

# **The Source of Hemifield Asymmetries in Visual Word Recognition**

**Carol Whitney and Michal Lavidor**

## **Abstract**

Left/right visual field asymmetries have been observed for the lexical-decision task with respect to the effects of string length and orthographic neighborhood size. Based on precise predictions arising from a computational model of letter-position encoding, we demonstrate that the visual field asymmetries can be reversed. These experimental results show that the asymmetries do not arise from hemisphere-specific methods of lexical access, but rather result from differing activation patterns at the sub-lexical level.

## **Introduction**

An experimental task that is often used to study visual word recognition is lexical decision, wherein the subject specifies whether or not a letter string is a word. Several visual field asymmetries have been observed for this task. Reaction times to stimuli presented in the right visual field (RVF) are unaffected by string length, while each additional letter increases left visual-field (LVF) reaction times by 20-30 ms [1]. Another asymmetry arises with respect to the effect of orthographic neighborhood size (N), the number of words that can be formed by changing one letter of the target to a different letter. (For example, PANE has many neighbors: CANE, PINE, PALE, PANT, etc.). Responses to high-N target words are facilitated (with respect to low-N words) under LVF presentation, but not under RVF presentation [2].

Due to the routing of the optic nerves at the optic chiasm, stimuli presented to the LVF are initially projected to the right hemisphere (RH), while RVF stimuli are projected

to the left hemisphere (LH). Therefore, such VF effects have often been taken to arise from hemispheric asymmetries in lexical access. For example, it has been proposed that the RH employs letter-by-letter access to the lexicon, while the LH uses parallel access, accounting for the asymmetry of the length effect [1].

However, brain-imaging studies suggest that there is a single route (and therefore a single mode) of lexical access through an area of left inferotemporal cortex, dubbed the Visual Word Form Area (VWFA) [3]. But this presents a quandary. How could such lexical-level asymmetries occur under a uniform method of access to the lexicon?

Whitney [4] has recently addressed this question under the SERIOL model of letter-position encoding. The SERIOL model is a computational framework which specifies how the early, retinotopic representation of a string is transformed into an abstract encoding of letter order [5]. Aspects of these transformations differ across hemispheres, yielding differing activation patterns. These activation patterns could potentially account for the observed asymmetries. This leads to the prediction that it should be possible to reverse the hemispheric asymmetries by manipulating activation patterns in a specific ways. Here we describe experiments confirming this prediction. We first review the SERIOL model, and then present the experimental results.

### **SERIOL Model**

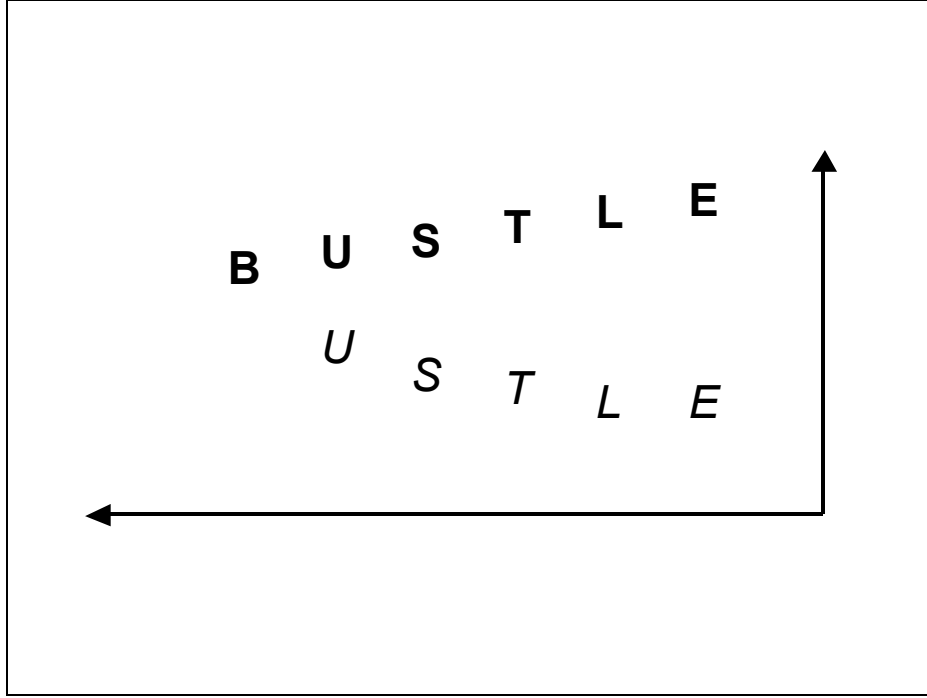
At the letter level, order is represented by sequential firing of abstract letter nodes, which are taken to reside in the VWFA. For example, the encoding of the string BIRD is that B fires, then I, then R, then D. This temporal representation is induced by the interaction of oscillatory letter nodes with input in the form of an activation gradient [6] across retinotopically organized feature nodes. This spatial gradient decreases from the

