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Development of Calculation Abilities in Middle- and Low-Income Children After Formal Instruction in School

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This study provides follow-up data on the development of calculation abilities in middle- and low-income children after formal instruction in first grade. Two conventional verbal calculation tasks (story problems, number-fact problems) and one nonverbal calculation task were used. Before formal instruction, middle-income kindergarten children performed better than low-income kindergarten children on both verbal calculation task, but the two income groups did not differ in performance on the nonverbal calculation tasks (Jordan, Huttenlocher, & Levine, 1992). After formal instruction in first grade, there still were no income group differences on the nonverbal calculation tasks. Moreover, there no longer were income group differences on number-fact problems. This finding was associated with the development of more effective calculation strategies among the low-income children. However, on story problems low-income children still performed more poorly than middle-income children. The findings show that even after formal instruction low-income children have difficulties with certain verbal arithmetic tasks.

This study provides follow-up data on the development of calculation abilities in young children from middle- and low-income families. In particular, we examined children's performance on verbal and nonverbal calculation tasks in first grade, after they had received formal instruction in addition and subtraction. In a prior study (Jordan, Huttenlocher, & Levine, 1992), the same children were given these calculation tasks in kindergarten, before they had been taught to add and subtract in school. The present study directly compares the calculation

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performance of middle- and low-income children in kindergarten with their performance in first grade.

Background

Research has shown that young children, regardless of socioeconomic background, develop a rich array of quantitative abilities before formal instruction in school (Ginsburg & Russell, 1981). For example, children from both middle- and low-income families learn essential counting principles, such as set enumeration, order invariance, and the cardinality rule, during early childhood. It is less clear, however, when young children from different socioeconomic backgrounds learn to calculate, which involves the transformation of sets by adding or subtracting elements. Although some studies report that children from different socioeconomic backgrounds develop early calculation abilities at about the same rate (Ginsburg & Russell, 1981), other studies report that middle-income children develop calculation abilities earlier than children from low-income or working-class families (Hughes, 1986; Saxe, Guberman & Gearhart, 1987). These apparently discrepant findings may be attributable to the use of experimental calculation tasks that differed in terms of verbal requirements and the availability of object referents, two variables that can affect young children's mathematical performance (Gelman & Gallistel, 1978; Levine, Jordan & Huttenlocher, 1992).

Investigations of language learning in early childhood have shown that young middle-income children are more skilled than their low-income peers in processing language that is "decontextualized" (i.e., abstract and remote vs. in the hear-and-now) and that middle-income children are more frequently exposed to such decontextualized language at home (Snow, 1983). These findings suggest that arithmetic calculation tasks using decontextualized language and conventional verbal procedures may present particular problems for young children from low-income families. For example, number-fact problems (e.g., "How much is 3 and 2?") and story problems (e.g., "Mike had 3 balls. He got 2 more. How many balls did he have altogether?") require children to understand and generate conventional verbal labels for numbers, to understand words for operations, and to comprehend various syntactic structures (Carpenter, Hiebert & Moser, 1981; Levine et al., 1992; Riley, Greeno, & Heller, 1983). A lack of this conventional knowledge might result in failure to solve a verbal calculation problem, even though the child may have an understanding of the numerical transformation involved in the problem.

In an initial developmental study, we compared the ability of 4-, 5-, and 6-year-olds to perform a nonverbal calculation task to their ability to perform verbal calculation tasks, that is story problems and number-fact problems (Levine et al., 1992). The nonverbal calculation task eliminated some of the sources of difficulty that may mask underlying abilities in calculation (e.g., use of number words or relational terms, lack of object referents). First, the child was shown a set of disks that was then hidden under a box. The child then watched the experimenter transform the set either by adding or subtracting disks through an opening in the side of the box. The transformed set was not revealed. The child's task was to construct an array that contained the same number of disks that were under the cover following the transformation. The experimenter did not use conventional number words nor was the child asked to generate them. This allowed us to examine children's calculation abilities on a completely nonverbal task. The story problems referred to object sets that were not physically present whereas the number-fact problems did not refer to concrete objects. On both story problems and number-fact problems, the experimenter's input and the child's output were verbal. Throughout the age range tested, it was found that children performed better on nonverbal problems than on story problems or number-fact problems. Children as young as 4 to 4 1/2 years of age achieved some success on nonverbal problems involving relatively small number sets. However, children did not achieve comparable levels of performance until 5 1/2 to 6 years of age on addition and subtraction story problems as well as on addition number-fact problems and not until 6 to 6 1/2 years of age on subtraction number-fact problems.

