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The effects of homonymous hemianopia in experimental studies of alexia

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ABSTRACT

Pure alexia is characterized by an increased word-length effect in reading. However, this disorder is usually accompanied by right homonymous hemianopia, which itself can cause a mildly increased word-length effect. Some alexic studies have used hemianopic patients with modest word-length effects: it is not clear (a) whether they had pure alexia and (b) if not, whether their results could be explained by the field defect.

Our goal was to determine if impairments in visual processing claimed to be related to alexia could be replicated in homonymous hemianopia alone.

Twelve healthy subjects performed five experiments used in two prior studies of alexia, under both normal and simulated hemianopic conditions, using a gaze-contingent display generated by an eye-tracker.

We replicated the increased word-length effect for reading time with right homonymous hemianopia, and showed a similar effect for a lexical decision task. Simulated hemianopia impaired scanning accuracy for letter or number strings, and slowed object part processing, though the effect of configuration was not greater under hemianopic viewing. Hemianopia impaired the identification of words whose letters appeared and disappeared sequentially on the screen, with better performance on a cumulative presentation in which the letters remained on the screen. The reporting of trigrams was less accurate with hemianopia, though syllabic structure did not influence the results.

We conclude that some impairments that have been attributed to the processing defects underlying alexia may actually be due to right homonymous hemianopia. Our results underline the importance of considering the contribution of accompanying low-level visual impairments when studying high-level processes.

1. Introduction

Pure alexia is a condition following left occipital damage in which normal reading fluency is impaired, while the ability to write and recognize other types of visual objects is relatively preserved. In some cases pure alexia may represent a disconnection syndrome (Damasio and Damasio, 1983; Geschwind and Fusillo, 1966), while in others it may be a selective visual agnosia, likely related to damage to word-processing regions such as the visual word form area or middle temporal gyrus (Leff et al., 2006; Price and Devlin, 2003). Regardless, one of the diagnostic features of pure alexia is an elevated word-length effect, in which the time taken to read a word is markedly increased by every additional letter it contains (Barton et al., 2014).

Many patients with pure alexia also have right homonymous hemianopia (Leff et al., 2001), however, and this hemianopia itself reduces reading efficiency when the defect affects the central 5° of vision (Trauzettel-Klosinski and Brendler, 1998; Zihl, 1995). As right homonymous hemianopia can also cause a moderately increased word-length effect (Leff et al., 2006), it can be difficult at times to determine whether the slowed reading of a patient represents hemianopic dyslexia or a mild form of pure alexia. Recent work with gaze-contingent displays that simulate hemianopia in healthy subjects have shown that word-length effects of up to 160 ms/letter can be due to the visual defect alone (Sheldon et al., 2012). This has raised concern because patients purported to have alexia in some studies have had a word-length effect less than this upper limit. In such patients it may be that reading problems are due to homonymous hemianopia alone. Indeed one review suggested that on the basis of modest word-length effects the diagnosis of pure alexia may need re-evaluation in 9 of 107 cases in the

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literature (Leff et al., 2001).

Some of these patients have been the subject of innovative studies designed to clarify the nature of the defect in orthographic processing, or identify the presence of broader processing deficits for other types of visual stimuli. The results of such studies can have important ramifications for our concepts and models of the impairment in pure alexia. However, if the diagnosis of pure alexia is in doubt, then inferences made from these results may not be valid. This would be particularly true if similar results could be obtained in subjects with right homonymous hemianopia alone.

Confirming that a patient has only right homonymous hemianopia and no other processing deficit potentially relevant to reading can be a challenge. With most occipital lesions the damage is not confined to striate cortex or the optic radiations but involves a variable degree of extra-striate damage. For this reason studies to isolate the effects of hemifield loss on tasks such as line bisection and visual search have been conducted with gaze-contingent displays that simulate homonymous hemianopia in healthy subjects (Mitra et al., 2010, Simpson et al. 2011). The findings in these types of studies can only be due to the field defect, as there is no question of cortical damage that might affect other cognitive processes.

