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The Structure of Abilities in Math-Precocious Young Children: Gender Similarities and Differences

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For this study of the organization of cognitive abilities and gender differences in young children advanced in mathematical reasoning, parents identified 778 preschoolers and kindergartners. After screening with 2 arithmetic subtests of standard intelligence tests, 310 high scorers (55% boys) were given 15 additional measures. Mean performance of these high scorers on all standardized measures was 1 to 2 standard deviations above the mean of the norming samples. Boys scored higher on 8 of 11 quantitative measures, 0 of 3 verbal measures, and 1 of 3 spatial measures, including quantitative and spatial working memory span. Three factors (quantitative, verbal, and spatial) were modeled using confirmatory factor analysis; patterns of relationships were similar for older and younger groups and for girls and boys. Spatial and quantitative factors were highly correlated; the verbal factor correlated weakly with the others but showed a stronger relationship with the spatial factor for boys than girls.

The early discovery of talent is the first step toward nurturing and expanding it. Talent in mathematical reasoning is highly valued and is basic to many career paths, especially those leading to science and technology. Yet few investigators have attempted discovery of mathematical precocity in young children, nor have they examined domain specificity, the relationship of other cognitive abilities to mathematical reasoning, or possible gender differences in this domain in the very young.

For older students who reason well mathematically and verbally, annual regional talent searches (Stanley, 1990) now involve around 160,000 seventh graders with academic aptitude measures, namely, Scholastic Aptitude Test (SAT) and American College Test (ACT) scores. A number of studies of gender differences and cognitive abilities related to advanced mathematical reasoning (e.g., Benbow, 1988; Benbow, Stanley, Kirk, & Zonderman, 1983; Casey, Nuttall, Pezaris, & Benbow, 1995; Dark & Benbow, 1990, 1991; Stanley, 1990) have been conducted with this age group.

A few studies of math-advanced elementary school children (Assouline & Lupkowski, 1992; Lupkowski-Shoplik, Sayler, & Assouline, 1993; Mills, Ablard, & Stumpf, 1993; Stanley, 1994) have encouraged earlier identification, and, indeed, some of the regional talent searches now involve fifth and sixth graders using tests such as PLUS, administered by the Educational Testing Service, and EXPLORE, administered by the American College Testing Bureau. Math-talented children younger than 10 years of age have largely been ignored, and issues of gender difference and relationships among cognitive abilities are unexplored in this group. This study is, we believe, the first to target math-advanced children identified as early as preschool and kindergarten. We examined relationships among mathematical, verbal, and visual–spatial abilities, as well as gender differences in performance in this group of young math-advanced children.

Individual Differences in Mathematical Development

Within the extensive literature on the early acquisition of mathematical skills, nearly all research has focused on the typical pace and sequence of skill acquisition, to the exclusion of individual differences other than those labeled *disabilities*. The few exceptions have examined differences in strategy use (e.g., Geary & Brown, 1991; Romberg & Collis, 1987; Siegler, 1988, 1991; Siegler & Campbell, 1990) but not rate of development, accompanying nonmathematical cognitive skills, or, with few exceptions (Geary, 1994), possible gender differences in any of these. Individual differences related to giftedness in mathematics have largely been ignored.

Some individual differences in children's strategy use are evident by first grade (Siegler, 1988, 1991, 1995). Nearly all beginners use multiple strategies of varying effortfulness and accuracy, but with experience, most children shift to retrieving facts from memory (Siegler, 1991); gifted children more frequently use retrieval strategies than do average

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peers (Geary & Brown, 1991). Siegler (1988) described strategy use in three subtypes of first graders: good students, not-so-good students, and perfectionists. The perfectionists had higher standards and did much more checking than the other two groups, even though they performed as well and could retrieve number facts from memory as well as the good students.

Domain Specificity in Precocious Young Children

Although mathematical precocity has not previously been studied in groups of very young children, very early advancement in other domains has been shown to be identifiable, specific, and stable. For example, one group of toddlers with precocious language was accurately described by parents and, over a period of 5 years, remained verbally advanced (Crain-Thoreson & Dale, 1992; Dale, Robinson, & Crain-Thoreson, 1995; Robinson, Dale, & Landesman, 1990). Another group of young children, ages 2–5 years, identified by their parents as advanced in general ability or in specific domains was, as a group, highly capable (mean IQs about 135). Only in domains in which parents had explicit mental norms was their domain-specific information congruent with children's performance on standardized measures such as the reading subtest of the Peabody Individual Achievement Test (PIAT; $r = .55$, $n = 236$). Parents' descriptions of children's early math abilities were more weakly correlated with math scores on the PIAT ($r = .34$, $n = 195$). As a group, the children remained advanced over a period of 2–5 years (Robinson & Robinson, 1992). The question remains open, however, as to whether children advanced in mathematics ability will be equally advanced in other cognitive domains or will show a degree of differentiation in mathematics as a specific ability (Lubinski & Humphreys, 1990).

Gender Differences in Mathematical Development

A sizable amount of literature (and sizable controversy) exists concerning gender differences in mathematics. In general, girls have been found to attain higher grades beginning in the primary years, although boys tend to do better on novel tasks (Kimball, 1989). By high school, differences in performance consistently favor boys (Hedges & Nowell, 1995; Hyde, Fennema, & Lamon, 1990). Among mathematically precocious youth (e.g., Benbow, 1988, and accompanying commentaries), striking gender differences are evident at the upper ranges. National samples of persons from eighth grade to young adulthood demonstrate higher variances in boys than girls in most cognitive test scores; boys are consistently overrepresented in the upper extremes in mathematics, representing small mean differences combined with small to moderate differences in variance (Hedges & Nowell, 1995).

Much less is known about gender differences among young children identified as precocious in mathematical development. Mills et al. (1993), examining a sample of academically talented students in Grades 2–6, found boys performing higher as early as second grade in application of prealgebraic algorithms and tasks involving mathematical concepts and number relationships but not on a task requiring judgment as the adequacy of information. Stanley (1994) reported similar differences for fifth and sixth graders.

