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Neuropsychologia 45 (2007) 2246–2257

NEUROPSYCHOLOGIA

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Top-down and bottom-up effects in pure alexia: Evidence from eye movements

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Received 17 July 2006; received in revised form 17 February 2007; accepted 19 February 2007
Available online 7 March 2007

Abstract

The eye movements of a patient with pure alexia, GJ, were recorded as he read sentences in order to explore the roles of top-down and bottom-up information during letter-by-letter reading. Specifically, the effects of word frequency and word predictability were examined. Additional analyses examined the interaction of these effects with the lower level influences of word length and letter confusability. The results indicate that GJ is sensitive to all four of these variables in sentence reading. These findings support an interactive account of reading where letter-by-letter readers use both bottom-up and top-down information to decode words. Due to the disrupted bottom-up processes caused by damage to the Visual Word Form Area or the input connections to it, pure alexic patients rely more heavily on intact top-down information in reading.

Keywords: Letter-by-letter reading; Pure alexia; Eye movements

1. Introduction

Pure alexia (also called letter-by-letter dyslexia, alexia without agraphia, spelling dyslexia, verbal dyslexia, word blindness, or letter confusability dyslexia) is an acquired reading disorder in which premorbidly literate individuals have extreme difficulty reading following a unilateral brain lesion, often to the left occipito-temporal region. In many patients, the reading disorder is often accompanied by a contralesional visual field cut (i.e., homonymous hemianopia; see Leff et al., 2001). Interestingly, while reading processes are disrupted, other cognitive skills, including other language skills such as writing, speaking, spelling, and listening comprehension are generally normally intact (Arguin, Fiset, & Bub, 2002; Chialant & Caramazza, 1998; Friedman & Alexander, 1984; Patterson & Kay, 1982; Shallice & Saffran, 1986; Warrington & Shallice, 1980).

Much of the research indicates that pure alexia arises from a low-level peripheral deficit that affects the normal activation of the orthographic representation of the stimulus (Behrmann, Plaut, & Nelson, 1998; Farah, 1991; Friedman & Alexander, 1984; Montant & Behrmann, 2001). That is, the deficit occurs early in processing at the level of extracting visual information from the text rather than at a higher-level of activating lexical or semantic representations. In fact, many patients display impairment even at the level of identifying letters presented in isolation (Miozzo & Caramazza, 1998; Patterson & Kay, 1982). This impaired ability to extract bottom-up information from the visual stimulus often manifests itself in a word-length effect; that is, the naming latencies of patients with pure alexia increase systematically as a function of the number of letters in the word. For such patients, naming latencies increase on the order of 1–3 s for each additional letter in the word. Furthermore, recent research has shown that the word length effect is also present in patients with pure alexia during sentence reading (Behrmann, Shomstein, Black, & Barton, 2001; Rayner & Johnson, 2005); the total fixation time spent on a word increases about 800 ms for each additional letter in the word (patient DM = 711 ms, patient PC = 943 ms, and patient GJ = 863 ms).

Further evidence to support a perceptual deficit comes from the fact that many word errors made by patients with pure alexia involve a substitution of letters, often orthographically similar in nature (e.g., mistaking *jay* for *joy*, *b* for *d*, *m* for *n*, etc.). Recent research by Fiset, Arguin, Bub, Humphreys, and Riddoch (2005) and Arguin et al. (2002) indicates that letter confusability is a

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0028-3932/$ – see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2007.02.026

primary factor in determining the amount of time that patients with pure alexia will spend on a given word. Arguin et al. (2002) found longer naming times and increased errors in words containing highly confusable letters (i.e., letters that are visually similar to many other letters) than in words containing less confusable letters. In fact, Fiset et al. (2005) found that when controlling words of varying lengths for the sum of the confusability of their constituent letters, the characteristic word length effect disappears. Thus, what seems to be driving reading difficulty in pure alexia is difficulty discriminating and identifying letters. Specifically, Fiset, Gosselin, Blais, and Arguin (2006) argue that patients with pure alexia have lost the ability to use the midrange spatial frequencies associated with the identification of letters. The impairment arises early in the word recognition process, making the activation of an adequate orthographic representation difficult. It should be noted that normal readers[1] are resistant to the letter confusability effect (Arguin et al., 2002; Fiset et al., 2005). It is likely that the ease with which normal readers can extract bottom-up information to identify letters creates a ceiling effect making it impossible to detect such a small effect outside an impaired reading system. Interestingly, Fiset, Arguin, and Fiset (2006) recently showed that when normal readers read text that is visually degraded with a low pass filter, they do display a letter confusability effect and behavioral results similar to that of patients with pure alexia. These results again suggest that the underlying deficit in pure alexia is in encoding an early orthographic representation from the visual stimulus.