In our review of the literature we identified two studies of perceptual mechanisms in alexia that involved patients with only modest word-length effects. One study of two patients (Rosazza et al., 2007) investigated the influence of orthographic structure with a series of experiments, including the presentation of the letters of words sequentially with or without disappearance of the letters as the next one appeared, and the identification of trigrams that did or did not have a syllabic structure. The results suggested that one patient had a failure of integration of letters into higher level orthographic units, while the other had preserved access to orthographic forms. However, both patients had word-length effects that were less than 160ms/letter. The second study (Sekuler and Behrmann, 1996) investigated the processing of letter strings, number strings, and simple object shapes, and concluded that alexic patients had additional defects in non-orthographic visual processing, and that therefore the impairment in alexia may not be selective for words. In this study, two of the four patients had word-length effects of about 100 ms/letter.

Our goal was to re-evaluate the results of these studies, by administering some of their key tests to healthy subjects under both normal viewing and simulated right homonymous hemianopia. If a similar pattern of impairment could be replicated under hemianopic conditions, then the relevance of these previously reported findings to alexic mechanisms must be questioned.

2. Methods

2.1. Subjects

Twelve healthy subjects (ten female) with a mean age of 24.8 years (s.d. 4.5) participated. All were right-handed except for one, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects were recruited through Craigslist and paid $10 per h. All had normal corrected vision, English as their first language and no report of reading problems. The institutional review boards of Vancouver General Hospital and the University of British Columbia approved the protocol, all subjects gave written informed consent, and the experiment was conducted in accordance with the principles of the Declaration of Helsinki.

2.2. Apparatus

Subjects sat 40 cm away from a 21-in. monitor with a screen resolution of 1024×768 pixels and refresh rate of 120 Hz. An Andrea NC-8 microphone (http://www.andreaelectronics.com) recorded vocal responses. A headrest and a chinrest stabilized the head. Eye movements were recorded using an Eyelink 1000 eye tracker (www.sr-research.com) with a temporal resolution of 1 ms, a spatial resolution of 0.25° and sample rate of 1000 Hz. Left eye movements were recorded during binocular viewing. Experiment Builder 1.10.1241 was used to present and analyze the experiment.

2.3. Procedure

A gaze-contingent display paradigm simulated complete right homonymous hemianopia in half of the sessions (Mitra et al., 2010). During hemianopic conditions, the entire screen to the right of the current point of fixation was set to the same luminance and color of the background. To guard against inadvertent viewing of stimuli, if the subject's gaze was directed outside of the monitor or if the eye tracker lost track of the pupil, as could occur if the subject pulled their head away from the head rest or closed their eyes, the entire screen assumed the color of the background.

Subjects completed two sessions, at least one week apart, one with full-field viewing, and the second with simulated right hemianopia. We randomized half the subjects to perform full-field viewing first, and the other half to perform hemianopic viewing first. Before each recording session, the eye tracker was calibrated using a nine-point grid spanning 30° right and 30° left of center. The calibration was accepted when the worst error point in the calibration was less than 1.5° and the average error less than 1.0°.

In each session, subjects performed five sets of experiments, in random order.

2.3.1. Word-length effect

2.3.1.1. Reading time. Subjects fixated on a central cross of 1.3° width. When ready, the examiner triggered the start of a trial with a key press. The cross was replaced by a central dot of 0.9° diameter at the same location. If fixation remained stable within 1° of this dot for 200 ms, a single word appeared centered on the middle of a white screen, composed of black upper-case letters in Arial 35-point font, with height of 1.6° of visual angle. If this fixation criterion was not met within 4 s, calibration was reassessed. The participant read the word aloud and then the examiner made a second key press to terminate the trial. A microphone recorded the subject's vocal response and the time between appearance of the word and the onset of their reply was the response time.

Recordings of each response were reviewed to ensure that the marker for latency had been triggered by reading of the word. We used an audio editor (Audacity 2.0.5, http://audacity.sourceforge.net) to verify the accuracy of the audio file response times reported by Experiment Builder. The trial was excluded if subjects did not read the entire word correctly.

There were 140 words, 20 for each of the 7 word lengths ranging from three to nine letters. Words were randomly selected for each subject from a database of 420 words, chosen from the MRC psycholinguistics database (www.psy.uwa.edu.au/MRCDataBase/uwa mrc.htm), with a mean Kucera–Francis written frequency of 380 (s.d. 3553) per million words (Sheldon et al., 2012).

2.3.1.2. Lexical decision task. To match the stimuli used by (Sekuler and Behrmann, 1996), we presented 3-, 5-, 7- and 9-letter words or non-words, of similar size and appearance as used for the reading time study above. Words were obtained from the English Lexicon Project and matched for written Kucera–Francis