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Working memory in children with specific learning disorders and/or attention deficits

Claudia Maehler *, &, Kirsten Schuchardt

University of Hildesheim, Universitätsplatz 1, 31141 Hildesheim, Germany

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ABSTRACT

Specific working memory deficits have been documented for different learning disorders (dyslexia, dyscalculia). Also children with attention deficit disorders (ADHD) have working memory problems especially with regard to executive functioning. There is a high rate of comorbidity of learning and attention disorders and yet, it is an open question, how this comorbidity might affect working memory functioning.

We tested six groups of children with dyslexia ($N = 31$), dyscalculia ($N = 18$), ADHD ($N = 34$), with dyslexia and ADHD ($N = 37$), with dyscalculia and ADHD ($N = 21$) and typically achieving control children ($N = 31$). Working memory was assessed by a battery of 16 phonological, visual-spatial and central executive tasks, according to the model of Baddeley (1986).

Results reveal distinct patterns of working memory deficits: dyslexia corresponds with deficits in phonological loop and dyscalculia with deficits in visual-spatial sketchpad. ADHD corresponds with deficits in central executive. No interaction effect could be detected. Thus, it should be concluded that the comorbidity leads to additive working memory deficits, i.e. children with both disorders must cope with broader deficits.

Children with specific learning disorders like dyslexia or dyscalculia experience significant difficulties in acquiring the core skills of reading, writing, and arithmetic from their very first days at school. The high rate of comorbidity with attention deficit and hyperactivity disorders (DuPaul, Gormley, & Laracy, 2013) gives rise for the question of shared underlying cognitive disabilities and will be examined in this study with regard to working memory functioning.

Dyslexia is characterized by a specific and significant impairment in the development of reading skills (often accompanied by poor spelling), dyscalculia by a specific impairment in the acquisition of mathematical skills. There are numerous approaches to the definition and diagnosis of these learning disabilities. Internationally recognized criteria for their diagnosis are specified in the conventional International Classification of Diseases (ICD-10) published by the World Health Organization (WHO, 2011). According to this system, learning disorders are present when individuals' abilities in the domains of reading, spelling, or arithmetic are substantially below their expected potential given their age, general intelligence, and education.

Despite increasing research interest in learning disabilities, consensus has not yet been reached on the specific cognitive deficits that underlie different learning disorders. For a long time dyslexia was considered to be caused by visual deficits while currently deficits in phonological information processing are demonstrated to be responsible (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Causation of dyscalculia is much less clear. Deficiencies in the memory of basic facts, immature strategies and a less developed number sense are taken into consideration (Geary, 2004).

Clinical experience tells us that for many children learning disorders lead to secondary problems, such as low self-esteem, school anxiety, depression, psychosomatic disorders, or antisocial behavior and attention deficit (hyperactivity) disorders (ADHD). A recent review taking a total of 17 studies published between 2001 and 2011 into account (DuPaul et al., 2013), found relatively high comorbidity of learning disorders and ADHD, with 31% to 45% of students with ADHD having learning disorders and vice versa. The variance between studies was due to different inclusion criteria in the different studies; nevertheless a tendency was found that comorbidity was highest for writing disorders, lesser for reading disorders and least (although still between 5% and 30%) for math disorder.

According to the International Classification of Diseases (ICD-10; 2011) ADHD is diagnosed on the basis of persistent, developmentally atypical and impairing symptoms of inattention, hyperactivity and impulsivity. Although ADHD is defined behaviorally, relevant (neuropsychological) research on ADHD has implicated deficits in executive functions as integral cognitive features of ADHD (Barkley, 1997; Pennington & Ozonoff, 1996). The behavioral problems become manifest in everyday situations at school or at home that require planning,

* Corresponding author.
E-mail address: maehler@uni-hildesheim.de (C. Maehler).

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self-control, and well structured behavior. Therefore parents and teachers are mostly asked to report the relevant data for the diagnosis.

It is obvious in everyday school life that children with ADHD are at risk for sufficient academic achievement: If we observe children in educational settings we might notice that especially inattention may lead to impaired participation and to less efficient information processing. On the other hand learning problems or disorders may in turn lead to inattention and agitation in learning situations because a child may be unable to cope with the demands of reading, writing or arithmetic. The comorbidity therefore does not imply a well defined causal relationship.

But taking the comorbidity into account gives rise to the search for common underlying causal factors. Given the typical problems of children with learning disorders and children with ADHD, information processing and executive functioning are viewed as probable basic risk factors that may cause both learning disabilities and disorders and attention deficit (hyperactivity) disorders (Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005). It is the concept of working memory that encompasses information processing, executive functioning and (selective) attention.

Working memory deficits are widely being discussed and identified as being related to learning disabilities. Although various models of working memory have been developed, the British model by Baddeley (1986) has proved a particularly useful theoretical tool in numerous studies on learning disabilities. According to this model, working memory comprises three components: the modality-free *central executive*, which is a kind of supervisory system that serves to control and regulate the occurring cognitive processes, and two slave systems, the *phonological loop* and the *visual-spatial sketchpad*. The functions of the central executive identified by Baddeley (1996) include a) coordinating the slave systems, b) focusing and switching attention, c) retrieving representations from long-term memory, and d) changing learning strategies. The two slave systems perform modality-specific operations. Verbal and auditory information is temporarily stored and processed in the phonological loop. Two components of the phonological loop are distinguished: the phonological store and the subvocal rehearsal process. The visual-spatial sketchpad is concerned with remembering and processing visual and spatial information; it comprises a visual cache for static visual information and an inner scribe for dynamic spatial information (Logie, 1995; Pickering, Gathercole, Hall, & Lloyd, 2001).

