Original Article

Incidence of Reading Disability in a Population-Based Birth Cohort, 1976-1982, Rochester, Minn

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- ***Objective*: To report the incidence of reading disability among school-aged children.**
- ***Subjects and Methods*: In this population-based, retrospective birth cohort study, subjects included all 5718 children born between 1976 and 1982 who remained in Rochester, Minn, after the age of 5 years. Based on records from all public and nonpublic schools, medical facilities, and private tutorial services and on results of all individually administered IQ and achievement tests, extensive medical, educational, and socioeconomic information were abstracted. Reading disability was established with use of research criteria based on 4 formulas (2 regression-based discrepancy, 1 non–regression-based discrepancy, and 1 low achievement).**
- ***Results*: Cumulative incidence rates of reading disability varied from 5.3% to 11.8% depending on the formula used. Boys were 2 to 3 times more likely to be affected than girls, regardless of the identification methods applied.**
- ***Conclusions*: In this population-based birth cohort, reading disability was common among school-aged children and significantly more frequent among boys than girls, regardless of definition.**

***Mayo Clin Proc*. 2001;76:1081-1092**

CI = confidence interval; DS = discrepancy [nonregression method]; IEP = Individual Education Program; ISD = Independent School District; LA = low-achievement [method]; LD = learning disability; RCDIM = Reading Center/Dyslexia Institute of Minnesota; RD = reading disability; RFM = regression formula–Minnesota; RFSh = regression formula–Shaywitz; RR = relative risk

Learning disabilities (LDs) can occur in the areas of basic reading skills, reading comprehension, written expression, mathematical calculation or reasoning, and listening and speaking. They have long been recognized for their educational, medical, and social importance.[1] Children with LDs are at risk, in our increasingly complex society, for long-term adverse personal and economic consequences.[2] However, the majority—approximately 80%—of children identified as having LDs have their primary academic problem in reading.[1-3]

The World Federation of Neurology defines reading disability (RD) as a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and sociocultural opportunity.[4] Despite the facts that RD has been the most frequently studied LD and that advances in neurology, genetics, psychology, and linguistics have been achieved, the origins of RD remain unsolved.[5-9] Furthermore, there have been no contemporary epidemiologic studies of the incidence of RD in the United States. However, prevalence rates of RD in the United States (eg, Connecticut Longitudinal Study) and Europe have been reported.[10-12]

For editorial comment, see page 1075.

Incidence, a measure of singular importance in epidemiology, is primarily used to estimate the risk individuals have of acquiring a particular condition. It is, therefore, useful for studying the relationship between etiologic factors and the development of specific medical conditions.[13] A birth cohort, consisting of all subjects born to mothers from a specific geographic community, provides the opportunity to study the natural selection of these subjects into different categories of risk for the specified condition. The use of a birth cohort minimizes many of the biases that can be encountered in studies based on prevalence cases (eg, net migration of children with LD into or out of the community).[14]

This report describes findings from an ongoing epidemiologic study of LD among all children born from 1976 through 1982 in Rochester, Minn. The study has 2 purposes: (1) to report the incidence rates for RD (cumulative and incidence density) overall and among boys and girls separately, from the ages of 5 to 19 years, with or without

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This project was supported by research grants HD29745 and AR30582 from the National Institutes of Health.

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comorbid conditions; and (2) to provide a detailed description of the methods and procedures used to identify all incidence cases of RD in this well-defined, population-based birth cohort.

SUBJECTS AND METHODS

Study Setting

The city of Rochester, Minn, is approximately 90 miles southeast of Minneapolis-St Paul. The 1990 population totaled 70,745 residents who were 96% white and fairly young (72% ≤45 years old). Eighty-two percent of adults graduated from high school, and the population is primarily middle class. The work force is predominantly employed in the health care, computer, and related service industries. With the exception of the place of employment, the characteristics of the Rochester population are similar to those of the US white population.[15]

The capacity for population-based epidemiologic research on LD in Rochester is the result of a unique set of circumstances. First, Rochester is relatively isolated in southeastern Minnesota, and as a result, virtually all medical care received by the residents of Rochester is provided locally by Mayo Clinic and Olmsted Medical Center and their 3 affiliated hospitals. Through the Rochester Epidemiology Project,[16] all diagnoses and surgical procedures recorded at the Rochester medical facilities are indexed for automated retrieval. This diagnostic index expedites retrieval of the unit (or dossier) medical record, which includes the history of all encounters in the hospital, community and ambulatory medical and social services, emergency department, outpatient clinics, and home visits as well as laboratory and psychological test results from birth until patients no longer reside in the community. Second, the evaluation and instructional resources of Independent School District (ISD) No. 535, the school system for the city of Rochester, are of high quality, and the district has a long tradition of excellent care and management of children with all types of handicapping conditions, including LD. Through a contractural research agreement, all public (19 primary, 3 junior high, 3 high schools) and nonpublic (12 primary, 10 junior high, 4 high schools) schools gave us permission to access their richly documented cumulative educational records for every child from our birth cohort. Third, under a second research agreement we also obtained permission to access the resources of the privately owned Reading Center/Dyslexia Institute of Minnesota (RCDIM). Their files included a pool of some 3000 evaluations and outcomes of tutorial instruction that spanned nearly 50 years.

1976-1982 Birth Cohort

Using Minnesota birth records, we first identified every child born between January 1, 1976, and December 31, 1982, to mothers who at the time of delivery were residents of any of the 5 townships within Olmsted County that constitute ISD No. 535. The birth cohort thus included 8548 children. Next, the current vital status for each subject (still living in Rochester, moved, or deceased) during the 1995-1996 school year was ascertained. To achieve this goal, all available resources from the Rochester Epidemiology Project, ISD No. 535, RCDIM, and Minnesota Department of Health Division of Vital Statistics were used. Detailed descriptions of these procedures have been reported earlier.[17]

The target population for the epidemiologic study of RD was the group of 5718 birth cohort children (2956 boys, 2762 girls) who at or after the age of 5 years still lived in Rochester, had moved, or had died. This 5-year cutoff was used because a child is unlikely to be diagnosed as having RD until entry into the school system. Birth cohort children who had moved (1412 boys, 1341 girls) or were known to be dead (44 boys, 33 girls) before the age of 5 years were excluded from the study. Analysis showed few differences between those who were excluded vs those who remained in the community.[17]

Identification of Potential LD Candidates

The starting point in accumulating all the information needed for identification of potential RD incidence cases (medical, school, and tutoring sources) was a review of the cumulative public and private school records for the 5718 study children in the birth cohort (Figure 1). More specifically, all children whose record suggested any type of difficulty in learning or performance were identified and classified as potential LD candidates (1961 with and 3747 without learning/performance concerns). However, to ensure reliable classification as a research-identified LD incidence case, complete information from 2 other independent sources (medical records and RCDIM files) was also used. The procedures for research identification of RD incidence cases are described below, and Figure 1 presents the order in which data were collected and emphasizes that we did not rely on school identification of RD.

