Math Learning Disability and Math LD Subtypes: Evidence from Studies of Turner Syndrome, Fragile X Syndrome, and Neurofibromatosis Type 1

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Abstract

The present study examined whether indicators of math learning disability are observed in 5- and 6-year-olds with neurofibromatosis type 1 (NF1) and in 5- to 6-year-old girls with Turner syndrome or fragile X syndrome. Data from 14 girls with Turner syndrome, 9 girls with fragile X syndrome, and 11 children with NF1 were compared to data from control participants matched on age, sex, IQ score, and grade level. The results indicate that girls with fragile X syndrome or Turner syndrome are significantly more likely to have specific math difficulties relative to their control group, with a larger effect size demonstrated by the group with Turner syndrome. Young children with NF1 had a heterogeneous profile not suggestive of specific math disability. The results are discussed in terms of their implications for understanding math disability subtypes and the identification of math difficulty in the early school years.

Relative to research on reading disability, research on math learning disability is very much in its infancy. Reading disability researchers have described core deficits (e.g., Morris et al., 1998; Vellutino, Scanlon, & Tanzman, 1994) and probable genetic etiologies (e.g., Grigorenko et al., 1997; Pennington et al., 1991) that underlie most cases of dyslexia and have demonstrated the efficacy of specific interventions (e.g., Scanlon & Vellutino, 1996; Vellutino et al., 1996). In contrast, math disability researchers are still working to define math learning disability and to identify underlying cognitive or genetic traits (e.g., Geary, 1993; Jordan, 2000). One approach to the study of math learning disability is to conduct longitudinal assessments of children at risk for poor math achievement. In this report, the first year of such a study is described.

Much of the research on children with math disability is focused on defining the phenotype(s) of this disorder. The current study contributes to this focus in several ways. This is a report of math performance among primary school-age children at risk for later math difficulty because of the presence of fragile X syndrome, Turner syndrome, or neurofibromatosis type 1 (NF1). One aim of the overall study is to describe the developmental trajectory for each of these disorders. Another aim is to contribute to existing knowledge on how to identify and define math learning disability and its potential subtypes. The data in this article are presented in the context of two questions:

1. Is there evidence of specific math learning disability in children from these populations during early primary school-age years?
2. Are there differences in performance profiles across the three groups that support the notion of math learning disability subtypes?

The task of defining mathematics learning disability is a challenging one, owing in part to the lack of consensus in defining and measuring learning disability (LD) per se. Current LD definitions are based on relatively poor achievement in reading, spelling, writing, or math. Despite inclusion of math achievement in these definitions, the LD literature is dominated by work on reading disability, and the terms learning disability and reading disability are often inappropriately treated as synonymous. However, the prevalence of math disability in school-age children, reported as approximately 6% (Badian, 1983), parallels or exceeds the reported frequency of reading disability. The disproportionate amount of research devoted to reading disability may reflect the more apparent societal concern with literacy than with numeracy (Fleishner, 1994). Recent trends include greater research attention to and funding for both math and science education than in the past (National Center for Educational Statistics, 1998). Still, our understanding of math LD is limited, and research on the genetic bases of math LD is even more limited (Geary, 1993).
Successful investigation of math disability is dependent on measuring an individual’s math proficiency, which leads to the question of how to effectively measure proficiency within a learning disability framework. Measurement criteria vary across studies, with no consensus or clear guidelines as to which cognitive features are at the core of math disability (Keogh, 1994). Math disability is sometimes regarded as a learning disability selective for poor math achievement (Rourke, 1993; Strang & Rourke, 1983) or as a component of a generalized LD that includes problems with reading, writing, and math (Fleishner, 1994). School-based and research-based definitions may differ, with school-identified children typically demonstrating low achievement in math and reading (Fleishner, 1994). The different approaches to measuring and defining math achievement include criterion-based (e.g., children in the lowest 10th–45th percentile among their grade-level peers) and discrepancy-based (e.g., discrepancy from grade-level score or from IQ score) models. In studies of math LD based on school-identified children, the study sample may not represent children with math LD identified by alternative criteria. For instance, many children identified by schools as having math LD do not have a deficit in the supporting cognitive components (e.g., number concepts) and typically show improved achievement in subsequent grades (Geary, 1990; Geary & Brown, 1991). In this study, math difficulties are viewed as a weakness relative to performance in other academic or cognitive domains. Particular attention is given to children whose scores fall within the range of the bottom 10th percentile from a normative sample. (See Teisl, Mazzocco, & Myers, 2001, for a discussion of this normative sample.)

There are notable similarities between acquired and developmental math disability (McCloskey, 1992), and qualitative differences between these categories support the relevance of a neuropsychological approach to the study of math skills performance in children with math LD. Theoretical links have been postulated between math achievement and visual–spatial (Battistia, 1980; Luria, 1966; Rourke, 1993; Semrud-Clarkman & Hynd, 1990) or lexical skills (Benson & Denckla, 1969). It appears that different components of mathematical thinking are linked to visual–spatial or linguistic representations (Dehaene, Spelke, Pinel, & Tsivkin, 1999). Thus, it is important to include measures from both of these domains in research on math skills performance. Similarly, reading and math disabilities have been described as similar (Kulak, 1993) and as co-occurring (Badian, 1983; Light & DeFries, 1993) in elementary school children. Thus, it is necessary to assess cognitive components of reading when evaluating which skills are associated with math ability. Math disability does not appear to be indicative of specific lateralized dysfunction (Shalev, Manor, Amir, Wertzman-Elad, & Gross-Tsur, 1995) but instead involves component skills across these and potentially other neuropsychological domains.

