Math Learning Disorder: Incidence in a Population-Based Birth Cohort, 1976–82, Rochester, Minn

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Objective.—To report the incidence of math learning disorder (Math LD) among school-aged children, overall and by gender. To compare incidence estimates obtained by using three different methods to identify Math LD cases. To assess the extent to which children manifest Math LD alone, versus Math LD with comorbid reading disorder.

Methods.—This is a population-based, retrospective, birth cohort study. Subjects included all children born 1976–82 who remained in Rochester, Minn after age 5 (N = 5718). Using records from all public and private schools, medical facilities, and private tutorial services, all individually administered intelligence quotient and achievement tests and extensive medical, educational, and socioeconomic information were abstracted. Math LD was established using research criteria based on 3 formulas (regression-based discrepancy, nonregression-based discrepancy, low achievement).

Results.—Cumulative incidence rates of Math LD by age 19 years varied from 5.9% to 13.8% according to the formula used. Boys were more likely to be affected than girls, with relative risk ratios from 1.6 to 2.2 depending on the formula applied. Many children with Math LD (35% to 56.7%, depending on the formula used to define Math LD) *did not* have a comorbid reading disorder.

Conclusions.—These results, from a community-based birth cohort, suggest that Math LD is common among schoolchildren, and is significantly more frequent among boys than girls, regardless of definition. Many children with Math LD *do not* have an associated reading disorder.

KEY WORDS: incidence; learning disability; math learning disorder

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Mathematics learning disorder (Math LD) is defined in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV), as mathematical ability that is substantially below that expected for chronological age, intellectual level, and educational experience.[1] Understanding mathematical concepts and performing mathematical operations are important skills for people living in a technologically oriented society.[2,3] Indeed, poor math achievement by US students has been a source of national concern for some time.[4] Despite the importance of mathematics, the majority of learning disability (LD) research has focused on reading.[2,5–9]

The DSM-IV also notes the lack of epidemiological data regarding Math LD, but estimates the prevalence of Math LD is 1% of school-age children.[1] This conflicts with research suggesting that the prevalence ranges from 4% to 6%.[5,10–14] Variations in the definition of Math LD and operational criteria for identifying cases in epidemiological research have contributed to uncertainty about the prevalence of Math LD.[15,16] Some researchers have reported that Math LD is more common among boys than girls.[13] Others have suggested that girls are equally or more likely than boys to have Math LD.[14,15] Previous studies have suggested that Math LD is as common as reading learning disorder (Reading LD), and have also reported widely varying estimates of the extent to which Math LD and Reading LD occur as comorbid learning disorders.[16–18] Also, to our knowledge, the literature does not include any contemporary studies of the incidence of Math LD in a population-based birth cohort.

In this paper, we report the incidence of Math LD in a population-based birth cohort of all children born 1976–82 in Rochester, Minn. We examine the variation in incidence resulting from the use of 3 different definitions of Math LD, and compare incidence rates between boys and girls. We also report the extent to which Math LD occurs as an isolated learning disorder, compared with its comorbid occurrence with Reading LD.

METHODS

A detailed description of the 1976–82 Rochester birth cohort and our study methods for determining the incidence of Reading LD in this cohort have been published.[19,20] In this paper, we summarize the methods as they were applied to our study of Math LD (Figure 1).

Study Setting

In 1990, the population of Rochester, Minn was 70 745, 96% white, and primarily middle class; 82% of adults were high school graduates.[19] The capacity for population-