first to the last letter. For the above example, B's features are the most highly activated, I's the next most, R's the next, and D's the least. Thus, for a language read from left to right, the spatial gradient decreases from left to right. We will concentrate on the formation of the spatial gradient, for this is the source of the differing activation patterns.

At the earliest visual levels, there is another activation pattern, arising from acuity. Acuity is highest at fixation, and falls off as eccentricity increases. In the RVF/LH, this acuity gradient decreases from left to right, so it is consistent with the desired spatial gradient. However, in the LVF/RH, the acuity gradient *increases* from left to right, so it is *not* consistent with the spatial gradient. Therefore, transformation of the acuity gradient into the spatial gradient differs across hemispheres. In the RVF/LH, the acuity gradient can serve as the spatial gradient. In the LVF/RH, the acuity gradient must be overridden via strong bottom-up excitation (to bring the first letter's features to a high activation level), and strong left-to-right lateral inhibition. That is, the first letter inhibits the second, and the first and second letters inhibit the third, etc., to create a decreasing gradient. Additionally, the RH features inhibit the LH features (to "splice" together the two halves of the spatial gradient for a centrally fixated string).

Since the spatial gradient is formed by differing methods in each hemisphere, the shapes of the resulting gradients may differ across hemispheres. This is especially true at large eccentricities. In the RVF/LH, there is a shallow spatial gradient, because the acuity gradient becomes less steep as distance from fixation increases. In the LVF/RH, there is a steep gradient across early string positions (one, two, and three), as the first letter strongly inhibits nearby letters. However, for letters nearer fixation, lateral inhibition may be insufficient to compensate for the increasing activation from increased acuity. Thus at

later string positions, the resulting gradient will become shallower, and may even cease to be monotonically decreasing for longer strings. See Figure 1. This analysis accounts for the interaction between string position, eccentricity, and visual field on letter perceptability observed in [7], as modeled in [5].



**Figure 1:** Spatial gradient formation for LVF presentation. X-axis represents distance from fixation, and Y-axis represents activation level. Boldface letters show bottom-up activation pattern, while italics show effects of lateral inhibition. Strong inhibition from the first letter has a large effect on the second and third letters. Due the relatively low activations of the initial letters and the increasing activation levels of the final letters, lateral inhibition fails to create a smoothly decreasing gradient across the later string positions.

We propose that these activation patterns are the source of the observed hemispheric asymmetries. For longer strings in the LVF/RH, the spatial gradient will not be smooth enough to accurately encode letter order, causing increased reaction times and a length effect. We assume that the N effect arises from top-down feedback from the word level to the letter level. For LVF strings, this feedback compensates for the strong lateral inhibition from the first letter to nearby letters. In the RVF, these letters are already relatively highly activated, and the additional input does not help.