Neuropsychological features other than those associated directly with mathematical knowledge- or skills-based math LD may also lead to poor math performance. These include working memory (McLean & Hitch, 1999), attentional or executive function skills (Geary, 1990), or characteristics that differentiate attention-deficit disorder (ADD) with hyperactivity from ADD without hyperactivity (Marshall, Schafe, O’Donnell, Elliott, & Handwerk, 1999). Each of these skills may contribute to the identification of math LD and to attempts to differentiate math LD subtypes.

Definitions of math LD should account for subtypes, because empirically based descriptions of children with math LD indicate heterogeneity in their cognitive profiles. Geary’s (1993) proposed math LD subtypes were considered in the design of the research reported in this report. These subtypes are based on children’s performance on specific arithmetic tasks and associated neuropsychological profiles, and they represent a greater specification of the dichotomous learning disability classification proposed by Rourke and colleagues (Harmedak & Rourke, 1994; Rourke, 1993; Strang & Rourke, 1983). They include semantic memory math disability, which often coexits with reading disability and is characterized by poor math fact retrieval and variable response times to retrieval problems; procedural math disability, characterized by the use of problem-solving strategies more commonly used by younger children, frequent errors in executing these strategies, and a poor understanding of associated concepts; and visual–spatial math disability, which involves difficulty with properly aligning numeric information, sign confusion, number omission or rotation, and general misinterpretation of spatially relevant numeric information (e.g., place values).

The relation between visual–spatial and math skills is an important component of the research presented in this article, because descriptions of each of the three disorders addressed herein—Turner, fragile X, and NFI—broadly refer to difficulty with math and visual–spatial skills. Each disorder has been proposed as an etiology of nonverbal learning disability (Mieziesjeksi & Hinton, 1992; Tstasani & Rourke, 1995) with varying degrees of support. However, each disorder is distinct from the others at the genotype and phenotype levels. A detailed review of each disorder is beyond the scope of this article; therefore, the reader is referred to more detailed reviews in each of the following brief summaries.

Turner syndrome results from the complete or partial loss of one of the two X chromosomes typically present in women. This sex chromosome abnormality occurs in approximately 1 in 10,000 live births (Hook & Warburton, 1983). The consequent physical phenotype is well described and typically includes short stature, webbed neck, and gonadal dysgenesis (as summarized by Rovet & Buchanan, 1999). Classic Turner syndrome (45X0) occurs only in females, and for this reason only girls
were included in the group of Turner participants in this study.

Although the psychological phenotype can be variable across affected individuals, mental retardation is uncommon, and the cognitive profiles of individuals with Turner syndrome are consistently reported as demonstrating relatively weaker performance in math, attention, and visual–spatial skills within the framework of typical overall levels of intellectual functioning (McCauley, Kay, Ito, & Treder, 1987; Pennington et al., 1985; Ross, Reiss, Freund, Roeltgen, & Cutler, 1993; Rovet, 1993; Silbert, Wolff, & Lilenthal, 1977; Williams, Richman, & Yarbrough, 1991). Girls with Turner syndrome are at increased risk of repeating an academic grade, and a significant proportion of females with Turner syndrome (albeit a minority, 12%) reported having repeated a year of primary school (van Borsel, Dhooge, Verhoye, Derde, & Curfs, 1999). On the basis of consistent reports of visual–spatial deficits, one can hypothesize that girls with Turner syndrome manifest a profile consistent with the visual–spatial math disability subtype. However, this hypothesis remains unsupported, and there is some evidence that the math LD and spatial difficulties are independent (Rovet, Szekely, & Hokenberry, 1994).

The relation between math and spatial abilities is complex, with some mathematical domains unrelated and other domains highly related to visual–spatial skills (Geary, 1996). Geometry is defined as the mathematical study of shape and space. It is thus not surprising that some studies find a relation between spatial abilities and math performance and others do not. It is reasonable to predict that girls with Turner syndrome, who tend to have spatial deficits, will show deficits in some areas of mathematics (e.g., geometry) but not in others (e.g., fact retrieval).

The cognitive deficits reported for girls with Turner syndrome may be associated with hormonal abnormalities associated with the syndrome. For instance, estrogen supplementation increases the speed of motor response and other nonverbal tasks but not the accuracy of performance on these tasks (Ross, Roeltgen, Feuillan, Kushner, & Cutler, 1998). More thorough reviews of Turner syndrome appear elsewhere (Ross & Zinn, 1999; Rovet & Buchanan, 1999).

Fragile X syndrome is the most common known familial cause of mental retardation and learning disability. It results from a single gene mutation on the X chromosome (Verkerk et al., 1991) and occurs in approximately 1 out of 4,000 live births (Sherman, 1996; Turner, Webb, Wake, & Robinson, 1996). Physical features of the syndrome are variable across affected persons, but the most frequently observed features include elongated or protruding ears, a long face, and hyperextensible joints (see Hagerman, 1996, for a review). The consequent psychological phenotype is also quite variable across affected individuals. Whereas the majority of males (Bailey, Hatton, & Skinner, 1998) and approximately 50% of females (Rousseau et al., 1994) with fragile X syndrome have mental retardation, approximately 50% of females do not have mental retardation yet may present with a learning disability. For this reason, only girls with fragile X syndrome were included in the present study. Moreover, the study sample included only girls with fragile X syndrome who did not have mental retardation and was thus representative of relatively higher functioning girls with fragile X syndrome.