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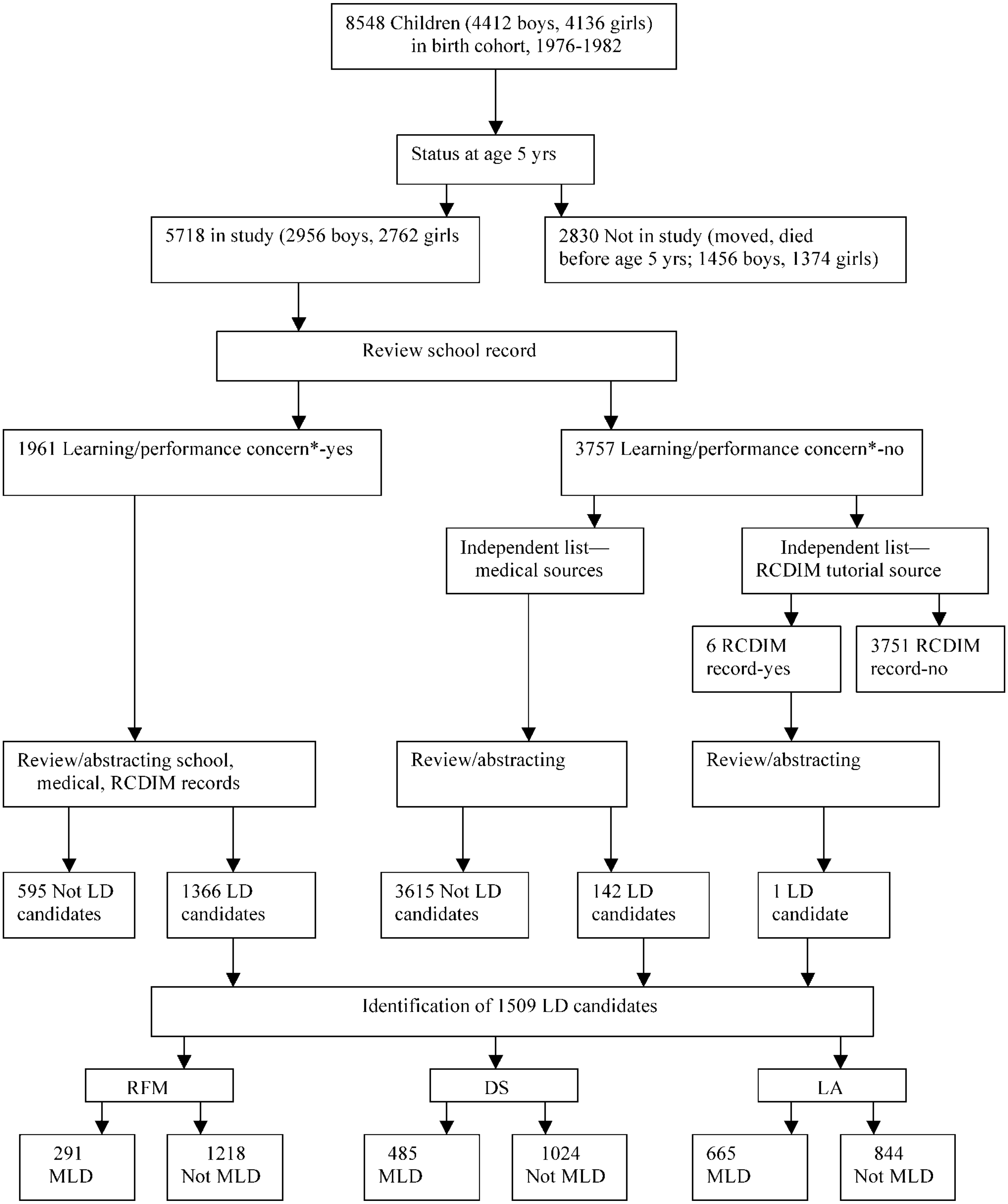

Figure 1. *Flow diagram describing identification of learning-disabled children among 1976–82 Rochester, Minn birth cohort. RCDIM indicates Reading Center/Dyslexia Institute of Minnesota; LD, learning disorder; RFM, regression formula–Minnesota; DS, discrepancy–nonregression method; LA, low-achievement method; and MLD, math learning disorder. *Evidence of learning/performance concern consisted of Individual Education Program (IEP) reports, report of IEP review, individual assessment/reassessment report forms, referral forms, medical or medication reports, private tutoring, private evaluation reports, individually administered ability and achievement tests, or any notation from teacher, parent, or other person related to any type of difficulties in learning or performance.*

based epidemiological research on LD in Rochester is the result of several unique circumstances. Because of Rochester's geographic isolation in southeastern Minnesota, greater than 95% of medical care is provided locally by Mayo Clinic, Olmsted Medical Center, and a few private practitioners. Through the Rochester Epidemiology Project, all diagnoses and surgical procedures recorded at these medical facilities, including affiliated hospitals, are indexed for computerized retrieval (Medical Diagnostic Index).[21] Each institution maintains a unit or dossier medical record. The medical records contain complete and detailed information from providers of all primary, specialty, inpatient, and outpatient care to local residents. This includes psychometric assessments and questionnaires, and psychological and psychiatric evaluations obtained during interdisciplinary assessments of children with learning problems.

Through a contractual research agreement, permission was obtained to review the records of Rochester public and private schools (Independent School District #535), including the complete school records of all children born in Rochester 1976–82 ever registered at any of the district's public, parochial, or private schools. The district also maintains records for all home-schooled children. Under a separate research agreement, we obtained permission to review the records of the Reading Center/Dyslexia Institute of Minnesota (RCDIM), the largest private tutoring agency in Rochester.

Identification of the 1976–82 Rochester Birth Cohort

The birth cohort included all children (N = 8548) born between January 1, 1976 and December 31, 1982 to mothers residing in the five Olmsted County townships comprising Minnesota Independent School District #535. Subjects were identified through the computerized birth certificate information from the Minnesota Department of Health, Division of Vital Statistics. Vital status for each member of the birth cohort during the 1995–96 school year was established. Children who still lived in Rochester until at least age 5 years were included in the study (n = 5718, Figure 1). An analysis of birth certificate data from children who moved away versus those who remained in the community was published previously.[19] Few differences were found, and these were unlikely to compromise the identification of LD cases. The study was approved by the Institutional Review Boards of Mayo Clinic and Olmsted Medical Center.

