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Developmental dyscalculia: prevalence and prognosis

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Abstract The prevalence of developmental dyscalculia (DC) in the school population ranges from 3–6 %, a frequency similar to that of developmental dyslexia and ADHD. These studies fulfilled the criteria for an adequate prevalence study, i.e., were population based, using standardized measures to evaluate arithmetic function. Although the variation in prevalence is within a narrow range, the differences are probably due to which definition of dyscalculia was used, the age the diagnosis was made and the instrument chosen to test for DC. The relative predominance of girls with DC may reflect a greater vulnerability to environmental influences alone or in addition to a biological predisposition. DC is not only encountered as a specific learning disability but also in diverse neurological disorders, examples of which include ADHD, developmental language disorder, epilepsy, treated phenylketonuria and Fragile X syndrome. Although the long-term prognosis of DC is as yet unknown, current data indicate that DC is a stable learning disability persisting, at least for the short term, in about half of affected children. The long-term consequences of DC and its impact on education, employment and psychological well-being have yet to be determined.

Key words Developmental dyscalculia – prevalence – prognosis

Prevalence

Precise knowledge regarding the prevalence of learning disabilities will enable the determination of the extent of learning disabilities within the normal population of school children, the delineation of risk factors in children with learning disabilities, the identification of subgroups of susceptible children and will aid in the development of therapeutic strategies. Public health issues have also become an overriding concern because services for learning disabilities are now mandated by law. Thus information about the prevalence, relative risk, individual susceptibilities, outcome, and effective therapeutic modalities is necessary to make rational decisions about the provision of funds necessary for medical and educational services (23).

To determine prevalence we must develop a scientific and clinical consensus as to what constitutes a learning disability and which definition best describes the problem. Since we do not yet have a biological marker for learning disabilities, there is still no correct definition or one single way to classify a child. For developmental dyscalculia (DC) several options are available; none of which is universally agreed upon. DC has been defined as a specific, genetically determined learning disability in a child with normal intelligence (29). This definition is consistent with the current concept of learning disabilities in the sense that they are brain-based disorders, governed by genetic influences occurring in children of normal intelligence (15, 23). However the usefulness of this definition is limited when it comes to the diagnosis of DC in children and distinguishing between children with DC and those who are weak in arithmetic. A more recent definition as per the Diagnostic and Statistical Manual–IV edition (DSM-IV) (2), defines DC as a learning disability in mathematics, the diagnosis of which is established when arithmetic performance is substantially below that expected for age, intelligence and education. The definition of "substantially" is vague, leaving the decision to the clinician. Alternative operative definitions of DC, like for other learning disabilities, rely on the discrepancy between intellectual potential and achievement, or a discrepancy of at least two years between chronological grade and level of achievement (20, 35, 40). The achievement-potential discrepancy definition will include gifted children whose achievement in a particular learning domain is within the normal range although considerably less than expected for intellectual potential. Since there are many reasons why a child may not perform up to ability aside from a specific learning disability, it is the clinician who ultimately will have to decide if the diagnosis is indeed a specific learning problem meriting educational interventions. The two year lag definition has limited usefulness for both younger children and older individuals where a 2-year discrepancy is not meaningful. The definition chosen may arbitrarily determine which child will benefit from educational interventions offered by school or government bodies (23). For example, children classified as learning disabled according to the achievement-potential discrepancy criterion may qualify for help even though their learning skills are in the normal range (8). Conversely, other children who are significantly impaired but do not fit the discrepancy criterion may find themselves ineligible for aid.

Prevalence studies on DC have been carried out in various countries using different definitions. In spite of the lack of definitional consistency, the prevalence of DC across countries is relatively uniform, ranging from 3–6 % in the normal population. This figure has been found in population studies carried out in the United States (5), England (30), Germany (25, 26, 28), Switzerland (47) and Israel (20). Although the DSM-IV (2) states that DC is a rare learning disability with a prevalence of 1 %, a more realistic estimate is 5 %, which is similar to that of developmental dyslexia and attention deficit hyperactivity disorder (ADHD). Unlike other learning disabilities for which there is generally a preponderance of boys relative to girls, the majority of the studies on DC have shown more equal ratios between the sexes.

The first prevalence study was carried out by Kosc (29) in Bratislava. He assessed 375 fifth-graders, 199 boys and 176 girls, selected at random from 14 fifth grade classes in 14 schools, using a 2 stage testing procedure. The first screening was based on tests that had been standardized in a Czechoslovak population assessing both simple geometrical problems, i.e., determination of the number of black dots placed in various patterns and calculations in addition, subtraction, multiplication and division. The 24 children (6.4 %) who scored at or below the lower 10th percentile were classified as having dyscalculia.