Women (Grigsby et al., 1999; Mazzocco, Hagerman, Cronister, & Pennington, 1992; Mazzocco, Hagerman, & Pennington, 1992; Mazzocco, Pennington, & Hagerman, 1993) and girls (Cornish, Munir, & Cross, 1998; Kvar, 1993; Mazzocco, 1998; Mazzocco, Baumgardner, Freund, & Reiss, 1998; Miezieski & Hinton, 1992) with fragile X syndrome demonstrate significantly weaker mathematics achievement relative to reading and spelling achievement and weak performance on tasks of visual mental rotation, but not across all areas of visual–perceptual skills performance. The most consistent domain-specific deficits reported are those described as executive functions (Mazzocco, Hagerman, Cronister, & Pennington, 1992; Mazzocco, Hagerman, & Pennington, 1992; Mazzocco et al., 1993; Simon & Keenan, 1998). Verbal skills are relatively intact, although weaker than those observed among sisters of girls with fragile X syndrome. Higher order aspects of language comprehension appear weaker among women with fragile X syndrome than in women from a comparison group (Simon et al., 2001), consistent with the notion of impaired executive functions. On the basis of the published research on fragile X syndrome and the proposed math disability subtypes (Geary, 1993), one can hypothesize that girls with fragile X syndrome would demonstrate a profile consistent with the procedural math LD subtype. Several recent reviews of the fragile X syndrome appear elsewhere (Hagerman, 1999; Mazzocco, 2000b), including reviews dealing specifically with females who have fragile X syndrome (Keysor & Mazzocco, in press; Lachiewicz, 1995).

Neurofibromatosis type 1 (NF1) is one of the most common single-gene disorders leading to central nervous system abnormalities. The prevalence of NF1 is approximately 1 in 4,000 persons (Huson, 1989), and learning disability is reported in approximately 30% (Riccardi, 1981) to 56% (Varmagh et al., 1988) of individuals who have the disorder. NF1 results from a single gene mutation on chromosome 17 that can occur sporadically or in familial fashion. This dominant gene is involved in cell growth and differentiation, and the gene mutation appears to be associated with the loss of such functions (Seizinger, 1993). Thus, benign and malignant tumor growth result in multiple organ systems, most typically presenting as subcutaneous growths, Lisch nodules on the iris of the eye, and lesions of the brain of unknown origin or structure. Physical features of NF1 vary across individuals with the disorder and within individuals with the
disorder over time. Diagnosis of NF1 is based on the assessment of these and other physical features and on family history of NF1, as established by the National Institute of Health Consensus Development Conference (1988). In view of the fact that males and females can be affected by NF1, both boys and girls with NF1 were included in the present study.

The consequent psychological phenotype is quite variable across affected individuals, both qualitatively and quantitatively. NF1 has been described as a nonverbal learning disability on the basis of visual–spatial and visual–motor integration difficulties (Varnhagen et al., 1988); yet NF1 has also been presented as a model of reading disability (Denckla, 1996) and as a learning disability characterized by language deficits that differ from those reported in children with reading disability (Cutting, Koth, & Denckla, 2001; Denckla, 1996; Mazzocco et al., 1995). Indeed, both spelling and math deficits have been reported in the same sample of participants (Stine & Adams, 1989), and there is no consensus on which learning disability model best describes the phenotype of NF1. More detailed reviews of NF1 appear elsewhere (North, 1997; Ozonoff, 1999).

Method

Participants

All of the participants in this study were drawn from a larger, ongoing longitudinal study of development of math skills during the primary school-age years. This Math Skills Development Project (MSDP) includes four groups of children. Three groups are composed of children with a genetic disorder associated with weak math achievement, including fragile X syndrome, Turner syndrome, or neurofibromatosis type 1. On the basis of current research findings of poor math achievement, these three genetic groups represent samples at risk for later math difficulties. The fourth group is from the prospective, school-based component of the MSDP research and includes 249 children (129 girls and 120 boys) who were enrolled in the MSDP as students in a general education half-day kindergarten program. Enrollment for the school-based sample was open to any kindergartner from each of seven participating schools, and this sample was not selected for any risk or lack thereof. A more detailed description of the recruitment for the school-based sample appears elsewhere (Mazzocco & Myers, in press). All of these children were evaluated during their kindergarten year. Due to relocation of several families, 235 children were evaluated during their second year in the study (Year 2). Selected children from this fourth group were included in a control group for each of the aforementioned three genetic groups, as described in detail for each group.

Girls with Turner Syndrome. Fourteen girls with Turner syndrome were recruited and evaluated as MSDP participants. Age and full scale IQ scores differed across the fragile X and school-based participant groups, so a subgroup of control participants was selected. Of the 120 girls in the school-based study, there were 30 who could be matched to an individual girl in the fragile X group on grade level (kindergarten/pre-K or second grade), age (within 2 months, n = 23; 6 months, n = 5; or 12 months, n = 3), and full scale IQ score (within

<table>
<thead>
<tr>
<th>Group</th>
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<th>Range</th>
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<td>89.7</td>
<td>79–101</td>
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<td>5.6–6.9</td>
<td>97.7</td>
<td>68–109d</td>
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<td>6.5</td>
<td>5.6–7.0</td>
<td>99.6</td>
<td>76–110</td>
</tr>
</tbody>
</table>

Note. NF1 = neurofibromatosis type 1; FSIQ = full scale IQ.

*all girls. a7 girls. b46 girls. cThe score of 68 was a minimum estimate, with an upper estimate of 81.
7 points, with 22 having scores within 4 points). These 30 children were included in analyses comparing fragile X to non–fragile X participants. The one exception to grade-level matching involved a girl with fragile X who was very young for Grade 1 (6 years 0 months) and who was matched with girls who had the same age at the end of kindergarten.

Matching criteria was possible for only 9 of the 14 girls with fragile X; the remaining 5 either had a full scale IQ > 12 points lower than the lowest score obtained from the school-based sample of girls (n = 2) or were more than 1 year younger or older than the youngest or oldest girl in the school-based study at the onset of their participation in the project (n = 3). Characteristics of these two groups of girls appear in Table 1.