A subsequent study compared the performance of 5- to 6-year-old middle- and low-income children on nonverbal problems, story problems, and number-fact problems (Jordan et al., 1992). None of the children had received formal instruction in calculation in kindergarten. As expected, the middle-income children performed significantly better than the low-income children on story problems and number-fact problems. However, the middle- and low-income children did not differ on the nonverbal calculation task, even though neither group approached ceiling level performance. The findings suggest that the ability to carry out numerical transformations on the nonverbal calculation task does not depend on structured experiences from caregivers at home. Rather, such skills appear to develop through the child's own experiences with adding and subtracting objects in the world. In a more recent study (Huttenlocher, Jordan, & Levine, in press) we have found that the ability to calculate on the nonverbal task is related to overall intellectual competence. That is, children with mild intellectual impairments perform worse than children without such impairments on the nonverbal calculation task.

Although there has been considerable interest in the development of calculation abilities in children from different socioeconomic levels, no studies have compared performance on verbal and nonverbal calculation tasks before and after formal instruction. In the present study we reassessed the calculation performance of the same children who were tested in the study by Jordan et al. (1992), one year after the initial kindergarten evaluation. We expected that there would still be no income level differences on the nonverbal calculation task. We were especially interested, however, in the extent to which low-income children improve their performance on the conventional verbal calculation problems after formal instruction.

In addition to examining children's calculation accuracy on the three problem types, we recorded their methods of calculation on individual problems (e.g., using fingers, counting without fingers). Before first grade, Jordan et al. (1992) found middle-income children used their fingers to represent numerosities on the verbal calculation tasks more often than low-income children and that this was associated with higher performance levels. In fact, the low-income kindergarten children almost never used their fingers on any of the verbal problems. Neither income group used their fingers on the nonverbal task, most likely because the numerosities were represented with objects. By observing children's calculation methods in first grade as well as in kindergarten we were able to document the strategy changes during this important age period.

We also analyzed children's errors on the calculation tasks. In particular, we examined whether errors were in the right direction (i.e., greater than the augend for addition or less than the minuend for subtraction). This indicates whether children have an understanding of the effects of addition or subtraction operations, even if they do not reach a correct solution (Jordan et al., 1992; Levine et al., 1992).

METHOD

Subjects

The original sample consisted of 42 kindergarten children from low-income families and 42 kindergarten children from middle-income families. Within each income level there was an equal number of boys and girls. We retested 57% of the children in the low-income group (10 children moved out of the area, 4 children were retained in kindergarten, 3 children were placed in special education classrooms) and 76% of the children in the middle-income group (9 children moved out of the area, 1 child was retained in kindergarten). As a result, the present first-grade sample consisted of 24 low-income children (16 girls, 8 boys) and 32 middle-income children (19 boys, 13 girls).

All of the children in the present first-grade sample were between 6 and 7.5 years of age with a mean age of 6.94 years (SD = .29) for the low-income group and 6.88 years (SD = .37) for the middle-income group. The low-income children were drawn from four schools in New Brunswick, NJ. The middle-income children were drawn from three other schools in New Brunswick as well as from several schools in neighboring middle-class school districts. All of the children came from homes where English is the primary language. The schools from which the low-income children were drawn serve families living in government-subsidized housing projects. Qualification for subsidized housing is based on income for a family of a particular size. The low-income children came from families that qualified for the free or reduced-price lunch program in school, indicating that they were at the poverty level. The schools from which the middle-income children were drawn serve families from middle-income neighborhoods. The middle-income children did not live in subsidized housing projects nor did their families qualify for the free or reduced-price lunch program in school. Principals and teachers reported that the middle-income children's families were not characterized by economic difficulty.

According to school personnel, 43% of the low-income children and 12% of the middle-income children came from single-parent homes. (In several cases, a child's parental situation was not known. In calculating the percentages, we did not include these children.) It should be noted that the percentage of low-income children from single-parent homes decreased from 69% in the original kindergarten sample to 43% in the follow-up first-grade sample. The percentage of middle-income children from single-parent homes was the same for the original and present samples (12%). The ethnic composition for the middle-income children was 66% white, 22% black, 3% Hispanic, and 9% Asian. For the low-income children, the composition was 4% white, 88% black, and 8% Hispanic. This breakdown is similar to that observed in the initial study.

