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Beyond the usual cognitive suspects: The importance of speechreading and audiovisual temporal sensitivity in reading ability

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ABSTRACT

The aim of this study was to clarify whether audiovisual processing accounted for variance in reading and reading-related abilities, beyond the effect of a set of measures typically associated with individual differences in both reading and audiovisual processing. Testing adults with and without a diagnosis of dyslexia, we showed that—across all participants, and after accounting for variance in cognitive abilities—audiovisual temporal sensitivity contributed uniquely to variance in reading errors. This is consistent with previous studies demonstrating an audiovisual deficit in dyslexia. Additionally, we showed that speechreading (identification of speech based on visual cues from the talking face alone) was a unique contributor to variance in phonological awareness in dyslexic readers only: those who scored higher on speechreading, scored lower on phonological awareness. This suggests a greater reliance on visual speech as a compensatory mechanism when processing auditory speech is problematic. A secondary aim of this study was to better understand the nature of dyslexia. The finding that a sub-group of dyslexic readers scored low on phonological awareness and high on speechreading is consistent with a hybrid perspective of dyslexia: There are multiple possible pathways to reading impairment, which may translate into multiple profiles of dyslexia.

1. Introduction

Developmental dyslexia (henceforth dyslexia) is a learning disorder characterized by severe difficulties in attaining an adequate reading level, despite normal intelligence and educational opportunities and in the absence of any sensory or neurological impairment (Lyon, Shaywitz, & Shaywitz, 2003). Since reading is an audiovisual process that requires learning and the automatization of systematic links between graphemes and phonemes, it is possible that reading impairment in dyslexia reflects an audiovisual processing deficit (see, for a review of the literature, Hahn, Foxe, & Molholm, 2014). In the present study, we tested this hypothesis by asking whether individual differences in audiovisual temporal sensitivity and in speechreading account for individual differences in reading and reading-related abilities among adult readers with and without diagnosed dyslexia, above and beyond other cognitive skills typically associated with reading. Looking into individual differences among readers with and without dyslexia also allowed us to contribute to another debate on the nature of dyslexia: Is dyslexia better explained by single or multiple deficit models?

Dyslexia represents a persistent condition rather than a transient developmental lag associated with the beginning of reading acquisition. In addition to manifest reading difficulties (e.g., Elbro, Nielsen, & Petersen, 1994), adults with dyslexia also show impaired phonological processing (e.g., Vellutino, Fletcher, Snowling, & Scanlon, 2004). Phonological awareness (the ability to perceive and manipulate the sound structure of spoken words) and letter naming (how quickly letters can be named) are two reading-related abilities that rely on phonological processing. Both abilities are impaired in adult dyslexic readers (e.g. Bekebrede, van der Leij, Plakas, Share, & Morfidi, 2010; Elbro et al., 1994; van Bergen, de Jong, Maassen, & van der Leij, 2014), leading many to believe that a phonological deficit underlies dyslexia (e.g., Snowling, 2000; Stanovich, 1988). Phonological awareness is fundamental for the learning and storing of mappings between visual symbols (graphemes) and letter sounds (phonemes) (Melby-Lervåg, Lyster, & Hulme, 2012). Hence, it has been described as the primary predictor of reading success (Bast & Reitsma, 1998; Caravolas, 2004; Høien, Lundberg, Stanovich, & Bjaalid, 1995; Melby-Lervåg et al., 2012; Müller & Brady, 2001; Öney & Durgunoğlu, 1997; Snowling, 2000; Stanovich & Siegel, 1994; Vellutino et al., 2004, Wimmer, Landerl, Linortner, &

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Hummer, 1991). Letter naming is hypothesized to reflect the ease of access to and retrieval of phonological codes for letters from long-term memory in children (e.g. Chiappe, Stringer, Siegel, & Stanovich, 2002; Pennington, Cardoso-Martins, Green, & Lefly, 2001; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Torgesen, Wagner, & Rashotte, 1994), adolescents (Pennington et al., 2001), and adults (Chiappe et al., 2002). It is an important predictor of reading fluency and dyslexia in alphabetic scripts in children (e.g., van den Bos, 1998; de Jong & van der Leij, 1999; de Jong & van der Leij, 2002; Kirby, Parrila, & Pfeiffer, 2003Georgiou, Parrila, Kirby, & Stephenson, 2008; Kirby, Desrochers, Roth, & Lai, 2008) and adults (Jones, Branigan, & Kelly, 2009).

In summary, adult dyslexic readers show difficulties not only in reading, but also in reading-related abilities, such as phonological awareness and letter naming. This wider reading profile has value in diagnosing individuals with dyslexia (e.g., Reynolds & Shaywitz, 2009). Moreover, adult dyslexic readers might have developed strategies to compensate for their difficulties in reading. Thus, they might not differ from typical readers in reading measures, but, when faced with tasks such as those measuring phonological awareness and letter naming, residual difficulties might become apparent. Hence, in this study, we assessed the associations of audiovisual processing with reading ability, but also with other reading-related abilities reflecting a phonological deficit in dyslexia (that is, phonological awareness and letter naming).

