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Research report

Developmental dyslexia and spatial relationship perception

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ABSTRACT

According to wide literature, a global impairment in the temporal and spatial domains as well as an increased crowding effect is common of dyslexics. The aim of the study was to evaluate if such subjects suffer from a more general impairment of spatial relationship perception (SRP) and in particular from anomalous spatial relationship anisotropy (SRA) thus accounting both for their global perceptual distortions and abnormal crowding. SRP of 39 young disabled readers and 23 normal subjects were measured by a specifically designed psychophysical technique based on circular and elliptical target recognitions. A general impairment of SRP characterized by increased horizontal/vertical anisotropy was found in the dyslexic sample compared to the controls. In the second part of the experiment, reading efficiency and reading time were measured by MNREAD© reading cards in standard conditions and after increasing horizontal spatial extension of the sentence by different values. We suppose this modification could well compensate the abnormal anisotropy found in dyslexics. Data obtained in the two groups were compared. A strong correlation between reading efficiency (a parameter we have specifically devised) and horizontal spatial text relationship values were present in the patients ($r = .87$, $p < .01$), but not in the controls. The same was found taking into consideration mean reading time ($r = -.82$, $p < .01$). We therefore gather that an alteration of SRP, characterized by an increased anisotropy may be involved in developmental dyslexia.

1. Introduction

Developmental dyslexia is a specific reading disability that affects approximately 4–10% of the population of school age (Rutter, 1978; Shaywitz et al., 1990). It has been defined as a reading difficulty despite adequate instruction and education, normal intellective capacities and socio-cultural situation and not caused by reduced visual acuity or psychiatric pathologies (Remschmidt et al., 1994). Over the last three decades, visuoperceptive abnormalities have been found to be associated with this pathology, suggesting that visual system impairment may play a causal role.

However, the nature of this deficiency is not clear. At present the most widely accepted theory, mainly based on contrast sensitivity (Lovergrove et al., 1980, 1982, 1986, 1990; Martin and Lovergrove, 1984; Lovergrove, 1991; Livingstone et al., 1991; Lehmkuhle et al., 1993; Cornelissen et al., 1995) is that dyslexic readers suffer from a deficit in the magnocellular system (Stein and Walsh, 1997).The magnocellular or transient system is sensitive to high temporal and low spatial frequencies (Legge, 1978) and seems to promote the saccades triggering via inhibition of the parvocellular or sustained system, which in turn would support word fixation during reading (Galaburda and Livingstone, 1993; Stein and Walsh, 1997).

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Indeed, anatomical and electrophysiological evidences have been provided by the same authors but as pointed out by Skottun (2000) after reviewing the main bibliography, the final evidence for a contrast sensitivity magnocellular-related deficit in dyslexia remains controversial.

Instead there is increasing evidence that a global distortion of the visual space both in the temporal and spatial domains takes place in dyslexic subjects. Such finding would rely on the impairment of psychophysical tasks such as motion perception (Cornelissen et al., 1995; Eden et al., 1996; Demb et al., 1998; Slaghuis and Ryan, 1999; Talcott et al., 2000; Hansen et al., 2001; Wilmer et al., 2004), contour integration (Simmers and Bex, 2001), spatial localization (Stein, 1989; Stein et al., 1989) and spatial relations representation (Pontius, 1981).

Coherent motion perception measures the sensibility to the shift of an array of dots moving coherently at the same speed and in the same direction, embedded in a field of incoherently moving random dots. A consistent body of literature maintains that the threshold for coherent motion detection and speed discrimination is impaired in dyslexic readers. The threshold for coherent motion perception is higher in dyslexics at luminance levels ranging from .4 to 130 cd/m^2, both in young and adult subjects (Cornelissen et al., 1995; Eden et al., 1996; Slaghuis and Ryan, 1999; Talcott et al., 2000; Hansen et al., 2001). Similarly, dyslexics perform worse than controls in discriminating the difference in speed of two moving sine wave gratings (Demb et al., 1998).

In the spatial domain, Simmers and Bex (2001) measured the threshold in detecting contours of paths made of Gabor patterns within a field of randomly oriented distracter elements. They found sensibility to be reduced in dyslexic subjects by a factor of two or three compared to normal readers, thence suggesting that some deficit in global processing takes place.