Identification of Potential Math LD Candidates

Phase 1

We reviewed the entire school record for every member of the birth cohort who enrolled in any public or private school in the district, including home-schooled children (''In study'' subjects). The subject was classified as ''Learning/performance concern–yes'' if the school record contained any form, test results, or remarks related to any learning problem or handicapping condition (n = 1961, Figure 1). The subject was classified as ''Learning/performance concern–no'' if the school record did not contain such information (n = 3757). Nineteen children with moderate to severe mental retardation (intelligence quotient [IQ] < 50) were excluded from further consideration.

For all subjects whose school records were designated ''Learning/performance concern–yes,'' we completed an additional, detailed review of each subject's school, medical, and RCDIM records. If these records contained at least one set of scores from individually administered IQ *and* academic achievement tests, the subject was designated as an ''LD candidate'' (n = 1366 at this stage).

Phase 2

For all 3757 subjects whose school records were designated ''Learning/performance concern–no,'' we conducted a computerized search of the Medical Diagnostic Index, using diagnostic terms for LD as well as a code indicating that psychometric testing had been completed. We also cross-matched these subjects with the RCDIM file. These two sources yielded an additional 143 LD candidates.

Phase 3

We then abstracted detailed information from the complete school, medical, and RCDIM records for all 1509 subjects who were designated as LD candidates in the previous steps. In addition to individually administered IQ and achievement test scores, we also abstracted other information including socioeconomic status, medical and comorbid psychological/psychiatric conditions, and details regarding any special education services that were provided.

For each child within each calendar year, all IQ and achievement test scores were used to form pairs of ability and achievement measures. All pairs of IQ–achievement measures were placed in chronological order for each subject.

Identification of Math LD Cases

We applied 3 different ability–achievement methods to the IQ and achievement scores of each subject classified as an LD candidate. In each formula, x is the full-scale IQ score and y is the achievement standard score.

1) Regression formula, Minnesota (RFM). $y < 17.40 + 0.62x$. This regression-based discrepancy formula is currently used in Minnesota.
2) Discrepancy formula (DS). For children in kindergarten through third grade, $y < x - 15$; for grades 4 through 6, $y < x - 19$; for grades 7 through 12, $y < x - 23$. This nonregression-based discrepancy formula was used by the local school system during several years when our subjects were in school.
3) Low achievement formula (LA). $x > 80$ and $y < 90$. This formula reflects recent trends toward LD definitions that emphasize low academic achievement among children with at least low average cognitive skills.[22] It is also comparable to the definition used in the most recently published study of the prevalence of Math LD.[10]

Table 1. Incidence of Math Learning Disorder, Identified by 3 Formulas Among 1976–82 Birth Cohort, Rochester, Minn*

	Math LD Formulas								
	RFM			DS			LA		
	All	Boys	Girls	All	Boys	Girls	All	Boys	Girls
Number with Math LD	291	199	92	485	336	149	665	417	248
Age met criteria, y; mean (SD)	8.8 (2.5)	8.8 (2.4)	8.8 (2.9)	8.3 (2.0)	8.5 (2.1)	8.1 (1.9)	9.7 (3.1)	9.4 (2.8)	10.1 (3.5)
Cumulative incidence, at age (y):									
7	1.3	1.4	1.2	2.1	2.6	1.7	2.1	2.4	1.9
9	3.8	5.1	2.3	6.9	9.0	4.5	7.1	9.1	5.0
11	4.9	6.7	3.1	9.0	12.0	5.8	10.0	12.8	7.0
13	5.3	7.1	3.4	9.3	12.4	5.9	11.0	14.1	7.6
15	5.6	7.6	3.6	9.6	12.8	6.1	12.5	15.7	9.1
17	5.9	7.7	3.8	9.7	13.0	6.2	13.4	16.2	10.4
19	5.9	7.8	3.9	9.8	13.2	6.2	13.8	16.7	10.8
RR, boys versus girls; (95% CI)	2.1 (1.6, 2.6)			2.2 (1.8, 2.6)			1.6 (1.4, 1.9)		

*(N = 5699); Math LD indicates math learning disorder; RFM, regression formula—Minnesota; DS, discrepancy; LA, low-achievement; RR, risk ratio; and CI, confidence interval.

Comorbidity of Math LD and Reading LD

After identifying all cases of Math LD, we determined the number of subjects with research-identified Math LD alone versus research-identified Math LD *and* Reading LD, for each of the 3 formulas. Reading LD cases among birth cohort members had been identified in a previous study.[20]

Statistics

Cumulative incidence rates were calculated according to the method of Kaplan and Meier.[23] Ninety-five percent confidence intervals (95% CI) about the point estimates were calculated using the Greenwood formula for the standard error. The cumulative incidence rates represent the likelihood that subjects who remained in Rochester throughout their school years (ie, by age 19 years) would be diagnosed as Math LD. Children in the birth cohort who did not meet research criteria for Math LD were censored on the initial occurrence of migration from the community, death, last follow-up date, or age 19 years. Cumulative incidence rates were calculated separately for boys and girls for each of the 3 LD definitions. Risk ratios (boys vs girls) and corresponding 95% CIs were determined using the regression coefficient and standard error for gender obtained by fitting Cox proportional hazards models.