Phase 1.—Typically, every child's learning and performance are observed by parents, teachers, physicians, and others. Therefore, every school record for each child in the birth cohort was thoroughly reviewed, page by page. This involved visiting all public and private schools and their administrative offices (school records of students who moved from the school district, were home schooled, were deceased, or had graduated are kept there). If the school record contained any evidence related to any type of difficulty in learning, performance, or any other potentially handicapping condition, the child was designated as "Learning/performance concern—yes" (Figure 1). This

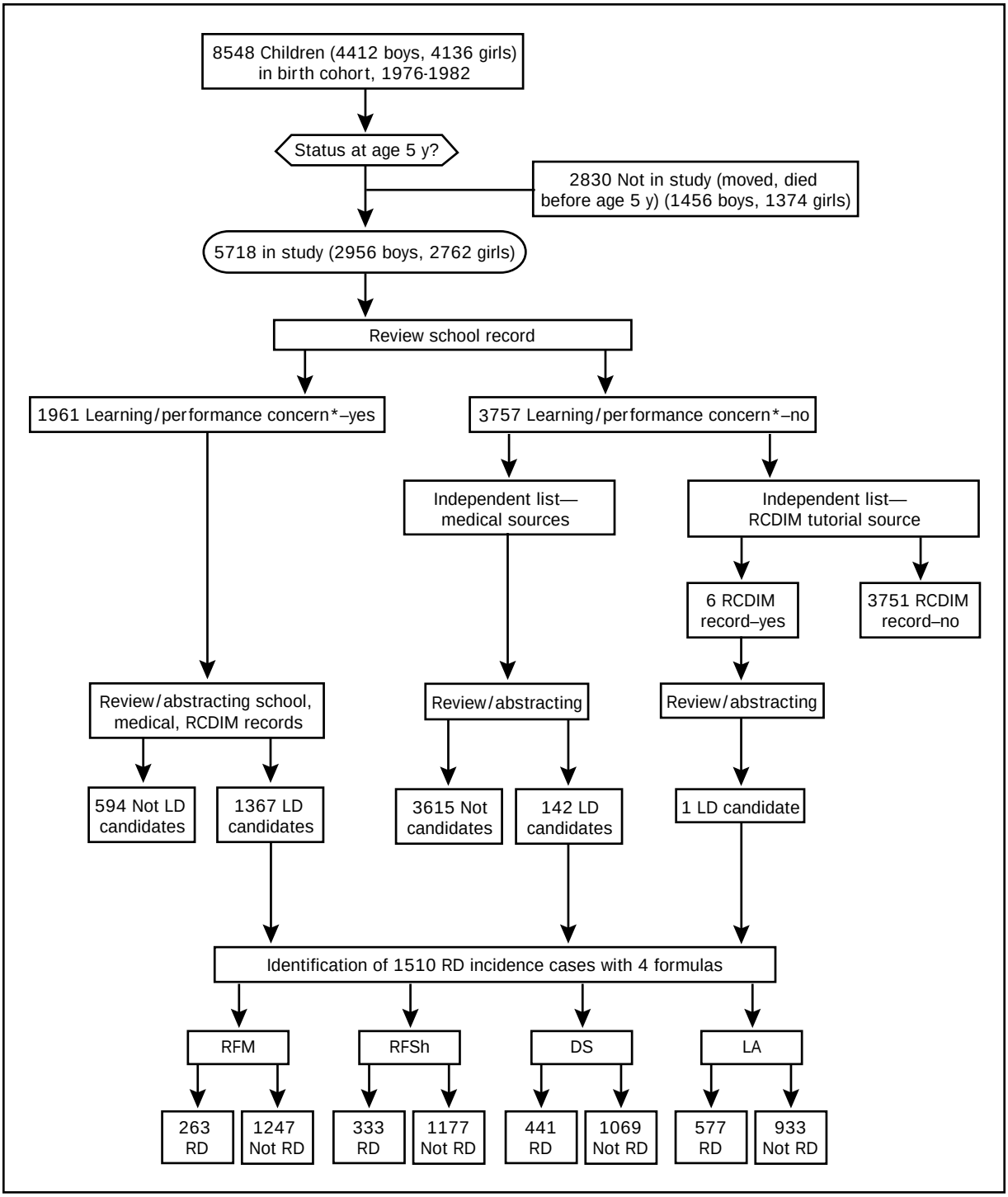

Figure 1. Flow diagram describing identification of children with reading disability (RD) among a Rochester, Minn, birth cohort, 1976-1982. *Evidence of learning/performance concerns consisted of Individual Education Program (IEP) reports, reports of IEP review, individual assessment/reassessment report 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. DS = discrepancy nonregression method; LA = low-achievement method; LD = learning disability; RCDIM = Reading Center/Dyslexia Institute of Minnesota; RFM = regression formula–Minnesota; RFSh = regression formula–Shaywitz.

group included 1961 children, 34% of the birth cohort. Evidence included Individual Education Program (IEP) reports, reports of periodic IEP review, Individual Educational Assessment/Reassessment Report forms, referral forms, medical reports or medication records, private tutoring or private evaluation reports, individual or group-administered ability or achievement tests, or any notations from teacher, parent, or other person related to any type of difficulty in learning or performance. Medical records as well as RCDIM files on this group of 1961 children were also reviewed for similar pieces of information. Seventeen children with severe mental retardation (IQ ≤50) were excluded from further consideration.

If individually administered cognitive and achievement tests and/or an IEP for reading, mathematics, or written language were present, those records were abstracted and children were designated as "LD candidates." This group included 1367 children, 26% of the birth cohort.

Phase 2.—Further work was done on the remaining 3757 children who were not suspected of having any problems in learning or performance. This group was categorized as "Learning/performance concerns—no" (Figure 1). This work consisted of 2 steps.