Spatial Ability and Mathematical Precocity

Spatial ability clearly relates to at least some forms of mathematical reasoning. Whether spatial visualization abilities are needed for very advanced mathematical reasoning has been called into question (Lubinski & Humphreys, 1990), but the spatial–mathematical synergy during the school years has not. (It should be noted, however, that Friedman, 1989, 1995, questioned whether spatial skills play as important a role as they have been accorded, especially in the face of higher correlations between verbal and mathematical skills.) Boys are more likely to use spatial strategies even when dealing with verbal word problems (McGuinness, 1993), but within samples selected for high ability, correlations between mathematical and spatial abilities are apparently higher in girls than boys (Friedman, 1995). This finding holds for high-ability samples after the correlation with verbal ability has been accounted for (Casey et al., 1995).

The age at which boys begin to exhibit higher spatial reasoning is not at all certain. Kerns and Berenbaum (1991), for example, found spatial ability differences in normally developing boys and girls ages 9 to 13 years, whereas others (e.g., Maccoby & Jacklin, 1974; Waber, 1976) have seen the differences emerging after puberty. In an earlier study in our laboratory, among children ages 42 to 88 months who were identified as gifted, gender differences within the verbal domain were not observed, but among the subgroup 66–88 months of age, gifted young boys not only were more advanced in spatial reasoning tasks but exhibited a spatial factor not seen in girls of comparable age and IQ (Stillman, 1982). The question of early gender differences in both mathematical and spatial precocity is thus still open.

Working Memory and Mathematical Skills

Case and his colleagues (e.g., Case, 1985, 1992) have investigated how working memory develops in relationship to Piagetian stages of cognitive development. To accomplish this task, they have developed a number of working memory tasks specific to different cognitive domains, including mathematics. Working memory has been shown to be domain specific for mathematics in 12- to 14-year-old students, including mathematically gifted students (Dark & Benbow, 1990, 1991). In written language tasks, individuals in the 5- to 19-year-old range show evidence of both general and task-specific working memory, but working memory may be more domain specific on nonverbal tasks (Swanson, 1996).

Methodological Approaches

Methods for studying the early development of quantitative skills have tended not to include standardized psychometric instruments. They have, however, included diverse methods such as verbal protocols (e.g., Ginsburg, Kossan, Schwartz, & Swanson, 1983), chronometric laboratory studies (e.g., Kaye, de Winstanley, Chen, & Bonnefil, 1989), naturalistic field observations (e.g., Saxe & Posner, 1983), and error analyses (e.g., Nesher, 1986). These methods yield rich, process-oriented observations but have offered little evidence regarding the structure of early mathematical abilities and their relationship to verbal and spatial abilities. Theory-based standardized psychometric measures are particularly useful when studying larger groups of children and when comparing abilities across domains. Structural equation modeling can be used to examine interrelationships among domain-specific factors underlying multiple measures of a domain.

The study reported here focuses on children first identified by their parents during preschool or kindergarten as advanced in mathematical reasoning and subsequently tested with a battery of psychometric measures at the beginning of kindergarten or first grade. The data permit us to explore a number of issues: (a) Can young children who are advanced in mathematical reasoning be located efficiently by soliciting parent nominations? (b) Do measures of these children's cognitive abilities in other domains also show advancement and, if so, to what degree? (c) How do measures in the verbal and visual–spatial domains relate to mathematical skills for subgroups divided by grade and gender? and (d) What, if any, cognitive gender differences emerge within this group of young precocious children?

Method

Participant Recruitment and Screening

In the spring of 1993, a broad-scale effort was launched in a metropolitan area (population of approximately 2,000,000) to solicit nominations from parents of children with advanced mathematical reasoning ability, strong numerical interest, or both. Rough guidelines were mentioned such as "asks questions about numbers or time" and "makes up games using numbers, such as playing store with prices"; for preschoolers, "uses adding and subtracting up to 5 and understands that these are related, knows that a dime is more than a nickel, plays board games involving counting spaces"; and for kindergartners, "makes small purchases, wants to learn to tell time, reads symbols such as plus and minus, reads speed-limit signs, may understand that multiplication is shorthand for adding."

Letters were sent to preschools and kindergartens, both public and private; special contacts were made with Head Start teachers as well as a similar state-funded early childhood program; and several local newspapers and talk shows carried stories about the project. The local school district sent letters to parents of kindergartners who had scored high on the Mathematics subtest of the Cognitive Abilities Test, which was administered to screen children for the highly capable program. In addition, nominations of children scoring 16 or higher on the Arithmetic subtest of an age-appropriate Wechsler intelligence test were sought from specialized public and private schools that required such testing for admission. To protect families' privacy, professionals invited parents to telephone our office. Because of a relative shortage of preschool female nominees and the slightly lower scores attained by this group, we extended our recruiting period for girls in the younger group by 3 months. In all, 798 children were nominated and 778 families returned consent forms.

Between March and June (September for younger girls), all nominees except those having already scored 16 or higher on the Arithmetic subtest of an age-appropriate Wechsler test were individually administered the Arithmetic subtests of the Kaufman Assessment Battery for Children (K-ABC; Kaufman & Kaufman, 1983) and the revised Wechsler Preschool and Primary Scale of Intelligence (WPPSI-R; Wechsler, 1989). Children aged 6 years were also given the Arithmetic subtest of the Wechsler Intelligence Scale for Children, 3rd edition (Wechsler, 1991). To qualify for the study, children were required to score at the 98th percentile or above on at least one measure, that is, at least 130 on the K-ABC or 16 on a Wechsler measure, but slightly lower scores were accepted for 4 boys for whom there was compelling evidence of special interest or knowledge. Testers were experienced psychometrists, graduate students in educational psychology, and Nancy M. Robinson.