RESULTS

Cumulative Incidence of Math LD by 3 Formulas and by Gender

Table 1 provides the cumulative incidence of Math LD at various ages up to 19 years, overall and separately for boys and girls, by each of the 3 formulas. Math LD was common, with cumulative incidence by age 19 years varying from a low of 5.9% (RFM) to a high of 13.8% (LA), depending on the Math LD definition. The mean age at diagnosis was similar for each Math LD definition and did not differ by gender within each definition. Males were more likely to have Math LD than females, with male:female relative risk ranging from 1.6 to 2.2. Cumulative incidence by each of the 3 formulas is depicted in Figures 2 and 3.

Among children with IQ scores between 50 and 79 (n = 91), 38 met the RFM, 33 met the DS, and 50 met the LA criteria for Math LD. If these children had been *excluded* from the analysis, the resulting cumulative incidence estimates by age 19 years would have been similar to the estimates noted above (5.2%, 9.3%, and 13.0% for the RFM, DS, and LA definitions, respectively).

On the basis of the ability and achievement measures that were used to identify a child with a Math LD, 86.7% of the children with Math LD (79.0%, 85.8%, and 83.9%, respectively, depending on the formula) had been administered an age-appropriate Wechsler scale for ability assessment. For math achievement, 76.5% of these children had been administered a Woodcock-Johnson test (59.1%, 70.3%, and 74.0% depending on the formula), whereas nearly all remaining children with Math LD had Wide Range Achievement Test scores.

Comorbidity of Math LD and Reading LD

For the 2 discrepancy-based definitions 56.7% (RFM) and 35.9% (DS) of subjects with Math LD *did not* have a coexisting Reading LD (Table 2). For the LA definition, 35% of the Math LD cases *did not* have a coexisting Reading LD.

Overlap Among Children With Math LD Identified by Different Classification Methods

Among the 5718 children in the birth cohort with Math LD, some subjects were identified as having Math LD by more than 1 method. The frequency and overlap of Math LD cases identified by the 3 formulas are presented in Figure 4.

Cognitive Profile of Math LD Cases

Children with Math LD had cognitive skills that were solidly in the average range, regardless of LD definition (Table 3). As expected, academic achievement in math is quite poor among the Math LD cases. However, Math LD

