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Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading

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Abstract

For assessing simultaneous visual processing in dyslexic and normal readers a multi-element processing task was used which required the report of a single digit of briefly presented multi-digit arrays. Dyslexic readers exhibited higher recognition thresholds on 4- and 6-digit, but not on 2-digit arrays. Individual recognition thresholds on the multi-digit arrays were associated with number of eye movements during reading. The dyslexic multi-element processing deficit was not accompanied by deficient coherent motion detection or deficient visual precedence detection and was independent from deficits in phonological awareness and rapid naming. However, only about half of the dyslexic readers exhibited a multi-element processing deficit.

Keywords: Developmental dyslexia; Multi-element arrays; Reading rate

1. Introduction

Developmental dyslexia is a learning disorder which hampers the development of age-appropriate reading despite conventional instruction, adequate intelligence and the absence of gross neurological pathology. It is assumed to be genetically mediated and affects between 5% and 10% of the population (Shaywitz, 1998). The dominant cognitive explanation links the difficulties in learning to read to preceding difficulties in language acquisition and specifically to a phonological deficit (e.g., Vellutino, Fletcher, Snowling, & Scanlon, 2004). The standard version of this explanation postulates deficient awareness for the phonemic segments of spoken words which limits the mapping of letters onto phonemes and, thereby, hinders the self-reliant decoding of new words and the efficient storage of the letter patterns of frequently encountered words. However, recently visual and visual-attentional deficits of dyslexic children were put forward as alternative explanation (Hari & Renvall, 2001; Stein & Walsh, 1997). These alternative accounts are of particular interest for explaining reading difficulties in regular orthographies such as Italian or German, where the mapping of letters onto phonemes is easier than in English, and where the acquisition of decoding is less of a hurdle. In such orthographies the problem of dyslexic readers does not become manifest as a sheer inability to read a new word or as gross misreadings, but as very slow, effortful, non-automatic reading (e.g., Landerl, Wimmer, & Frith, 1997; Wimmer, 1993). A recent demonstration of this reading problem was provided by Ziegler, Perry, Ma-Wyatt, Ladner, and Schulte-Körne (2003) who found for dyslexic German children (11-year-olds) a reading onset latency increase of more than 300 ms per additional letter for both short words and pseudowords (3–6 letters long), whereas the reading time of normal readers increased only 30–50 ms per additional letter. Ziegler et al. (2003) interpreted this finding as a limitation to serial grapheme–phoneme conversion.

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The most direct demonstration of the serial reading strategy of developmental dyslexic children in regular orthographies comes from a series of eye movement studies of an Italian research group (De Luca, Borelli, Judica, Spinelli, & Zoccolotti, 2002; De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999; Zoccolotti et al., 1999). These studies documented for dyslexic children a substantially higher number of fixations during reading compared to normal readers. The high number of fixations is primarily caused by short eye movements in the reading direction since the proportion of regressions made by the dyslexic readers was low. A similar pattern was found for German dyslexic children (Hutzler & Wimmer, 2004).

These reading difficulties of dyslexic children in consistent orthographies resemble the difficulties shown by cases of an acquired disorder known as letter-by-letter reading (e.g., Behrmann, Shomstein, Black, & Barton, 2001). After brain insult, formerly normal readers lose their ability to process words as a whole and are forced to rely on a slow and laborious serial letter-by-letter decoding strategy during reading. This reading strategy leads to a massive word length effect on reading time and is dominantly interpreted as reflecting a general difficulty to perceive multiple visual forms simultaneously (Farah & Wallace, 1991). The demonstration of the difficulty with the simultaneous perception of multiple visual forms in letter-by-letter readers typically relied on variants of the partial report method of Averbach and Sperling (1968) which requires reporting only a single element of briefly represented multi-element arrays in response to a post-stimulus cue. In a study with letter-by-letter readers, Kinsbourne and Warrington (1962) showed that the tachistoscopic recognition thresholds were normal when a single form had to be identified, but dramatically impaired when identification of more than one form was required. This result was also found for non-nameable visual forms (Friedman & Alexander, 1984). This and several other findings led to the conclusion that the locus of impairment in cases of letter-by-letter readers is in the early stages of visual processing (for review see Farah & Wallace, 1991).

In the field of developmental dyslexia, this visual interpretation has received little attention. An early study by Morrison, Giordani, and Nagy (1977) presented eight elements—letters, geometric and abstract forms—in a circular array for 150 ms and cued the position of the to-be-reported element at varying time intervals (0–2000 ms). A dyslexic deficit was found, but only when the cue was delayed for about 750 ms and not when the cue was presented after 300 ms or less. This evidence for unimpaired multi-element processing when the cue followed shortly after array presentation can be questioned since no mask was used. A systematic study by Enns, Bryson, and Roes (1995) avoided this interpretational problem, but nevertheless arrived at a similar conclusion. In this study the stimulus arrays—strings of 1–5 letters in length—were masked after being presented for 150 ms. When the cue—a probe letter—was presented simultaneously with the array and participants had to indicate whether the probe was present in the array (identification task), disabled readers (15-year-olds) did not differ from age controls. However, when participants had to indicate the position of the probe letter (location task) then the dyslexic readers showed impaired performance for the longer 4- and 5-letter stimuli. This finding is relevant, as in reading both the identities and the position of the letters of a word are of crucial importance. Recently, a deficit of dyslexic readers with position encoding was shown by Pammer, Lavis, Hansen, and Cornelissen (2004).

1.1. The present study

The studies by Morrison et al. (1977) and Enns et al. (1995) were done with English dyslexic readers. We reasoned that a visual deficit with multi-element processing may become more readily apparent for German dyslexic readers who—different from their English counterparts—are diagnosed via slow reading speed and not by a high error rate. We attempted to provide direct evidence for a serial reading strategy of our dyslexic participants by examining their eye movements during word and pseudoword reading. The main question was, whether slow serial reading is associated with a general visual perceptual deficit for multi-element arrays. Multi-element processing was measured in a stringent and sensitive manner. In correspondence with the original partial report method (Averbach & Sperling, 1968), one position of multi-element arrays was cued for report, so that correct performance depends on both identity and position encoding. The cue was presented immediately after array presentation to avoid memory problems. However, masking of the stimulus prevented that correct performance could be based on processing the after-image of the stimulus. We chose digits instead of letters as elements of the arrays as one could reason that dyslexic readers are less frequently exposed to letter string processing than normal readers. The main new feature of the present task is that, instead of a fixed presentation time, an adaptive staircase procedure was applied to determine individual presentation time thresholds for reliable performance. Thresholds were estimated for arrays of varying lengths (2-, 4-, and 6-digit arrays). If dyslexic readers suffer from deficient multi-element processing then—corresponding to the findings with letter-by-letter readers—the increased number of elements should have a stronger effect on presentation time thresholds for dyslexic readers than controls.

Although the focus of the present study is on multi-element processing, we also report the findings of a visual precedence detection task, which presented two