Children with Neurofibromatosis Type 1 (NFI). Eleven children (including 7 girls) with NFI were recruited and evaluated as kindergarten or first-grade MSDP participants. Of the 249 kindergartners in the school-based study, there were 66 who could be matched to an individual child in the NFI group on sex, grade level (kindergarten or first grade), age (within 3 months), and full scale IQ score (within 5 points; within 3 points for 53 control children). The exception to IQ matching involved a boy with NFI whose full scale IQ score was estimated in light of challenging testing behavior. A score of 68 was calculated as a minimum estimate, and an upper range estimated composite score of 81 was based on the subtests for which the examiner least questioned testing validity. This boy was matched to two boys whose IQ scores were 76 and 81. Children tested during the summer were considered to be in the grade they had just completed rather than in the grade they were scheduled to enter. There were 66 children from the school-based sample who were included in analyses comparing NFI versus non–NFI participants. See Table 1 for a summary of the participant group characteristics.

Procedure

Each child individually completed a battery of psychoeducational and neuropsychological measures. The testing occurred over 1 to 2 days for children in the genetic groups, and during two to three 1-hour sessions that occurred during the school day for the children in the school-based sample. Only the measures included in this report are described.

For each child, the Stanford-Binet Intelligence Scale—Fourth Edition (SB-IV) was administered as an overall measure of intellectual functioning (Thorndike, Hagen, & Sattler, 1986). The eight age-appropriate subtests that were administered included three in the Verbal Reasoning area, two in the Short-Term Memory area (including a verbal Sentence Memory task, and a nonverbal Bead Memory task), two visual/abstract reasoning tasks that involved matching block designs to a model presented by the examiner; and one quantitative reasoning task that included basic quantity awareness tasks and numeration items similar to an achievement test. The composite (or full scale) IQ was used to select matched participants between the genetic and control groups. Area and select subtest scores were examined as potential sources of group differences.

Additional measures of math skills included the KeyMath—Revised achievement test (Connolly, 1988) and the Test of Early Math Ability—Second Edition (TEMA-2; Ginsburg & Baroody, 1990). The KeyMath—Revised (KM-R) is a standardized achievement test with limited age-appropriate subtests for children in kindergarten or Grade 1. Therefore, only three subtests, Numeration, Geometry, and Measurement, were administered to all children in the present study. The TEMA-2 is a measure of formal and informal early math concepts, facts, and skills, and is normed for children ages 3 years to 8 years 9 months.

The Visual–Perceptual measures included in the study were the four motor-reduced subtests of the Developmental Test of Visual Perception—Second Edition (DTVP-2; Hammill, Pearson, & Voress, 1993), the Beery Visual Motor Integration task (VMI; Beery, 1989), and the subtests from the Abstract/Visual Reasoning area of the SB-IV. The DTVP-2 subtests administered each required a selection from three to five choices, and the four tasks involved matching figures on the basis of direction (Position in Space), identifying shapes in embedded designs (Figure Ground), Visual Closure skills with abstract objects, and matching shapes (Form Constancy).

To measure reading-related and other verbal skills, the Woodcock-Johnson—Revised Letter Word Identification (LWID) subtest (Woodcock & Mather, 1989) was administered, which involved use of symbols, reading letters, and recognizing single words. In first grade, performance on the nonword reading subtest (Word Attack) is more indicative of reading disability than is Letter Word Identification because of the phonological decoding skills involved in the successful performance on Word Attack. However, the majority of the participants in this study were tested in kindergarten, when the LWID subtest is a more developmentally appropriate measure.

From each of these measures, a standardized, age-referenced score was derived. Additional standardized scores were obtained from the SB-IV Verbal Reasoning area and verbal Short-Term Memory subtest. Nonstandardized scores were also obtained from a measure of rapid automatized naming (RAN) of colors (Denckla & Rudel, 1976). Many of the children were not yet able to recognize letters and numbers; therefore, letter and number RAN were not included in the present study.

In addition to these variables, qualitative measures were also obtained based on data derived from the total MSDP Year 1 (kindergarten) sample of 249 children. The total MSDP group TEMA-2 and LWID percentile scores were calculated to establish which scores fell at or below the bottom 10th
percentile or at or above the 90th percentile. For each set of analyses reported further on, the number of children in the present study who scored within these ranges of scores was examined as a function of group (genetic versus control group). This frequency-based analysis was carried out for both TEMA-2 or LWID scores. For both TEMA-2 and LWID scores, participants scoring at or below the 10th percentile had standard scores < 86. Scores at or above the 90th percentile were TEMA-2 scores > 121 and LWID scores > 116.

Results

The results are presented separately for each of the three genetic groups. For each group, assumptions of normality could not be verified due to the small sample size for the genetic groups (see Table 1). Therefore, non-parametric comparisons were carried out. In cases of tied rankings, tied z and p values are reported. Frequency comparisons were based on chi-square statistics, with a Fisher’s exact test implemented in each case, because expected cell values fell below 5.

For each set of group comparisons, preliminary analyses were carried out to verify the expected lack of statistically significant group differences on age or full scale IQ scores. Profiles were examined for support of specificity of math difficulty in each group. Group comparisons were carried out using standardized test scores or other continuous variables presented in Figure 1. Finally, qualitative analyses were carried out to address the degree to which each of these groups represented a group at risk for early math difficulty and to address the potential nature of such difficulty. All group comparisons were carried out as two-tailed analyses. Group means for comparisons that indicated significant differences are summarized in Table 2. The frequencies with which individuals were found to be at risk for math LD according to particular measures are presented in Table 3.

