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# Do all visual deficits cause pure alexia? Dissociations between visual processing and reading suggest "no"

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ABSTRACT

Pure alexia is a deficit of reading affecting the ability to process a word's letters in parallel. Instead, a slow, effortful letter-by-letter reading strategy is employed. It has been claimed that a visual impairment caused the reading impairment. The present study compares visual processing and word reading of a patient with severe visuospatial deficits due to probable posterior cortical atrophy (PCA) to two patients with pure alexia. A double dissociation emerged between visual processing and word reading: The participant with PCA was severely impaired in all visual tasks but read fluently while the patients with pure alexia read slowly but exhibited better preserved visual processing. It is concluded that a visual impairment does not inevitably lead to pure alexia, and that this syndrome is more plausibly conceived of as an orthographic deficit. In addition, the PCA patient's hypometabolism was assessed, and the interaction of the dorsal and ventral visual stream in word reading is discussed.

## 1. Introduction

Reading is a relatively recent cultural invention that has received attention from scientists of various disciplines. Understanding the psychology and anatomy of reading has been of major interest for experimental psychologists (Balota, Yap, & Cortese, 2006; Rayner, Pollatsek, Ashby, & Clifton, 2012), neuropsychologists (Leff & Starrfelt, 2013; Rapp, Folk & Tainturier, 2001), and neuroscientists (Cattinelli, Borghese, Gallucci, & Paulesu, 2013; Cohen & Dehaene, 2009; Price, 2012). Touching all three disciplines, the study of acquired disorders of reading has been very influential for cognitive models of reading. For example, patients with surface dyslexia have been taken to support different – incompatible – cognitive models of reading (e.g., Blazely, Coltheart, & Casey, 2005; Woollams, Ralph, Plaut & Patterson, 2007). Models, in turn, have been applied to neural activation involved in mapping visual information on conceptual representations and phonological output (Binder et al., 2016; Cattinelli et al., 2013; Hoffman, Lambon Ralph, & Woollams, 2015).

Pure alexia is a neuropsychological syndrome defined as a severe peripheral impairment of reading in the absence of a comparable impairment of writing or aphasic symptoms (Starrfelt & Shallice, 2014). Thus, patients with pure alexia may be able to write spontaneously or to dictation but are unable to read. Some patients cannot identify individual letters (cf. Binder & Mohr, 1992) while others may be able to identify letters but have difficulties with words. Rather than identifying a word's letters in parallel, they follow an effortful and slow letter-by-letter reading strategy which results in the pathognomonic word-length effect, that is, an increase in reading times with each additional letter. The word length effect has been reported to vary between 200 miliseconds and several seconds per letter (Leff, Spitsyna, Plant & Wise, 2006; Patterson & Kay, 1982; Pflugshaupt et al., 2009; Shallice, 1988; Staller, Buchanan, Singer, Lappin & Webb, 1978).

The anatomical basis of pure alexia has become clearer in the last fifteen years or so whereas the underlying cognitive deficit has remained a matter of debate (Behrmann, Nelson, & Sekuler, 1998; Habekost, Petersen, Behrmann & Starrfelt, 2014; Howard, 1991; Patterson & Kay, 1992; Patterson & Lambon Ralph, 1999; Yong, Warren, Warrington & Crutch, 2013). Speech production deficits cannot be held responsible, nor has the visual field defect, reported for the majority of pure alexic patients (Leff et al., 2001), been shown to cause the reading

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impairment (e.g., Bormann, Wolfer, Hachmann, Lagrèze, & Konieczny, 2014; Sheldon, Abegg, Sekunova & Barton, 2012). Since standard, paper-pencil based tests of visual processing were unaffected, Warrington and Shallice (1980) suggested that their participant suffered from 'word-form dyslexia', that is, impaired access to a visual lexicon (cf. Pflugshaupt et al., 2011). Other researchers have localized their participants' functional deficits at the level of integration of letters into syllables (Rosazza, Appollonio, Isella & Shallice, 2007) or access to abstract graphemic representations (Miozzo & Caramazza, 1998; Schubert & McCloskey, 2013). All these accounts have in common the assumption of an orthography-specific deficit in pure alexia, albeit at different levels.

In contrast, another group of accounts reject this assumption and propose that patients with pure alexia suffered from a subtle visual impairment. These so-called visual accounts of pure alexia come in different variants. Leff and Starrfelt (2013) distinguish between three different families of approaches, which should not be considered mutually exclusive. First, some researchers have suggested that patients with pure alexia are impaired in processing visual stimuli in parallel (e.g., Farah, 2004). This position assumes that when it comes to the identification of visual stimuli in parallel, patients with pure alexia are impaired, be it letters or visual features. Letters in a word were but one example. Farah and Wallace (1991), for example, showed that their participant with pure alexia was impaired in tasks requiring matching of multiple and complex nonlinguistic visual stimuli. In addition, they observed an interaction of visual quality of printed words and their length. According to the additive-factors logic, the length effect in pure alexia results from an impairment at the same level affected by the visual quality of the stimuli, namely visual perception. Mycroft, Behrmann and Kay (2009) investigated seven patients with pure alexia on processing tasks involving both linguistic as well as non-linguistic stimuli. They found impaired visual processing of both types of stimuli in all participants. In addition, the degree of reading impairment, as measured by the word length effect, and impaired processing of other visual material and the effect of visual complexity were highly correlated.