Badian's study (5) assessed the prevalence of arithmetic disabilities in American children in grades 1–8. In a single school, 1476 children were studied, using the Stanford Achievement Test. A learning disability was defined as a score at or below the 20th percentile. Of the children, 6.4 % had arithmetic learning disabilities, either as a specific learning disability or in combination with reading disabilities: the prevalence of arithmetic as a specific learning disability was 3.6 % and 2.7 % for combined reading and arithmetic problems. In this study there were relatively more boys than usually found for the population with arithmetic disorders. The male:female ratio was 2.5:1.0 for the total number of children with arithmetic and reading disorders, 2.2:1.0 for arithmetic problems as a specific problem, in comparison to 1.7:1.0 for reading disabilities.

More than one prevalence study have been carried out in Germany. Klauer (28) estimated the prevalence of DC at 4.4 %, with a slight overrepresentation of girls. In this study, 546 3rd graders were examined from 26 representatively chosen mainstream classes from one city in Germany. The children all underwent a general achievement test for the third grade which assesses arithmetic, reading and spelling. DC was diagnosed if the score achieved by the child was at least 2 SD below the mean performance of the group. The prevalence for dyslexia was also estimated and found to be 3.7 %, slightly less than that of dyscalculia. In 2 other studies, the prevalence was found to by 6.6 % with equal numbers of boys and girls affected (25, 26). The populations studied were inner city Berlin (neighborhoods in the eastern and western part of the city) (26) and in a rural area of Germany (25). The studies were population based, each one testing almost 200 students, with nearly equal numbers of boys in girls from 8 different schools. The measures chosen had been validated in normal German population. The definition used for a specific learning disability was the discrepancy between arithmetic skills and other learning domains.

Von Aster et al. (48) estimated the prevalence of dyscalculia in Switzerland at 4.7 %. The instrument used was the Neuropsychological Test Battery for Number Processing and Calculation in Children which tests number principles, number reasoning and magnitude estimation. The sample was composed of 279 2nd and 4th grade children, 8 to 10 years of age from 4 schools representative of the socio-demographic characteristics of Zurich.

Lewis, Hitch and Walker (30) set out to study the prevalence of dyscalculia in the context of reading attainment since arithmetic disorders have also been perceived to reflect a more generalized impairment of language related processes (10). Essen-

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tially all 9 and 10 year old children in an English educational district – which included both rural and urban areas – were tested. Out of a total of 1206 children, 1056 (497 girls and 559 boys) participated in the study. The arithmetic test used was the Young's Group Mathematics Test, a group administered test that assesses calculation abilities of the four basic arithmetic operations: addition, subtraction, multiplication and division. Achievement was defined relative to aptitude as estimated by the Raven's Coloured Progressive Matrices. Children were classified as having a learning disability in arithmetic or reading using a "cutoff approach" rather than the aptitude-achievement discrepancies. Children with standardized arithmetic scores below 85 whose aptitude and reading scores were equal to or exceeded 90 were classified as having DC. If the arithmetic and reading scores were both below 85 and aptitude above 90, they were classified as having both reading and arithmetic learning disabilities. Finally, a child was classified as having a specific learning disability in reading if both arithmetic and aptitude scores were above 90 and reading below 85: 1.3 % had a specific arithmetic disability, 2.3 % arithmetic and reading disabilities while the largest group were those children with reading disabilities affecting 3.9 % of the population. There were 3 times more boys than girls with reading disabilities but for arithmetic the ratio of boys to girls was closer to 1:1. These authors concluded that while some arithmetic disorders may result from reading disabilities, there is a subgroup of children with arithmetic disorders that can not be attributed to a general deficit in language-related processing. The authors explain their low prevalence of arithmetic disorders as a function of the arithmetic test used as well as the definition they chose to use.

The estimated prevalence of DC among elementary school children in Israel was 6.5 % (20). The population studied included all 10–11 year old children attending 5th grade in municipally run schools. The definition chosen was a two year discrepancy between achievement and grade level and the paradigm used was a two-stage screening process. Using an initial screening procedure for arithmetic skills and then an individually administered arithmetic test, a cohort of 140 children with DC was identified. The cohort was characterized by a slightly higher prevalence of girls than boys (1.1:1.0), which is similar to that of other population studies of dyscalculia. In this population reading problems were found in only 17 % of children while the majority had DC as an isolated learning disability. It is noteworthy, however, that children with the dual diagnosis of DC and dyslexia were more profoundly impaired on arithmetic skills and had overall poorer performance on neuropsychological tests than children with DC alone or DC and ADHD (42).