Of the 778 children whose parents agreed to participate, 348 met the inclusion criteria. Our target, based on the sample sizes needed for a subsequent intervention, was originally 77 boys and 77 girls at each grade level. All eligible girls were included in the final sample, but the kindergarten female group remained below quota ($n = 61$) despite protracted recruitment efforts. Substantially more boys than girls were both nominated and met the criteria for inclusion, particularly in first grade, so we randomly dropped 9 kindergarten and 29-first grade boys, which resulted in 61 kindergarten girls, 78 kindergarten boys, 77 first-grade girls, 94 first-grade boys, and a total of 310 children in the final sample.

Administration of Cognitive Measures

Between July and October of the same year, as they were entering kindergarten or first grade, the 310 selected children were given an extensive battery of psychometric measures, listed and briefly described in Table 1. Subtests were administered in a fixed order, usually in one session with breaks as needed. As during screening, testers were experienced psychometrists, graduate students in school psychology, and Nancy M. Robinson. All protocols were checked twice for accuracy of scoring.

The measures included the battery were chosen to represent quantitative, verbal, and visual–spatial domains. One measure in each domain tapped working memory. Most of the measures were drawn from well-known, nationally standardized instruments with satisfactory reliability and validity and therefore are not further described here. Four measures are, however, not standardized and require description.

Two measures of numerical understanding were drawn from the work of Okamoto and Case (Okamoto 1992a; Okamoto & Case, 1996), building on Case's (1985, 1992) neo-Piagetian theory of the role of conceptual structures in children's arithmetic competence. These structures, which constitute powerful organizing schemata within a domain such as mathematics, develop recursively in stages, permitting increasingly complex higher order organizations of units and operations, first tentatively coordinated and then integrated, each level leading eventually to a new transition.

The Number Knowledge Test (Okamoto & Case, 1996) consists of 36 items divided into five levels corresponding roughly to the competence demonstrated by normally developing 4-, 6-, 8-, 10-,

Table 1
Cognitive Measures Administered

Measure
Quantitative
Stanford–Binet IV: Quantitative (Thorndike, Hagen, & Sattler, 1986: miscellaneous word problems)
Stanford–Binet IV Number Series (predicting next two items in a series of numbers)
Key Math, Revised: Numeration (Connolly, 1988: enumeration, counting, place value)
Key Math, Revised: Geometry (shapes, patterns, specialized terms)
Key Math, Revised: Problem Solving (word problems)
Woodcock–Johnson, Revised: Calculation (Woodcock & Johnson, 1989, 1990: mixed written calculation problems)
Number Knowledge[a] (Okamoto & Case, 1996)
Word Problems[a] (Okamoto, 1992a)
Counting Span[a] (Case, 1985)
Verbal
Stanford–Binet IV: Vocabulary (definitions)
Stanford–Binet IV: Comprehension (practical reasoning)
Stanford–Binet IV: Memory for Sentences (immediate repetition of sentences)
Visual–spatial
Stanford–Binet IV: Pattern Analysis (copying designs with patterned cubes)
Stanford–Binet IV: Matrices (choosing which of 5 alternatives would complete 2 × 2 and 3 × 3 matrices; deciphering letter placement in complex matrices)
Visual–Spatial Span[a] (Crammond, 1992)

[a] Nonstandardized measures described in text.

and 12-year-olds. The items tap mastery of the number system in terms of functions such as comparison and operations (at the highest level, e.g., "Which is closer to 1: −0.2 or 1.8?" "How much is 248 divided by 4?").

The Word Problems subtest (Okamoto, 1992a) consists of 16 problems presented verbally by the examiner as well as by visual words and pictures. The word problems are organized into three levels representing increasing complexity in change, combine, and comparison functions. For example, at Level 3, the child is asked, "There are 9 roses. There are 3 more roses than tulips. How many tulips are there?" The highest level was reported by Okamoto (1992b) to correspond to approximately fourth-grade competence. All items were administered; the child's score was the total correct.

The Counting Span Test (Case, 1985) materials comprise 18 sets of 21.6 cm × 29.2 cm pages, three trials at each of six levels consisting of one to six pages per item. On each page, a number of randomly arrayed yellow and green dots are placed. Children were instructed to touch and count only the green dots and to recall each number in order after the last page had been shown.

The Visual–Spatial Span Test (Crammond, 1992) consists of a series of 4 × 4 matrices (2 cm × 2 cm cells) presented on successive notebook pages of standard (21.6 cm × 29.2 cm) size. The 15 stimuli consisted of three sets at each of five successive levels, each level presenting 1 more black cell than the level before, for a maximum of 5 black cells in the matrix of 16 cells. No symmetrical patterns were included. After a sample trial, each matrix was exposed for 2 s, after which a blank matrix was exposed on which the child recorded the black cells. Testing continued through Level 5 or until the child missed all three items at a single level. The child's score was the total number of items correct.

Results

Screening Procedures and Sample Selection

The results of the screening procedures are summarized in Table 2. Note that because some children were accepted on the basis of previously administered Wechsler scores, not all participants were administered the K-ABC. Unless children qualifying by reported WPPSI-R scores had been tested in our center, their scores were omitted from this analysis.

Kindergartners as a group earned higher standard scores on the K-ABC subtest than did preschoolers. Boys' standard scores were higher than girls' on both the K-ABC and WPPSI-R subtests and at both grade levels.

Percentages of nominees by racial and ethnic background were as follows, with figures for the selected sample in

Table 2
Sample Sizes, Means of Standard Scores, Standard Deviations, and Two-Way Analyses of Variance of Screening Measures

	Group								
	Preschool		Kindergarten		Grade[a]		Gender[a]		Interaction[a]
Measure	Girls	Boys	Girls	Boys	*F*	ES	*F*	ES	*F*
WPPSI-R									
N	143	167	201	248					
M	13.2	13.9	13.6	14.1	2.05	.11	6.34*	.19	.03
SD	3.0	3.2	3.0	3.1					
K-ABC									
N	125	149	199	242					
M	111.8	116.6	116.1	120.2	19.68***	.34	21.45***	.36	.22
SD	11.2	13.9	11.4	13.0					

Note. ES = effect size; WPPSI-R = Wechsler Preschool and Primary Scale of Intelligence—Revised; K-ABC = Kaufman Assessment Battery for Children.