1. These children were cross-matched ("Independent list—medical sources") against the computerized diagnostic index of all who had a diagnosis of LD, RD, or similar terms from a broad list of diagnoses used by physicians at that time (eg, dyslexia, developmental agnosia, developmental agraphia, comprehension disorder, writing problem) at local medical facilities. Children who were coded for "psychometric testing" were also included. The interdisciplinary assessments in the medical system were completed by a pediatrician, psychologist, and/or psychiatrist who specialized in the identification of LDs and behavioral problems.

2. These children were also cross-matched with the RCDIM file to determine if they had ever received private tutorial services ("Independent list—RCDIM tutorial source").

These 2 independent sources yielded an additional 143 "LD candidate" children who did not have any evidence of problems with learning or performance in the school records. However, they had individually administered ability and achievement tests at medical and/or RCDIM facilities only.

Phase 3.—For all 1510 LD candidate study subjects, detailed information about the following areas, from the 3 independent sources, were abstracted and entered into the database: cognitive ability, academic achievement, attention-deficit/hyperactivity disorder, visual and hearing problems, major psychiatric disorders, mental retardation, motor impairment, frequency of school moves, school absenteeism, family alcohol and other drug abuse, family abuse and neglect, family socioeconomic status, and other family data. However, in this report we present incidence rates for RD regardless of the presence or absence of any comorbid conditions, in order to represent the identification, diagnostic, and instructional issues faced daily by professional staff.

All scores from individually administered IQ and achievement tests among the 1510 LD candidates were recorded. For each child within each calendar year, all IQ and achievement test scores were used to form pairs of concurrent ability and performance measures. Within each child's data, all pairs of IQ-achievement measures were put in chronological order.

Identification of RD Incidence Cases

Four formulas (described below) were then applied, and the child was designated as an RD incidence case or not, based on the magnitude of severity in learning to read that was present (ie, the discrepancy between expected and observed reading performance). The earliest date among the IQ-achievement pairs (designated as the "critical pair") that yielded the obligatory discrepancy represented for research purposes the date of RD diagnosis and classification as an RD incidence case. Those critical pairs of IQ and achievement reading scores were also used to calculate mean IQ and achievement scores among all RD incidence cases.

Four ability-achievement discrepancy methods were applied to each subject classified as an LD candidate. Of these, two were regression-based formulas, and the third was a straightforward numerical discrepancy between standard scores for intelligence and achievement and was not regression based. The fourth method simply identified children who were believed to have satisfactory learning ability but whose reading standard scores were at or below the 25th percentile for grade placement ("low achievers").

In each of the following formulas, X is equal to the study subject's IQ score, and Y represents the predicted standard score from the reading achievement test:

1. Regression formula–Minnesota (RFM), $Y<17.40+0.62X$, issued by the Minnesota Department of Education[18]: Children classified as having RD by this formula had standard scores in reading achievement that were more than 1.75 SD below their predicted standard score from an individually administered measure of cognitive ability (IQ). The value 0.62 represents the correlation between IQ and achievement used in the formula from the state of Minnesota.

2. Regression formula–Shaywitz (RFSh), $Y<23.67+0.58X$, developed by the authors[19] from their own sample of children: This regression-based formula is derived from the discrepancy between the observed Woodcock-Johnson

reading decoding score vs that predicted from the regression of Woodcock-Johnson on Full Scale IQ; a discrepancy greater than 1.5 SD (achievement lower) was used to classify a subject as having RD. This regression-based method was used because Woodcock-Johnson and IQ measures were correlated 0.58 in their sample. Using the values reported in Fletcher et al[19] (mean of 100 and SD of 15 for Woodcock-Johnson and IQ, with a correlation of 0.58 between these 2 measurements), our subjects were classified as having RD when their observed Woodcock-Johnson reading achievement level was <23.67+0.58(IQ).

3. Discrepancy (DS)–nonregression method: This method was used in ISD No. 535 before 1989 and included the school years of the children in our birth cohort. By using this approach, differences between standard scores on measures of intelligence and aptitude and measures of reading achievement that were believed to be important varied by grade as follows: (1) kindergarten-3rd grade, 15 or more standard score points difference, with achievement lower; (2) 4th-6th grade, 19 or more points difference, achievement lower; and (3) 7th-12th grade, 23 or more points difference.

4. Low-achievement (LA) method: $X \geq 80$ (aptitude) and $Y \leq 90$ (achievement) represents a controversial but recurring issue in identifying RD.[19-21]

In addition, children who had an IEP issued for reading were designated as "school-identified RD," while those identified as having RD by 1 or more of our 4 approaches were classified as "research-identified RD."[12]

Statistical Analysis

To estimate the probability that an individual will fulfill our research criteria for RD between 5 and 19 years of age, cumulative incidence rates were calculated according to the method of Kaplan and Meier.[22] Children in the birth cohort were censored on the initial occurrence of emigration, death, last follow-up date, or the age of 19 years. Cumulative incidence rates were estimated overall for boys and girls separately and by each of the 4 formulas described earlier. Ninety-five percent confidence intervals (CIs) on cumulative incidence were based on the Greenwood formula.[23]

For age- and sex-specific incidence density, the number of new RD cases diagnosed during specified periods of time was divided by the total "person-time" of observation. The relative risk (RR) of boys to girls was then calculated by the ratio of these incidence density rates. The 95% CIs were constructed about the point estimates of incidence and incidence ratios (RRs) with assumption of a Poisson error distribution. Differences in RRs were tested by use of Poisson regression models.

Group comparisons were made with use of the Pearson χ^2 test (for nominal factors) or the Wilcoxon rank sum test (for ordinal or continuous factors) as appropriate. All tests were 2-tailed, and P values less than .05 were considered statistically significant. The strength of the association between sex and type of schooling was summarized by an odds ratio.

RESULTS

Incidence

Cumulative incidence rates, for boys and girls combined, with or without comorbid conditions, by age 19 years vary according to the RD method applied. Results are as follows (Figure 2): 5.3% (95% CI, 4.7%-5.9%) by the RFM; 6.7% (95% CI, 6.0%-7.4%) by the RFSh; 8.9% (95% CI, 8.1%-9.6%) by the DS method; and 11.8% (95% CI, 10.9%-12.7%) by the LA method. Cumulative incidence rates for boys and girls are given in Figure 3.

