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Title: Developing Number Sense in Kindergartners at Risk for Learning Difficulties in Mathematics

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Abstract

Background / Context: A disproportionate number of children from low-income families come to kindergarten without the skills necessary for success in formal mathematics and are over-represented in the population of students with diagnosed mathematics difficulties and disabilities (Jordan & Levine, 2010). Poor mathematics achievement can have far-reaching consequences. Low-income students are likely to be less prepared than middle-income students in the important STEM disciplines for which mathematics is a prerequisite. Mathematics proficiency has long been seen as a gateway to highly sought after professions in science, technology, engineering, and mathematics (National Mathematics Advisory Panel, 2008).

Until recently, early intervention for children in mathematics has been overlooked, especially with the emphasis on literacy in kindergarten and early elementary school (Gersten Jordan, & Flojo, 2005). However, in its recent report, *Mathematics Learning in Early Childhood: Paths toward Excellence and Equity* (National Research Council, 2009), the Committee on Early Childhood Mathematics emphasized that number competence is of primary importance for success to school mathematics.

Most children come to school with number competencies that are developed through their informal experiences (Ginsburg, Lee, & Boyd, 2008). Researchers have defined interrelated number competencies that are highly associated with later success in school mathematics. These competencies, also referred to as *number sense*, involve understanding of whole numbers, number operations, and number relations (Malofeeva, Day, Saco, Young, & Ciancio, 2004). In particular, they include recognition that numbers represent quantities and have magnitudes, that counting is guided by principles related to one-to-one correspondence, fixed order, and cardinality, and that sets can be transformed through addition and subtraction (Gelman & Gallistel 1978; Griffin, 2004).

In recent longitudinal work, Jordan and colleagues (Jordan, Kaplan, Ramineni, & Locuniak 2009; Jordan, Glutting, & Ramineni, 2009; Jordan, Glutting, Ramani, & Watkins, 2010; Locuniak & Jordan, 2008) found that core number competencies in kindergarten (counting, number knowledge, and number operations) are highly predictive of mathematics computation and problem solving proficiency through at least third grade, even when controlling for reading, age, and general cognitive factors. They also found that the vast majority of children lacking in these competencies are from low-income populations (Jordan, Kaplan, Locuniak, & Ramineni 2007; Jordan, et al., 2006). Similar results have been reported with shorter-term studies (Clarke & Shinn, 2004; Lembke & Foegen, 2009; Methe, Hintze, & Floyd, 2008). Moreover, number competence in preschool predicts performance on similar measures in kindergarten (VanDerHeyden, Broussard, & Cooley, 2006). If, as suggested, early number competencies mediate success in school mathematics, it would be especially important to determine whether these competencies can be developed through targeted interventions to change learning outcomes (VanDerHeyden, 2010).

Purpose / Objective / Research Question / Focus of Study: In the present study, we developed and tested a purposeful eight-week number sense intervention for kindergartners from low-income families. Kindergarten is an important time to provide educational interventions. If children leave kindergarten with weak number competencies, they enter first grade at a disadvantage and may never catch up to those who started with good number competencies (Jordan et al., 2009). Such a consequence is reported in the content area of reading (Juel, 1988).

The intervention was based on the premise that weaknesses in key number competencies underlie mathematics difficulties and that these competencies can be developed early through

targeted instruction. It emphasized whole number concepts related to counting, comparing, and manipulating sets. To help children attend to number, we used consistent representations (primarily chips, black dots and fingers) and centered activities on a number list from one to ten. Previous work has shown that young children often focus on perceptual variables in tasks rather than on relevant numerical information in mathematics-related activities (Rousselle, Palmers, & Noël, 2004). Finger counting was an area of particular focus. Fingers are an accessible resource for representing numbers and counting, and low-income kindergartners use their fingers less often than middle-income children (Jordan, et al., 1992; Jordan, Kaplan, Ramineni, & Locuniak, 2008).

The study used a pretest, post test, and delayed post test design. Children were randomly assigned either to the intervention condition or a "business as usual" control group. Dependent variables included a validated assessment of numeracy indicators as well as a measure of mathematics achievement.