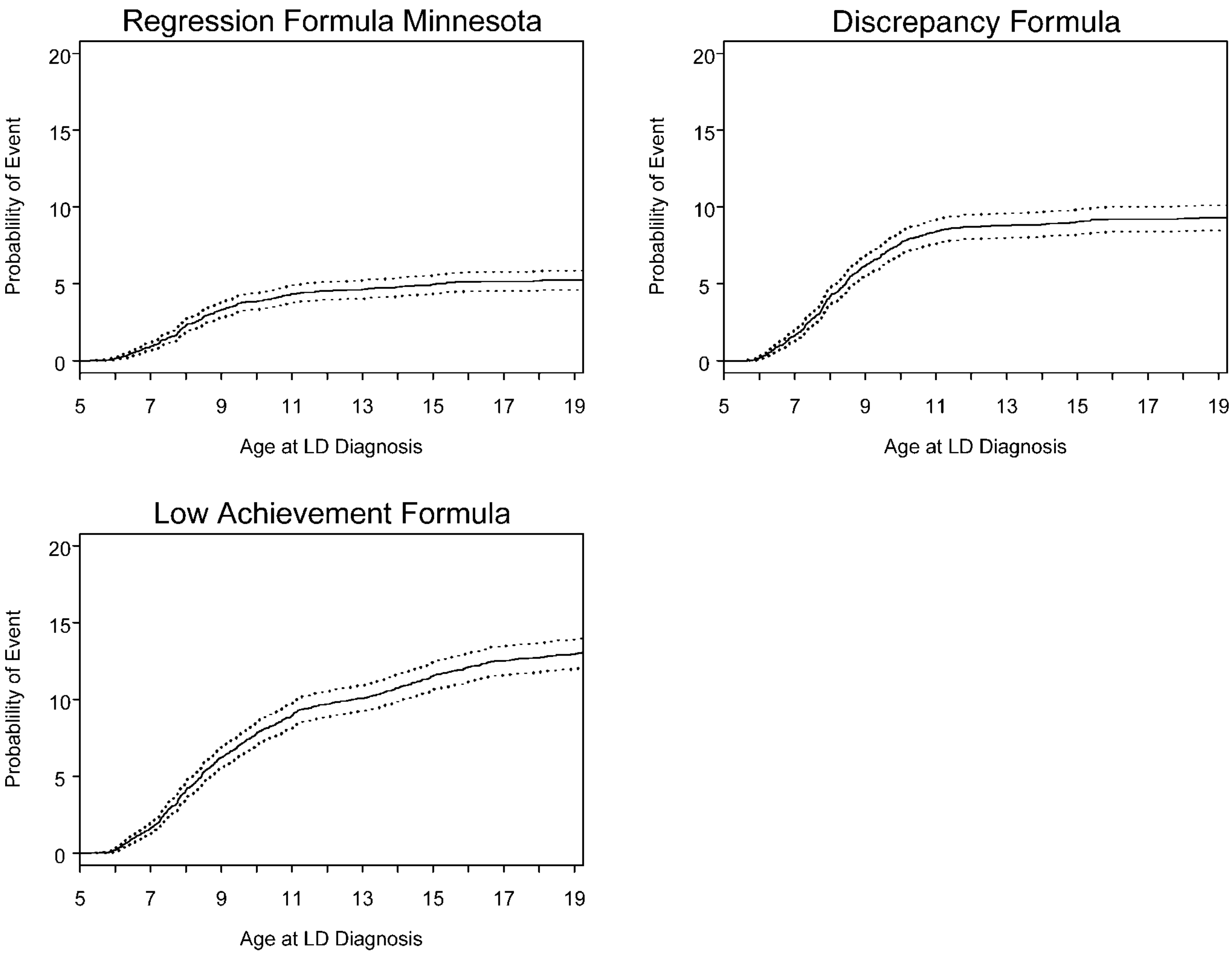

Figure 2. *Cumulative incidence rates of mathematics learning disorder for males and females combined, identified by each formula among 1976–82 birth cohort, Rochester, Minn, by age. Lines represent cumulative incidence rate with associated 95% confidence interval.*

cases identified by the LA and DS formulas appear to have mean math achievement scores that are better than the cases of Math LD defined by the RFM formula. In particular, among the cases identified by more than 1 formula, the median achievement scores were significantly higher at the time a subject was identified by either the LA or DS formula compared to the RFM formula (all $P < .001$, Wilcoxon signed rank tests).

Site of Assessment and Sources of Data

We did not depend on school identification of Math LD to determine the incidence rates of Math LD. School-identified cases had records indicating the presence of an Individual Educational Program (IEP) specifying services for Math LD. Of the 504 cases of research-identified Math LD identified by either of the 2 discrepancy formulas, 251 were *not* identified as Math LD by the schools (ie, did not have an IEP for math; Table 4). Also, 15 of these 251 Math LD cases were identified by our research criteria *solely* by information from the medical and RCDIM records (ie, the school record did not include any information to indicate that the student had problems in learning or school performance or an IEP for math). Furthermore, among the 287 Math LD cases identified solely by the LA formula, 183 were not identified as Math LD by the school.

Of the 504 cases of research-identified Math LD defined by either of the 2 discrepancy formulas, 238 had at least some test results from sites other than the school. Similarly, for the 287 Math LD cases identified solely with the LA formula, 146 had at least some testing performed at a site other than school.

DISCUSSION

This report of the incidence of Math LD in a population-based birth cohort indicates that Math LD is common, affecting many children at some time during their school years. *Prevalence* studies have reported rates ranging from 4% to 6%.[5,10–13] However, prevalence studies are subject to bias due to children with Math LD moving into or out of the community, with no way to determine the extent, or the effect, of such movement. Birth cohort-based *incidence* studies minimize this bias by identifying cases of Math LD that arise naturally in a well-defined population. Thus, incidence rates represent a more precise description of the occurrence of Math LD.[24] Our results support the notion that Math LD is an important problem