Age- and sex-specific incidence rates for each of the 4 methods are given in Figure 4. Boys consistently had higher incidence rates than girls. Sex-specific RD incidence rates per 1000 person-years of observation (Table 1) varied from 6.33% for boys with RD (95% CI, 5.45%-7.21%) and 2.13% for girls with RD (95% CI, 1.61%-2.65%) identified by RFM to 12.96% for boys (95% CI, 11.67%-14.26%) and 6.56% for girls (95% CI, 5.63%-7.50%) by the LA method. This led to differences in estimates of RRs among methods. When the RFM was implemented, the male/female RR was 2.98 (95% CI, 2.26-3.97), while with use of the LA method, the male/female RR was 1.98 (95% CI, 1.66-2.35); boys were consistently at greater risk for RD than girls. The mean age of RD diagnosis was 8.8 years and, depending on the research method applied, was not significantly different between boys and girls (P=.60 by RFM; .80 by RFSh; .52 by DS; .99 by LA).

The mean number of IQ measures among all RD incidence cases was 3.6 by RFM, 3.6 by RFSh, 3.2 by DS, or 3.3 by LA, and achievement tests were administered, respectively by method, 4.1, 4.1, 3.9, or 3.9 times from the ages 5 to 19 years, accumulated from 3 independent sources. The number of IQ and achievement tests for boys and girls diagnosed as having RD within each formula was not significantly different. Approximately 89% of the RD children (91%, 90%, 91%, and 87%, respectively, depending on method used) had been administered an age-appropriate Wechsler scale for ability assessment. For reading achievement, 80% of the RD cases had been administered a Woodcock-Johnson test (74%-82%, depending on method), while 16% of the RD children had Wide Range Achievement Test scores.

When the IQ scores within the critical pair of IQ-achievement tests (ie, those used to designate the child as having RD) were analyzed, results showed that the full IQ score was significantly higher for boys than girls, regard-

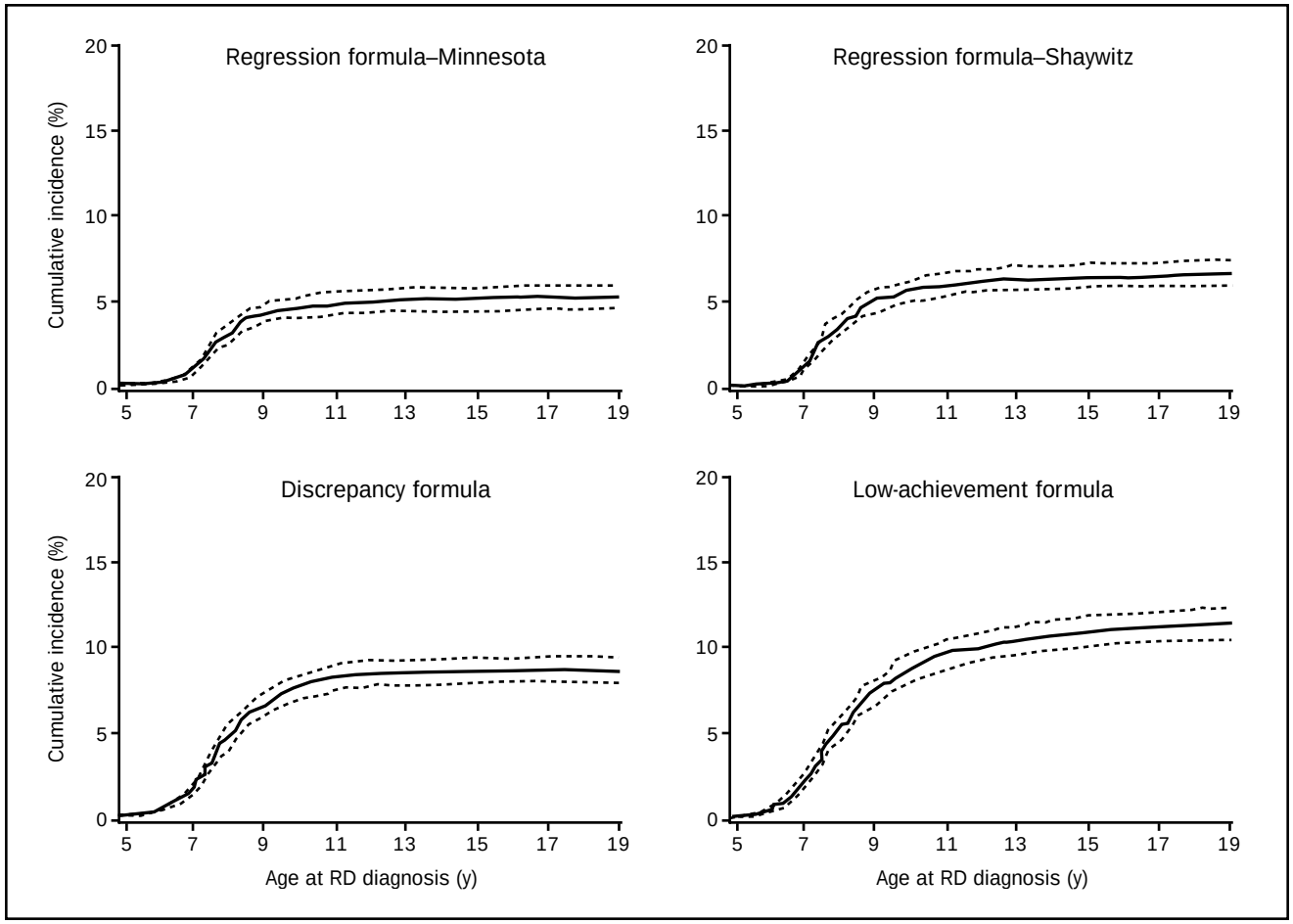

Figure 2. Cumulative incidence rates of reading disability (RD), for boys and girls combined, identified by each formula among a Rochester, Minn, birth cohort, 1976-1982, by age. Lines represent cumulative incidence rates with associated 95% confidence intervals.

less of the RD method used. For example, when the RFM was used, the mean IQ score for girls was 100.1, and for boys it was 107.2 ($P<.001$). When the LA method was used, the mean IQ score for girls was 97.3, and it was 100.4 for boys ($P<.001$).

Overlap Among RD Children Identified By Different Classification Methods

Among the 5718 children in the birth cohort (after exclusion of 17 children with severe mental retardation), 689 RD children (unique cases) were identified by the 4 methods. However, some study subjects were identified as having RD by more than 1 method. The frequency and overlap of RD children identified by the 4 methods are given in Table 2.