**Full scale IQ score**
Stanford-Binet Intelligence Scale—Fourth Edition (SB-IV)

**Verbal / Reading scores**
SB-IV Verbal Reasoning area (a composite of three verbal subtest scores)
SB-IV verbal Short-Term Memory subtest (Sentence Memory)
Woodcock-Johnson—Revised Letter Word Identification (academic achievement)
Rapid Automated Naming (colors) response time in seconds

**Visual–spatial, visual–perceptual, and visual–motor scores**
Developmental Test of Visual Perception-2, four motor-reduced subtests
(Position in Space, Figure Ground, Visual Closure, and Form Constancy)
SB-IV nonverbal Short-Term Memory subtest (Bead Memory)
SB-IV Visual/Abstract Reasoning area score (visual–spatial and motor)
Beery Visual Motor Integration (VMI)

**Math-related scores**
SB-IV Quantitative Reasoning (QRI) subtest
Test of Early Math Ability—Second Edition (TEMA-2) quotient
KeyMath–Revised achievement test, age-appropriate subtests (Numeration, Geometry, and Measurement)

**Math performance consistency**
Frequency of scores that fall in normative sample–based 10th and 90th percentiles

Turner vs. Control Participants

Preliminary analyses using unpaired Mann-Whitney tests were carried out to verify that there were no statistically significant group differences on Full Scale IQ score, $z = -1.53, p = .12$, or age, $z = -1.26, p = .21$. Unpaired analyses were also carried out to examine possible group differences for the primary variables of interest (presented in Figure 1). Within the domain of verbal/reading measures, there were no statistically significant group differences on the SB-IV Verbal Reasoning Area score or the WJ-R Letter Word Identification subtest, $ps > .29$. However, girls with Turner syndrome had significantly longer response times on the RAN (colors) task, $z = -2.71, p < .01$.

On the four motor-reduced visual–perceptual tasks from the DTVP-2, no significant group differences emerged. The girls with Turner syndrome received a lower mean score on the visual closure subtest, but this difference was not significant, $p = .05$. Remaining DTVP-2 $ps$ were all $>.12$. The visual–spatial tasks that did include a motor component were the VMI and the SB-IV Pattern Analysis area; on both of these variables, girls with Turner syndrome had significantly lower scores, $z = -2.97, p < .01$, and $z = -2.50, p < .02$, respectively.

On various measures of mathematics performance or achievement, performance among the girls with Turner syndrome was comparable to or lower than that observed for girls in the comparison sample. Girls with Turner syndrome had significantly lower scores on TEMA-2, with a mean score in the low average range versus an average mean score seen in the control group, tied $z = -3.65, p < .001$. On the Numeration and Measurement subtests of the KeyMath–Revised, the group of girls with Turner syndrome had mean scores that were comparable to those observed in the control group, $ps > .18$, and well within the average range. Numeration scores were $9.9 \pm 1.9$ and $10.8 \pm 2.1$ for the two groups, respectively. Measurement scores were $11.07 \pm 2.8$

**FIGURE 1.** Primary variables of interest for all group comparisons.
TABLE 2
Group Means for each Genetic Group and its Matched Control Group

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<tr>
<th>Measure</th>
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<td>ns</td>
<td>ns</td>
<td>ns</td>
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<tr>
<td>SB-IV</td>
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<tr>
<td>Visual Reasoning</td>
<td>80.3</td>
<td>15.0</td>
<td>91.5*</td>
<td>11.5</td>
<td>80.8</td>
<td>16.8</td>
</tr>
<tr>
<td>Bead Memory</td>
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<tr>
<td>Beery VMI</td>
<td>82.9</td>
<td>12.2</td>
<td>94.0**</td>
<td>10.1</td>
<td>82.9</td>
<td>10.3</td>
</tr>
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<td>Math</td>
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<tr>
<td>SB-IV QR</td>
<td>93.9</td>
<td>10.7</td>
<td>98.9b</td>
<td>10.7</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>TEMA-2</td>
<td>85.6</td>
<td>10.6</td>
<td>98.7***</td>
<td>11.7</td>
<td>82.8</td>
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<td>Key Math</td>
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<td></td>
</tr>
<tr>
<td>Numeration</td>
<td>ns</td>
<td>ns</td>
<td>8.6</td>
<td>1.6</td>
<td>10.2*</td>
<td>1.9</td>
</tr>
<tr>
<td>Geometry</td>
<td>11.5</td>
<td>3.4</td>
<td>13.3*</td>
<td>3.3</td>
<td>9.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Measurement</td>
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<td>ns</td>
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</tr>
</tbody>
</table>

Note: Values are listed only if a significant difference emerged or if the comparison approached significance, p < .10; ns indicates values of p > .12. NF1 = neurofibromatosis type 1; SB-IV = Stanford-Binet Intelligence Scale–Fourth Edition; WJ-R = Woodcock-Johnson Psychoeducational Battery; LWID = Letter Word Identification; RAN = rapid automated naming; DTVP-2 = Developmental Test of Visual Perception–Second Edition; VMI = Visual Motor Integration task; QR = Quantitative Reasoning; TEMA-2 = Test of Early Math Ability–Second Edition.

and 11.62 ± 2.2, respectively. Although girls with Turner syndrome had a significantly lower Geometry subtest score, this score was nevertheless in the average range, tied z = −2.31, p < .03. There was no significant group difference on the SB-IV Quantitative Reasoning score, with average scores reported for each group, p = .05.