Questionnaires regarding the content of children's first-grade mathematics programs were given to the 13 teachers of the participating children. All of the teachers reported that they had taught children to solve both story and number-fact problems in school. They reported using a combination of drill (e.g., flashcards) and contextual learning with concrete manipulatives (e.g., blocks, chips, crayons, unfix cubes). Ten of the 13 teachers reported that they taught children to use their fingers for counting. The remaining three teachers, who taught a total of 12 middle-income children in the study, reported that they did not teach or encourage finger counting. This teaching difference will be considered in the Results section. According to teacher reports, conventional textbooks were used, and the scope and sequence of arithmetic instruction was similar for all of the children.

Materials and Procedure

Experimental Calculation Tasks. The set of addition and subtraction calculations given to the children in kindergarten was re-administered to each child in the same problem-type formats: (1) nonverbal problems, (2) story problems, and (3) number-fact problems. In the initial kindergarten study, children were given a fourth problem type, word problems (e.g., "How much are 3 apples and 2 apples?"). We did not include this problem type in the present study because children's performance on these problems did not differ significantly from their performance on either the story problems or the number-fact problems (see Jordan et al., 1992, for a detailed discussion).

In order to avoid ceiling effects, six problems were added to the original set of 14 calculations: one addition problem and one subtraction problem involving larger numerosities as well as four 3-term problems involving both addition and subtraction. (Pilot testing indicated that these additional problems are appropriate

TABLE 1
Calculations Given to Children on Each of the Three Problem Types

1 + 1
2 − 1
2 + 2
4 − 1
1 + 3
2 + 4
4 − 2
5 − 4
4 + 1
5 − 3
3 + 4
6 − 2
3 + 2
7 − 4
5 + 3
8 − 5
2 + 2 − 1
4 + 1 − 3
2 + 6 − 3
3 + 5 − 2

for children in the middle of first grade.) Table 1 shows the calculations that were given to the children. The calculations were the same for each problem type. The 14 original calculations were administered first, and their order was the same as that used in the initial study.

Materials for the *nonverbal calculation problems* included two 28 cm × 15 cm cardboard mats, a set of 20 black disks (1.9 cm in diameter), a box, and a cover. One of the sides of the cover had an opening so the experimenter could easily put in or take out the disks. The experimenter and the child sat on opposite sides of a table; each with a mat in front of him- or herself.

For addition problems, the experimenter placed the set of disks comprising the augend in a horizontal line on her mat and then covered it. The experimenter then put the set of disks comprising the addend in a horizontal line in full view of the child and slid them under the cover through the side opening, one at a time. The two terms of the problem were never simultaneously in view. The child then indicated how many disks were under the cover by placing the appropriate number of disks on his or her mat. The child selected the disks from an open box. A comparable procedure was used for subtraction problems, but in this case the disks comprising the subtrahend were removed from under the cover, one at a time. No verbal labels were provided on any of the problems, nor was the child asked to generate them.

The *story problems* were presented orally. The verbal content was intended to be as simple as possible. The addition story problems required children to join two sets of objects (e.g., "Beth has *m* balloons. Steve gives her *n* more balloons. How many balloons does Beth have altogether?"); the subtraction story problems required them to separate a set of objects (e.g., "Jack has *m* balloons. Diane takes away *n* of his balloons. How many balloons does Jack have left?"). The 3-term problems required children to join and then separate set of objects (e.g., "Jenny has *m* peanuts. Michael gives her *n* more peanuts. Then he takes *y* peanuts back. How many peanuts does Jenny have now?"). The same verbs and syntactic structures were used for all of the problems. The following objects were referred to once in an addition story problem and once in a subtraction story problem: apples, pennies, cookies, balloons, oranges, crayons, and marbles. The four 3-term problems referred to gumballs, candles, candy canes, and peanuts, respectively. The names of the actors were varied to sustain children's interest.

The *number-fact problems* also were presented orally. The experimenter read the addition number-fact problems as "How much is *m* and *n*?", the subtraction number-fact problems as "How much is *m* take away *n*?", and the 3-term problem as "How much is *m* and *n*, take away *y*?" Unlike the story problems, no reference was made to objects.

For both the story and the number-fact problems, the child was asked to respond to each item with a number word. The experimenter did not suggest strategies on any of the calculation tasks, allowing children to choose their own method for solving each problem. Upon request, or if the child clearly did not appear to be attending, the experimenter repeated a problem once. For each of the three experimental calculation tasks, the total possible score ranged from 0 to 20.

