

Impact of attentional dysfunction in dyscalculia

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Significant educational delays, even in the absence of cognitive-processing deficits, can be attributed to the inability to sustain attention¹. The relation between dyslexia and attention deficits is well established^{2,3}. Although research on the relation between dyscalculia and attention deficits is limited, evidence is mounting for a pivotal relation between these two disorders. Indeed, attention deficits may be more strongly associated with dyscalculia than with dyslexia.

The prevalence of dyscalculia in school-age children has been found to be at least 6%⁴⁻⁶. Studies have shown that some overlap between dyscalculia and dyslexia occurs. In one USA study, 6.4% of students aged 6 to 14 years had dyscalculia, 3.7% of whom had delayed skills in mathematics alone, while 2.7% had delayed skills in both reading and mathematics⁵. Several of these population studies have shown that attention deficits may be more strongly associated with dyscalculia than with dyslexia. In a non-referred cohort of 3029 Israeli 11-year-old school children, 185 (6.5%) were diagnosed with dyscalculia⁶, 26% of whom had symptoms of attention-deficit-hyperactivity disorder (ADHD). In a non-referred sample of students in Connecticut aged between 7½ and 9½ years, only 15% of the children diagnosed with dyslexia also exhibited inattention³.

Relations between attention and reading

While ADHD can exacerbate the severity and impact of dyslexia, these two disorders appear to have different etiologies^{2,7}. Dyslexia is now considered to be most highly associated with disorders of phonological awareness; attentional disorders have only a limited association with such phonological deficits⁸.

Pervis and Tannock⁹ examined both the pragmatic and semantic language abilities of children with ADHD as well as the impact of concurrent reading disability (RD) on their performance. A total of four groups was examined: students with ADHD-only, RD-only, ADHD + RD, and a control group. Language abilities were investigated using a task that required

recall of a lengthy narrative, and tests that assessed knowledge of the semantic aspects of language. The results generated two central findings: regardless of their RD status, children with ADHD exhibited difficulties in organizing and monitoring their story retelling; and regardless of their ADHD status, children with RD demonstrated deficits in receptive and expressive semantic language abilities. Thus the language problems encountered by children with ADHD without RD appear to reflect difficulties with language use (i.e. pragmatics) rather than deficits in the basic subsystems of language.

Deficits in executive functions, the regulatory processes responsible for organizing and monitoring the processing of information and mobilizing attention, appear to account for these pragmatic difficulties encountered by children with ADHD. Shaywitz et al.¹⁰ found that when children with comorbidity for RD and ADHD were examined, both the linguistic deficits associated with RD and the behavioral characteristics associated with ADHD were apparent but not synergistic. They concluded that RD and ADHD represent separate disorders that frequently co-occur. Pennington et al.¹¹ examined two cognitive domains, phonological processes and executive functions, in students with RD and ADHD. Both RD groups (RD-only and RD + ADHD) were significantly impaired compared with the control and ADHD-only groups on tests of phonological processing, but performed normally on tests of executive function. The ADHD-only group had an opposite profile and was significantly different from both RD groups and from the control group on tests of executive function. Thus, a double-dissociation between the RD-only and ADHD-only groups occurred. The comorbid group resembled the RD-only group. Furthermore, children of the RD + ADHD group have most of the deficits of both 'pure' groups. Dyslexia typically reflects insufficient phonological-processing abilities, while ADHD typically reflects a deficiency in executive functioning. This latter deficit in executive functioning is pivotal when considering dyscalculia.

Relations between attention and arithmetic

Students with attention deficits appear to be at a significant disadvantage when performing certain arithmetic calculations^{12,13}. In numerical computations every fine detail, such as the precise location of decimal points and differences in operational signs, is relevant for a successful completion of the task. Computation requires students to mobilize and sustain an adequate level of attention while working from textbooks, copying from the chalkboard, or monitoring their own work. Two of the more common signs of attentional difficulty in arithmetic are error patterns that are likely to be random (i.e. when a student misses relatively easy items while succeeding on more difficult ones) and a greater frequency of errors near the end of a test.

There is increasing evidence that attentional problems place students at increased risk for deficits in arithmetic rather than reading. Zentall¹ reported arithmetic computation as the area in which students with attentional problems were most likely to show diminished classroom performance. He also reported that when keeping IQ, reading ability, and problem structure constant, boys with attentional disorders had lower arithmetic problem-solving scores in specific arithmetic concepts and lower computational performance¹⁴.

Shalev et al.¹⁵ examined the attentional, behavioral, and emotional characteristics of 140 children with dyscalculia using the Child Behavior Checklist (CBCL). Higher mean scores on attentional problem subscales were strongly associated with difficulties in arithmetic for both boys and girls. Thus, children with dyscalculia often displayed behaviors consistent with ADHD.

Badian⁵ found that the largest subgroup of students with dyscalculia had attentional-sequential dyscalculia (42%), i.e. difficulty attending to signs in calculation procedures or forgetting decimal points. These students added and subtracted inaccurately, frequently omitted one of the numbers when adding, or failed to add a carried digit. They also had great difficulty remembering the multiplication tables and other number facts, and they tended to have a very low score on the sequential factor consisting of the arithmetic, digit-span, and coding subtests of the Wechsler Intelligence Scales for Children. This sequential factor tends to be impaired in children with learning and attentional problems¹⁶.