Research has provided numerous indications that specific learning disabilities are associated with working memory impairments (Alloway & Gathercole, 2006; Pickering, 2006a). There is considerable evidence that children with specific reading disabilities/dyslexia have deficits in phonological processing and storage (Pickering, 2006b; Schuchardt, Maehler, & Hasselhorn, 2008; Swanson, 2006; Vellutino et al., 2004). Further evidence suggests that these children also experience deficits in central executive functioning (Brandenburg et al., 2014; Landerl, Bevan, & Butterworth, 2004), but when the demand for phonological processing is controlled for in the central executive memory tasks, this deficit seems to disappear (Schuchardt et al., 2008). For children with dyscalculia empirical evidence suggests that the visual-spatial sketchpad and the central executive seem to be particularly impaired (Passolunghi & Siegel, 2001; Passolunghi, 2006; Schuchardt et al., 2008; van der Sluis, van der Leij, & de Jong, 2005), while findings on the phonological loop are inconsistent (see Geary, Hamson, & Hoard, 2000 vs. Swanson & Sachse-Lee, 2001; or Landerl et al., 2004).

Working memory deficits in children with ADHD have also been discussed for quite a while. Results, again, are inconsistent, although there is a kind of consensus that an impairment of working memory exists independent of language or learning disorders and independent of general intelligence (Martinussen & Tannock, 2006). Evidence with regard to the exact location of possible deficits is heterogeneous, probably due to the heterogeneous population of children with AD(H)D, and the tasks differences. An exploratory meta-analysis of 26 studies (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005), that considers tasks for the two modalities (verbal and spatial) and two types of processing (storage only vs. storage and manipulation) reveals the most severe deficit in the functioning of visual-spatial sketchpad as well as in central executive processing of spatial information. There were also phonological deficits observable, but to a lesser extent. The results of the meta-analysis are in line with several more recent studies that report deficits in the visual-spatial domain (Alloway, Gathercole, & Elliott, 2010; Kibby & Cohen, 2008) and in central executive functioning (Cornoldi et al., 2001).

Taken together the empirical findings reveal a solid body of evidence for working memory deficits underlying both learning disorders and attention deficit disorders. Poor working memory has been found to be closely associated both with low academic achievement (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Gathercole & Alloway, 2008) and with some of the attention problems typical for children with ADHD (Gathercole et al., 2008).

There are indicators for specific deficits with regard to specific working memory functions and subsystems (see above) but at the same time studies have shown a considerable overlap of working memory problems in children affected by learning and/or attention deficit disorders. Furthermore, other studies also report distinct and shared deficits, for example processing speed seems to be impaired in children with reading difficulties and those with ADHD and therefore might explain the comorbidity of both disorders (McGrath et al., 2011; Shanahan et al., 2006). Yet, there are no studies that allow a direct conclusion by investigating the different groups of children and different comorbid combinations (dyslexia, dyscalculia and ADHD) within the same design and by using for all of them a wide range of working memory tasks. Furthermore, the heterogeneous body of evidence might be due to varying inclusion and exclusion criteria for the examined learning disorders. By defining "pure" groups according to ICD-10 and using a broad battery of tasks within the theoretical framework of the Baddeley (1986) working memory model we hope to identify possible distinct and common deficits. Running this kind of study we addressed the following research question: Given the empirical evidence of working memory deficits underlying both learning and attention deficit disorders, could the comorbidity be explained by shared working memory deficits?

To answer this question we analyzed commonalities and differences in working memory in children with dyslexia and/or attention deficit disorders and with dyscalculia and/or attention deficit disorders. School achievement tests were administered to all children for both reading/writing and mathematics in order to exclude children with combined disorders of scholastic skills.

1. Method

1.1. Design

We used a three-factor design: (1) presence or absence of dyslexia, (2) presence or absence of dyscalculia, and (3) presence or absence of attention deficit hyperactivity disorder. To this end, we identified five groups of children with disabilities based on the ICD-10 criteria for specific disorders: children with specific disorders of attention deficit hyperactivity disorder without learning difficulties (*ADHD*), children with specific reading disorders (*Dyslexia*), children with comorbid disorders of ADHD and dyslexia (*ADHD + Dyslexia*), children with specific disorders of arithmetical skills (*Dyscalculia*), children with comorbid disorders of dyscalculia and ADHD (*ADHD + Dyscalculia*), and formed a control group (*C*) of typically achieving children matched for chronological age.

1.2. Participants

One hundred seventy-two 2nd to 4th grade students participated in the study. The diagnosis ADHD was made by an assessment of parents and teachers according to assessment forms CBCL and TRF (German version). This is a not a clinical diagnosis but only a parents' and teachers'