During the testing, the experimenter recorded the child's answer as well as the strategy used to solve each problem. The following categories were used, similar to those described by Siegler & Shrager (1984) and Levine et al. (1992): (a) fingers strategy, (b) counting strategy, and (c) unobserved strategy. Children were classified as using a *fingers* strategy if they explicitly counted on their fingers, either orally or by moving their fingers or head. Children were classified as using a *counting strategy* if they displayed counting behaviors without using their fingers (e.g., subvocalizing the number sequence, moving lips). Finally, children were classified as using an *unobserved strategy* when they answered without using their fingers and without counting overtly. In this case, children may have been retrieving the answer from memory, guessing, or using covert strategies (Siegler & Robinson, 1982; Geary & Burlingham-Dubree, 1989).

Achievement Tests. To examine general mathematics achievement in the two income groups, the Written Calculation and Applied Mathematics Problems subtests of the Woodcock—Johnson Tests of Achievement—Revised (WJTA-R; Woodcock & Johnson, 1989) were administered to each child. The Mathematics

Calculation subtest requires children to solve written number-fact problems, while the Applied Problems subtest requires them to solve various kinds of orally presented problems.

All of the tasks were administered to children individually in school. The order in which the three experimental calculation tasks were presented was counterbalanced within each income group. The calculation tasks were given in one 15 to 20-min session. The mathematics achievement tests were administered in another session, usually several weeks after the children were given the calculation tasks. The calculation tasks were given in February and March, and the achievement tests in March and April.

RESULTS

The mean calculation scores (percentage correct) broken down by problem type and income level are displayed in Table 2. Preliminary analyses showed that neither the main effects nor the interactions involving sex of subjects, operation, or order of presentation of the three calculation tasks were significant. Thus, these factors were eliminated from subsequent analyses.

An analysis of variance (ANOVA) was performed on children's calculation scores with income level (low vs. middle) as a between-subjects factor and problem type (nonverbal, story, number-fact) as a within-subjects factor. There were significant main effects of income level, $F(1, 54) = 4.57$, $p < .03$, and problem type, $F(2, 108) = 13.8$, $p < .0001$, as well as a significant Income Level × Problem Type interaction, $F(2, 108) = 4.48$, $p < .01$. Simple effects analyses showed that middle-income children performed significantly better than low-income children on story problems ($p < .001$); there were no effects of income level on either nonverbal problems or number-fact problems. Contrasts revealed no significant differences among the three problem types for the middle-income children. For the low-income children, story problems were more difficult than both nonverbal problems and number-fact problems ($p < .01$ in each case). Analysis of individual performance patterns showed that in first grade only 4% of the low-income children performed better on story problems than on number-fact problems, whereas in kindergarten 75% performed better on story problems than on number-fact problems.

TABLE 2
Mean Calculation Scores (Percentage Correct) by Problem Type and Income Level

	Low-Income	Middle-Income
Nonverbal problems	79 (15)	81 (10)
Story problems	66 (25)	81 (16)
Number-fact problems	81 (21)	88 (13)

Note. Standard deviations are in parentheses.

TABLE 3
Mean Calculation Scores (Percentage Correct) in Kindergarten for the Follow-Up and the Original Samples

	Follow-Up	Original
Low-Income		
Nonverbal problems	63 (20)	59 (19)
Story problems	37 (15)	35 (16)
Number-fact problems	22 (15)	23 (14)
Middle-Income		
Nonverbal problems	67 (14)	64 (18)
Story problems	59 (25)	55 (25)
Number-fact problems	53 (30)	49 (30)

Note. Standard deviations are in parentheses.

Kindergarten Performance of Children in the Follow-up Sample

As reported in the Method section, the rate of attrition between kindergarten and first grade was relatively high for the low-income children, and the percentage of low-income children from single-parent homes was smaller in the present follow-up sample than it was in the initial sample. Furthermore, some of the original low-income children were retained in kindergarten or placed in special education classrooms. Therefore, it is possible that the 24 low-income children in the follow-up sample showed a different pattern of performance on the experimental calculation problems in kindergarten than the whole group of 42 low-income children in the initial study. To address this issue, we performed an ANOVA on the kindergarten calculation scores of only the middle- and low-income children who participated in the follow-up study. The results showed the same pattern as that obtained for the entire group of children who were tested in the initial study. That is, a significant Income Level × Problem Type interaction, $F(2, 108) = 46.72$, $p < .0001$, indicated that in kindergarten the middle-income children performed significantly better than the low-income children on both story problems and number-fact problems ($p < .0001$ in both cases, simple effects analyses) but the two groups did not differ in performance on nonverbal calculation problems. The percentage correct scores for the follow-up ($n = 56$) and original samples ($n = 84$) in kindergarten were essentially the same (see Table 3).