As mentioned before, reading impairment might reflect a deficit in audiovisual processing and, indeed, children and adult dyslexic readers have been shown to inadequately process audiovisual objects, for instance, while being presented with audiovisual and unisensory letters and speech sounds (Blau, van Atteveldt, Ekkebus, Goebel, & Blomert, 2009; Blau et al., 2010; Froyen, Willems, & Blomert, 2011; Kast, Bezzola, Jäncke, & Meyer, 2011; Kronschnabel, Brem, Maurer, & Brandeis, 2014; Mittag, Thesleff, Laasonen, & Kujala, 2013), while identifying unisensory and audiovisual speech (e.g., Hayes, Tiippana, Nicol, Sams, & Kraus, 2003), and while matching non-linguistic audiovisual materials (e.g., rectangles and tones, Widmann, Schröger, Tervaniemi, Pakarinen, & Kujala, 2012). For a subset of the sample of participants tested in this study, we have recently shown differences between dyslexic and typical adult readers in their audiovisual temporal sensitivity (Francisco, Jesse, Groen, & McQueen, 2017). Adult typical and dyslexic readers performed a simultaneity judgment task, in which participants had to indicate whether or not auditory and visual components of speech and non-speech stimuli presented with different stimulus onset asynchronies (SOAs) occurred simultaneously. The speech stimuli elicited the McGurk effect (McGurk & MacDonald, 1976), a perceptual illusion that is characterized by the joint interpretation of incongruent auditory and visual speech. For example, when hearing the syllable /apa/ while seeing a speaker pronouncing /aka/, participants often report perceiving /ata/ — referred to as a fusion response. Using McGurk stimuli provides at least two advantages. First, it allows one to analyze different measures: Proportion of fusion responses, proportion of auditory-based responses, and proportion of visually-based responses. Second (if using different SOAs), it allows one to test whether temporal sensitivity judgments have consequences for identification (given that a congruent stimulus, in contrast, will almost always be identified in the same way). The non-speech stimuli used in our study showed a woman clapping her hands. We showed that adult dyslexic readers had a wider time window of perceived audiovisual synchrony than typical readers, for both speech and non-speech stimuli, that is, they judged asynchronous events as being in-synchrony more often than typical readers.

These results on the perceived simultaneity of audiovisual speech events were in line with those of other studies reporting dyslexic adults' extended temporal windows when judging the temporal order of audiotactile, visuotactile, and audiovisual events compared to typical readers (Hairston, Burdette, Flowers, Wood, & Wallace, 2005; Laasonen et al., 2002). We and others (Hairston et al., 2005; Wallace & Stevenson, 2014) have argued that such an expanded time window could result in difficulties in processes that are dependent on the rapid and accurate integration of cues from multiple senses, such as reading (see Froyen, Van Atteveldt, Bonte, & Blomert, 2008). Expanding the temporal window over which auditory and visual events are seen as synchronous could result in inappropriate grapheme-phoneme correspondences and, consequently, in less efficient decoding. Moreover, it might lead to substantial difficulties in the construction of strong reading representations, in that the wider windows will lead to greater ambiguity in the correspondences between the auditory and the visual elements of a word (Hairston et al., 2005; Wallace & Stevenson, 2014).

Even though these studies provide evidence for an audiovisual deficit in dyslexia, the nature of the relationship between audiovisual processing and reading remains mostly unknown. Studying individual differences could help clarify this relationship. For instance, in an event-related potential (ERP) study testing typical, reading impaired and severely reading impaired children, Žarić et al. (2014) found that individual differences in ERP measures of letter-speech sound integration correlated with reading fluency, suggesting that early audiovisual speech integration processes scale with individual differences in reading ability. Gullick and Booth (2014) investigated the relationship of behavioral performance and brain function related to phoneme–grapheme integration with connectivity in the arcuate fasciculus. In a range of children with different reading abilities, they showed that both response accuracy and brain activity for audiovisual rhyme judgments were predictive of fractional anisotropy along the arcuate fasciculus. Fractional anisotropy reflects the degree of directional diffusivity of white matter voxels. Higher values are taken to reflect greater connectivity between brain regions and thus more efficient processing of information along a specific tract. These studies stress the importance of considering individual differences in reading, reading-related abilities associated with phonological processing, and audiovisual processing in order to understand how reading ability and audiovisual processing are related.

In the present study, we aimed to test whether individual differences in audiovisual processing account for variance in reading, and in reading-related abilities tapping into phonological processing. Individual differences in reading and reading-related abilities have been described in dyslexic adult readers (e.g., Ramus et al., 2003; Rosen, 2003). Such differences may be due to individual differences in distinct cognitive processes. Therefore, to pinpoint the nature of the contribution of audiovisual processing to reading, the effect of cognitive abilities typically associated with reading also ought to be considered. Since the ability to learn to read depends on the acquisition of a variety of different types of knowledge and skills (c.f. Vellutino et al., 2004), we selected a set of distinct cognitive abilities typically associated in the literature with reading ability. First, working memory has been consistently associated with reading, at least in children (Christopher et al., 2012; Swanson, Howard, & Saez, 2006; Swanson, Zheng, & Jerman, 2009) and adolescents (Christopher et al., 2012). It has a fundamental role in: a) establishing stable associations between lexical and sublexical components of spoken and printed words; and b) encoding, storing, and retrieving the different types of information entailed in learning to read (Vellutino et al., 2004). Second, inhibitory control may be related to reading in adults, as it impacts working memory and its contents (Hasher, Zacks, & May, 1999). It ensures that information in the memory buffer is restricted to goal-relevant information, for instance, by preventing any activated but goal-irrelevant information from entering working memory. In a large-sample study, reading-impaired children and adult readers were shown to have greater difficulty in preventing irrelevant information from entering working memory (Chiappe, Siegel, & Hasher, 2000). Third, processing speed is also typically associated with reading. Dyslexic adult readers (Breznitz & Meyler, 2003; Laasonen, Lahti-Nuuttila, & Virsu, 2002; Stoodley & Stein, 2006; Wolf, Bowers, & Biddle, 2000) and children (Pennington & Bishop, 2009; Wolf et al., 2000) show slower processing speed than typical readers across a range of tasks both in the visual and in the auditory modality.