The frequency of TEMA-2 scores that fell within the 10th and 90th percentiles differed across the two groups. Among the 14 girls with Turner syndrome, 43% (6 girls) had TEMA-2 scores < 86, versus 10% (7) of the 69 girls from the control group, χ²(1, N = 83) = 9.43, Fisher’s exact p < .01. None of the girls with Turner syndrome and 6% (4) of

TABLE 3
Percentage of Children with Test Scores in At-Risk Ranges

<table>
<thead>
<tr>
<th>Group</th>
<th>TEMA-2</th>
<th></th>
<th>LWID</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>% &lt; 86</td>
<td>% &gt; 121</td>
<td>% &lt; 86</td>
</tr>
<tr>
<td>Turner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic</td>
<td>14a</td>
<td>43</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Matched control</td>
<td>69a</td>
<td>10</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Fragile X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic</td>
<td>9a</td>
<td>56</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Matched control</td>
<td>30a</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>NF1</td>
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<td>18</td>
<td>0</td>
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<tr>
<td>Matched control</td>
<td>66c</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: NF1 = neurofibromatosis type 1; TEMA-2 = Test of Early Math Ability–Second standard score; LWID = Woodcock-Johnson Letter Word Identification standard score.
aAll girls. b7 girls. c46 girls.
the girls in the control group had a TEMA-2 score equivalent to the top 90th percentile TEMA-2 group. The distribution differed for LWID scores. Among the 14 girls with Turner syndrome, none had a LWID score < 86, versus 7% (5) of the 69 girls from the control group. Two (14%) of the 14 girls with Turner syndrome, and 4 girls (6%) from the control group received a LWID score at or above the 90th percentile. These differences in rate were not significant unless noted otherwise.

**Fragile X vs. Control Participants**

In view of the small sample size available for this comparison, nonparametric procedures were employed because the data were not normally distributed. Preliminary analyses using the unpaired Mann-Whitney U test were carried out to verify that there were no statistically significant group differences on age, tied z = -.63, p = .53, or full scale IQ score, tied z = -1.05, p = .29.

Mann Whitney U tests were also carried out to examine possible group differences for the primary variables of interest (presented in Figure 1). There were no statistically significant group differences on the verbal/reading measures, including the SB-IV Verbal Reasoning Area score, the SB-IV vocabulary and verbal short-term Sentence Memory subtest, the WJ-R Letter Word Identification subtest, and the RAN, ps > .63. On the four motor-reduced visual-perceptual tasks from the DTVIP-2, no significant group differences emerged, ps > .25. The two visual–spatial scores that did include a motor component were the VMI and the SB-IV Abstract/Visual Reasoning area scores. Girls with fragile X syndrome received lower mean scores for both of these variables, but the group difference was not statistically significant in either case, ps = .05 and .074, respectively.

In contrast, there were several statistical group differences on various measures of mathematics performance or achievement, with lower scores among the girls with fragile X syndrome relative to scores obtained by girls in the control sample. Girls with fragile X syndrome had significantly lower quotient scores on TEMA-2, with a below-average mean standard score versus an average mean score in the control group, tied z = -2.17, p < .03. The girls with fragile X syndrome also received lower scores on three of the four age-appropriate KeyMath–Revised subtest scores. On the Numeration subtest, girls with fragile X syndrome had a low average mean scale versus an average mean scaled score seen in the control group, z = -2.15, p < .04. On the Geometry subtest, girls with fragile X syndrome had a lower but average mean scaled score versus the higher average mean score shown in the control group, z = -3.00, p < .01, and a low average mean scaled score versus the average mean score seen in the control group, z = -2.21, p < .03. There was no group difference on the Measurement subtest of the KeyMath–Revised, z = -2.43, p = .06, with average scores in each group (9.8 ± 1.6 and 11.1 ± 2.5, respectively), nor on the SB-IV Quantitative Reasoning score, p = .29.

The frequency of LWID scores that fell within the 10th and 90th percentiles was the same for the two groups. One of the girls with fragile X syndrome (11%) and 3 (10%) of the girls from the control group scored in the bottom 10th percentile (< 86) on LWID. None of the girls in either group scored in the top 10th percentile. In contrast, 5 girls with fragile X syndrome (56%) and 5 girls from the control group (20%) had a TEMA-2 score < 86, χ²(1, 39) = 4.32; but this difference was not significant, Fisher’s exact p = .085. Significant group differences did emerge if low TEMA-2 scores were defined as < 87, with 67% and 20% of the fragile X and control girls, respectively, scoring below 87, χ²(1, 39) = 7.08, Fisher’s exact p < .02. None of the girls with fragile X syndrome, and 3 (10%) of the girls in the control group, had a TEMA-2 score > 121.

**NF1 vs. Control Participants**

Preliminary analyses using unpaired nonparametric statistics were carried out to verify that there were no statistically significant group differences on age or Full Scale IQ score, tied zs = -.96 and -3.6, respectively, ps > .33. Potential group differences in mean scores were examined using analyses parallel to those described for the Turner and fragile X groups for variables presented in Figure 1. From these analyses, no significant group differences emerged, ps > .10. Individual test group means, as well as the range of scores for each test, were comparable across the NF1 and control groups. The primary variable of interest, the TEMA-2 score, was average for both groups, 100.1 ± 17.3 and 104.4 ± 13.0, respectively.

There were differences in the proportion of children scoring within the 10th or 90th percentiles on the TEMA-2, although these differences were not comparable to those observed for the Turner and fragile X groups and were not statistically significant. Two of the children with NF1 (18%) and 5 children (8%) from the control group scored at the bottom 10th percentile (< 86) on the TEMA-2, p = .26. A similar difference in rate was seen for children scoring at or above the 90th percentile: 2 (18%) children with NF1 and 5 (8%) children from the control group had TEMA-2 scores > 121. For LWID scores, none of the children with NF1 and 3 children from the control group (5%) had an LWID score < 86; a comparable proportion (18%) of the children in either group (2 and 12, respectively) scored at or above the 90th percentile on LWID.