Calculation Strategies

Table 4 shows the mean percentage of trials on which middle- and low-income first-grade children used finger, counting (without fingers), or unobserved strategies for each problem type. Also displayed for each problem type and income group is the mean percentage of trials on which a particular strategy, when applied, produced a correct answer. As noted earlier, three first-grade teachers who taught 12 of the middle-income children reported that they did not encour-

TABLE 4
Mean Percentage of Trials on Which a Strategy Was Used and Mean Percentage of Trials on Which a Strategy Produced a Correct Answer

	Unobserved		Count		Fingers	
	% Trials	% Correct	% Trials	% Correct	% Trials	% Correct
Middle-Income (Fingers Encouraged; *n* = 20)						
Nonverbal	58	89	37	75	04	59
Problems	(25)	(13)	(23)	(20)	(07)	(40)
Story	71	82	03	46	26	80
Problems	(32)	(20)	(06)	(50)	(33)	(22)
Number-Fact	60	89	10	77	30	86
Problems	(32)	(20)	(18)	(37)	(34)	(16)
Low-Income (Fingers Encouraged; *n* = 24)						
Nonverbal	45	88	48	76	09	72
Problems	(30)	(16)	(31)	(30)	(20)	(26)
Story	63	70	06	39	30	76
Problems	(33)	(06)	(09)	(41)	(35)	(30)
Number-Fact	40	93	10	81	50	78
Problems	(30)	(14)	(18)	(26)	(38)	(22)
Middle-Income (Fingers Discouraged; *n* = 12)						
Nonverbal	46	92	53	72	00	
Problems	(23)	(09)	(24)	(23)		
Story	88	82	10	69	02	100
Problems	(11)	(16)	(10)	(34)	(04)	
Number-Fact	73	88	23	66	02	60
Problems	(17)	(18)	(18)	(38)	(07)	

Note. Standard deviations are in parentheses; Percent trials do not always sum to exactly 100 in each row because of rounding.

age the use of finger strategies during addition and subtraction tasks. We placed these children in a separate section on the table. Because the 12 children used their fingers less often than the other subjects, they were excluded from the following analyses involving finger strategies.

We first examined the extent to which the low- and middle-income children used their fingers on the three experimental calculation tasks. Table 4 indicates that the low-income children tended to use their fingers more often than the middle-income children, especially on number-fact problems. However, an ANOVA on the number of trials on which the first-grade children used their fingers, with income level as a between-subjects factor and problem type as a within-subjects factor, showed neither a main effect of income level nor an Income Level × Problem Type interaction. A significant main effect of problem type, $F(2, 84) = 23.91$, $p < .0001$, indicated that children in both income groups used their fingers most often on number-fact problems, at an intermediate level on story problems, and least often on nonverbal problems. This finding is consistent with the level of representation provided in each problem type (i.e., number-fact problems did not refer to object sets, story problems referred to object sets that were not physically present, and nonverbal problems provided object sets).

The finding that middle- and low-income first graders do not differ significantly in frequency of finger usage contrasts with our initial finding (i.e., in kindergarten middle-income children used their fingers more often than low-income children on the verbal calculation problems). In our next analysis, we directly compared the frequency with which the follow-up children used finger strategies in kindergarten to the frequency with which they used these strategies in first grade. An ANOVA on the percentage of trials on which finger strategies were used on the verbal calculation problems in kindergarten and in first grade with grade and income level as between-subjects factors and problem type as a within-subjects factor showed a significant Income Level × Grade interaction, $F(1, 42) = 3.88$, $p < .05$. Simple effects analyses indicated that the middle-income children did not change significantly between kindergarten and first grade in the percentage of trials on which they used their fingers, but the low-income children showed a significant increase ($p < .01$). There were no significant interactions involving problem type. The mean percentage of trials on which low-income children used their fingers was 5% in kindergarten vs. 40% in first grade (story and number-fact problems combined); for the middle-income children the corresponding percentages were 17% in kindergarten vs. 28% in first grade.

