplitudes from 150 to 360 ms. These results are entirely consistent with the proposal that longer words require increased processing time at the letter stage, followed by more efficient processing at the lexical stage.

A subsequent ERP experiment revealed more detail about the early, increased activity for longer words (Hauk, Davis, Ford, Pulvermuller & Marslen-Wilson, 2006). In this study, the increased activity extended from 90 ms to 220 ms, while the decreased activity began after 300 ms. Crucially, the length effect was initially right lateralized (at 90 ms) and then became left lateralized (at 200 ms). This shift demonstrates that the early length effect is not simply due to increased visual angle for longer words, because such an effect would be symmetric. Moreover, it supports the claim of serial processing. The first half of a centrally-fixated word falls in the left visual field (LVF) and is projected to the right hemisphere (RH), while second half falls in the RVF and is projected to the LH (Hunter, Brysbaert & Knecht, 2007). Hence, the lateralization shift is consistent with the letters of the first half of the word being processed prior to those of the second half.

Next we consider degraded presentation under the SERIOL account. In this case, bottom-up processing may fail to correctly form the monotonically decreasing activation gradient that drives the serial processing, as discussed in more detail below. Therefore, the activation gradient is supplemented by a top-down attention gradient. If the activation gradient is formed in a top-down manner, it may be less finely tuned than when it is formed via automatic, bottom-up processing. This could increase per-letter processing time at the letter level, and/or provide a non-optimal orthographic encoding that reduces the advantage for additional letters at the lexical level. Either factor would shift the inhibitory/facilitative balance for additional letters, creating an inhibitory length effect.

In summary, the LCD and SERIOL models offer radically different accounts of length effects. In the LCD model, there are two completely different methods of lexical access – a parallel bottom-up one under normal presentation, and a top-down serial one under degraded conditions. In the SERIOL model, there is a single serial mechanism of lexical access. Under normal presentation, serial processing is carried out in a purely bottom-up manner. Inhibitory and facilitative influences of additional letters cancel, giving no behavioral length effect. Under degraded conditions, visual attention contributes to the activation gradient that drives the serial processing. If the inhibitory influence of additional letters now outweighs the facilitative one, a length effect emerges.

Which account is more consistent with the evidence?

3.0 The Data

In their fMRI experiment, Cohen *et al.* (in press) progressively degraded words via three different manipulations: (a) rotation; (b) shift of retinal position from the RVF to the LVF; (c) increased spacing between letters. There were five levels within each mode of degradation; ranging from undegraded (level 1) to maximally degraded (level 5). For all modes, a behavioral length effect was present at levels 4 and 5, but not levels 1 – 3.

Analysis of the fMRI data showed the following. For level 1 in the position and spacing modes, parietal activation did not differ from rest. For all modes, parietal activation increased with degradation level. (Parietal activation differed from rest in rotation level 1. The different modes were blocked, so the parietal activation for rotation level 1 likely reflects the overall difficulty of the rotation manipulation.)

The authors interpreted these results as support for their proposal of parallel processing under normal presentation and serial processing under degradation. However, the pattern of results is not actually consistent with this account. If the onset of the length effect at level 4 reflects a switch to an entirely different type of processing requiring the parietal lobes, parietal activation should show a large jump between levels 3 and 4, and should be similar across levels 4 and 5. However, examination of Figure 5 shows that this is not the case. For all degradation modes in both hemispheres, parietal activation was similar for levels 3 and 4, and jumped between levels 4 and 5.