Using only the 3 methods based on the discrepancy concept, we found 467 (134 + 70 + 263) unique cases of research-identified RD (RFM, RFSh, DS) (Table 2). Of these 467, 462 (99%) were identified among the children suspected of having problems in learning and performance (Table 3). An additional 5 RD cases (1%) were found among the children not suspected of having any problems in learning and performance. Furthermore, among the 462 unique RD cases, 150 (32%) were in children identified only by research criteria (ie, they did not have an IEP for reading); 312 (68%) were identified by both research and school criteria. Among the 312 RD children identified both through the school and by our research criteria, 73.1% were boys. In the group of 150 RD children identified solely by research criteria, 73.3% were boys. There is no significant difference in male preponderance between these 2 groups ($P=.95$).

Among the children who were reported to have some types of problems with learning or performance, 305 had school-identified RD. These 305 children were identified only by school criteria (ie, received an IEP in reading) and did not meet any of the discrepancy-based research criteria (Table 3). Our attention was also drawn to a larger group of 600 children who had some type of learning and perfor-

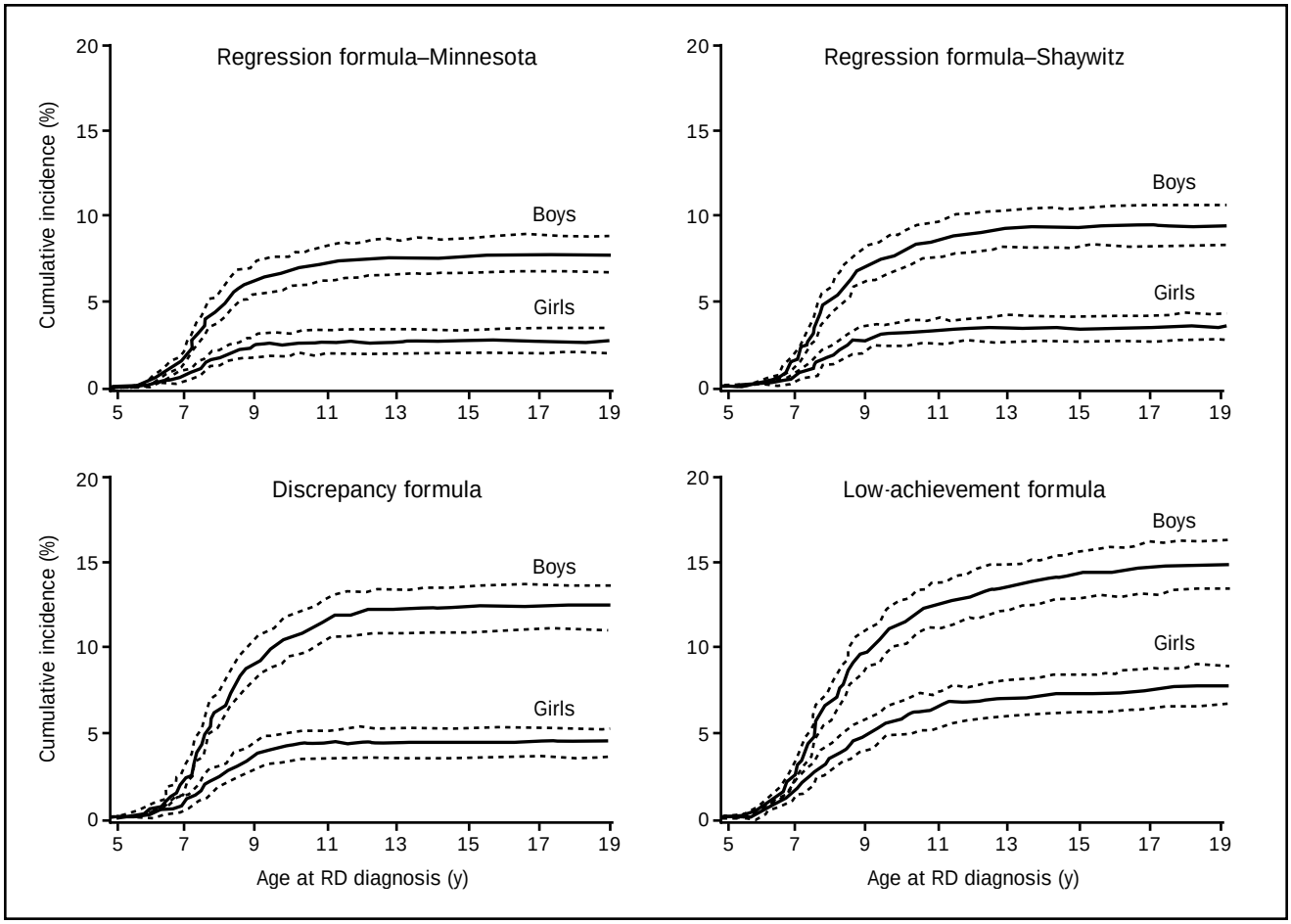

Figure 3. Cumulative incidence rates of reading disability (RD), identified by each formula among a Rochester, Minn, birth cohort, 1976-1982, by age and sex. Lines represent cumulative incidence rates with associated 95% confidence intervals.

mance problems and were tested but not identified as having RD by the school (ie, did not receive an IEP in reading), nor did they meet our research criteria for RD. These 2 groups of children (305 + 600) probably represent the expected variability in the normal distribution of reading ability that has been hypothesized.[24]

Site of Assessment and Sources of Data Used

The site of RD assessment (school, medical facility, private tutoring center) was also analyzed among the 467 unique cases of RD identified by the 3 discrepancy methods. Of them, 278 RD children (60%) had their RD assessment at school only, and 161 RD children (34%) also had medical facility and other private evaluations in addition to their school-based assessment. Finally, 28 RD children (6%) had none of the IQ or achievement tests done at school. All RD evaluations were completed by various combinations of classroom teachers, LD teachers or tutors, psychologists, and social workers.

Public vs Private School

We also examined the association between sex and type of schooling among the RD children. For example, among the 263 RD children identified by the RFM, 223 (85%) attended only public school, 31 (12%) were enrolled at various times in both public and private schools, and 9 (3%) consistently attended private school. Eighty percent of the RD children enrolled at some point in a private school were boys, compared with 75% of RD children enrolled only in public schools (P=.49; odds ratio, 1.34). Furthermore, the degree of association was similar regardless of method used to identify RD.