To determine whether first-grade children's frequency of finger usage varies according to problem difficulty, we ranked the calculation items from easiest to hardest for the two income groups combined. The calculations then were divided into two groups: The 10 "easy" problems comprised the first half of the ranking (sums or minuends of 5 or less) and the 10 "hard" problems comprised the second half (sums or minuends of 6 or more and the four 3-term problems). We performed an ANOVA on the number of trials on which fingers were used with income level as a between-subjects factor and problem type and problem difficulty (easy vs. hard) as within-subjects factors. There was a significant main effect of problem difficulty, $F(1, 42) = 72.14$, $p < .0001$, such that children in both income groups used their fingers more often on hard problems than on easy problems. This finding was true for both income levels and on each problem type. On nonverbal problems the mean percentage of trials on which children used their fingers was 3% for easy calculations vs. 12% for hard calculations. On story problems the mean percentage of trials was 18% for easy calculations vs. 38% for hard calculations. On number-fact problems the mean percentage of trials was 26% for easy calculations vs. 51% for hard calculations.

We also examined whether there were income group differences in the frequency with which a strategy produced a correct answer. Table 3 indicates that, overall, children in both income groups tended to use finger and counting (without fingers) strategies effectively. An ANOVA on the percentage of correct responses on problems where finger and/or counting strategies without fingers were used (strategies combined) with income level as a between-subjects factor and problem type as a within-subjects factor showed no significant effects of income level or problem type. An ANOVA on the percentage of correct responses where strategies were not visible (unobserved) also showed no significant income group differences on any of the problem types, although the low-income children tended to be less accurate on story problems. There was a significant main effect of problem type, F (2, 82) = 7.2, $p < .001$, such that accuracy for unobserved strategies was lower on story problems than on either nonverbal problems or number-fact problems ($p < .05$, Tukey tests; one low-income subject who had no unobserved strategies on number-fact problems was removed from the analysis).

Error Analysis

Children's errors were examined to determine whether they reflect an understanding of addition and subtraction operations. We coded errors as being in the right direction if they were greater than the augend on addition problems or less than the minuend on subtraction problems (e.g., $5 + 3 = 7$ would be in the right direction but $5 + 3 = 4$ would be in the wrong direction; problems with three terms were excluded from this analysis). Table 5 shows the mean percentage of total errors that were in the right direction, broken down by income level, grade, problem type, and calculation strategy (fingers and/or counting without fingers vs. unobserved). On *nonverbal problems,* children's errors tended to be in the right direction, regardless of income level, grade, or calculation strategy. On *story problems,* middle-income children's errors tended to be in the right direction at both grades and for both calculation strategies. By first grade, the low-income children also were making mostly right direction errors on story problems when finger and counting strategies were used (88%); when strategies were not observed only 66% of the low-income children made errors in the right direction (vs. 81% for the middle-income children), suggesting some random guessing or use of the wrong operation (i.e., adding instead of subtracting). On *number-fact problems,* children in both income groups made fewer errors in the right direction than they did on the other two problem types. The mean percentage of right direction errors for the low-income children in first grade was particularly low when strategies were not observed (40%). However, this figure reflects the performance of a few children as only five children made any errors when strategies were not observed on number-fact problems. Three of the five children made no errors in the right direction when strategies were not observed and the other two made all of their errors in the right direction.

TABLE 5
Mean Percentage of Total Errors in Right Direction by Income Level, Grade, Problem Type, and Calculation Strategy

	Problem Type					
	Nonverbal		Story		Number-Fact	
	K	1	K	1	K	1
Fingers/Count						
Low	90 (29)	90 (29)	50 (0)	88 (16)	55 (46)	73 (28)
	$N = 12$	$N = 12$	$N = 3$	$N = 16$	$N = 6$	$N = 11$
Middle	93 (17)	97 (12)	98 (7)	98 (7)	88 (31)	75 (45)
	$N = 12$	$N = 18$	$N = 12$	$N = 12$	$N = 15$	$N = 12$
Unobserved						
Low	92 (17)	92 (14)	76 (24)	66 (43)	51 (22)	40 (55)
	$N = 20$	$N = 7$	$N = 24$	$N = 15$	$N = 24$	$N = 5$
Middle	87 (23)	98 (8)	90 (14)	81 (28)	62 (34)	77 (38)
	$N = 32$	$N = 16$	$N = 25$	$N = 19$	$N = 27$	$N = 8$

Note. Standard deviations are in parentheses. The number of children making errors, by income level, grade, problem type, and calculation strategy, also is indicated. The total number of low-income children is 24 and total number of middle-income children is 32. K = kindergarten, 1 = first grade.