Dyscalculia subtypes

Rourke¹⁷ theorized that at least two different profiles of neuropsychological assets and deficits are associated with impaired mathematics performance in children. One group of children with mathematics impairment (group A, i.e. arithmetic) had relatively intact reading and spelling skills. Their poor performance on measures of visuospatial skills was suggestive of right-hemispheric dysfunction. These children were thought to have a form of non-verbal learning disabilities, with deficits in tactile and visual attention but relative strengths in auditory and verbal attention. A separate group of children (group R-S, i.e. reading-spelling) had both poor arithmetic and poor reading performance. These students did well on non-verbal problem-solving tasks, but had deficiencies in verbal/auditory-perceptual tasks. They appear to have an opposite profile with deficits in auditory and verbal attention, but relative strengths in tactile and visual attention.

Geary¹⁸ used a cognitive approach to examine development of the subskills that underlie basic arithmetic. He found two distinct functional deficits in children with dyscalculia:

procedural and memory retrieval. Procedural deficits are mediated by poor attentional and active working memory skills. The computational errors made by these children are due to their tendency not to monitor their work when solving problems. Memory retrieval deficits often covaried with dyslexia, suggesting a more general deficit in representation or retrieval from semantic memory. In short, inattention yields procedural errors, while poor memory yields factual errors. Thus, Geary expanded the subtyping of dyscalculia outlined by Rourke¹⁷. One of his subtypes was associated with a dysfunction of visuospatial skills (Rourke's group A). Two further subtypes were proposed: one involved difficulties in arithmetic fact retrieval, including such problems as the memorization of arithmetic tables (mathematics facts); the other involved difficulties in the use of arithmetical procedures such as counting strategies, carrying, and borrowing.

Ackerman et al.¹⁹ demonstrated that students with attentional deficits had delayed automatization of recall of arithmetic facts, which presaged later arithmetical difficulties. They also showed that many children with attentional difficulties with normal reading ability exhibited delayed automatization of number facts early in their school careers. They argued that traditional standardized achievement tests may not be sensitive to this form of automatization failure because of overly generous time limits, which permit the use of more time-consuming counting strategies. This research suggests the existence of common factors influencing arithmetic and sustained attention which may not be present between reading and attention. Badian⁵ suggested that many children make arithmetic errors because of a general attentional deficit rather than because of a specific mathematical deficit. The impact of executive control and attentional allocation on arithmetic skills is considered a general deficit of attention^{17,20,21}.

Executive functioning: the link between attentional and arithmetic problems

The relation among attention, automatic recall of mathematics facts, and recall and execution of mathematical procedures is complex (Fig. 1). Denkla¹⁶ proposed that working memory may be the zone of overlap in the cognitive profiles of children with learning and attentional problems. Working memory coupled with inhibition is currently believed to be the key element in executive function, which in turn is linked to the diagnosis of ADHD²². Executive function involves the organization of output over a prolonged time frame; it bridges the gap between 'knowing' and 'doing'¹⁶. Learning and memory are grouped together and then staged as encoding, consolidation, storage, and retrieval processes. Of these four processes, encoding and retrieval appear to be suboptimal in students with attentional problems²³.

Poor active working memory contributes to poor procedural skills and delayed development of basic mathematics facts²⁴. Working memory involves many neurocognitive operations, including rate of memory decay, the ability to allocate attention, and the level of activation associated with problem encoding¹⁸. Slow counting speed or fast memory decay could result in failure to develop automatic arithmetic fact representations in long-term semantic memory. Differences in memory span between typically developing children and children with dyscalculia can also be attributed to the inability to allocate attention and return to task²⁵.

Conversely, Zentall and Smith²⁶ found that speed of addition might be a marker for academic and behavioral dysfunction. In a recent study, 27 students with mathematics disability were compared with 56 typically developing students on a computerized continuous performance task²⁷. Compared with control children, subjects with dyscalculia made more omission errors and had more inconsistent response times.

Impact of psychostimulant medication on arithmetic performance

Treatment with methylphenidate can result in improvement in arithmetic performance. Carlson et al.²⁸ found that when compared with a placebo, treatment with methylphenidate resulted in improved performance on an assessment of divided attention using a dual-task technique. Subjects were required to complete arithmetic problems presented on a computer screen by typing two-digit answers. On half of the trials the subjects were required to terminate a computer-generated tone before or after the arithmetic-problem presentation. They found that treatment with methylphenidate resulted in significantly faster reaction times to tone probes and faster answers to arithmetic problems when the two tasks did not overlap in time. When dual processing taxed cognitive capacity, methylphenidate still improved accuracy on the primary arithmetic task but at the expense of speed of reaction time to tone probes. The results showed that when children with ADHD fail to allocate available resources to a primary cognitive task, treatment with methylphenidate may result in reallocation of existing cognitive capacity from a secondary task to the primary task.