Many brain-damaged patients who display letter-by-letter reading patterns have damage to the Visual Word Form Area (VWFA) of the brain. This area is located within the occipito-temporal sulcus next to the left fusiform gyrus (Brodmann's area 37). In individuals without brain damage, the VWFA shows sensitivity to visually presented alphabetic stimuli. The fact that this area is insensitive to textual variations including changes in surface features such as font, size, and letter case, and responds similarly to stimuli presented at different locations within the visual field suggests that the VWFA is responsible for abstract visual word form perception (see McCandliss, Cohen, & Dehaene, 2003 for a recent review). This specialization of invariant word form properties in this area is specific to the visual modality as auditory stimuli do not produce activation of this brain region (Dehaene, Le Clec'h, Poline, Le Bihan, & Cohen, 2002, but see also Price & Devlin, 2003, who argue that the VWFA plays a more general role in processing and is not limited to visual word form representations). Damage to this area of the brain, then, disrupts the automatic activation of the abstract visual representation of a word form without damaging other language skills such as listening comprehension.

Despite their brain damage, there is much research indicating that higher-order lexical factors are intact in patients with pure alexia and influence cognitive processing while reading. However, the extent to which these factors are apparent differs drastically from patient to patient (Arguin, Bub, & Bowers, 1998; Behrmann et al., 1998, 2001; Greenwald & Berndt, 1999; Montant & Behrmann, 2001; Sieroff, Pollatsek, & Posner, 1988; Warrington & Shallice, 1980). Although patients with pure alexia do make errors when reading, they often compute word-length relatively accurately, making letter substitution errors rather than letter omission errors (Riddoch, 1990). Furthermore, many patients display a word-superiority effect showing greater performance (as measured by faster naming times and fewer errors) on words than nonwords (Bowers, Bub, & Arguin, 1996; Buxbaum & Coslett, 1996; Greenwald & Berndt, 1999; Hanley & Kay, 1996; Lambon Ralph, Hesketh, & Sage, 2004; Reuter-Lorenz & Brunn, 1990). It should be noted, however, that some patients show no difference in reporting letters from letter strings that are words versus nonwords, again illustrating the variability across patients (Kay & Hanley, 1991; Warrington & Shallice, 1980).

Response time tasks such as naming and lexical decision have shown that patients with pure alexia are sensitive to lexical properties of the word including word frequency (Behrmann et al., 1998, 2001; Bowers et al., 1996; Chialant & Caramazza, 1998; Fiset, Arguin, & McCabe, 2006; Greenwald & Berndt, 1999; Montant & Behrmann, 2001), word concreteness (Behrmann et al., 1998), regularity (Bowers et al., 1996), orthographic neighborhood size (Arguin & Bub, 2005; Arguin et al., 2002; Montant & Behrmann, 2001), and imageability (Behrmann et al., 1998; Buxbaum & Coslett, 1996; Fiset, Arguin, & McCabe, 2006; Greenwald & Berndt, 1999). Thus, it seems that for many patients with pure alexia, many higher-order lexical factors influence reading.

The influence of both low-level (bottom-up) and higher-level (top-down) factors in pure alexic patients has only recently been explored within the context of sentence reading (Behrmann et al., 2001). Behrmann et al. monitored the eye movements of two patients with pure alexia (DM and PC) and found that they were both sensitive to lexical effects of word frequency and word imageability. Furthermore, they found significant main effects of word length and word frequency as well as an interaction between these two factors. That is, patients made more fixations on (1) longer words than shorter words and (2) low frequency words than high frequency words, indicating that both lower-level factors (the number of letters in a given word) and higher-level factors (word frequency) play a role in patient reading. Furthermore, the interaction indicated that the frequency effect was more pronounced for longer words than shorter words. Behrmann et al. explained this finding as follows: longer words take longer to process and, as such, allow more time for lexical factors to influence processing.

Behrmann, Moscovitch, Black, and Mozer (1990) and Behrmann et al. (1998) have attempted to account for the impaired and intact cognitive abilities in pure alexic patients using the Interactive Activation Model (IAM) of letter and word perception that has also been used to model normal reading behaviors (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). The IAM adopts three levels of processing units (a visual letter feature level, an abstract letter level, and a

[1] Here and elsewhere throughout the paper, the phrase "normal skilled readers" refers to research conducted on literate, college-aged individuals.