Analysis of Individual Data

We analyzed the data of individual children to examine more carefully the strategy changes that occurred between kindergarten and first grade for middle- and low-income children. First, we examined the performance of children who used their fingers frequently in kindergarten (defined as greater than 50% of the trials). On *story problems,* four children (all middle-income) used their fingers frequently (M = 68%). The mean percentage correct for these children was 89% in kindergarten (vs. the middle-income group mean of 59%). In first grade, each of these four children decreased their frequency of finger use by at least 55 percentage points (M frequency = 10% of trials). However, their accuracy remained high (mean percentage correct = 86% vs. the middle-income group mean of 81%). On *number-fact problems,* six children (five middle-income and one low-income) used their fingers frequently in kindergarten (M = 78%). The mean percentage correct for the five middle-income children was 68% in kindergarten (vs. the middle-income group mean of 53%); the low-income child received a percentage correct score of 50%, also higher than the low-income group mean of 23%. None of these children used their fingers on any of the number-fact trials in first grade. However, their mean percentage correct in first grade remained high (M percentage correct for middle-income children = 80% vs. the middle-income group mean of 88%; the one low-income child who used his fingers frequently received a perfect score).

Conversely, frequent finger counters in first grade usually did not use their fingers in kindergarten. Of the 10 children (2 middle-income, 8 low-income) who used their fingers on more than half of the *story problem* trials in first grade (M = 73%), only 1 child used her fingers on any of the story problem trials in kindergarten (this child used her fingers on 14% of the trials in kindergarten vs. 90% in first grade). The mean percentage correct was 81% in first grade vs. 38% correct in kindergarten. Of the 19 children (4 middle-income and 15 low-income) who used their fingers on more than half of the *number-fact problem* trials in first grade (M = 74%), only 2 used their fingers on any of the number-fact problem trials in kindergarten (these 2 children used their fingers on 5% of the trials in kindergarten vs. 60% in first grade). The mean percentage correct was 81% in first grade vs. 21% in kindergarten.

Overall, these longitudinal data indicate that on story problems and number-fact problems children progress from not using fingers (as exemplified by low-income kindergartners), to using them frequently (as exemplified by middle-income kindergartners and low-income first graders), and finally to not using them (as exemplified by middle-income first graders). The third progression seems to be associated with children's increased use of direct retrieval and/or mental computational strategies. Whether low-income first graders eventually make the transition from using figures to not using fingers on story and number-fact problems remains an open question.

Achievement Tests

Grade-equivalent scores were obtained for Written Calculation Problems and Applied Problems subtests of the WJTA-R. Children's performance on the Written Calculation Problems and Applied Problems subtests supports the data obtained for the experimental verbal and nonverbal calculation tasks. That is, an ANOVA with income level as a between-subjects factor and mathematics task (Written Calculation Problems, Applied Problems) as a within-subjects factor revealed a significant Income Level × Mathematics Task interaction, $F(1, 54) = 13.82$, $p < .001$. Simple effects analyses showed no significant effect of income level for Written Calculation Problems, but a significant effect of income level for Applied Problems ($p < .002$), a measure that relies more heavily on comprehension of verbal input. The mean scores for Written Calculation problems were 2.1 (SD = 0.4) for the low-income children and 2.0 for the middle-income children (SD = 0.5). The mean scores on Applied Problems were 1.7 (SD = 0.7) for the low-income children and 2.4 (SD = 0.1) for the middle-income children.

DISCUSSION

This study provides longitudinal data on the development of calculation abilities in children from middle- and low-income families before and after formal instruction in school. The period between kindergarten and first grade is particularly important as children are faced with the task of assimilating the informal mathematics knowledge they have acquired before instruction with the more formal mathematics skills they are being taught in school. Before formal instruction, the middle-income children performed better than the low-income children on story problems and number-fact problems, but the two income groups did not differ on nonverbal problems (Jordan et al., 1992). This finding suggests that both middle- and low-income children develop calculation skills on the nonverbal task through their own experiences with adding and subtracting objects in the world, rather than through conventional instructional methods. After formal instruction in first grade, the middle- and low-income children still did not differ on nonverbal problems, as we expected. Moreover, the two income groups no longer differed on number-fact problems. The low-income children, however, continued to perform more poorly than the middle-income children on story problems, indicating that despite formal instruction in addition and subtraction low-income children have difficulties with certain conventional verbal arithmetic tasks.