**Correlation Analyses**

In addition to group performance, correlates of math performance were examined separately for each of the three genetic groups and the corresponding control group. Of interest was whether there were correlations between the TEMA-2 and either the LWID or the
DTVP-2 Position in Space (PS) subtest. These variables are positively correlated in the entire MSDP normative sample (Mazzocco, 2000a). There were no statistically significant or even marginally interesting Spearman rank correlations between TEMA-2 and PS with the exception of the control sample used in the Turner syndrome analyses. In this group of 69 girls, the correlation was comparable to that reported for the normative sample (Mazzocco, 2000a) from which these girls were drawn, \( r = .41, p < .01 \). Correlations between TEMA-2 scores and LWID scores were statistically significant for all three control groups used for the three genetic groups, \( r \) values ranging from .54 to .65, \( p < .0001 \) to .01. There was no association between TEMA-2 and LWID scores for the girls with fragile X or Turner syndrome, \( ps = .29 \) and .07, respectively. The lack of significant differences could potentially be related to low statistical power with these small samples of 9 and 14 girls, respectively; however, when 14 girls from the Turner control group were randomly selected for inclusion in correlational analysis, the TEMA-2 / LWID correlation remained significant, although weaker, \( r = .67, p < .01 \). Moreover, the correlation was significant among the 9 children with NF1, \( p < .01 \). Examination of scatterplots for these 12 correlations was consistent with the results indicating significant associations or lack thereof.

**Discussion**

**Math Skills in Children with Turner Syndrome, Fragile X, or NF1**

The first aim of this study was to address whether there is evidence of specific math learning disability in children from the populations studied, particularly during the early primary school-age years. The results support the notion of deficient math performance in Turner and fragile X syndromes, both relative to other areas of performance within each group and relative to performance of peers matched by age, sex, grade level, and full scale IQ. This notion was supported despite the small samples sizes. If a low TEMA-2 score in kindergarten or Grade 1 is an indicator of risk for later math difficulty, results from the frequency ratio comparisons indicate a twofold to fourfold increase in at-risk status in these two groups relative to other girls of similar ages and IQ scores. Math difficulties have been reported for adult and older school-age girls for both fragile X (Grigsby et al., 1999; Grigsby, Kemper, Hagerman, & Myers, 1990; Kovan, 1993; Mazzocco, 1998; Mazzocco et al., 1993; Miezejeski & Hinton, 1992) and Turner syndromes (Mazzocco, 1998; Rovet, 1993; Rovet et al., 1994). The present data are thus consistent with previous reports in the literature and indicate that math difficulties are apparent by the early school years. The implications thus point to early intervention as a goal for diminishing the degree of math difficulty in girls with either syndrome, although the precise nature of such intervention was not addressed by this study.

The data from the Turner syndrome group have additional similarities to previous reports in the literature regarding qualitative and quantitative aspects of math skills in these girls. In the present study, 43% of the 14 girls who participated had a TEMA-2 score that fell in the below-average range (see Table 3) and in a range reported for only 10% of girls of the same age with similar grade level placements and full Scale IQ scores. The 10% frequency in the control group is comparable to reported indices of LD prevalence and consistent with the definition of these low TEMA-2 scores at the bottom 10th percentile. The 43% rate seen in girls with Turner syndrome is consistent with Rovet’s 1993 report that 55% of girls with Turner syndrome had learning disabilities that in every case included difficulty with arithmetic. The girls in Rovet’s study were older; their mean age was 12 years. The current findings suggest that approximately the same frequency is evident much earlier, by age 6. It remains to be seen whether the 43% of girls in the present study will manifest arithmetic problems at age 12. In reports by Rovet and colleagues, basic concept skills appear intact in girls with Turner syndrome, and in the present study this was also the case with basic numeration skills. One difference between Rovet’s reports and the present study concerns the weaker performance by girls with Turner syndrome relative to the control group on the KeyMath-Revised Geometry subtest (Rovet et al., 1994). However, the finding that this relatively lower level of performance was nevertheless in the average range is consistent with Rovet’s findings.

The data for the NF1 group are more heterogeneous than the data for the Turner syndrome and fragile X groups, which is consistent with the overall findings of cognitive skills in this group, summarized elsewhere (Ozonoff, 1999). In this study, group means from the NF1 group did not suggest a specific math deficit in NF1 in kindergarten and Grade 1, and the higher rate of low TEMA-2 scores was not significant. As many children in the NF1 group scored above the 90th percentile as scored below the 10th percentile. However, this does not necessarily indicate that later difficulties will not emerge for some children with NF1. In view of the small sample size, a smaller effect size than is seen in the first two groups may be present, but if so it is unsupported by the present data. This notion is supported by the observation that the ratio of low TEMA-2 scores in NF1 versus control participants was similar (2.25:1), albeit lower, than the significantly higher ratio observed between girls with versus without fragile X syndrome (2.5:1).

**Math LD Subtypes**

The second aim of this study was to address whether differences in math performance profiles were seen across the three groups and whether such differ-
ences support the notion of math learning disability subtypes. Although it would be premature to conclude that each disorder examined in this study represents a specific subtype, the findings do suggest that the nature of the math difficulties differs across the three groups. Profiles of math scores differed across the three groups, and different patterns of correlations and at-risk frequency rates were observed in the three genetic groups.

Although children with NFI showed no profile of significant deficits on any measure on the basis of group mean comparisons, TEMA-2 scores in this group were associated with LWID scores; there was no such association in the two remaining genetic groups. This association is of interest given the inconsistent reports of nonverbal (Stine & Adams, 1989; Varnhagen et al., 1988) and verbal deficits (Cutting et al., 2001; Denckla, 1996; Mazzocco et al., 1995) in children with NFI and the observations from the latter finding that verbal deficits in NFI differ from those observed in more typical cases of children with reading disability. Future studies are needed to assess whether the lack of significant findings would persist with a larger sample size, in support of significant but weaker effect sizes, and whether math difficulties reported with NFI are not evident until after the age of 6 years.