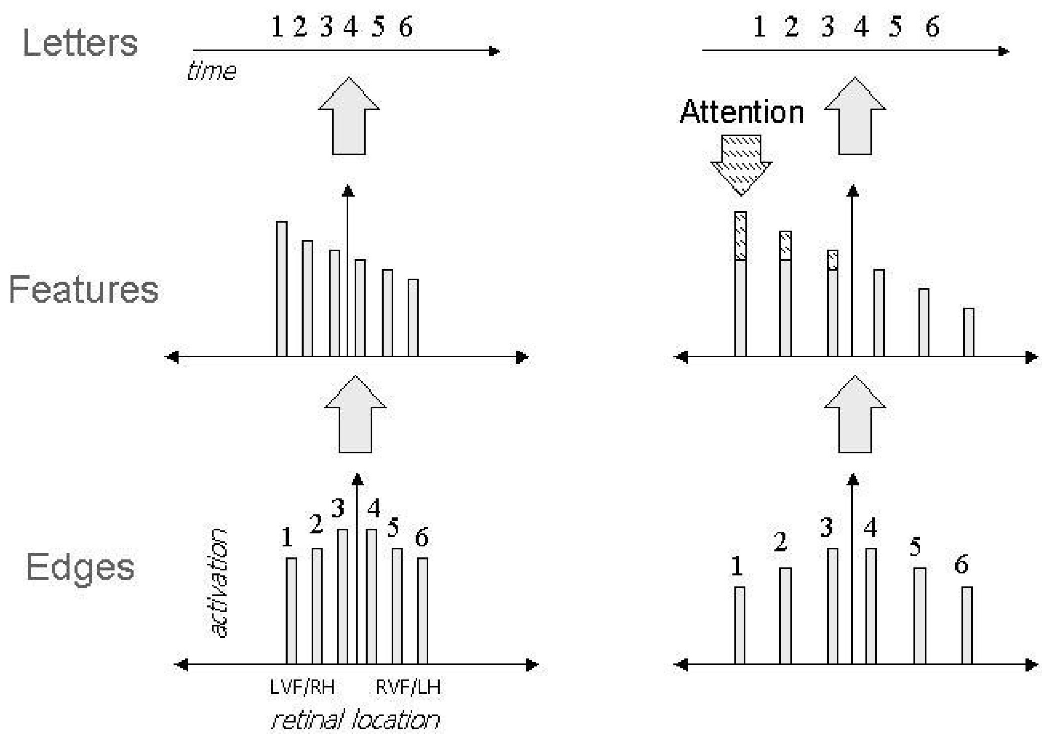

Figure 2: Proposed activation patterns at the edge, feature, and letter levels for the letters of a centrally presented six-letter word under normal spacing (left column) versus wide spacing (right column). *Activation* refers to the total amount of neural activity devoted to representing a letter (at the edge and feature levels) over a given time period. At the edge level, activation reflects acuity. As the edge level activates the feature level, a monotonically decreasing activation gradient is normally formed via learned, hemisphere-specific processing (middle frame, left column). If the letter spacing is too wide, this bottom-up processing would be insufficient to yield a decreasing activation gradient in the LVF/RH (middle frame, right column). Top-down allocation of attention would be required to supplement the activation gradient. In both cases (normal and wide spacing), activation at the feature level determines timing of firing of the corresponding letter at the letter level, yielding a serial encoding of letter order. Wide spacing yields larger variations in feature-level activations, so per-letter processing time increases at the letter level, which would create a length effect.

Under the SERIOL account, parietal activation contributes to the normal processing mechanism, as follows. For canonical presentation, the activation gradient is formed via learned hemisphere-specific processing, which involves left-to-right lateral inhibition for letters initially projected to the RH. (See Whitney (2001) for details.) The manipulations used by the authors would affect the ability of this left-to-right inhibition to form a decreasing activation gradient within the RH. If the distance between the first and last LVF letter is too large (i.e., too many letters, or too much space), the left-to-right lateral inhibition will not have sufficient “reach” to form a smoothly decreasing activation gradient, as discussed in Whitney (2004b). If the string is rotated too far, lateral inhibition along the horizontal axis will not have much effect on subsequent letters. In these cases, formation of the activation gradient may require supplementation of a top-down attention gradient, as illustrated in Figure 2. This would explain the increasing parietal activation with increasing degradation.

Therefore, parietal activation and the length effect are related under the SERIOL account, but are not required to be in lockstep. Under somewhat degraded conditions, visual attention may supplement bottom-up processing to create a finely tuned activation gradient, yielding no length effect. Under greater degradation, top-down attention may be insufficient to fully compensate, creating a length effect. This explains how parietal activation could be similar for levels 3 and 4, with a length effect at 4, but not 3.

Furthermore, there are highly relevant data that the target article did not address. It is well known that presentation to the LVF normally yields a length effect in lexical decision (Young & Ellis, 1985). The SERIOL model implies that this length effect stems from a non-optimal activation pattern at the retinotopic level. If so, it should be possible to abolish the length effect by correcting the activation pattern. Based on precise predictions from the SERIOL model, we manipulated contrast levels at specific string positions in order to optimize the LVF activation gradient. As a result, the LVF length effect was abolished, for the first time (Whitney & Lavidor, 2004). This capability to control the length effect demonstrates identification of its source. It is now incumbent upon researchers who offer an alternative account of the length effect to explain this finding. If, as the authors of the target article would have us believe, the length effect arises from abnormal serial analysis, how could changing the contrast of some letters convert this serial processing to normal parallel analysis?

The authors do reference Whitney & Lavidor (2004), but only to say that the account offered there cannot explain the parietal activation observed in their experiment. While Whitney & Lavidor (2004) did not include a role for the parietal lobes, Whitney & Cornelissen (2005) propose that induction of top-down attention gradient is necessary in learning to read. I had since concluded that an attention gradient is also employed by skilled readers to process non-canonical formats (pers. comm. to Andrew Ellis, 2007). The present fMRI data support this pre-existing assumption. As discussed next, this proposal allows a more realistic account of the observed size of the length effect than the LCD account.

In levels 4 and 5 of the target fMRI experiment, the behavioral length effect was 19 ms/letter for all degradation modes, which is on par with the size of the length effect usually observed under LVF presentation. The authors propose that this reflects serial allocation of attention across the letter string. However, top-down allocation of attention operates far too slowly to yield seriality at this time scale; studies have shown that serial covert shifts of attention take at least 300 ms per shift (Horowitz et al., 2004). In contrast, the SERIOL model proposes that serial processing is driven in a bottom-up manner by a retinotopic activation gradient, and that top-down imposition of a *static* attention gradient can supplement this activation gradient. Serial processing does not depend on shifts of attention, but rather is carried out automatically via interaction of the activation gradient with oscillatory letter units (Whitney, 2001). This explains how the parietal lobes could contribute to serial processing without the requirement of attentional shifts at an unrealistic time scale.

Thus, what we think of as parallel processing - the ability to process many letters within a single fixation – is likely very rapid serial processing. This should not be confused with the possibility of overt seriality. For example, there is a large length effect (~160 ms) in naming one-syllable versus three-syllable pseudowords (Valdois et al., 2006). Phonological assembly for multi-syllable pseudowords may require syllable-by-syllable analysis, with multiple fixations. Such overt serial processing differs from the very rapid, automatic seriality proposed to occur within a fixation.

In conclusion, the target article has problems on three fronts. (1) The authors' data are not consistent with their own account. (2) The authors incorrectly conclude that the SERIOL framework cannot account for their data. (3) The authors cannot explain related data generated by the SERIOL model (Whitney & Lavidor, 2004). For a discussion of other advantages of SERIOL over the LCD model, such as the ability to account for perceptual patterns, see Whitney & Cornelissen (2008). For a more detailed discussion of evidence for serial processing, and refutation of arguments against seriality, see Whitney (in press).

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