It is possible that ceiling effects on the experimental number-fact problems masked real calculation differences between the middle- and low-income children in first grade. A set of more difficult number-fact problems involving larger numerosities might have been more sensitive to group differences in performance level. However, examination of performance on the Written Calculation subtest of the WJTA-R, where ceiling effects were not a problem, suggests that this was not the case. That is, there were no differences between the low- and middle-income children on the WJTA-R's more challenging set of number-fact problems. In contrast, we found that the low-income first-grade children performed more poorly than their middle-income peers on the WJTA-R Applied Problems subtest, a measure that requires children to solve orally presented arithmetic problems. This finding provides further evidence that story problems are relatively difficult for low-income children. Entwisle and Alexander (1990) also report that mathematics applications and mathematics calculation (as measured by another standardized test) are differentially responsive to environmental factors.

Although low-income children perform less well than middle-income children on story problems, their performance on both verbal problem types suggests considerable progress since kindergarten. Clearly, formal instruction in first grade has an important influence on the development of conventional verbal calculation skills, especially for low-income children. This finding is consistent with the work of Bisanz, Dunn, & Morrison (1991), who report that amount of schooling influences accuracy on number-fact problems more than age. The acquisition of appropriate methods for calculating in first grade (e.g., finger counting) seemed to result in an increase in accuracy on the verbal calculation tasks for the low-income children in our study. Recall that in kindergarten the low-income children rarely used their fingers to represent numerosities. In first grade, however, many of the low-income children used their fingers on the verbal calculation tasks, and the use of this strategy was associated with higher performance levels. The middle-income children, on the other hand, began to learn finger strategies in kindergarten, most likely from caregivers outside of school. Interestingly, analyses of individual data showed that children who used their fingers frequently in kindergarten did not use them frequently in first grade, although they still maintained a high level of accuracy. These children seem to have developed more efficient methods for solving verbal calculation problems (e.g., retrieval of answers from memory).

In first grade, the low-income children performed better on number-fact problems than on story problems. In kindergarten, we observed the opposite pattern (i.e., the low-income children performed better on story problems than on number-fact problems). In our developmental study with 4- to 6-year-old children (Levine et al., 1992) we also found that subtraction story problems were easier than subtraction number-fact problems. Before children are taught to use their fingers or other forms of representation, story problems may be easier because they provide a meaningful context and refer explicitly to object referents, whereas number-fact problems do not. Simple story problems encourage young children to imagine an array of an initial numerosity and transform it by adding or subtracting items as described. As numerosities increase, however, it may be more difficult for children to form accurate mental representations. As a result, they may need to use their fingers or other concrete objects to represent numerosities or to memorize number facts. At some point, they may become more comfortable with number-fact problems and even prefer them to story problems. Siegler and Robinson (1982) report that, when asked, many young children indicated that they preferred to hear addition problems in a number-fact problem format (e.g., "How much is 2 + 3?") than in a story problem format. This suggests that it might be easier for young children to map numbers onto fingers than it is to map the objects referred to in story problems.

Kerkman and Siegler (1993) found that low-income children choose calculation strategies in adaptive ways on number-fact problems and that these choices are similar to those of middle-income children. For example, children in both income groups spontaneously used "backup" strategies, such as finger counting, on difficult problems where correct answers were unlikely without such strategies (or, in other words, by retrieving answers from memory). These results are consistent with our findings. That is, we found that both middle- and low-income children use their fingers more frequently on the calculation items in the hardest half of our problem set and less frequently in the easiest half. This finding was true regardless of problem type.

In conclusion, our results indicate that formal instruction in first grade decreases the large difference between middle- and low-income children in the ability to solve number-fact problems that existed in kindergarten. This seems in large part to result from the development of more effective calculation strategies in low-income children. Such strategies were available to middle-income but not to low-income children before first grade. Despite these gains, however, the low-income children continue to experience relative difficulties on conventional story problems. Because it is widely reported that the academic delays of low-income children are likely to increase in the elementary school years (e.g., Coleman et al., 1966; Lazar, Darlington, Murray, Royce, & Snipper, 1982) future research should examine more precisely the instructional factors that lead to improved mathematics performance in this population.

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