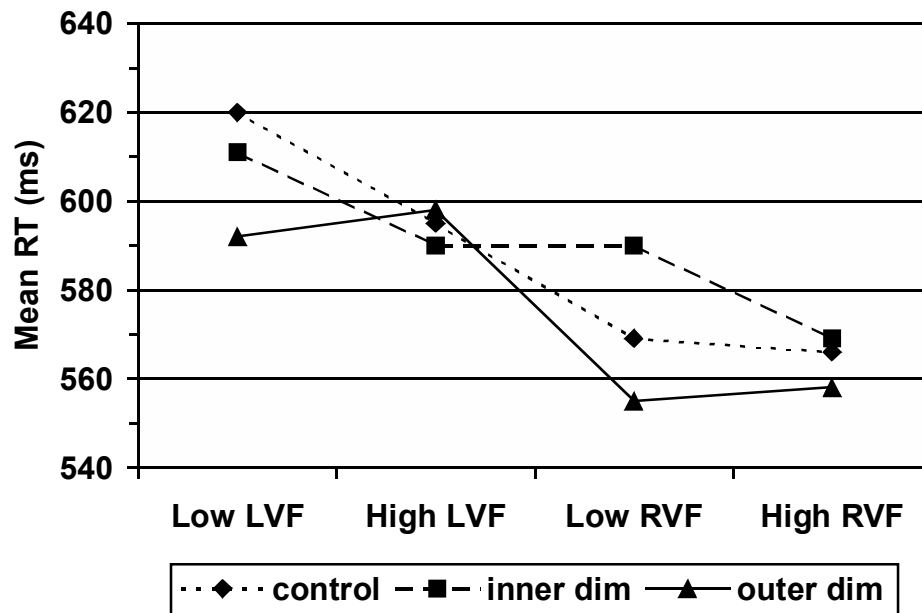
If these analyses are correct, it should be possible to reverse the hemispheric asymmetries by manipulating the activation patterns. This can be accomplished via adjustments of contrast levels at specific letter positions in the stimuli.

## Experiments

In Experiment 1, we tested this account of the N effect, using four-letter stimuli. The RVF/LH activation pattern can be recreated in the LVF/RH by reducing bottom-up input to the first and fourth letters. This reduces lateral inhibition to the second and third letters, and compensates for reduced inhibition at the fourth letter, creating a smooth, shallow gradient. This should cancel the N effect by speeding processing for low-N words, making them as fast as high-N words. Thus the counterintuitive prediction is that such degradation should yield *facilitation* for low-N words, relative to normal presentation conditions. The LVF/RH pattern can be recreated in the RVF/LH by reducing bottom-up input to the second and third letters. This should create an N-effect by slowing processing of low-N words.

Thus, we presented the stimuli under three conditions: normal, reduced contrast of the first and fourth letters (*outer-dimmed*), and reduced contrast of the second and third