Setting: Children were drawn from the same school district in the Mid Atlantic region of the United States. The schools were the lowest performing in the school district on the state mathematics tests at third grade and served low-income communities.

Population / Participants / Subjects: Participants were recruited from kindergarten classes in five schools. Because all participants were attending schools primarily serving low-income families, we considered them at risk for mathematics underachievement. The percentage of children enrolled in the free/reduced lunch program ranged from 79% to 95% in each school, with the mean being 91%. There were 126 participants, all of whom took the pretest. Out of those children, four moved out of the district before the end of the study period (two intervention and two control children) and one intervention child was chronically absent during the study period and could not complete the post testing. This left a total of 121 participants who completed the study. A power analysis for a repeated measures ANOVA was performed with α=. 01, an effect size of η^2=. 2, and a desired power of .95, which resulted in a required sample size of 90 students. Fifty-two of the children were girls (43%) and 69 were boys (57%). Sixty-seven of the students were identified as African American (55%), 45 as Hispanic (37%), seven as Caucasian (6%), one as Asian, and one as bi-racial, all by teacher report. Thirty of the Hispanic students (25%) were identified as English Language Learners (ELL).

In each of the five participating schools, half of the participants were randomly selected for the intervention while the other half were assigned to a business as usual control group. Because the interventions were carried out in groups of 4, there were a few extra children in the various schools who were assigned to the control group, accounting for the unequal numbers in the intervention and control conditions. Participants were stratified by kindergarten class.

Intervention / Program / Practice: Intervention Training: The scripts were presented to the student instructors in the fall of the school year along with the rationale for each activity. Important methods, including the use of pointing gestures, how to correct errors, and use of instructional materials were highlighted at weekly group training sessions. Pairs of instructors then practiced teaching the lessons to each other. Suggestions for improvements and clarifications were shared in group sessions

To assess whether the intervention procedures were carried out as designed, three intervention lessons were audio-recorded for each of the six instructors. The recorded lessons occurred in the early, middle, and late stages of the program. Two research assistants checked the intervention recordings against the written lesson scripts, one of whom was not involved in carrying out the interventions. It was found that instructors followed the scripts carefully, with no substantive deviation. All lessons were completed as well as one hundred percent of the activities in the lessons.

The intervention was designed to augment the regular kindergarten mathematics program. Skills were reviewed incrementally over the course of the 24 lessons. A compare and contrast approach was used throughout the activities. For example, opposites such as before/after, addition/subtraction, n+1/n-1 were presented simultaneously. Intervention lessons were scripted with carefully chosen vocabulary (e.g. before, after, plus, minus, bigger, smaller, more, less, altogether, etc.). As new mathematics vocabulary was introduced, the lessons focused on the meaning of the word with respect to number. Activities focused on recognizing and naming quantities up to four instantly, without counting (verbal subitization), number recognition, associating numerals to quantity, number sequencing, number magnitude comparisons, number plus (or minus) one principle, part-whole relationships, and using counting to solve number problems, At the end of each session children played the *Great Race Game*, adapted from Ramani and Siegler (2008). The game board was a colorful number list with numbers one to ten. Each number was enclosed in a square and a starting place was marked at just before the number one. To determine the number of spaces to move, the child used a spinner divided into two regions, one region containing the number 'one' and the other region containing the number 'two.' After the child spun a 'one' or a 'two', they were required to 'say' their move using a prescribed format that encouraged 'counting on.' if a child was on three and spun "+2", when the child landed on five, the instructor would say, "That's right, five is two after three," or "That's right, three plus two makes 5."

Measures: The Number Sense Brief (NSB) (Jordan, Glutting, Ramineni, & Watkins, 2010) is an untimed measure that takes approximately 20 minutes to administer. The items assess counting skills and principles, number recognition, number knowledge, and number operations. The total raw score was 42. General mathematics achievement was assessed using the *Woodcock-Johnson III Tests of Achievement* (Woodcock, McGrew, & Mather, 2007).

Research Design: A pretest, immediate post test, and delayed post test design was used. Children were individually pretested on both the number and mathematics achievement measures within a 2-week window. The intervention was carried out in small groups of four children per instructor. The intervention groups met for three 30-minute sessions per week over an 8-week period for a total of 24 lessons. The interventions were carried out during a time when children were not receiving their regular mathematics or literacy instruction. Groups were seated at a small table, either in their classroom or an area just outside of the classroom. During the week following the last lesson, children were individually post-tested. Approximately six weeks later, children were tested again with the same measures.