Comparisons Between RFSh and LA Method

Shaywitz[6] has commented that some children who have difficulty learning to read will be overlooked if LA methods are used. For example, when we applied the RFSh formula to our LD candidates, 333 RD children were identified (Table 2). Of these, 300 (90%) were also identified as

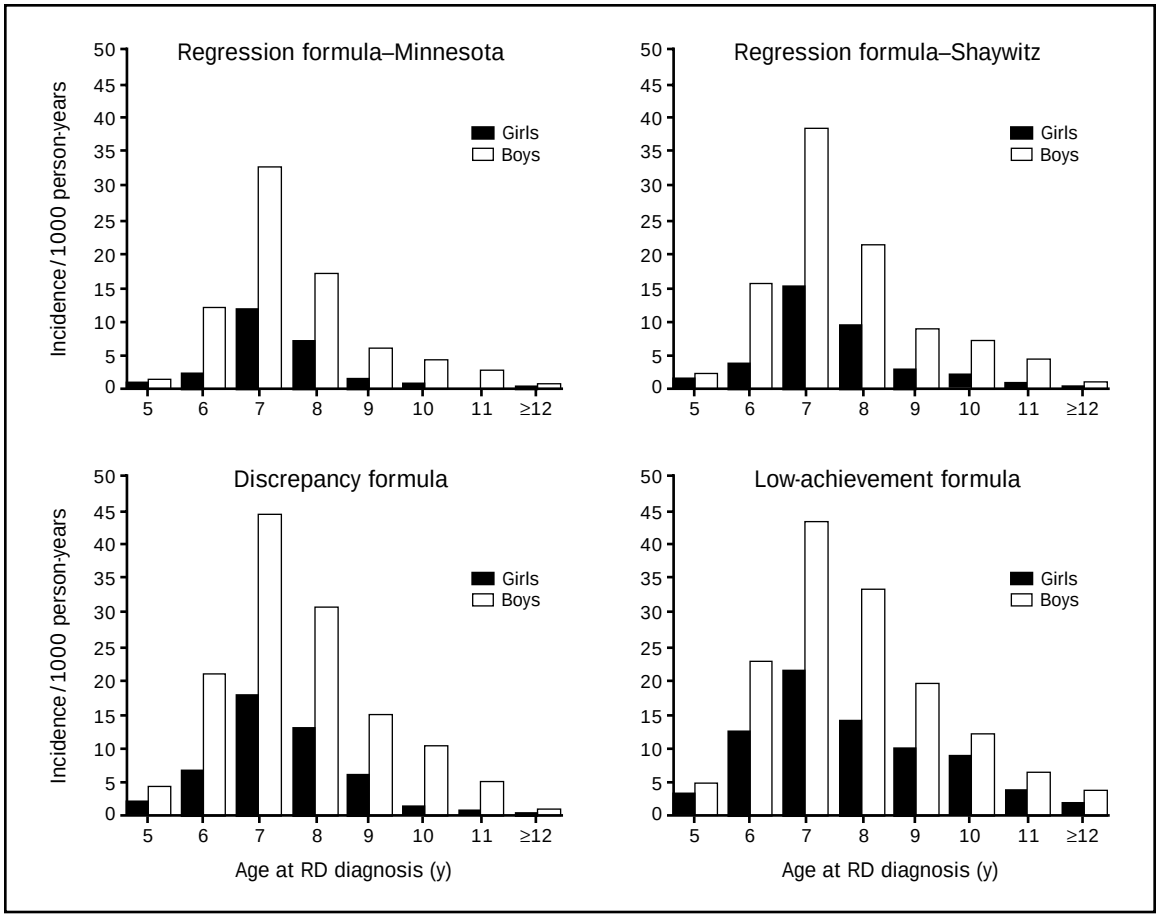

Figure 4. Age- and sex-specific incidence rates of reading disability (RD) identified by 4 formulas among a Rochester, Minn, birth cohort, 1976-1982.

having RD by our LA criteria (Table 2, LA column, 16 + 45 + 3 + 236). However, the remaining 33 RD children (10%) would not have been identified if the LA method was used alone. Further, we compared the IQ scores between the 300 RD children identified by the RFSh and by our LA criteria (mean full IQ score = 103) and the 33 RD children who were not identified by our LA method (mean full IQ score = 112). These IQ scores are significantly different ($P<.001$).

An additional 222 RD children were identified by the LA method only. The mean IQ score of 95 among these 222 RD children was significantly lower ($P<.001$) compared with the mean IQ score of 104 among the 333 RD subjects identified by RFSh.

DISCUSSION

The cumulative incidence data, based on the population-based Rochester birth cohort, suggest that RD is relatively common among school-aged children. Between 5.3% and 11.8% of children were identified as having RD by 19 years of age (depending on classification method used). Also, boys were at 2 to 3 times the risk of having RD as girls, regardless of the identification method applied. These findings differ from those of Shaywitz et al[12] who have suggested that the risk for RD is not substantially different between boys and girls. However, it is unlikely, with use of 3 independent sources to search for every RD child in our birth cohort, that any boy or girl with RD was overlooked. A sensitivity analysis strongly suggests that our male/female RR ratios were not attributable to unidentified RD cases. Nevertheless, we can still ask what number of girls would need to have been overlooked in our birth cohort of 5718 if in fact the incidence rate of RD is equal between boys and girls. By applying our observed incidence rate among boys (6.33/1000 person-years using the RFM method) to the total number person-years among girls (30,089.33 person-years), we would predict 190 cases among girls, if the risk of RD were equal in boys and girls. Since we identified 64 RD cases among girls, this implies that we overlooked 126 girls with RD (66%), an unlikely possibility given our methods for complete ascertainment.

Table 1. **Incidence of Reading Disability Per 1000 Person-Years Identified by 4 Formulas in a Rochester, Minn, Birth Cohort, 1976-1982 (N=5718)***

	RD formulas							
	RFM		RFSh		DS		LA	
Variables	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
No. of RDs	199	64	246	87	329	112	387	190
Incidence/1000 person-years (%)†	6.33	2.13	7.93	2.92	10.85	3.81	12.96	6.56
95% CI	5.45-7.21	1.61-2.65	6.94-8.92	2.30-3.53	9.68-12.02	3.10-4.51	11.67-14.26	5.63-7.50
RR (M/F)†	2.98		2.72		2.85		1.98	
95% CI	2.26-3.97		2.14-3.48		2.31-3.54		1.66-2.35	

*CI = confidence interval; DS = discrepancy; LA = low-achievement; M/F = male/female; RD = reading disability; RFM = regression formula–Minnesota; RFSh = regression formula–Shaywitz; RR = relative risk.
†Directly adjusted to age distribution of the entire birth cohort.