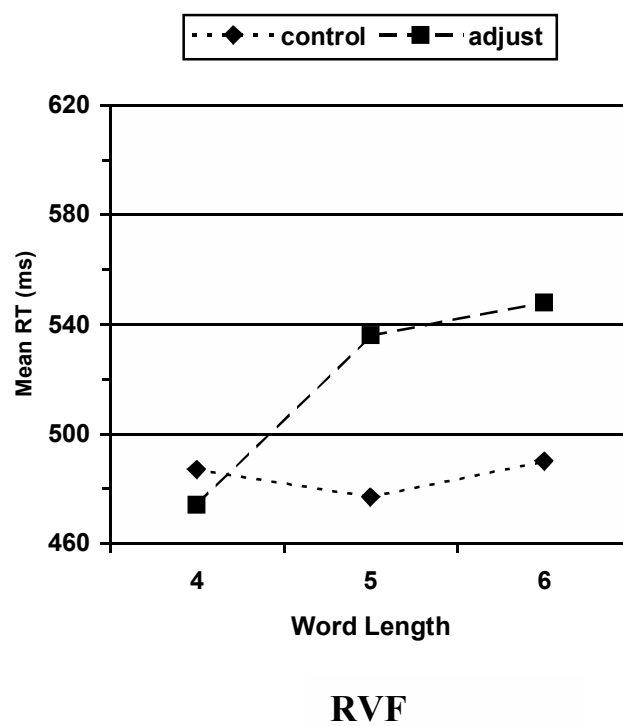
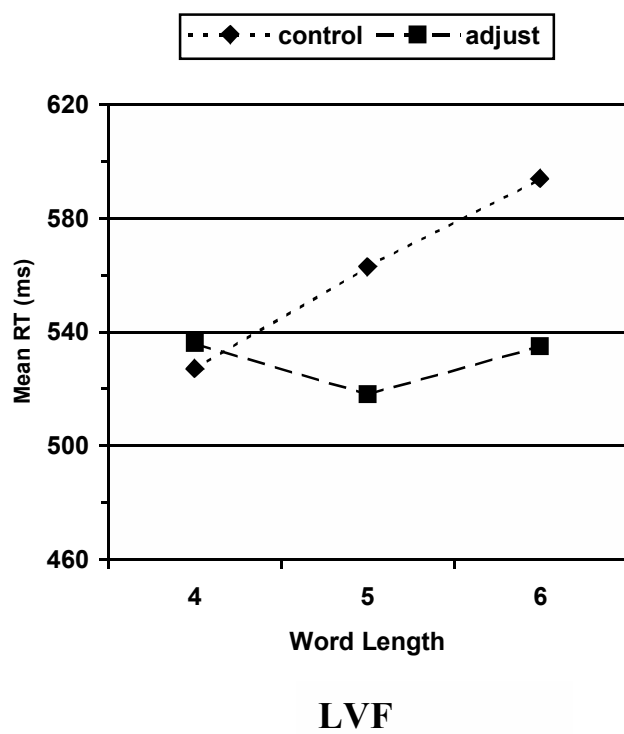
letters (*inner-dimmed*). There was an interaction between presentation type, visual field, and orthographic neighborhood size [ $F(2,36)=6.3$ ,  $p<0.01$ ] on reaction times to words. Posthoc Bonferroni ( $p<0.05$ ) comparisons yielded that for LVF words, the N effect occurred under both the control and inner-dimmed conditions, but not the outer-dimmed condition. For RVF words, the N effect emerged only under the inner-dimmed condition. See Figure 2, which shows that the asymmetry of the N-effect was reversed in the predicted ways.



**Figure 2:** Results from Exp. 1 for word stimuli, by N (Low, High) and visual field for each presentation condition. Note that the N effect disappears in the LVF outer-dimmed conditions because low-N words are facilitated, becoming as quickly processed as high-N words.

In addition to the demonstrating the source of the asymmetry, these results also reveal the primary locus of the N-effect, a question of some debate [8]. Since letter-specific manipulations modulated that effect, it must arise at the letter level, via top-down feedback from the word level.

In Experiment 2, we tested the analysis of the length effect, using stimuli of four to six letters. In the LVF/RH, contrast was increased at the second and third letters and decreased at the sixth letter to produce a smooth gradient. This should cancel the length effect via facilitation for longer words. In the RVF/LH, this same manipulation should create a length effect by degrading a previously smooth gradient. Thus, stimuli were presented under two conditions: normal, and with the above manipulation (*adjust* condition). The interaction between presentation condition, visual field, and word length on reaction times was significant for word stimuli ( $F(2,44)=16.84$ ,  $p<0.001$ ). Posthoc Bonferroni ( $p<0.05$ ) comparisons yielded that for LVF words, a length effect occurred only under the control condition. For RVF words, a length effect occurred only under the adjust condition. Figure 3 shows that robust facilitation for longer words under LVF adjust condition brings their reaction times down to the level of four-letter words. A similar effect was also seen for the non-words.



**Figure 3:** Results from Exp. 2 for word stimuli, by visual field and length for each presentation condition.



Thus the SERIOL model has yielded precise predictions that have proved correct. These experimental results provide strong support for that model, and demonstrate that the length and N effects are not inherent features of RH processing. Rather, they result from differing activation patterns. In sum, the present results help answer key questions in the much-studied area of visual word recognition: how letter-position is encoded, the locus of the N-effect, and the source of hemispheric asymmetries.

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