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Atypical perceptual processing of faces in developmental dyslexia

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ABSTRACT

Developmental Dyslexia (DD) is often attributed to phonological processing deficits. Recent evidence, however, indicates the need for a more general explanatory framework to account for DD's range of deficits. The current study examined the specificity versus domain generality of DD by comparing the recognition and discrimination of three visual categories (faces and words with cars as control stimuli) in typical and dyslexic readers. Relative to controls, not only did dyslexic individuals perform more poorly on word recognition, but they also matched faces more slowly, especially when the faces differed in viewpoint, and discriminated between similar faces (but not cars) more poorly. Additionally, dyslexics showed reduced hemispheric lateralization for words and faces. These results reveal that DD affects both word and face, but not car, processing, implicating a partial domain general basis of DD. We offer a theoretical proposal to account for the multifaceted findings and suggestions for further, longitudinal studies.

1. Introduction

Developmental dyslexia (DD), also known as 'specific reading disability', is a disorder in which children with normal intelligence and sensory abilities show substantial deficits in reading. Although most research on DD has been conducted with children or adolescents, the reading difficulties can persist across the lifespan (Shrewsbury, 2016) and can adversely affect the work participation of such individuals (de Beer, Engels, Heerkens, & van der Klink, 2014).

Despite decades of research, the underlying psychological bases of DD continue to be debated (for reviews see, Démonet, Taylor, & Chaix, 2004; Habib & Giraud, 2012). The commonly held view is that DD arises from deficient phonological representations and, indeed, phonological impairments are among the most common symptoms associated with DD (Vellutino, Fletcher, Snowling, & Scanlon, 2004). However, DD is also related to deficits in orthographic processing (Badian, 2005; Hasko, Groth, Bruder, Bartling, & Schulte-Körne, 2013; Pugh et al., 2000), visual and auditory processing (Clark et al., 2014; Farmer & Klein, 1995), attention (Facoetti et al., 2006) and procedural learning (Nicolson & Fawcett, 2007) and intervention along a host of different domains can result in improvement in DD (Hasko, Groth, Bruder, Bartling, & Schulte-Körne, 2014; Heim, Pape-Neumann, van Ermingen-Marbach, Brinkhaus, & Grande, 2014). The multi-faceted nature of DD has led researchers to search for a general explanation to account for the diversity of deficits, although there remains no clear consensus on this topic (Hari & Kiesilä, 1996; Nicolson & Fawcett, 2011; Stein & Walsh, 1997; Vidyasagar & Pammer, 2010).

Just as with the cognitive profile, there is also substantial controversy regarding the underlying neural abnormalities associated with DD. For example, many recent studies have uncovered a variety of signatures of the disorder (compared with typical readers), including reduced BOLD signal in left extrastriate cortex (Langer, Benjamin, Minas, & Gaab, 2013; Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Pugh et al., 2000; Wandell, Rauschecker, & Yeatman, 2011), lower amplitude magnetoencephalography signals in the vicinity of the left inferior occipitotemporal cortex (Salmelin, Service, Kiesila, Uutela, & Salonen, 1996), as well as changes in gray-white matter proportion and in the integrity of white matter tracts in these same regions (see Richlan, Kronbichler, & Wimmer, 2012; Wandell et al., 2011). Others have argued that alterations in temporo-parietal cortex constitute the neural basis of DD (Raschle, Zuk, & Gaab, 2012), although these alterations are often observed in conjunction with changes in occipitotemporal cortex.

The differences in left ventral occipitotemporal (VOT) cortex in DD, relative to controls, are consistent with a deficit in visual processing in some, if not all, individuals with DD. A key question is whether this visual recognition deficit is restricted to written words i.e., is domain specific or, alternatively, extends to the processing of other classes of visual stimuli (for a review see, Schulte-Körne & Bruder, 2010) and is more domain general. This

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controversy bears on more general arguments about domain-specificity within the visual system, particularly with regard to the visual word form area (Dehaene & Cohen, 2011; Dehaene, Cohen, Morais, & Kolinsky, 2015; Price & Devlin, 2011; Roberts et al., 2012; Vogel, Petersen, & Schlaggar, 2014). A highly informative contrast, and the focus of this paper, concerns the nature of the visual abilities of adults with DD and whether their recognition impairment extends beyond words to another specific category of stimuli, namely faces.

1.1. Interdependence of word and face processing

Words and faces constitute an interesting matched pair because, even though they are entirely unrelated in terms of image statistics, they both require distinguishing a large number of homogeneous exemplars and the perceptual expertise of literate individuals is greatest for these two classes of visual stimuli. Much evidence has suggested that words and faces are recognized by independent mechanisms: words by the Visual Word Form Area (VWFA) in VOT in the left hemisphere (LH) (Petersen, Fox, Posner, Mintun, & Raichle, 1988), and faces by the Fusiform Face Area (FFA) in an approximately homologous region in the right hemisphere (RH) (Kanwisher, McDermott, & Chun, 1997), although this strictly binary account has not been as strongly endorsed recently (Dehaene et al., 2015).