Research into dose-response effects of methylphenidate treatment²⁹⁻³¹ has shown benefit in arithmetic performance from a relatively low dose of methylphenidate (0.3 mg/kg/dose). Quite frequently, this cognitive benefit is overlooked by parents, teachers, and pediatricians as they are more focused on the behavioral effects of methylphenidate (i.e. controlling hyperactivity).

Children who have academic and attentional problems, but do not display hyperactivity (ADHD-predominantly inattentive type), are less likely to be considered as candidates for treatment with psychostimulant medication. However, the

combined effect of mild difficulties in attention and arithmetic may contribute to serious underachievement. A recent study examined the possibility that students with attentional problems without hyperactivity (ADD/noH) may be more impaired in arithmetic than students with inattention and hyperactivity (ADHD)³². This relation was examined by comparing 24 students with ADHD and 20 students with ADD/noH. The mathematics test scores for students with ADD/noH were significantly lower than those for students with ADHD. This was consistent with the findings of increased rates of dyscalculia in students with ADD/noH³³. Marshall et al. also indicated in their study, that the reason why the relation between attentional problems and arithmetic disability is underreported is because it is underinvestigated³².

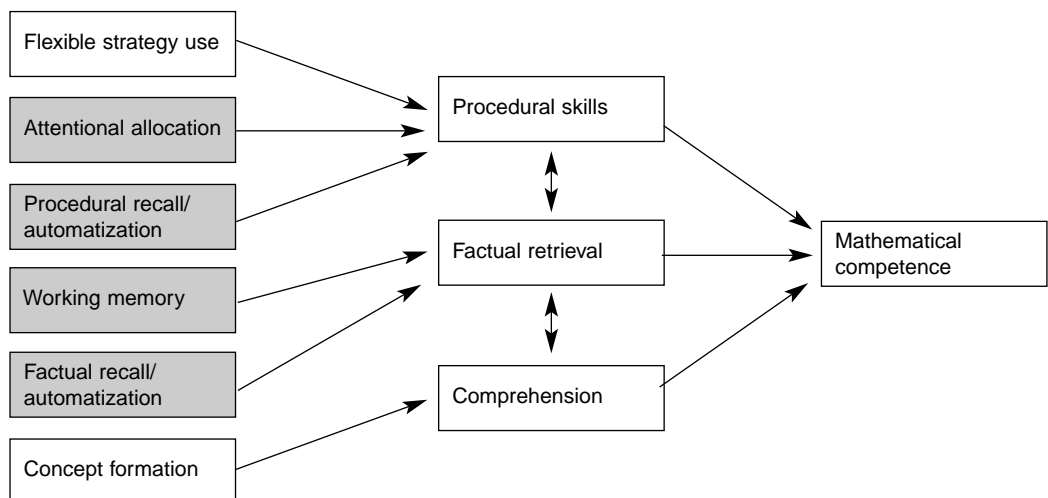
Implications for clinical management and research

Because of the cumulative nature of mathematics, early identification of dyscalculia and remediation is essential. It is far less likely that a child will catch up in mathematics than in any other type of learning disability. Insensitivity to dyscalculia is often minimized because of a perceived narrow impact for such a disability compared with dyslexia. Dyscalculia has a significant impact on the ability of adults to understand and interpret the technologic aspects of modern society. It has been shown that children use mathematics performance as a basis of how they perceive their own intellectual ability³⁴.

Given the strong relation between attentional and arithmetic problems, it is prudent for students with attentional problems to be screened for dyscalculia as well as for other learning disorders. Moreover, students who are encountering significant difficulty with arithmetic should have inattention ruled-out as a contributing factor. Because this is a subject area that is taken so seriously by children, parents, and teachers, it is imperative that the nature of the individual child's dyscalculia and/or attentional problems is fully identified, and then explained in terms that are understandable to parents and child.

Direct remediation of dyscalculia may require breaking down complex mathematics problems into individual sub-components and allowing the child to master each sub-component as an end in itself. For example, a child who has difficulty recalling facts could be given practice drills to see

Figure 1: Relation among attention, automatic recall of mathematics facts, and recall and execution of mathematical procedures. Some research supports the impact of attention (shaded process areas).



how many problems can be solved in a limited period of time. A child who had problems recalling the sequence of a procedure or algorithm can be allowed to explain the procedure, then attempt to solve it. If a child has an attentional problem, treatment with psychostimulant medication and cognitive management may be effective.

The identification and treatment of other neurodevelopmental disabilities such as dyslexia are important components of management. Language therapy for children with language disabilities may improve mathematics comprehension and the ability to understand and solve word problems. Controlling the psychosocial sequelae of mathematics disabilities is also important. Parents and teachers need to be aware of the toll that mathematics disabilities has on a child's self-esteem.

Further research is needed on the core deficits associated with dyscalculia and their relation to attention deficits. Particular emphasis must be given to the two subtypes of attentional difficulties (ADHD and ADD/NoH) and the three subtypes of dyscalculia (visuospatial, procedural, and memory).

Accepted for publication 15th April 1999.

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