Furthermore, girls were not overlooked by school staff. For example, among 203 girls who received the IEP for reading (tutorial service provided by school), 119 (59%) did not meet our research criteria for RD (Table 3). Also, girls were not hidden among the 143 children evaluated through the medical system (Table 3; 72 girls vs 71 boys), which also supports our efforts at complete ascertainment.

Our study is unique insofar as data related to incidence of RD are few. The incidence studies of RD reported to date have methodological shortcomings. The British National Child Development Study[25] is not, strictly speaking, an incidence study because the investigators did not adhere to strict birth cohort and RD criteria. About 10% of their subjects "had barely made a start with reading" at the age of 7 years; girls were "better readers than boys." A birth cohort study from Hawaii reported that 9.5% (13% boys and 6% girls) had "school achievement problems"[26]; later, 3% had "serious reading problems."[27]

Despite the close relationship between incidence and prevalence, each measure provides a different type of information with different utility.[28] Prevalence rates are used primarily as a measure of the burden of the condition (in this case RD) on the community and are less desirable for etiologic studies.[28] In the absence of reliable incidence RD studies, we can tentatively, with caution and with certain important assumptions in mind (for example, the degree to which demographic and personal characteristics in the incidence and prevalence cases are congruent), compare incidence rates achieved from our population-based birth cohort with prevalence studies done on other community samples. Lovell et al[29] tested all 1205 third-year students in 22 junior high schools and found 8.4% of boys and 3.8% of girls to be "backward readers." Berger et al[10] concluded that, in a sample from an urban London, England, school, dyslexia occurred in about 14.4% of boys and 5.1% of girls, whereas in their Isle of Wight sample, prevalence rates were 5.6% for boys and 2.1% for girls. A large, prospective study by Flannery et al[11] in which 32,223 children were individually tested found that boys were about 1.9 to 2.4 times more likely to have RD than were girls, results very similar to ours.

Shaywitz et al[12] used a stratified random selection procedure to identify a sample of 414 kindergartners in the Connecticut public school system. Subjects were followed and individually tested at third grade. Using explicit criteria, Shaywitz et al identified RD in 18 (9%) of the boys and 13 (6%) of the girls in their sample. Although they reported no significant difference in prevalence between boys and girls, their observed RR of 1.5 (95% CI, 0.75-2.97) still suggested some increased risk for boys. All our estimated RRs, ranging from 1.98 to 2.98 (depending on method of classification), fall within their CI, suggesting that the find-

Table 2. **Number of Children With Reading Disability Identified by 1 Formula or by Any Combination of 4 Formulas in a Rochester, Minn, Birth Cohort, 1976-1982***

Formula for RD identification				Overlap	
RFM	RFSh	DS	LA	No. of RD children	No. of RD children
			X	222	222
		X		79	134
		X	X	55	
	X			1	70
	X		X	16	
	X	X		8	
	X	X	X	45	
X	X			6	263
X	X		X	3	
X	X	X		18	
X	X	X	X	236	
263	333	441	577	689	689

*Abbreviations are defined in the first footnote to Table 1. Pattern of Xs within a row represents the combination of research formulas identifying children as having RD.

Table 3. **Research-Identified* vs School-Identified† Children With Reading Disability in a Rochester, Minn, Birth Cohort, 1976-1982‡**

	LD candidates					
	With learning/performance concern (n=1367)§			Without learning/performance concern (n=143)//		
School identified†	Research-identified RD*	Not research-identified RD	Total	Research-identified RD*	Not research-identified RD	Total
IEP for reading–yes						
Girls	84	119	203	0	0	0
Boys	228	186	414	0	0	0
Total	312	305	617	0	0	0
IEP for reading–no						
Girls	40	262	302	1	71	72
Boys	110	338	448	4	67	71
Total	150	600	750	5	138	143
Total						
Girls	124	381	505	1	71	72
Boys	338	524	862	4	67	73
Total	462	905	1367	5	138	143

*Research-identified RD = 3 discrepancy formulas (RFM, RFSh, DS) used to identify RD children (n=462 + 5 = 467).
†School-identified RD = school assigned IEP for reading (n=617).
‡IEP = Individual Education Program; LD = learning disability; other abbreviations are defined in the first footnote to Table 1.
§RD candidates = children who had individually administered IQ and achievement tests and/or IEP for RD and who are from "Learning/performance concern–yes" group.
//RD candidates = children who had individually administered IQ and achievement tests and who are from the "Learning/performance concern–no" group.

ings from our study and theirs may not be as discrepant as they initially appear. Rather, it is possible that the "true" RR is closer to 2.5, but the sample used by Shaywitz et al[12] was not large enough to detect this level of risk. For example, they observed a prevalence of RD of 6% for girls vs 9% for boys, with a total sample size of 414 subjects. Their sample size provided only a 21% chance of declaring the observed difference statistically significant. To have 80% power to detect an RR of 2.5 (eg, a difference of 4% vs 10%), a total sample size of 540 subjects would have been needed. Our cumulative incidence rate (by the RFSh method) of 6.4% (95% CI, 5.7%-7.0%) by the age of 12 years was similar to the prevalence of research-identified RD in the third-grade sample presented by Shaywitz et al[12] (7.5% [95% CI, 5.0%-10.0%]), suggesting that we did not fail to identify substantial numbers of RD cases. Subsequently, Shaywitz et al[30] have also concluded that "[r]eading disability … affects boys and girls equally." This interpretation appears unwarranted and goes beyond their data presented on 18 RD boys and 13 RD girls identified among 414 third-grade public school students in Connecticut.[12]

There is a longstanding controversy about whether a genuine difference exists in the likelihood of RD between sexes or whether affected boys are simply more likely to be referred because of their behavior. Shaywitz et al[12] have cautioned against relying solely on school identification of RD. In their research-identified sample of RD subjects (contrary to their school-identified sample), girls and boys were diagnosed equally as having RD. In our birth cohort, though, no matter who identified the RD children and regardless of the criteria applied, boys were significantly more likely to be identified as having RD. Furthermore, no matter whether the RD child was enrolled in a public or a private school, more than three quarters of the RD children were boys.