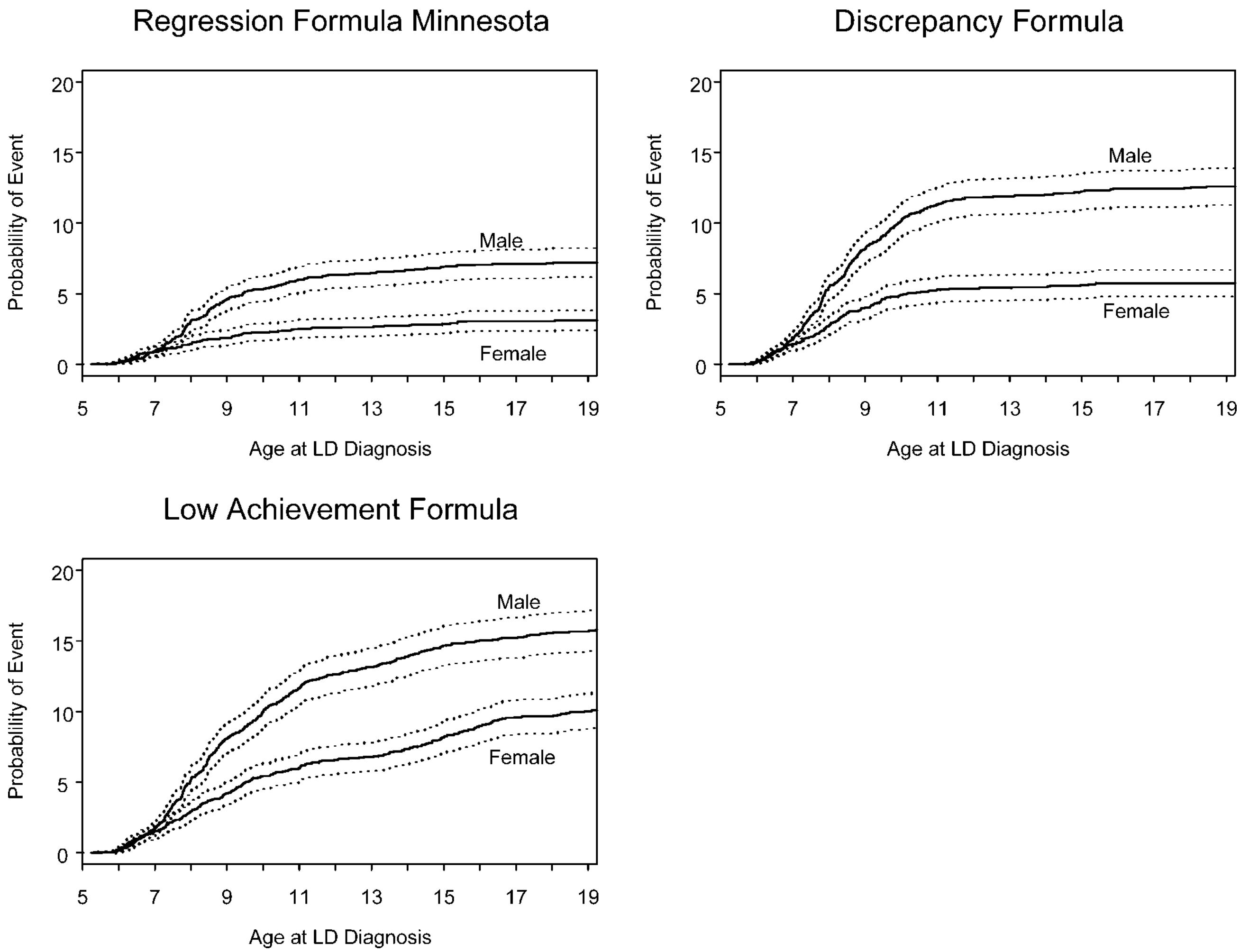

Figure 3. *Cumulative incidence rates of mathematics learning disorder identified by each formula among 1976–82 birth cohort, Rochester, Minn, by age and sex. Lines represent cumulative incidence rate with associated 95% confidence interval.*

that deserves attention from both researchers and educators.

The issue of defining LD has been a source of controversy and confusion.[25] This confusion is reflected in the widely varying criteria used by different states to identify children with LD who will receive special educational services.[26,27] Researchers have highlighted the need for considering a broad array of LD definitions until 1 definition is validated.[28] The absence of an agreed-upon definition or a biological marker has hampered epidemiological research efforts in the LD field.[4,29] Thus, we used 3 different definitions of LD in our study. The results clearly indicate the impact of definition on incidence rates of Math LD, with a tendency for the discrepancy-based formulas to identify fewer cases (5.9%, 9.8%) compared to the low-achievement definition (13.8%). Until 1 definition of Math LD is clearly identified as the most valid and reliable, we believe it is premature to limit epidemiological studies to a single definition.

Low-achievement definitions have been advocated as a more appropriate way to identify children with LD.[30,31] Prior studies of Math LD have used varying low-achievement definitions.[11,13,32] In applying a low-achievement definition of LD, IQ scores are only used to determine that the child has ''normal'' intelligence. IQ and achievement scores are *not* directly compared. We used an IQ cutoff

Table 2. Overlap Between Reading and Math Learning Disorders Among Those With a Math Learning Disorder*

	Math LD Formulas†		
Type of Learning Disability Number With Math LD	RFM n = 291 (%)	DS n = 485 (%)	LA n = 665 (%)
Math LD only	165 (56.7)	174 (35.9)	233 (35.0)
Math LD & Reading LD	126 (43.3)	311 (64.1)	432 (65.0)

*Math LD indicates math learning disorder; RFM, regression formula–Minnesota; DS, discrepancy; LA, low-achievement; and Reading LD, reading learning disorder.

†Based on the two discrepancy formulas (n = 504), 179 (35.5%) had math only, and 325 (64.5%) had math and reading. For those diagnosed with LA only (n = 287), 127 (44.3%) had math only, and 160 (55.7%) had math and reading.