[a] ES = $(M_1 - M_2)/(MSE)^{1/2}$.

*$p < .05$. ***$p < .001$.

parentheses: 76% (73%) Caucasian, 12% (15%) Asian, 6% (5%) African American, 3% (4%) Hispanic, 1% (1%) Native American, 2% (1%) other. Boys represented 55% of the 321 preschool and 55% of the 457 kindergarten nominees.

Parental education was high for both nominees and selected children. Fathers of nominees reported a mean of 17.0 years of education (*SD* = 3.0); mothers reported a mean of 16.3 years (*SD* = 2.7). Means were slightly higher for the parents of the final sample: fathers, 17.4 years (*SD* = 2.8); mothers, 16.9 years (*SD* = 2.6).

Test Performance of Selected Group

Table 3 describes the sample characteristics by grade and gender as well as the means, standard deviations, and results of the two-way analyses of variance (based on Type III sums of squares) conducted on the psychometric measures administered to the 310 children selected to participate in the study. Age-normed standard scores are reported wherever possible. They are not available for the Key Math (KM) Problem Solving because the children were too young; they are also unavailable for Number Knowledge, Word Problems, Counting Span, and Visual–Spatial Span. Grade differences on these raw score measures were therefore to be expected.

For the group as a whole, performance was advanced not only on the measures of mathematical abilities but on the other measures as well. Mean standardized scores on the quantitative subtests of the Stanford–Binet (SB) were 1 to 1.4 standard deviations above the mean of the norming group and 1.4 to 2 standard deviations above the mean of the norming group on KM and Woodcock–Johnson (WJ) quantitative subtests. Mean scores on the verbal and visual–spatial subtests of the SB were approximately 1 standard deviation above the mean of the norming group.

Gender Differences

As noted above, our recruitment yielded a higher number of male nominees and qualifiers at both grade levels, despite reminders to nominators to consider girls and our specific recruitment of kindergarten girls.

Note, in Table 3, that gender differences, where found, tended to be confined to the mathematics subtests and the visual–spatial working memory span task but not the other visual–spatial tasks or the verbal tasks. Only 1 of the 17 Grade × Gender interactions reached the .05 level of significance.

Because gender differences in adolescents and young adults have been reported to be most pronounced at the upper ranges of ability, we also examined the proportion of girls and boys whose scores were highest within our distribution. Table 4 presents the percentage of boys scoring within about the top 5% of our group on each measure. Because slightly more than half the children in both grades received top scaled scores of 19 on KM Numeration, and 22% of kindergartners and 36% of the first graders received scaled scores of 19 on KM Geometry, we show raw scores for these subtests. Tests of the significance of the difference between proportions (both chi-square and Fisher exact) show overrepresentation of boys among highest scorers on the mathematics subtests. Significant differences in the proportion of boys among top scorers were not demonstrated on the verbal and visual–spatial subtests.

Organization of Cognitive Abilities

Using multiple-group structural equation modeling (Abbott & Berninger, 1993; Bentler, 1992) of the raw scores corrected for age, we examined the relationships among the quantitative, verbal, and visual–spatial measures, separately for kindergartners and first graders and for boys and girls. The specific aims were to examine the organization of cognitive abilities in these groups as well as to examine possible developmental and gender differences.

We investigated the organization of cognitive abilities by examining the fit of different factor structures using multiple-group confirmatory factor analysis of (a) the covariance matrices for kindergartners and first graders and (b) the covariance matrices for boys and girls. To adjust for variations in age, age in days was partialed out of the zero-order correlation matrices. Because of the restriction of range due to a floor effect (see Table 3), Number Series was omitted from this analysis. The screening measures were also omitted because of their restricted range.

The correlations among the 14 measures for kindergartners (n = 129) and first graders (n = 162) and standard deviations are shown in Table 5. Correlations have been reported to four decimal places for archival purposes so that others can reanalyze the data based on the covariances among the indicators (Bentler, 1992).

The results from the multiple-group confirmatory factor analysis are shown in Table 6. Included in the first column of Table 6 is the information about which factors were modeled. As shown in Table 6, indicators of the quantitative factor included the SB Quantitative, KM Numeration, KM Geometry, KM Problem Solving, WJ Calculation, Word Problems, Number Knowledge, and Counting Span. Indicators of the verbal factor included SB Vocabulary, SB Comprehension, and SB Memory for Sentences. Indicators of the visual–spatial factor included SB Pattern Analysis, SB Matrices, and Visual–Spatial Span.

Because Z statistics greater than 2.0 are statistically significant at $p < .05$, each of the indicators has a significant factor loading (standardized path coefficient) with its factor. In the unconstrained multiple-group model the factor loadings and correlations among the factors were freely estimated for kindergartners and first graders. The $\chi^2(148, N = 291) = 234.3$ and the comparative fit index was .94 (Bentler, 1990), indicating an excellent fit of this model to the data. The visual–spatial factor showed much stronger relationships with the quantitative factor than did the verbal factor, and, in turn, the visual–spatial and verbal factors were only weakly correlated. Most of the subtests demonstrated high factor loadings.