Moreover, spatial localization seems to be affected in dyslexic children (Stein, 1989; Stein et al., 1989; Solman and May, 1990) as well as spatial relations representation (Pontius, 1981). In particular Solman and May (1990) showed that the size of spatial discrepancy was greater in disabled readers compared to normal readers when asked to point the location of a briefly displayed stimulus (shape or letter), and Pontius (1981) showed that almost 80% of the recruited sample of dyslexics had difficulty in the performance of a figure rotation task. It is noteworthy to pinpoint that both in the spatial and temporal domains the visual perception is affected by a certain degree of horizontal/vertical anisotropy, as shown for misalignment tasks (Yap et al., 1987; Westheimer, 2005), horizontal displacements (Westheimer, 2005; Feng et al., 2007) and motion detection perception (Van de Grind et al., 1993; Raymond, 1994).

Actually, it is difficult to establish a link between such heterogeneous anomalies that suggest a global distortion of the visual space and the typical dyslexic reading pattern.

Looking for more direct elements accounting for lexical disability, some investigations have suggested that dyslexics' reading is impaired by crowding (Bouma and Legein, 1977; Atkinson, 1991, 1993; Spinelli et al., 2002; O'Brien et al., 2005; Martelli et al., 2009). Crowding, described for the first time by Korte in 1923, is defined as the deleterious influence of nearby contours on visual discrimination (Levi, 2008). It relies on excessive feature integration, acting over a large area so as to comprise flanking stimuli together to the target (Pelli et al., 2004).

Two main theories have been advocated to explain its psychophysical basis. Reciprocal inhibitory effect by nearby letters was proposed initially by Estes (1972, 1974) and Bjork and Murray (1977) and more recently by Chung et al. (2001). As an alternative, crowding has been attributed to a spatial mislocalization leading the features of adjacent letters to be mixed and melted (Wolford, 1975; Krumhansl, 1977; Krumhansl and Thomas, 1977; Strasburger and Rentschler, 1995; Wilkinson et al., 1997; Parkes et al., 2001; Levi et al., 2002; Pelli et al., 2004; Strasburger, 2005). Whatever its effect is on letters perception, crowding is characterized by the critical center-to-center spacing between target and flankers, that is the threshold separation between target and flankers beyond which the target becomes recognizable. Its value is .1° in the normal fovea (Bouma, 1970; Toet and Levi, 1992; Liu and Arditi, 2000) and increases with eccentricity by a constant ratio of about 0.4–0.5 (Bouma's law) (Bouma, 1970; Toet and Levi, 1992). Hence, the critical spacing describes the size of the integration fields within which features are subjected to suppression or mislocalization.

Interestingly, crowding is found to be anisotropic (Feng et al., 2007; Levi, 2008) so that horizontally arranged flanks are more effective than verticals for stimuli projected along the horizontal meridian. This characteristic may be related to the anisotropy of the spatial integration fields across the central 10° visual field as found in normal subjects (Bouma, 1970; Toet and Levi, 1992).

Due to this anisotropy, such interaction fields are elliptical in shape in periphery, with the main axis radially oriented toward the fixation point (Toet and Levi, 1992). Although it has not been investigated so far, it is arguable that crowding reinforcement in dyslexic subjects may be related to anisotropic changes of the interaction zones. However it is unlikely that abnormal crowding in disabled readers may directly account for the other global configuration-related alterations as mentioned before, since the effect of the interaction zones is thought to be local, promoting the integration of single features across neighbour regions for tasks involving acuity and hyperacuity (see Levi et al., 1985).

In line with the previous findings, we have recently found that a mild global horizontal/vertical asymmetry characterises the visual space of normal subjects (Aleci et al., 2010). Thence, as a starting hypothesis, we wonder if such an asymmetry may dictate at the same time the physiological anisotropy of the interaction zones as well as the mild horizontal/vertical asymmetry found to be proper of different tasks in the spatial and temporal domains.

Upon this theoretical basis, increased asymmetry of the overall visual space in dyslexic readers on one hand could augment the anisotropy of the interaction zones, thus reinforcing crowding and on the other hand it may account for the reported global distortion of the visual space.

Therefore, in the first part of this experiment we measured the amount of spatial anisotropy in disabled readers without using integration tasks as in previous studies but by directly evaluating the spatial relationship perception (SRP) of the subjects along the horizontal and vertical meridians of the visual field. We define SRP as the visual function able to detect the difference between the extent of an arbitrary shape, such