Shaywitz et al[7] have also shown, using the functional magnetic resonance imaging technique, evidence for sex differences in brain organization and in the locus of phonological representation. The 19 boys in that study tended to engage the left inferior frontal gyrus during reading, whereas the 19 girls activated both left and right inferior frontal gyrus. Shaywitz stated, because of women's bilateral representation for phonological processing, "women tend more often than men to compensate for dyslexia."[31] Thus, girls and women may compensate for a deficit in reading more easily than boys and men. This trait may explain why more boys than girls were identified as having RD in our population-based birth cohort. Further, girls with RD in our sample had a significantly lower mean IQ score than boys with RD. This finding may help to explain why some girls cannot compensate well enough for their reading problems and subsequently demonstrate RD. However, the mean IQ scores for both sexes were in the average range.

For any study results to be applicable elsewhere or for replication and interpretation to be possible, a detailed description of study methods is essential. To this end, the Research Committee for the Council for Learning Disabilities proposed minimum standards for LD research.[32] They recommended that the following basic criteria should be gathered to describe the sample: sex, age, grade, time in special education, type of special education, race, socioeconomic status, and specific IQ and achievement test results.[33-35] Morris et al[35] added to this list "peak criteria," namely, specific scores, exclusionary criteria, and details about who evaluated the child. We have followed these proposed peak criteria and Council for Learning Disabilities research guidelines.

Shaywitz[6] has stated that every child presenting with learning problems, even if reading difficulties are not explicitly reported, should be considered for an RD evaluation. We identified 1961 children (34%) from our population-based birth cohort of 5718 who experienced possible, even remotely related problems with learning or performance that were reported at medical institutions, schools, or tutorial facilities. Further, we accumulated an average of 2 individually administered IQ and 3 individually administered achievement tests on 1510 children (26%) in our birth cohort. Boys and girls had equal numbers of both types of tests.

Our case finding goes beyond a school-defined sample of RD students. Among our RD subjects, 35% had a combination of evaluations at medical, school, or other private sites, and 6% of the RD subjects had none of their evaluations performed at school; 5 RD subjects were identified by our research criteria through medical and private facilities only. A total of 305 children identified only by school as having RD were provided with IEPs for reading; 150 RD children identified only by our research criteria did not. Finally, we used 4 different methods to identify RD children, from restrictive (RFM) to very broad (LA).

Currently there are no universally accepted tests, assessment batteries, or standards for identifying children with LD.[1] The concept of aptitude-achievement discrepancy was introduced in 1964 by Bateman,[36] adapted and extended by the US Congress and US Office of Education,[37,38] and, while it is increasingly controversial, exists in most definitions of LDs[39]; 94% of states include the aptitude-achievement discrepancy in their criteria.[40]

Cognitive, genetic, and neurologic characteristics are similar between discrepant poor readers (ie, those with a significant discrepancy between learning ability and academic progress) and nondiscrepant poor readers (those now often called "low achievers").[19,21,41] It is still unclear whether the sole use of a low achievement definition reliably identifies children with RD.[42] Shaywitz[6] has stated that school-aged children may in the future be diagnosed as having RD if they meet either discrepancy criteria relative to IQ or low achievement criteria relative to chronologic age. Our preliminary results suggest that 10% of our RD subjects would not be identified as having RD if only the LA formula were used. Those 10% with RD had a mean IQ score of 112, markedly higher than the IQ score of 103 in RD children identified by both RFSh and LA criteria. Shaywitz[6] found that 25% of RD children who were extremely bright met discrepancy criteria only and would have been excluded from special education services if the low achievement criterion was the only one employed. In our sample, 222 additional RD children were identified by the LA method, beyond the 333 children determined to have RD by RFSh. The mean IQ score of 95 in those 222 RD children (low achievers) was considerably lower than the mean IQ of 104 among the 333 RD students. However, psychometrically, both of these mean scores would be termed middle-average in nature.

We have operationalized the diagnosis of RD with 4 identification methods. These are surrogates for comprehensive evaluation procedures and do not address contemporary diagnostic issues such as assessment of phonological processing deficits.[8,19] Instead, we have applied the most widely used approaches to determine eligibility for RD intervention. However, criteria for defining RD should be modified as new and convincing data from well-designed studies become available.[42]

While our results are of interest, several potential limitations should be considered in the interpretation of these data. First, although this study was population based, there was considerable emigration (43%) of the original 1976-1982 birth cohort of 8548. Potential bias issues have been addressed,[17] and we found only slight differences existed between the sample of children who remained in Rochester and those who did not. When all birth certificate characteristics (child and parents) were considered in a multivariate logistic regression model, the parents of migrants (ie, those who left the community) were somewhat more educated, mothers of migrants were slightly younger and had fewer prenatal visits, and migrant children were more likely to be nonwhite. These features, in the context of the large number of children from the birth cohort who remained in the community (5718), are unlikely to compromise our incidence rates, or alter our other findings. A second potential limitation is imposed by the possibility for underascertainment. Since no screening measures were performed on each child in this retrospective study of 5718, it is possible that some RD children remain unidentified. However, it should be emphasized that 3 independent, complementary sources of data (school, medical, private resources) were used for the identification of incidence cases of RD. Fi-

nally, generalization of these incidence rates should be tempered since Rochester is primarily a white, middle-class community; inferences to other populations or settings may be limited. Even so, results from this study provide a much-needed baseline for comparison with populations in other locations.[5,34]

In summary, our population-based, retrospective, epidemiologic study of a birth cohort provides a powerful opportunity for the study of RD. These data demonstrate that RD is common among children and should be included among the differential diagnoses considered in children having problems with academic achievement. Moreover, these data suggest that this diagnosis should be given a higher prior probability in boys than in girls.

We acknowledge Leonard T. Kurland, MD, for his vision in initiating the Rochester Epidemiology Project. We also thank Susanne L. Daood, MA, and Bruce Spotts, BS, for primary data analysis, V. Shane Pankratz, PhD, Amy L. Weaver, MS, and Sarah E. Thieling, MS, for subsequent analyses and data processing, Diane M. Siems, BS, Study Coordinator, Candice T. Klein, BS, Peg Farrell, RN, and other members of the LD team for data collection, Sondra L. Buehler for assistance in manuscript preparation, and ISD No. 535 and the RCDIM for their cooperation and collaboration.

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