To examine whether the factor structures for the two age

Table 3
Sample Sizes, Means of Standard Scores, Standard Deviations, and Two-Way Analyses of Variance of Scores of Selected Children on Tests in Battery

	Group								
	Preschool		Kindergarten		Grade[a]		Gender[a]		Interaction
Measure	Girls (*n* = 61)	Boys (*n* = 78)	Girls (*n* = 77)	Boys (*n* = 94)	*F*	ES	*F*	ES	*F*
				Math					
SB Quantitative									
M	62.4	60.7	60.7	61.0	1.42	.14	1.07	.12	2.42
SD	4.6	5.4	5.3	6.2					
SB Number Series									
n	29	49	69	92					
M	55.7	57.3	59.3	62.0	20.26***	.65	6.48*	.37	.02
SD	5.2	6.8	6.4	7.6					
KM Numeration									
M	16.7	17.3	16.2	17.3	.55	.09	8.41*	.34	.25
SD	2.6	2.3	2.6	2.6					
KM Geometry									
M	14.7	14.1	15.6	15.5	9.65**	.36	1.46	.14	1.07
SD	3.3	3.7	3.1	3.3					
KM Problem Solving									
M	1.4	1.9	2.9	4.4	83.07***	1.05	21.00***	.53	4.46*
SD	1.0	1.6	1.6	2.7					
WJ Calculation									
M	118.0	121.5	122.1	129.0	10.34**	.37	8.87**	.34	.58
SD	14.9	17.8	14.1	16.5					
Number Knowledge									
M	13.1	15.0	19.6	22.8	172.30***	1.53	23.24***	.56	1.50
SD	2.5	4.8	4.4	5.4					
Word Problems									
M	2.8	5.0	8.5	10.4	167.87***	1.50	24.60***	.57	.06
SD	2.4	4.0	4.0	3.8					
Counting Span									
M	5.0	5.5	6.7	7.2	70.80***	.97	6.15*	.29	.00
SD	1.3	1.7	1.9	1.9					
K-ABC Arithmetic (screen)									
n	43	65	78	85					
M	120.6	126.8	123.7	130.3	5.93*	.30	20.02***	.56	.14
SD	8.4	10.2	8.5	11.1					
WPPSI-R Arithmetic (screen)									
M	15.7	16.2	16.2	16.4	2.83	.19	3.53	.22	.21
SD	1.6	2.0	1.8	2.0					
				Verbal					
SB Vocabulary									
M	60.7	59.7	60.4	59.1	1.06	.12	2.20	.17	.07
SD	6.6	7.7	6.3	6.6					
SB Comprehension									
M	59.5	58.6	60.6	59.8	.82	.10	.99	.11	.15
SD	6.8	5.9	6.8	8.2					
SB Sentences									
M	59.9	57.7	59.8	59.5	.22	.05	2.47	.18	2.24
SD	8.3	8.8	6.9	8.0					
				Visual–Spatial					
SB Pattern Analysis									
M	58.0	58.4	60.6	60.9	7.85**	.32	.16	.05	.01
SD	7.3	7.7	7.8	9.3					

Table 3 (*continued*)

Measure	Group: Preschool: Girls (n = 61)	Group: Preschool: Boys (n = 78)	Group: Kindergarten: Girls (n = 77)	Group: Kindergarten: Boys (n = 94)	Grade[a] F	Grade[a] ES	Gender[a] F	Gender[a] ES	Interaction F
SB Matrices									
M	59.2	58.3	59.7	59.7	2.63	.19	.13	.04	.05
SD	5.7	5.1	6.5	7.2					
Visual–Spatial Span									
M	3.5	4.3	5.7	6.1	61.93***	.91	6.55*	.29	.58
SD	1.8	1.9	2.4	2.5					

Note. Average test age for preschool girls and boys was 5.4 and 5.6 years, respectively. Average test age for kindergarten girls and boys was 6.5 and 6.5 years, respectively. The *n*s vary only slightly by subtest except as noted. Note how few kindergartners solved any Stanford–Binet Number Series items. According to the manual, zero scores are considered inaccurate and are therefore treated as missing data. ES = effect size; SB = Stanford–Binet; KM = Key Math; WJ = Woodcock–Johnson; K-ABC = Kaufman Assessment Battery for Children; WPPSI-R = Wechsler Preschool and Primary Scale of Intelligence.

[a] $\mathrm{ES} = (M_1 - M_2)/(\mathrm{MSE})^{1/2}$.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

groups differed, a second multiple-group factor analysis was run with the factor loadings of each indicator and the covariances among the three factors constrained equal for kindergartners and first graders. For this constrained model, $\chi^2(165, N = 291) = 295.5$, and the comparative fit index was .91. The difference in chi-square between the constrained and the unconstrained was 61.2 ($df = 17$, $N = 291$, $p < .001$). Follow-up Lagrangian multiplier tests (Bentler, 1992) indicated that the following constraints accounted for most of the decrease in fit: (a) the correlation

Table 4

Percentage of Boys Among Highest Approximately 5% of This Group on Screening and Battery Subtests

Subtest	Kindergarten: % boys	Kindergarten: Top %	Kindergarten: χ^2	Kindergarten: p[a]	First grade: % boys	First grade: Top %	First grade: χ^2	First grade: p[a]
Screen (total group)								
K-ABC Arithmetic (SS)	87	6	5.82	.02	76	6	5.16	.02
WPPSI-R Arithmetic (SS)	75	3	1.47	.30	76	4	3.10	.08
Math								
SB Quantitative (SS)	75	6	1.08	.26	75	5	1.40	.29
SB Number Series (SS)	83	8	1.24	.40	82	7	2.95	.12
Key Math Numeration (raw)	86	5	2.49	.24	88	5	3.60	.07
Key Math Geometry (raw)	100	4	3.93	.07	75	5	1.37	.30
Key Math Problem Solving (raw)	100	4	3.98	.07	100	3	4.23	.06
WJ Calculation (SS)	100	5	5.58	.02	100	5	7.79	.00
Number Knowledge (raw)	100	6	6.58	.01	83	7	4.03	.04
Word Problems (raw)	100	5	5.65	.02	71	4	0.77	.46
Counting Span (raw)	82	8	3.02	.11	73	6	1.51	.35
Verbal								
SB Vocabulary (SS)	83	4	1.78	.24	40	3	.46	.66
SB Comprehension (SS)	40	4	.61	.65	67	5	.53	.52
SB Memory for Sentences (SS)	62	6	.09	1.00	62	6	.19	.73
Visual–Spatial								
SB Pattern Analysis (SS)	62	6	.09	1.00	70	6	.94	.51
SB Matrices (SS)	50	6	.55	.70	75	5	1.37	.30
Visual–Spatial Span (raw)	57	5	.00	1.00	67	3	.35	.69

Note. These figures represent the highest scoring children on each subtest, according to standard scores (SS), except as noted. The proportion closest to the top 5% is shown. For Key Math Numeration and Geometry, so many children attained the top standard score (19) that we show the raw scores. Boys constituted 55% of both the kindergarten and first-grade samples. K-ABC = Kaufman Assessment Battery for Children; WPPSI-R = Wechsler Preschool and Primary Scale of Intelligence—Revised; SB = Stanford–Binet; WJ = Woodcock–Johnson.