Other researchers have proposed that in pure alexia, processing of specific spatial frequencies is impaired. This account is based on the observation that removing specific frequency bands from visually presented words causes a length effect in unimpaired readers and also leads to an effect of letter confusability, a measure of how easily a letter can be identified and distinguished from others (Fiset, Arguin, Bub, Humphreys & Riddoch, 2005; Fiset, Gosselin, Blais & Arguin, 2006).

However, there have been problems with both accounts. First, the difficulties of pure alexia patients are not limited to multiple items. Duncan et al. (2003) as well as Starrfelt, Habekost and Leff (2009) demonstrated that patients with pure alexia also have difficulties processing individual items, for example, letters, so that their impairment is not limited to parallel processing of multiple items. Second, the hypothesis of a processing deficit for specific spatial frequencies fails to account for the reading impairment of at least one patient who was found to perform normally in a task that involved processing of Gabor gratings, specifically in the frequency spectrum argued to be affected in pure alexia (Starrfelt, Nielsen, Habekost & Andersen, 2013).

Although these two specific proposals of an underlying visual impairment have not received unequivocal support, many authors continue to favor a visual impairment underlying pure alexia although the deficit remains to be specified (Behrmann et al., 1998; Behrmann, Shomstein, Black & Barton, 2001; Mycroft et al., 2009; Starrfelt et al., 2009). The fact that many patients with pure alexia are impaired in processing individual letters (Arguin & Bub, 1993; Duncan et al., 2003; Starrfelt et al., 2009) is in line with this assumption. A visual deficit as the underlying cause for pure alexia has been claimed to be more parsimonious as it does not require the assumption of brain regions specific for orthographic processing. This position basically predicts that visual impairments should lead to pure alexia. More specifically, visual hypotheses of pure alexia predict a correlation between visual processing and word reading: With a more severe visual impairment, word reading should be more affected. In addition, the WLE should be larger with a more severe visual impairment. These predictions are central to the present study.

At least one study recently addressed these predictions of the visual hypotheses, with negative outcome. Yong, Warren, Warrington and Crutch (2013) investigated two patients with severe visual processing deficits due to Posterior cortical atrophy (PCA) a neurodegenerative syndrome most commonly caused by Alzheimer's disease (e.g., Benson, Davis, & Snyder, 1988; Crutch et al., 2012). Patients with PCA develop severe visual impairments in the face of better preserved episodic memory and other cognitive functions. Typically, these visual deficits go along with reading impairments (Mendez, Ghajarania & Perryman, 2002) which, in a cognitive model, can be classified as a peripheral reading impairment (Mendez, Shapira & Clark, 2007). Yong et al. (2013), however, documented severely impaired visual processing across a range of tasks, yet only slightly elevated word reading times. Crucially, the PCA patients did not exhibit a WLE the size of pure alexic patients.

The discussion about the underlying cognitive impairment is mirrored at the level of anatomy. In general, pure alexia as a syndrome is associated with lesions in the left posterior hemisphere (Starrfelt & Shallice, 2014), more specifically with lesions to the ventral occipito-temporal cortex (vOTC) or mid fusiform gyrus (Leff & Starrfelt, 2013; Leff et al., 2006), resulting from occlusion of an early segment (P1, P2) of the posterior cerebral artery (Leff et al., 2006). One group of authors considers the vOTC to be specifically involved in orthographic processing (Dehaene & Cohen, 2011). For example, Gaillard et al. (2006) documented reading and reading-related neural activity in a patient with a tumor in the vOTC. After surgical resection of that tumor, the patient suffered from pure alexia with a marked WLE, and fMRI did no longer show activation related to words. Other studies, reviewed by Dehaene and Cohen (2011), have shown reading tasks to activate the left vOTC, irrespective of where the stimuli appear, case of the stimulus words, or type of script (e.g., Kanji versus Kana). In addition, alexia can result from white matter lesions to connections to or from the vOTC. For example, Cohen et al. (2004) as well as Epelbaum et al. (2008) documented pure alexia after surgical lesions isolating the vOTC from its input while others have documented alexia following lesions to the vertical occipital fascicle (Bartsch, Biller & Homola, 2014).

In contrast, an alternative role of vOTC in vision may involve processing of high spatial frequency information (e.g., Roberts et al., 2013; Woodhead, Wise, Sereno & Leech, 2011). For example, Woodhead et al. (2011) measured neural responses to sine-wave gratings with different spatial frequencies: The left vOTC exhibited a preference for high spatial frequencies while the right vOTC exhibited a preference for lower spatial frequencies. Accordingly, Roberts et al. (2013) reported reduced contrast sensitivity for high spatial frequencies in patients with left vOTC lesions. These patients were also impaired in word reading with elevated reading times typical for pure alexia. At the same time, the participants exhibited increased response times to objects and other non-linguistic visual stimuli with comparable spatial frequency information.

A lesion in the left vOTC, thus, seems to affect processing of specific spatial frequency information irrespective of the type of visual stimulus with words being but one type of stimulus. Interestingly, this specialization may not be present in very young children without orthographic knowledge but seems to develop at a later age. Ossowski and Behrmann (2015) assessed detection of high spatial frequency Gabor patches in young children and college students in the left and right visual field. An advantage for the right visual field (left hemisphere) was observed only for adult participants. In children, the difference was not significant but there was a correlation between recognition of letters presented in the right visual field and processing of the Gabor patches. Ossowski and Behrmann (2015) argued that rather than being a precursor for