There is no satisfactory answer as to why the usual predominance of boys with learning disabilities is not replicated in DC. Many authors have attributed learning disabilities in arithmetic to factors other than brain-based neurological deficits, including lower socio-economic status (9), mathematical anxiety (13), overcrowded classes (17), more mainstreaming, fewer resource rooms as well as arithmetic curricula which have not undergone field testing (32); all of which may preferentelly impact more on girls versus boys.

Prognosis

The methodological technique which can best teach us about the natural history of phenomena such as cognitive disabilities is a well-planned longitudinal study. Criteria for such studies include choice of population-based cohorts, a large enough sample to insure against sampling errors, valid assessment tools, matched control groups and sufficiently long follow-up periods (38). Since there are few longitudinal studies on DC available, we thought it appropriate to discuss the natural history of DC in the context of other developmental disorders, namely developmental dyslexia.

Longitudinal studies of dyslexia indicate that for many children the problem may be long-standing (7, 36, 37). Shaywitz et al. (45) , using a longitudinal paradigm, studied children in first, third and fifth grade. Among the children originally identified as being dyslexic in first grade, 80 % had a good outcome. However, the children identified as dyslexia in fifth grade did not outgrow their reading problem when reexamined in ninth grade (46). An equally grimmer prognosis for children having reading problems as early as second grade was documented by Satz et al. (37); very few of the children that they tested achieved grade level reading skills by fifth grade. The Isle of Wight study of dyslexia began where the previous two studies left off, assessing 9 year old boys. The authors of this longitudinal study found that more than half of the boys classified as dyslexic at 9 years of age continued to be dyslexic five years later, in addition to doing poorly in spelling and math (36). Among the children who improved, only 6 % achieved age level reading abilities. Interestingly their improvement in arithmetic over the 5 year follow-up was greater than their improvement for reading. Other long-term studies of dyslexic individuals indicate that the outcome continues to be poorer than for their non-dyslexic peers particularly in academic, professional and social domains. The outcome may be modified by socio-economic status, i.e., substantially poorer when the subjects are from a low socio-economic group (27) to near normal when the subjects come from middle class families (34).

The information on follow-up of DC is very limited and the adult outcome of children with DC is not known. Children with mathematical disabilities diagnosed in first grade appear to improve, at least in their counting abilities by the time they are retested in second grade (16). Fazio (14) has also documented improvement in kindergarten children with developmental language disorders and arithmetic disorders over a 2 year period. We have followed longitudinally a group of 140

10–11 year old children with DC, reexamineding them at age 13–14 years (43). Their performance 3 years after the original diagnosis was still poor, 95 % of them scoring in the lowest quartile of their school class and almost half continued to meet research criteria for DC. The methodological criteria we employed when conducting this study were faithful to those recommended for a follow-up assessment in the field of LD (38). First, our sample was a population-based cohort composed of all children (n = 3029) attending fourth grade in the municipally run schools. Second, using research criteria, we identified 185 children with DC; 140 of whom were studied in depth. Third, 88 % (123/140) of the children, who were given the diagnosis of DC at the beginning of the study, were reexamined three years later on individually administered arithmetic, reading and spelling tests. Finally, at each time point, the results of the children with DC were compared to those obtained from an appropriate control group. We are presently reexamining these children, 6 years after the original diagnosis as this cohort is finishing their secondary school studies.

Factors associated with persistence of DC were severity of the arithmetic disorder at the time of the original diagnosis and the presence of arithmetic problems in siblings of the proband. Factors which were not associated with persistence were socio-economic status, gender, the co-occurrence of another learning disability and the extent or types of educational interventions received by these children (43).

Children with persistent DC also had more emotional and behavioral problems than children with non-persistent DC (Table 1). The children were assessed for emotional and behavioral problems using the Child Behavior Checklist (CBCL) (1) at both 5th grade, at the time of the initial diagnosis, and grade 8, at the time of follow-up. The CBCL is a parent report questionnaire that assesses behavior and emotional problems in children aged 4–18 years old. The behavior and emotional problems are classified as wide-band syndromes (internalizing and externalizing) and further classified into narrow-band syndromes (1). Internalizing narrow-band syndromes are anxiety/depression, somatic problems and withdrawal. The externalizing narrow-band syndromes are aggression and delinquent behavior. Problems in the attentional, social and thought domains are not classified as externalizing or internalizing syndromes.

