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Review article

Mental rotation and motor performance in children with developmental dyslexia

Sandra Kaltner *, Petra Jansen

Institute of Sport Science, University of Regensburg, Germany

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ABSTRACT

We compared the performance of normal-reading ($N = 14$) and dyslexic children ($N = 14$) in a chronometric mental rotation task (cMRT) using letters, animals and pseudo-letters, which are objects that look like letters. In a typical chronometric mental rotation task two items are presented simultaneously on a screen whereby the right item is a rotated version of the left item and could be the same or a mirror version of the left item. The mental rotation paradigm is an appropriate method to test predictions of two different approaches trying to explain the problems for dyslexics when reading. According to the functional coordination deficit (FCD) model dyslexics show a failure in suppression of symmetry in the representation of graphemic material and therefore cannot decide whether the letter is normal or mirrored because of an ambiguous mapping between phoneme and grapheme representations. Therefore, the deficits of dyslexic children regarding mental rotation performance are restricted to the stimulus "letters". According to findings that propose the involvement of the cerebellum in mental rotation tasks and a cerebellar deficit in dyslexia, an impaired mental rotation is expected affecting all types of stimuli. To investigate the involvement of the cerebellum, motor performance was additionally assessed because the cerebellum plays an important role in motor functions and motor imagery. For the cMRT we found that the dyslexic children show both slower reaction times regarding the stimulus "letters" and "pseudo-letters" and increased overall reaction times compared to non-dyslexic children. The mental rotation effect was more pronounced in dyslexic children than in normal readers. In contrast to previous approaches, the results of our study support the idea that poor results in mental rotation result from deficits in mental rotation itself rather than from a decision problem after mental rotation which supports the predictions of the cerebellar deficit hypothesis. However, since the impairment of dyslexics regarding mental rotation performance is letter-specific and motor results show no differences between dyslexic and non-dyslexic children, further approaches next to the cerebellar deficit hypothesis must be taken into account, especially in consideration of the fact that there are a number of causes for the failure in reading.

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* Corresponding author at: University of Regensburg, Universitystreet 31, 93053 Regensburg, Germany. Tel.: +49 941 507 5131.
E-mail addresses: sandra.kaltner@ur.de (S. Kaltner), petra.jansen@ur.de (P. Jansen).

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1. Introduction

1.1. Developmental dyslexia

According to the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000) developmental dyslexia is defined as a specific and persistent failure to acquire efficient reading skills despite normal intelligence, sufficient motivation, adequate sensory abilities and appropriate reading instruction. Dyslexia is the most common of the learning disabilities; its clinical prevalence is ranging from 5% up to 17.5% (Shaywitz, 1998). Results concerning the sex ratio of this specific reading disorder remain controversial. Whereas Flannery, Liederman, Daly, and Schultz (2000) reported a clear sex bias toward males irrespective of severity of disability or comorbidities like attentional disorders, Shaywitz, Shaywitz, Fletcher, and Escobar (1990) interpreted the imbalance as referral bias. Dyslexic children show clinical features such as impaired reading comprehension skills, problems in word recognition and poor oral reading skills performance compared to normal reading children of a comparable age, intelligence and education level (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000).

One characteristic symptom of dyslexia is the reversal error: a bias to reverse both the order of letters within a word (for example "was" instead of "saw") and the orientation of single letters (for example "b" vs. "d") (Lachmann, Schumacher, & van Leeuwen, 2009). The functional-coordination deficit (FCD) model (Lachmann, 2002) concentrates on the explanation of this type of error. According to this theory, reversal errors result from a failure to suppress symmetry generalization in reading. Symmetry generalization is a tendency to generate mirror images as well as other orientations of an object and to store them in the same category as the original. Neurologically, mirror images and other orientations activate similar patterns of neural activity as the upright original (Lachmann, 2002). This facilitates the recognition of an object in different orientations (object constancy). In learning to read, however, such a mechanism is a hindrance. Problems occur, for instance, when graphemes in different orientation or mirror images like "b" and "d" have different phonology, but are stored under the same category. As a consequence, two different letters share one common phonological representation. However, this one-to-one relation between the grapheme and the phoneme representation is essential in learning to read. Normal readers suppress the symmetry generalization while learning to read, children with developmental dyslexia do not. The FCD approach assumes that symmetry generalization problems are not restricted to letters that have symmetrical counterparts, like "b", "d" and "p" (Rusiak, Lachmann, Jaskowski, & van Leeuwen, 2007).

Dyslexics show different patterns of reading and writing problems which led to the distinction between three subgroups: (1) dysphonetics; (2) dyseidetics (3) dysphoneidetics, a mixture of both deficits. Dysphonetics show phonological processing deficits, whereas in dyseidetics visual deficits lead to problems in recognizing the visual gestalt and therefore to a slowed direct access to the lexicon (Boder, 1970). According to the Dual Route Cascade model (DRC; Coltheart, Curtis, Atkins, & Haller, 1993), words follow two different routes: regarding frequent words there's a direct route from the visual gestalt of the word to its phonology and meaning (lexical semantic route), whereas the second route is restricted to non-words, which are irregular words, where a grapheme-to-phoneme conversion of individual letters takes place (grapheme-to-phoneme route; Coltheart et al., 1993). Thus, problems in the first route lead to deficits in word-reading, whereas the second route is involved in non-word reading (Lachmann, Berti, Kujala, & Schröger, 2005). Thus, Coltheart (1996) suggested that performance in