[a] Fisher's exact test, two-tailed.

Table 5

Correlations Among Measures and Standard Deviations for Kindergarteners (n = 129 Below Diagonal) and First Graders (n = 162 Above Diagonal)

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	*SD*
V1	—	.4641	.3556	.5000	.4278	.3071	.4307	.2041	.2126	.0483	.1452	.2165	.3031	.2290	1.94
V2	.2197	—	.2782	.6068	.6569	.6438	.7220	.2397	.1490	.0777	.1295	.2203	.2963	.2675	3.64
V3	.3158	.3027	—	.2639	.1948	.3187	.2627	.1625	.1645	.1810	.1665	.2785	.2950	.1252	2.72
V4	.1893	.5034	.2954	—	.6768	.5317	.6868	.2751	.1366	.1047	.0785	.2307	.2988	.3281	2.42
V5	.1675	.4474	.1731	.6099	—	.5787	.7418	.3268	.1084	.0365	.0788	.3329	.2938	.2967	4.20
V6	.3342	.5673	.2607	.5128	.5814	—	.3260	.3045	.2686	.1714	.2686	.3088	.3059	.2630	4.00
V7	.3171	.6528	.2666	.6197	.6370	.7473	—	.2971	.1258	.0714	.0937	.2362	.3170	.3052	5.23
V8	.1970	.4174	.1641	.3849	.4275	.4463	.5119	—	.0256	−.1024	.0872	.2836	.2313	.3273	1.91
V9	.3644	.0450	.2399	.2024	.1458	.2308	.1952	.1241	—	.4572	.3691	.1314	.1670	.0944	2.19
V10	.2838	.0740	.2043	.1882	.0970	.1942	.2150	−.0124	.6053	—	.2290	.0615	.0382	−.0559	2.51
V11	.3538	.0276	.2174	.0726	.0353	.2180	.2060	.1393	.5878	.4654	—	.1474	.0581	.1191	3.40
V12	.2477	.3487	.2003	.2900	.3943	.2698	.3642	.3298	.1628	.0426	.0279	—	.2684	.3960	5.58
V13	.2054	.2981	.2145	.3562	.2995	.3360	.2858	.2784	.0418	.0162	.0652	.2625	—	.3112	4.13
V14	.2221	.3809	.3108	.2193	.3779	.2876	.3889	.4161	.1221	.0271	.0485	.3395	.0779	—	2.48
SD	1.71	2.72	3.02	1.38	4.06	3.48	4.03	1.54	2.84	2.82	4.00	4.82	2.99	1.89	—

Note. V1 = Stanford–Binet (SB) Quantitative; V2 = Key Math Numeration; V3 = Key Math Geometry; V4 = Key Math Problem Solving; V5 = Woodcock–Johnson Calculation; V6 = Word Problems; V7 = Number Knowledge; V8 = Counting Span; V9 = SB Vocabulary; V10 = SB Comprehension; V11 = SB Memory for Sentences; V12 = SB Pattern Analysis; V13 = SB Matrices; V14 = Visual–Spatial Span.

between spatial and quantitative factors is significantly greater, $\chi^2(1, N = 291) = 5.75$, $p < .016$, in the kindergarten sample (.89) than in the first-grade sample (.64); (b) the factor loading for Memory for Sentences is significantly greater in the kindergarten sample than in the first-grade sample, $\chi^2(1, N = 291) = 5.15$, $p < .023$; and (c) the factor loading for KM Problem Solving is significantly greater in the first-grade sample than in the kindergarten sample, $\chi^2(1, N = 291) = 18.60$, $p < .001$.

Table 7 shows the correlations among the 14 measures for girls ($n = 127$) above the diagonal and the correlations for boys ($n = 164$) below the diagonal, as well as the standard deviations.

The results from the multiple-group confirmatory factor analysis for boys and girls are shown in Table 8. Factors are listed as for Table 6.

Each of the indicators has a significant factor loading (standardized path coefficient) with its factor. In the unconstrained multiple-group model, the factor loadings and correlations among the factors were freely estimated for boys and girls. The $\chi^2(148, N = 291) = 226.7$, and the compar-

Table 6

Standardized Path Coefficients and Test Statistics (Z) for Confirmatory Factor Analysis for Kindergarten and First-Grade Children

Relationship	Kindergarten Path	Kindergarten *Z*	First grade Path	First grade *Z*
Factor → measure				
Quantitative → SB Quantitative	.37	4.11	.54	7.18
Quantitative → Key Math Numeration	.71	8.96	.82	12.19
Quantitative → Key Math Geometry	.35	3.91	.34	4.28
Quantitative → Key Math Problem Solving	.70	8.72	.79	11.62
Quantitative → WJ Calculation	.72	9.15	.83	12.63
Quantitative → Word Problems	.82	10.78	.72	10.27
Quantitative → Number Knowledge	.89	12.50	.87	13.50
Quantitative → Counting Span	.58	6.94	.37	4.65
Verbal → SB Vocabulary	.87	10.02	.86	6.89
Verbal → SB Comprehension	.70	7.97	.53	5.29
Verbal → SB Memory for Sentences	.68	7.70	.43	4.61
Visual–Spatial → SB Pattern Analysis	.54	5.46	.57	6.20
Visual–Spatial → SB Matrices	.42	4.27	.54	5.85
Visual–Spatial → Visual–Spatial Span	.50	5.10	.62	6.76
Factor intercorrelations				
Quantitative ↔ Verbal	.28	2.99	.23	2.45
Quantitative ↔ Visual–spatial	.89	9.79	.64	8.06
Verbal ↔ Visual–spatial	.21	1.56	.24	2.15

Note. SB = Stanford–Binet; WJ = Woodcock–Johnson.