At fifth grade, children who ultimately developed persistent DC had significantly more parent reported problems on the narrow-band syndromes of attention problems ($t(113) = 2.47$, $p<.02$) and anxiety/depression ($t(113) = 1.99$, $p < .05$), and the wide-band syndrome of internalizing problems ($t(113) = 1.95$, $p < .06$) than children who developed non-persistent DC. At eighth grade, there was a decrease for both groups in mean level of behavior problems but for the most part, parents of children with persistent DC continued to report more problems for their children than did parents of children with non-persistent DC. Children with persistent DC were reported to have significantly more thought problems ($t(113) = 2.23$, $p<.03$) and problems of delinquency ($t(113) = 1.92$, $p < .05$) than children with non-persistent DC.

Table 1 CBCL means and standard deviations for children with persistent DC (PDC) and non-persistent DC (NPDC)

CBCL	Fifth Grade PDC M±sd	NPDC M±sd	Eighth Grade PDC M±sd	NPDC M±sd
Withdrawn	3.64±3.63	2.80±3.19	2.43±3.28	2.56±2.53
Somatic problems	1.87±2.50	1.27±1.85	1.07±1.88	0.58±1.04
Anxiety/ depression	5.59±4.84	4.00±3.67	4.64±5.14	3.59±3.72
Social problems	3.00±3.17	2.29±2.95	1.71±2.42	1.44±2.06
Thought problems	1.05±1.38	0.66±1.20	0.82±1.22	0.41±0.72
Attention problems	6.32±4.32	4.49±3.60	4.96±4.82	3.80±3.52
Aggression	8.64±5.86	7.58±6.10	6.27±6.82	5.37±5.13
Delinquency	1.87±1.93	1.46±2.31	1.30±2.18	0.66±1.33
Internalizing problems	10.82±9.23	7.86±6.93	7.89±8.67	6.58±5.82
Externalizing problems	10.52±7.37	9.03±7.92	7.57±8.78	6.03±6.15
Total behavior problems	34.09±23.08	26.92±22.38	24.84±24.31	19.36±14.93

Developmental dyscalculia and other neurological and psychological conditions

DC is common in many neurological disorders, and in some it is the most frequently encountered learning disability (18). Epilepsy, for example, carries an undue risk of DC. Among the learning problems these children have, the academic skill most likely to be impaired is arithmetic (39). The cognitive profile for chromosomal disorders such as Turner's syndrome (47) and Fragile X syndrome includes dyscalculia (22). DC is also common in children with phenylketonuria who have been appropriately treated by diet (33) and in children with ADHD (12).

DC is a frequently encountered learning problem in children with delayed language development. We found that kindergarten children with developmental language disorder perform less well on arithmetic than controls even though there was no difference in their level of intelligence (44). Their arithmetic skills were impaired in all domains tested. A more pervasive problem in language affecting both receptive and expressive skills was associated with deficits in number reasoning and arithmetic operations. Expressive language deficits, on the other hand, correlated mainly with impaired

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counting skills. In a second study, we assessed arithmetic skills in 61 elementary school children in 3rd–6th grades who had been diagnosed in kindergarten as suffering from developmental language delay. Fifty-five percent were diagnosed with DC, a figure 10-fold greater than the 5–6 % in the normal population, and ADHD was present in 25 % (21). In this study, we were unable to correlate the type of language impairment, i.e., receptive or expressive, with different arithmetic functions, i.e., number comprehension and production, number facts and number calculation. We hypothesized that the relationship between DC and developmental language disorders may be rooted in impaired linguistic skills, which underlie both the language disorder and the arithmetic dysfunction. Alternatively, both disabilities may reflect a single brain disorder with abnormalities in contiguous areas of the cortical networks involving both language and arithmetic.