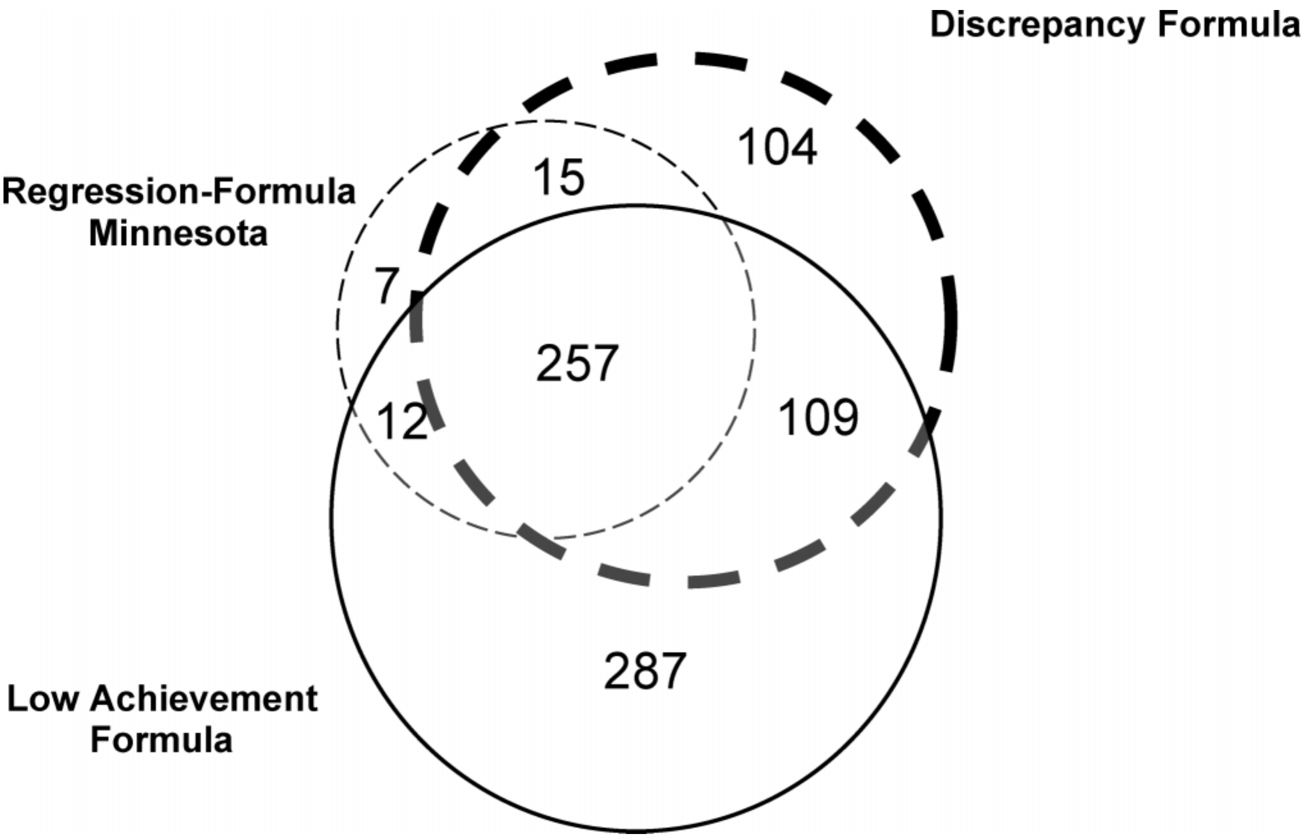

Figure 4. *Overlap of mathematics learning disorder cases identified by 3 different formulas among subjects in the 1976–82 Rochester, Minn birth cohort.*

of 80 and an achievement score cutoff of 90 to identify children with scores in the lowest 25% of the distribution of math achievement, consistent with the cutoffs used by Shaywitz et al[33] in the Connecticut Longitudinal Study and with our Reading LD study.[20,30]

Our results represent the first report of the incidence of Math LD based on comprehensive information from both public and private school and medical records for an entire birth cohort. Previous studies of the prevalence of math LD depended on screening of public school records without access to medical records or information from private schools.[5,10] Although the investigators directly tested subjects, they remained dependent on public school records to identify children at risk for LD. This method would fail to detect cases of Math LD among children who had been identified outside of the public school system. Reading LD studies have revealed the problems associated with using schools as the only source of infor-

Table 3. Mean Full IQ and Academic Achievement of Children With a Math Learning Disorder*

	Math LD Formulas					
	RFM		DS		LA	
	Cognitive	Achievement	Cognitive	Achievement	Cognitive	Achievement
Number with Math LD	291		485		665	
All Math LD						
Mean (SD)	102.1 (14.3)	74.2 (11.1)	107.1 (13.0)	83.4 (13.7)	97.8 (10.1)	81.9 (8.1)
Median	102	75	107	84	97	84
Range	55–143	23–95	68–151	23–131	80–143	23–90
Math only	165		174		233	
Mean (SD)	101.4 (14.1)	74.4 (10.8)	104.0 (13.9)	81.1 (14.6)	99.6 (10.8)	84.8 (6.6)
Median	101	75	103.5	81.5	99	86
Range	55–143	23–95	68–150	23–131	80–143	23–90
Math & Reading	126		311		432	
Mean (SD)	103.2 (14.6)	74 (11.6)	108.8 (12.1)	84.6 (13.1)	96.9 (9.5)	80.3 (8.4)
Median	102	75.5	109	86	96	82
Range	56–133	46–95	74–151	46–131	80–126	46–90

*IQ indicates intelligence quotient; Math LD, math learning disorder; RFM, regression formula–Minnesota; DS, discrepancy; and LA, low-achievement.