Table 7
Correlations Among Measures and Standard Deviations for Boys (n = 164 Below Diagonal) and Girls (n = 127 Above Diagonal)

Variable	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	*SD*
V1	—	.3775	.1940	.2342	.1997	.3106	.3454	.0877	.3006	.2344	.1580	.1497	.2186	.1256	1.53
V2	.4089	—	.2615	.4951	.6227	.5281	.6280	.1912	.1118	.0303	.0616	.3144	.3412	.2795	3.29
V3	.3781	.3134	—	.1359	.0798	.2836	.1212	.1067	.1448	.1319	.0387	.1225	.1328	.1397	2.82
V4	.4685	.5686	.3210	—	.5333	.5411	.5605	.1355	.2140	.1314	.1174	.2851	.2357	.1954	1.53
V5	.3655	.5329	.2537	.6530	—	.5203	.5981	.2876	.1736	.0929	.1626	.4182	.3329	.2938	3.93
V6	.3449	.6450	.3266	.4988	.5972	—	.5457	.3718	.2169	.1272	.2491	.3770	.3324	.3281	4.37
V7	.4221	.7151	.3346	.6795	.7257	.7006	—	.2205	.2850	.1446	.2386	.2777	.2437	.2803	4.98
V8	.2428	.3017	.2085	.3522	.3980	.3088	.4124	—	.1439	.0313	.1718	.3441	.2188	.3621	1.89
V9	.2280	.1567	.2381	.1741	.1386	.2745	.1372	.0206	—	.5527	.4570	.0418	.0099	.0822	2.55
V10	.1170	.1408	.2327	.1638	.0852	.2523	.1593	−.1153	.5232	—	.3280	−.0761	−.0328	−.0187	2.89
V11	.2580	.1222	.2653	.0739	−.0081	.2754	.1106	.0081	.5026	.3616	—	.0841	−.0578	.1234	3.55
V12	.2746	.2594	.3121	.2375	.3335	.3122	.2919	.2552	.2217	.1449	.0983	—	.2480	.4212	5.46
V13	.2876	.3067	.3237	.3678	.2948	.3270	.3633	.2622	.1835	.0772	.1208	.2811	—	.2692	3.71
V14	.2925	.3086	.2467	.3494	.3465	.2904	.3602	.3379	.1423	−.0034	.0808	.3465	.2317	—	2.48
SD	2.23	4.36	3.56	2.64	5.40	4.76	6.48	2.00	2.69	2.95	4.06	6.03	4.10	2.42	—

Note. V1 = Stanford–Binet (SB) Quantitative; V2 = Key Math Numeration; V3 = Key Math Geometry; V4 = Key Math Problem Solving; V5 = Woodcock–Johnson Calculation; V6 = Word Problems; V7 = Number Knowledge; V8 = Counting Span; V9 = SB Vocabulary; V10 = SB Comprehension; V11 = SB Memory for Sentences; V12 = SB Pattern Analysis; V13 = SB Matrices; V14 = Visual–Spatial Span.

ative fit index was .94, indicating an excellent fit of this model to the data.

To examine whether the factor structures for boys and girls differed, a second multiple-group confirmatory factor analysis was run with the factor loadings of each indicator and the covariances among the three factors constrained equal for girls and boys. For this constrained model, $\chi^2(165, N = 291) = 263.9$, and the comparative fit index was .92. The difference in chi-square between the constrained and the unconstrained was 37.2 ($df = 17, N = 291, p < .05$), indicating that the factor loadings and the correlations among the factors were highly similar for boys and girls. Follow-up Lagrangian multiplier tests (Bentler, 1992) indicated that the following constraint accounted for most of the decrease in fit: The correlation between verbal and spatial factors is significantly greater, though modest, for the boys (.36) than for the girls (.07), $\chi^2(1, N = 291) = 4.21$, $p < .05$.

Discussion

To our knowledge, this study is the first effort to identify and describe mathematical advancement at so early an age. This study yields convincing evidence that such children can be identified by their parents and teachers and that as a group such children tend to be almost as advanced in verbal and visual–spatial skills on psychometric measures as on measures of mathematical skills (see Table 3). Although boys' level of performance was higher on measures of mathematical skills and visual–spatial working memory span, the underlying relationships among cognitive factors were for the most part similar in girls and boys, with the exception that, for the boys, the correlation between verbal and spatial factors ($r = .36$) was greater than for the girls ($r = .07$).

Identification

Parents identified 778 children who were then in preschool or kindergarten. When these children were seen in our laboratory, the mean scores of each subgroup were at least 1 standard deviation above the mean of the general population, with the exception of the preschool girls' scores on the K-ABC, which were about 0.8 standard deviations above the general norms. Similar to the results of our previous studies of toddlers who were verbally precocious (Robinson et al., 1990) and preschoolers thought to be gifted in a variety of domains (Robinson & Robinson, 1992), the method of parent nomination in response to community advertising appears to yield an appropriate population for study. We cannot, of course, know how many children we missed who were equally or even more advanced. The advanced educational level of the parents is not unexpected but, despite our efforts to encourage nominations from Head Start and similar organizations, we may have missed children in lower socioeconomic groups.