Data Collection and Analysis: A series on one-way ANCOVAs were conducted to test whether the mean gains between pretest and immediate posttest and delayed posttest for total and subarea scores from the NSB and WJ Achievement Test differed between groups (intervention group vs. control). In addition to *p* values, effect sizes are reported using r^2 coefficients. Although children were randomly assigned to the intervention and control groups, pretest scores from the NSB and/or pretest scores from WJ served as the covariate(s). The covariate(s) served the dual purposes of: (a) minimizing any potential confounding that might be attributable to prior mathematics knowledge between the two groups and (b) reducing unexplained variance, and thereby, increasing the power of the analyses to detect treatment effects. Three combinations of covariates were employed: (a) pretest scores from the NSB, (b) pretest scores from WJ, and (c) pretest scores from both the NSB and WJ. The reason for including both a variety and combination of covariates is that the processes and strategies subsumed under the construct of early mathematics knowledge are broad and span a variety of tasks. At pretest the correlation between the NSB and the WJ total score was .68.

Findings / Results: Figure 1 displays the mean NSB scores at pre, post, and delayed post test. Table 1 presents *p* values and effect sizes. Effect sizes are presented only for analyses where group differences reached statistical significance. Results were consistent across the ANCOVA models for the NSB and associated subareas; in all instances, the intervention group obtained significantly higher and meaningful adjusted outcome scores at posttest as well as at delayed posttest. For the WJ, the results were significant at posttest but not a delayed posttest and only for the calculation problems subtest.

Conclusions: Building on other investigations (e.g., Baroody et al., 2009; Chard et al., 2008; Ramani & Siegler, 2008), the present randomized controlled study demonstrates that key areas of number sense can be boosted in kindergartners with established risk for mathematics difficulties or disabilities, many who come to school with far ewer learning experiences than their middle-income counterparts. These gains were successfully captured on a number sense assessment tool that is sensitive to short-term progress in kindergarten and there was some transfer to more conventional written calculation tasks. Although most children seemed to gain from their regular mathematics curriculum, the intervention provides them with added benefits in a relatively short time period. This type of number sense intervention, which can easily be implemented in kindergarten classrooms, holds promise for evidence based response- to-intervention (RTI) service delivery models in schools. The intervention could be used for time-limited prevention of mathematics difficulties, or it could be expanded beyond eight weeks for more intensive ongoing assistance, with the aim of preparing children for success in primary-school mathematics.

A limitation of the study is the lack of a small group intervention comparison group, one that did not involve numbers. It is possible (although not likely) that the number sense gains seen in the intervention group were due to special treatment more generally, rather than to the specific number activities. We felt it important, however, to determine initially whether we could boost children's number sense performance relative to a business as usual control, and the finding that the intervention children changed most in the areas we emphasized (e.g., number recognition, number knowledge, calculation) argues against Hawthorne effects. In a follow-up study, we included a language intervention condition, carried out in small groups, for comparison to the number sense condition. Preliminary analyses suggest the number sense intervention beat out the language intervention on mathematics but not on language outcomes.