Consistently, a recent theoretical proposal (Behrmann & Plaut, 2013; Plaut & Behrmann, 2011) postulates that, because of specific constraints on neural and cognitive development, these domains are interdependent, both structurally and functionally (for related ideas, see Dehaene & Cohen, 2007; Dehaene et al., 2010). According to this proposal, due to within-category exemplar homogeneity, both words and faces place extensive demands on high-acuity vision. As a consequence, words and faces compete for representational space in both hemispheres in the region of extrastriate cortex adjacent to higher-level retinotopic cortex that encodes central visual information (Levy, Hasson, Avidan, Hendler, & Malach, 2001), notably including both the VWFA and FFA. Additionally, in order to minimize connection length and overall axon volume, word representations are further pressured to be more proximal to language/phonological processing, which is left-lateralized in most individuals, and so the LH visual area is increasingly tuned for the representation of orthographic inputs. Because the image statistics of words and faces differ so greatly, the two types of stimuli cannot be fully co-localized and so, by virtue of competition from word representations in the LH, face representations gradually, although not exclusively, become more right-lateralized. As a result of these cooperative and competitive dynamics over the course of development, in the typical mature state, words are more strongly represented in the LH and faces are more strongly represented in the RH. However, both domains are processed bilaterally, such that the efficacy and degree of hemispheric lateralization of the two domains is causally linked and subject to a variety of factors that vary across individuals. In light of this theoretical proposal, one might predict an impairment in DD for both word and face processing.

1.2. Face processing in developmental dyslexia

In contrast with the view above, domain specific accounts of DD predict that face processing should be normal in DD. Although the existing literature on face processing in DD is not extensive, at first glance it might appear to support these accounts. For example, Brachacki, Fawcett, and Nicolson (1994) reported no difference between DD and non-DD individuals in face recognition. Similarly, Smith-Spark and Moore (2009) found that DD and non-DD university students did not differ in the speed or accuracy with which faces were named, although the non-DD group was significantly faster to name early- than late-acquired faces of famous individuals. Also, several studies have demonstrated that DD individuals were unimpaired in recognition memory for unfamiliar faces (Rüsseler, Johannes, & Münte, 2003) and performed normally when ordering unfamiliar faces in an old/new sequence (Holmes & McKeever, 1979).

Closer examination, however, suggests that the existing results are less than definitive. First, some studies may have been insensitive to group differences because performance was at ceiling (e.g., Brachacki et al., 1994), consistence with findings demonstrating that DD participants perform similarly to typical readers in simple tasks, and group differences emerge only when task difficulty is increased (dual task, inserting noise, or increasing perceptual demands) (Fawcett & Nicolson, 1992; Gabay, Schiff, & Vakil, 2012; Sperling, Lu, Manis, & Seidenberg, 2005; Yap & van der Leij, 1994; Ziegler, Pech-Georgel, George, & Lorenzi, 2009). Second, previous studies focused more on the mnemonic than perceptual aspects of face perception, showing no group differences in recognition memory and/or naming when participants were able to encode the faces well (large size faces, long exposure duration etc.) (Brachacki et al., 1994; Rüsseler et al., 2003; Smith-Spark & Moore, 2009). One recent study that examined the perceptual, rather than mnemonic, performance of DD individuals found that they were not only impaired at face perception but were also impaired at perceiving other visually complex stimuli, especially when within-class stimuli need to be differentiated (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015). Given the ambiguity of the existing empirical findings, the current study aimed to assess the integrity of face processing skills in DD adults to determine whether, and to what extent, face perception and its lateralization is adversely affected in this population. Such findings will help adjudicate between a domain-specific versus more domain-general account of the disorder.

In the current work, we test the face perception performance of DD individuals in a number of investigations, each of which is designed to elucidate, in detail, the extent and nature of any observed impairment. For example, in addition to quantifying performance during matching of upright faces, we compare the performance of the DDs and controls for upright and inverted faces to determine whether the DD individuals exhibit the standard decrement when faces are misoriented, the so-called 'face inversion' effect (Bruce, Valentine, & Baddeley, 1987). We also explore the effect of viewpoint, or depth rotation to assess whether the DDs show the expected cost in matching faces shown across different viewpoints. Last, we examine the integrity of face perception under conditions when faces are parametrically morphed to be increasingly perceptually alike, thus allowing us to carefully characterize performance as a function of task difficulty. Together, these manipulations provide sensitive measures of the strengths and weaknesses of face perception in DD. We also examine the DD's performance on a control stimulus set, cars, to determine whether any deficits observed for faces might be a result of a general visual processing impairment that affects many visual classes and not just words and faces. Finally, motivated by the interdependent hemispheric account (see above), using a divided field paradigm, we compare the hemispheric lateralization effects for cars, words and faces in DD and control participants.

2. Experiment 1: Face matching across inversion and viewpoint

2.1. Participants

Thirty participants, 15 with DD (9M, 6F) and 15 matched controls (9M, 6F) participated in this experiment. Of the participants,