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Dyslexic children fail to comply with the rhythmic constraints of handwriting



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ABSTRACT

In this study, we sought to demonstrate that deficits in a specific motor activity, handwriting, are associated to Developmental Dyslexia. The linguistic and writing performance of children with Developmental Dyslexia, with and without handwriting problems (dysgraphia), were compared to that of children with Typical Development. The quantitative kinematic variables of handwriting were collected by means of a digitizing tablet. The results showed that all children with Developmental Dyslexia wrote more slowly than those with Typical Development. Contrary to typically developing children, they also varied more in the time taken to write the individual letters of a word and failed to comply with the principles of isochrony and homothety. Moreover, a series of correlations was found among reading, language measures and writing measures suggesting that the two abilities may be linked. We propose that the link between handwriting and reading/language deficits is mediated by rhythm, as both reading (which is grounded on language) and handwriting are ruled by principles of rhythmic organization.

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1. Introduction

From the first studies on Developmental Dyslexia (DD), anecdotes and experimental evidence have reported that children with DD often suffer from fine and gross motor difficulties, like motor coordination, poor balance and clumsiness (Capellini, Coppede, & Valle, 2010; Nicolson & Fawcett, 1990). In addition, increasing evidence suggests that children at familial risk for DD show slow motor development at infancy (Viholainen, Cantell, Lyytinen, & Lyytinen, 2002). When the association between DD and motor disorders is examined, it is often narrowed to a comorbidity between DD and other developmental disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) and Developmental Coordination Disorder (DCD) (Ramus, Pidgeon, & Frith, 2003; Rochelle, Witton, & Talcott, 2009). These observations notwithstanding, prior research on DD has focused on reading problems while neglecting motor problems. One exception that links motor deficits to dyslexia is the automaticity/cerebellar hypothesis of Nicolson and Fawcett (Nicolson & Fawcett, 1990, 2011), which states that a dysfunction at the level of the cerebellum is responsible for the comorbidity between dyslexia and dysgraphia (see also Lam, Au, Leung, & Li-Tsang, 2011). Other exceptions are Wolff (2002), where some motor skills are studied in relation to dyslexia, (see also Wolff, Michel, Ovrut, & Drake, 1990) and Thomson, Fryer, Maltby, and Goswami (2006) (see also Thomson & Goswami, 2008). In this line of research, it is reported that dyslexic students anticipated an isochronic-pacing metronome signal when tapping by significantly longer intervals than controls did and showed difficulties in reproducing patterned rhythms of tones separated by a sequence of long and short inter-tap-intervals (Wolff, 2002). Thomson et al. (2006) and Thomson and Goswami (2008) further developed this line of research and found within-individual variability in the internal consistency of a tapping rate and an association between motor and auditory rhythmic sensitivity on the one hand and literacy on the other (see also Flaunacco et al., 2014 for the relation between rhythmic perception and reading). These studies point out the importance of rhythmic timing for both language and motor skills and suggest that the link between reading and motor deficits is mediated by rhythm. Timing is also the main feature of Llinás's (1993) physiological account for dyslexia. Llinás defined dyslexia as "dyschronia" since, aside from their strictly linguistic deficits, dyslexic participants show difficulties in generating fast recurring sequences of movements. According to Llinás, rhythmicity is the ability to generate a sequence of rhythmic events that are time locked to each other. In Llinás's model, the lack of appropriate triggering or resetting of neuronal oscillations at 40 Hz or 10 Hz might affect certain temporal aspects of cognition. Here, we study handwriting, a motor activity, which requires the generation of rapid repeated events and is ruled by principles of rhythmic organization. We explore the hypothesis that children with DD experience a deficit in the temporal binding of events, which discloses a difficulty to comply with the principles of isochrony and homothety (see Section 1.5 for an exhaustive discussion of the key questions of this study).

1.1. Principles of the rhythmic organization of handwriting

Handwriting (and other motor activities) is ruled by two principles of rhythmic organization: isochrony and homothety. The principle of isochrony (Binet & Courtier, 1893; Stetson & McDill, 1923; Viviani & Terzuolo, 1982) asserts that the speed of movement execution is proportionally related to the length of its trajectory in order to keep the movement duration approximately constant. This relation between movement velocity and its linear extent, which seems to be an ordinary feature of different types of movement, has been observed both in humans (e.g., Freund & Büdingen, 1978; Viviani & Terzuolo, 1982) and in non-human primates (Sartori, Ciani, Bulgheroni, & Castiello, 2013). Previous studies have shown that the total writing duration remains invariant irrespective of the size of the word or letter (Freeman, 1914; Lacquaniti, Terzuolo, & Viviani, 1983; Viviani & Terzuolo, 1983). This implies that there is a compensation mechanism whereby writing speed changes in accordance to the size of what is being written, i.e., the writer naturally increases the speed of handwriting when asked to write bigger. The principle of homothety (Lashley, 1951; Viviani & Terzuolo, 1982) guarantees the invariance of the relative duration of a movement's components under a number of possible variations in the duration of the very same movement. In handwriting, this principle predicts that the

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