Appendices

Appendix A. References

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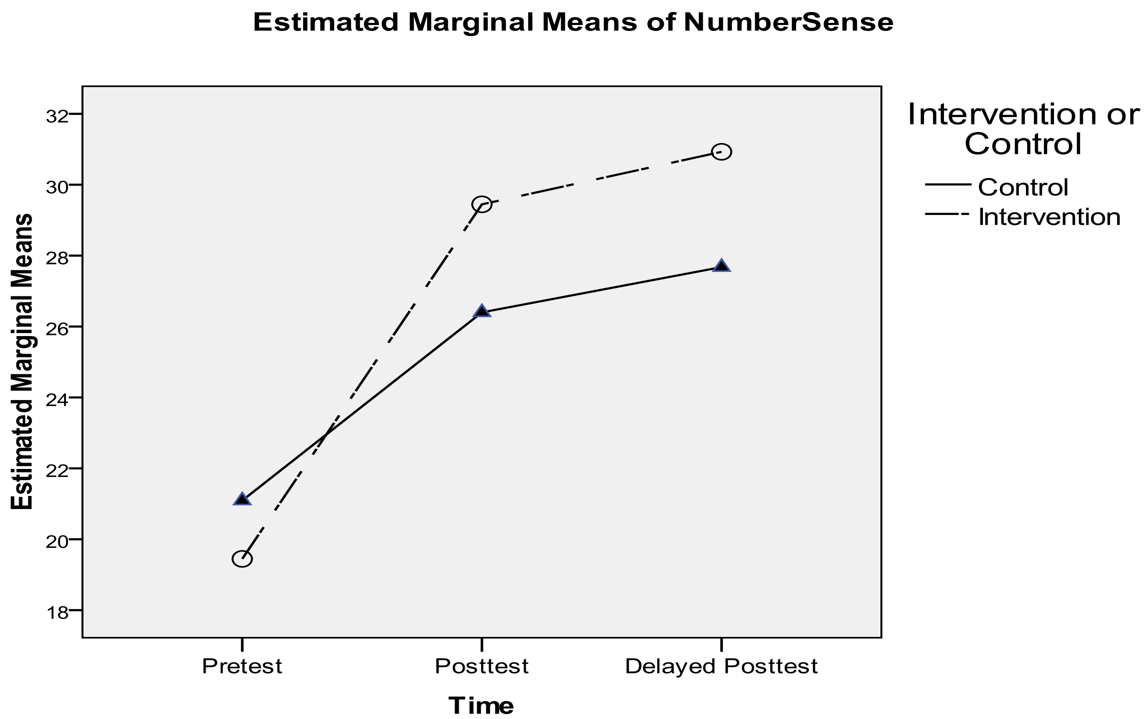
Appendix B. Tables and Figures
TABLE 1

Analysis of Covariance Results Evaluating Intervention Effectiveness

Dependent Variable	Covariate					
	NSB Pretest Alone		**WJ Total Pretest Alone**		**Both NSB & WJ Total Pretest**	
	p	R^2 [1]	***P***	R^2	***p***	R^2
Total Score NSB posttest	.001	.302	.001	.266	.001	.304
Total Score NSB delay	.001	.299	.001	.267	.001	.301
Number Recognition NSB posttest	.001	.319	.001	.280	.001	.320
Number Recognition NSB delay	.001	.302	.002	.266	.001	.302
Number Knowledge NSB posttest	.001	.267	.002	.241	.001	.270
Number Knowledge NSB delay	.001	.282	.001	.260	.001	.284
Story Problems NSB posttest	.001	.314	.001	.299	.001	.316
Story Problems NSB delay	.001	.299	.001	.281	.001	.300
Number Combinations NSB posttest	.014	.181	.033	.159	.009	.184
Number Combinations NSB delay	.002	.235	.009	.209	.009	.209
Total Score from WJ posttest	.021	.180	*Ns*		.014	.160
Total Score from WJ delay	*ns*		*Ns*		*ns*	
AP Score from WJ posttest	*ns*		*Ns*		*ns*	
AP Score from WJ delay	*ns*		*Ns*		*ns*	
CP Score from WJ posttest	.004	.227	.013	.204	.003	.229
CP Score from WJ delay	*ns*		*Ns*		*ns*	

Note. NSB = Number Sense Brief, WJ = Woodcock-Johnson; AP = Applied problems; CP = Calculation Problems. Effect sizes (i.e., standardized beta coefficients) are presented only in instances where results were statistically significant; *ns* = not statistically significant.

[1] R^2 represents multiple correlation coefficients squared. Values equal to .02 are considered small but meaningful effect sizes; those at .13 are considered to be moderate effect sizes, and those at or above .25 are considered to be large effect sizes (cf. Cohen, 1988, pp. 413-414). R^2 statistics were originally derived as standardized beta coefficients and converted using criteria established by Keith (2006).


Estimated Marginal Means of NumberSense
Estimated Marginal Means
32
30
28
26
24
22
20
18
Pretest
Posttest
Delayed Posttest
Time
Intervention or Control
Control
Intervention