Table 4. Research-Identified* versus School-Identified† Children With Math LD in a Rochester, Minn, Birth Cohort, 1976–82‡

	LD Candidates					
	With Learning/Performance Concern (n = 1366)			Without Learning/Performance Concern (n = 143)		
School-Identified	Research-Identified Math LD	Not Research-Identified Math LD	Total	Research-Identified Math LD	Not Research-Identified Math LD	Total
IEP for Math—Yes	253	263	516	0	0	0
IEP for Math—No	236	614	850	15	128	143
Total	489	877	1366	15	128	143

*Research-identified Math LD indicates 2 discrepancy formulas (RFM, DS) used to identify children with Math LD (n = 489 + 15 = 504).

†School-identified Math LD indicates school-assigned IEP for Math (n = 516).

‡ IEP indicates Individual Education Program; LD, learning disability; other abbreviations are defined in the first footnote to Table 1.

mation for population-based studies of LD.[20,33] The 2 studies of Math LD included only subjects enrolled in public schools, potentially introducing bias related to excluding students enrolled in private schools.[5,10] Our study, in contrast, included students enrolled in both public and private schools, as well as information from the students' medical records. In fact, we found that 49.8% of the 504 cases of Math LD (identified by either of the discrepancy formulas) were *not* identified at school. Similarly, 63.8% of the 287 cases of Math LD identified solely by the LA formula were *not* identified at school.

Our findings indicate that, regardless of how Math LD is defined, boys are more likely to be affected than girls. Male:female relative risks ranged from a low of 1.6 for the LA definition to 2.2 for the DS definition. Our findings are comparable to those of Badian,[13] who reported a M:F ratio of 2.5:1 in a prevalence study of Math LD in public school children from grades 1–8. However, Gros-Tsur et al[10] and Lewis et al[5] reported a gender ratio of 1:1 for children with Math LD in their prevalence studies of Math LD, but only among public school children at ages 11–12 and 9–11 respectively. These latter 2 studies are not directly comparable to ours, since they involved only children in public school, only at 2 ages and, most importantly, since they determined the prevalence of Math LD at specific ages and not the cumulative incidence of Math LD.

Our results indicate that, although the number of our Math LD incident cases includes a significant number of children who have comorbid Reading LD, a substantial percentage have Math LD alone. For the RFM, 56.7% of subjects with Math LD *did not* have an associated Reading LD. For the DS and the LA, the figures were lower (35.9% and 35% respectively). Twin studies of the genetics of Math and Reading LD have suggested some common genetic influences that may explain the frequent comorbidity of these LDs; however, these same studies have indicated that genetic influences on Math and Reading LD are not entirely the same.[32,34] The prevalence studies cited earlier all involved a low-achievement definition of Math LD and have reported widely varying rates of comorbidity for Math and Reading LD at different grade levels (17% to 56%).[5,10–13] Since our results represent the comorbidity of Math and Reading LD across the students' entire educational experience (ie, from grades K-12), we believe that we have presented a more comprehensive description of this association. Previously, we reported that the cumulative incidences of Reading LD in this birth cohort, on the basis of the RFM, DS, and LA definitions, were 5.3%, 8.9%, and 11.8% respectively, by age 19 years.[20] Clearly, children in this birth cohort were just as likely to have Math LD as they were to have Reading LD. Given the educational focus on reading achievement, it is critical for school staff to be aware that, regardless of how LD is defined, a significant number of children with Math LD do not exhibit associated reading problems. Case finding and intervention strategies that focus exclusively on reading achievement will therefore fail to identify and provide educational services for many children with Math LD.

Several potential limitations of this research should be noted. This is a retrospective study. A parent or professional (in the medical or school setting) had to suspect that a child had some learning or school problem and document that concern. However, a large number of birth cohort subjects underwent psychometric testing at some point during their school years, making it unlikely that cases of Math LD were missed. The cumulative incidence of Math LD by age 19 years, ranging from 5.9% to 13.8% across the 3 definitions also suggests that it is unlikely that we failed to detect large numbers of Math LD cases. The population of Rochester, Minn has been demonstrated to be representative of the US white population, which limits our ability to generalize our findings to populations that include larger numbers of children of other racial or ethnic backgrounds.[19–21] Finally, a substantial proportion of the original children in this birth cohort were excluded from the study because they did not remain in Rochester until age 5, the usual age of school enrollment. Nevertheless, our detailed comparison of the students ''In study'' and ''Not in study'' strongly indicates that the included children are representative of the entire birth cohort.[19] Among the 4908 children who were *not* research-identified Math LD cases, 74% were over age 17 at the time of data abstraction and 26% emigrated at a median age of 7.4 years, suggesting that there would be few additional potential Math LD cases among these 4908 subjects.

CONCLUSION

In this study, we demonstrated that Math LD occurs frequently and is more common in boys than in girls. LD definition has a major impact on the likelihood that a child will be identified with Math LD. Children with Math LD often do not have an associated Reading LD. In our technologically oriented society, proficiency in math is an important skill. The results of this study clearly highlight the need for further research related to identifying and providing appropriate assessment and intervention services for the many US children with Math LD.

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