Table 2 Percentage of children with persistent and non-persistent dyscalculia falling into the clinical range on the CBCL at diagnosis (time 1 (5th grade)) and follow-up (time 2 (8th grade))

	Persistent dyscalculia N = 56	Non-persistent dyscalculia N = 59	Total sample N = 115
Narrow-band syndromes			
Withdrawn			
Time 1	21 %	15 %	18 %
Time 2	11 %	2 %	7 %
Somatic problems			
Time 1	21 %	5 %	13 %
Time 2	7 %	0 %	3 %
Anxiety/depression			
Time 1	12 %	3 %	8 %
Time 2	12 %	3 %	8 %
Social problems			
Time 1	25 %	19 %	22 %
Time 2	11 %	8 %	10 %
Thought problems			
Time 1	12 %	8 %	10 %
Time 2	5 %	0 %	3 %
Attentional problems			
Time 1	25 %	8 %	16 %
Time 2	14 %	10 %	12 %
Delinquent behavior			
Time 1	12 %	8 %	10 %
Time 2	5 %	2 %	3 %
Aggression			
Time 1	7 %	8 %	8 %
Time 2	5 %	3 %	4 %
Broad-band syndromes			
Internalizing problems			
Time 1	28 %	14 %	21 %
Time 2	16 %	3 %	10 %
Externalizing problems			
Time 1	18 %	10 %	14 %
Time 2	12 %	5 %	9 %
Total behavior problems			
Time 1	34 %	25 %	30 %
Time 2	21 %	5 %	13 %

Clinical range = 98th percentile for narrow-band problems, 95th percentile for broad-band problems, 90th percentile for total behavior problems.

Emotional and behavioral problems are prevalent in children with developmental disorders, including DC (4, 6, 19, 24, 31, 41). An abnormal linguistic profile in early childhood is predictive of symptoms of hyperactivity, anxious/passive symptoms and level of social competence 7 years later (6). Up to 70 % of adolescents who were diagnosed 10 years previously in preschool with language disorders will have behavioral disorders (3). We studied the emotional and behavioral problems in a population of children with persistent and non-persistent DC (43). The percentage of children with DC who, according to the CBCL, had emotional and behavioral problems several enough to warrant referral was in excess of that expected in the normal population. For the CBCL, the 98th percentile is used to differentiate between clinical and non-clinical cases for the narrow-band syndromes, the 95th percentile for the total behavior problems. Table 2 presents the percentage of DC children with clinical level problems on the CBCL at the fifth and eighth grades. While it is clear that the prevalence of emotional and behavior problems in children with persistent DC and non-persistent DC is greater than in the normal population, this is particularly true for children with persistent DC. Clinical-level social problems typify both groups at both time periods. Attention problems and internalizing problems are particularly severe in the persistent DC groups, especially at fifth grade.

There appears to be a direct correlation between the severity of developmental disorder and the behavioral phenomena. Beitchman et al. (6) reported that 12 year old children who were diagnosed with pervasive language disorders at age 5 had more evidence of impaired social competence and externalizing disorders, such as delinquency, on the CBCL than children whose language disorder was less severe. Similarly, in our population, children with an initially more profound impaired performance in arithmetic were more likely to have persistent DC and children with persistent DC manifested more severe behavioral dysfunction than children with non-persistent DC (Table 2). The impaired behavior was manifested both in terms of mean level of problems and in percentage of children with problems in the clinical range. One can argue that the developmental cognitive disorders contribute to behavioral problems, or that behavioral disorders impair cognitive and learning skills; however, perhaps the underpinning of both can be best explained by the basic neurological dysfunction.

Future directions

DC remains a relatively under-investigated learning disability; therefore, the avenues for further research are plentiful. The assumption that DC has a biological basis needs to be explored. Both family genetic studies of DC and functional MRI studies could further our understanding of the disorder. Genetic studies in which families with a history of DC are genotyped would provide a means for identifying the genes or perhaps the single gene associated with DC. The use of fMRI has already contributed to our understanding of the neurobiology of normal arithmetic function (11) and will undoubtedly be useful in identifying areas of the brain involved in dyscalculia.

The environmental contribution to DC also needs further investigation. A systematic investigation of the impact of the environment on DC is necessary for three reasons. One, the origin of DC in some children may be environmentally based. Two, the environment potentially can act as a moderator of DC, that is, it can influence both the severity and the persistence of DC. Lastly, the extent to which children with DC develop attendant behavior problems may be related to their home and educational environments.

Outcome for all developmental disabilities, regardless of development period, is the result of the ongoing transaction between the vulnerable organism and his environment. Longitudinal research is a powerful way to trace organism-environment transactions. It provides a way to investigate the general and individual developmental course of disabilities, such as DC. Such studies are sorely lacking in the area of DC. Only through continued evaluation of children with DC and their proximal environments from early childhood until adulthood will the developmental pathways of DC be delineated.

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