Girls with Turner or fragile X syndrome both demonstrated deficits in math performance, but there were important differences between these two groups. It is important to establish that in this study, the girls with Turner syndrome were representative of the population from which they were drawn, whereas the girls with fragile X syndrome were representative of higher functioning girls with fragile X syndrome (i.e., those who lacked mental retardation). In this study, girls with fragile X syndrome showed lower mean scores on the TEMA-2 relative to girls with Turner syndrome; however, their overall full scale IQ scores were also lower than those in the Turner group, even if not in the mental retardation range. The actual discrepancy between each genetic group's performance and that of its respective control group was largest for girls with Turner syndrome. There was a higher percentage of girls with weak TEMA-2 scores in the fragile X control group relative to the Turner control group, most likely linked to the overall lower full scale IQ score in the former. The 10% rate of low TEMA-2 scores in the Turner control group is consistent with frequency statistics of learning disability overall and with the definition of low TEMA-2 score in this study as a score representative of the bottom 10th percentile of normative scores. Thus, it is interesting to note that the degree of increase in at-risk status (defined as presence of a TEMA-2 score < 86) was nearly twice as great in the Turner group (4.3:1) than in the fragile X group (2.5:1) despite the relatively greater frequency of low scores in the fragile X group. It is also important to note the strength of these findings in spite of such small sample sizes.

Neither the Turner nor the fragile X groups demonstrated reading-related differences, although girls with Turner syndrome had slower response times on the color rapid naming task. Slower RAN performance has been reported in older girls with Turner syndrome (Waber, 1979) and may be related to slower processing time in general, as has been reported on other tasks with different samples (Lasker, Mazzocco, Denckla, & Zee, 2000; Ross & Zinn, 1999; Waber, 1979). It has also been suggested that slower color naming is linked with attentional difficulties and not with reading disability (Tannock, Martinussen, & Frijters, 2000). Girls with fragile X syndrome demonstrated lower performance on a measure of number sense, whereas girls with Turner syndrome did not. Girls with Turner syndrome scored significantly lower on several visual–perceptual or visual–motor tasks, whereas girls with fragile X syndrome did not. This does not necessarily indicate a visual–spatial path to math deficits in girls with Turner syndrome; at least as measured by the TEMA-2/PS correlation, this was not supported, which is consistent with suggestions that the math and visual–spatial deficits in Turner syndrome are independent of each other. The work of Rovet and colleagues (Buchanan, Pavlic, & Rovet, 1998; Rovet et al., 1994) has suggested that both functions may be related to working memory demands. There is additional evidence of executive dysfunction in Turner syndrome (Temple, Carney, & Mullarkey, 1996), and its role in math performance of girls with Turner syndrome is in need of additional exploration. The pursuit of this question is one of the aims of the ongoing research program.

These important group differences do, nevertheless, support a spatial deficit in the Turner group. This finding does not often appear with the types of tasks administered in cognitive studies of math LD, such as those of Geary (e.g., 1990, 1992). These findings support the position proposed by Geary (1993) that spatial deficits are distinct cognitively and, perhaps, neurologically from other math deficits. In the fragile X group, the numeration deficits could reflect fact retrieval deficits, procedural deficits, or some combination. Future work with these groups, particularly as the sample sizes per grade increase, will serve to assess error patterns and neuropsychological correlates to math performance and will thus clarify these issues. Current efforts are under way to examine category-specific groups of items to determine more specifically whether these three genetic groups represent models for different math learning disability subtypes. The preliminary data presented in this report suggest that these efforts are warranted.

Assessing Early Mathematics Ability

In this report, reference to math difficulty pertains specifically to children whose TEMA-2 score was in the bottom 10th percentile. The category math disability is not used, because a primary
aim of the ongoing research is to help define and identify math disability. A finding relevant to this issue concerns the greater sensitivity of the TEMA-2 for identifying weak math performance in kindergarten or first grade compared to other measures used. The patterns of average KeyMath-Revised and SB-IV Quantitative Reasoning scores reported for each at-risk group supports the need to avoid basing LD assessment on individual subtests or measures at the floor of their standardization, despite the rigorous standardization of the measures.

In practice, it is important to consider which tests are likely to be used when testing kindergartners or first-graders in school settings for early identification of LD, including math LD. Early identification in kindergarten of children who are likely to struggle in mathematics is more difficult than early identification of children who will succeed (e.g., Teis et al., 2001). The identification of early math difficulty screenings and associated core deficits of math difficulty are among the aims of the ongoing research program. More thorough recommendations for early screening will be possible when math learning disability is better understood and, therefore, better defined. There is no evidence of a single core deficit comparable to that proposed for reading disability, although more detailed assessment is necessary to address this notion further.

The aim of the present study was not to provide definitive guidelines for the diagnosis of math LD and its subtypes, but one aim was to address whether there is support for the notion of at-risk status and math LD subtypes in the early school years. This notion was supported by the present study; young children at risk for math LD have different profiles that may indicate a subtype of core or associated deficits. Many questions remain, such as the role of attention, linguistic features, and visual–spatial and executive skills in successful mathematics achievement. Future studies from the ongoing research program as well as from research by several others (e.g., Geary, 1990, 1992, 1993; Geary & Brown, 1991; Jordan, 2000; Shalev et al., 1995) include but are not limited to the examination of the change in math performance profiles observed over time. It remains to be seen how the profiles observed in the children from the present study will change with age in and across the three groups examined and whether the nature of math difficulties for children in each group becomes more or less homogeneous over time. Also of interest are the patterns to emerge from correlational studies of associated neuropsychological variables in the genetic and normative sample groups. Through these efforts, we strive to better identify math LD and its subtypes and, thus, to identify the possible genetic and cognitive underpinnings of math performance and difficulty.

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AUTHOR’S NOTES

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