Table 8
Standardized Path Coefficients and Test Statistics (Z) for Confirmatory Factor Analysis for Girls and Boys

Relationship	Girls		Boys	
	Path	Z	Path	Z
Factor → measure				
Quantitative → SB Quantitative	.41	4.52	.51	6.78
Quantitative → Key Math Numeration	.77	9.68	.77	11.32
Quantitative → Key Math Geometry	.25	2.71	.41	5.29
Quantitative → Key Math Problem Solving	.68	8.21	.76	11.10
Quantitative → WJ Calculation	.76	9.57	.79	11.71
Quantitative → Word Problems	.74	9.16	.76	11.20
Quantitative → Number Knowledge	.78	9.91	.90	14.52
Quantitative → Counting Span	.36	3.90	.46	5.98
Verbal → SB Vocabulary	.87	8.45	.87	9.68
Verbal → SB Comprehension	.63	6.51	.60	7.12
Verbal → SB Memory for Sentences	.53	5.52	.58	6.88
Visual–spatial → SB Pattern Analysis	.64	6.35	.54	6.03
Visual–spatial → SB Matrices	.49	4.84	.53	5.92
Visual–spatial → Visual–Spatial Span	.57	5.74	.55	6.13
Factor intercorrelations				
Quantitative ↔ Verbal	.33	3.33	.27	3.09
Quantitative ↔ Visual–spatial	.73	8.60	.76	10.07
Verbal ↔ Visual–spatial	.07	0.53	.36	3.25

Note. SB = Stanford–Binet; WJ = Woodcock–Johnson.

Relationships Among Cognitive Abilities

The means reported in Table 3 reveal that, on all the standardized measures, the children in this study demonstrated advancement. On the SB subtests, mean performance hovered around 1 standard deviation above the mean, or the 84th percentile, in all domains. On the KM measures, advancement was even more pronounced, with mean scaled scores 1.7 to more than 2 standard deviations above the mean, and in WJ Calculation scores, performance was approximately 1.5 standard deviations above the population mean.

Ordinarily, such across-the-board advancement would suggest the operation of a general, or g-factor, cognitive ability, but the results of the structural equation modeling suggest that, even at this age, relatively coherent, nonredundant underlying factors have emerged. With highly gifted adolescents, similarly, evidence has been found for greater differentiation than in the general population (Benbow et al., 1983).

Within our group, correlations were strongest between visual–spatial and mathematical skills, as expected by some authors (Benbow, 1988; Casey et al., 1995; Geary, 1994) but not by others (Friedman, 1995). The correlations between verbal and mathematical abilities and between visual–spatial and verbal abilities were of considerably lower magnitude. It should be noted that the visual–spatial skills tapped here were measured by two-dimensional reasoning tasks that would have been excluded by Friedman (1989, 1995) in favor of three-dimensional visualization tasks, whereas other factor analysts such as Carroll (1993) include such tasks in a spatial visualization factor.

Even though scores on the three working memory subtests were modestly correlated with one another, our data for younger children are consistent with those of Dark and Benbow (1991) that working memory is domain specific for quantitative tasks. Counting Span loaded on the quantitative factor, Visual–Spatial Span loaded on the visual–spatial factor, and another memory task, Memory for Sentences, loaded on the verbal factor. The model we tested accounted for these relationships by factor intercorrelations rather than cross-factor correlations.

The period of kindergarten to first grade may be too brief to yield developmental trends in differentiation of abilities, but we did note that the relationship between spatial and mathematical abilities was significantly lower in the older group than the younger, suggesting increased differentiation. Even so, the coherence of the quantitative factor even in the younger group suggests that to some extent precocity in young children is accompanied by early differentiation of abilities. We had been led to a similar conclusion by the results of a 5-year study (Dale et al., 1995) of children who had been verbally precocious as toddlers and who continued to show specific advancement in verbal abilities. It has been suggested that the high correlation between verbal and mathematical skills seen in older students may be a produc of common educational experience (Friedman, 1995), and i may be that the picture seen prior to formal schooling reflects a different sort of experiential effect.

Gender Differences

Gender differences were apparent in every analysis. Mor boys than girls were nominated; of those nominated, mor boys than girls qualified; and, on the psychometric battery boys' scores in the mathematical domain were significantl higher than the girls' on 8 of the 11 mathematical subtest When only the top 5% of the distributions of the scores wer examined, boys were significantly overrepresented on several of the mathematical subtests. For the boys, verbal an visual–spatial factors were more highly correlated, although, for the most part, the relationships among the cognitive subtests and factors were similar for boys and girls

This study was intended to evaluate whether gender di ferences observed in math-talented older children and ad lescents are also present in younger, math-talented childre The reasons for such gender differences are beyond t purview of the study. Our data do not suggest that paren are differentially overlooking their math-talented girls, b cause, if they had, the girls nominated for this study wou be expected to attain scores at least as high as the boys'

Geary (1994) and Benbow (1988) have tended to favor biological explanations for gender differences, although they clearly have not denied that social factors play a role as well (Saxe, Guberman, & Gearheart, 1987). Geary (1994) suggested that the underlying biological difference may reside in a visual-spatial male advantage derived on an evolutionary basis, with the advancement in mathematical reasoning therefore being secondary. Within our math-precocious group, the boys demonstrated no overall superiority in visual-spatial reasoning on the SB Pattern Analysis and Matrices subtests, although they did somewhat better than the girls on the visual-spatial working memory span subtest as well as the quantitative working memory span subtest. If anything, then, it may be that for this group working memory span played the more critical role.

Even though these mathematically precocious children are among the youngest examined in this way, they already have years of living behind them, thoroughly entangling nature and nurture. Boys may more frequently show early signs of interest in and ability with numbers and quantitative relationships; on the other hand, parents may be more sensitive to such cues from boys than girls. The experiences offered by parents, as well as the children's own play preferences (e.g., for activities involving countable objects vs. social play; Maccoby & Jacklin, 1974), surely interact with whatever biological propensities exist. Extensive further research will be needed to sort out the nature of such interactions.

Our study demonstrates that precocity in mathematical ability can indeed be identified at an early age. By implication, this finding suggests that educational adjustments may be imperative even in kindergarten to nurture such children's curiosity and excitement in a domain so critical.

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