Title: Effects of Intensive Early Interventions in Mathematics and Attention for Low-Performing Preschool Children

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Abstract

Problem / Background / Context:

Mathematical knowledge at school entry is the strongest predictor of later academic achievement (Duncan et al., 2007). Although low-income preschool and kindergarten children possess less extensive mathematical knowledge than their middle-class peers (Jordan, Huttenlocher, & Levine, 1992; Starkey & Klein, 2008), some Tier 1 mathematics interventions significantly reduce this SES gap (e.g., Casey, Kersh, & Young, 2004; Clements & Sarama, 2007; Greenes, Ginsburg, & Balfanz, 2004; Klein & Starkey, 2004). However, there is a subset of pre-k children who are not as responsive to these generally effective Tier 1 interventions. Failure to address the special learning needs of these young children who struggle with mathematics from an early age has significant consequences. Low income children who enter and exit kindergarten below the 10th percentile in mathematics have a 70% chance of scoring below the 10th percentile five years later and these achievement gaps only widen over time for the lowest performing children (Morgan et al., 2009). Research indicates that the academic trajectories for young at-risk children can be significantly altered by intensive early interventions, although the evidence for reading is more extensive than it is for mathematics (reviewed in Fletcher, Lyon, Fuchs, & Barnes, 2007). There is a clear need to test the effectiveness of intensive, early math interventions for children who enter pre-k with very low levels of mathematical knowledge.

Learning disabilities are heterogeneous; many struggling learners have difficulties in more than one academic domain and in domain-general cognitive processes such as attention and working memory that may support learning. Domain general cognitive instruction (e.g., in working memory) results in short term effects on trained cognitive skills, but the evidence that such interventions result in improved academic outcomes is currently weak (meta-analysis in Melby-Lervag & Hulme, 2012). What is largely missing from the research base are studies that focus on the multi-faceted nature of learning difficulties by combining skills-specific and domain-general cognitive interventions (Barnes, Fuchs, & Ewing Cobbs, 2010).

With respect to mathematics, there is converging evidence for a strong link with attention. Behavior genetic studies show that mathematics ability and inattentiveness are phenotypically and genetically correlated (Greven et al., 2014). Similarly, neuropsychological and longitudinal studies show links between attention and mathematical cognition (Ansari et al., 2007; Ashkenazi & Henik, 2010; Barnes et al., 2014; Dehaene, Piazza, Pinel, & Cohen, 2005; LeFevre et al., 2011). Attention has been highlighted as a domain-general candidate for early training (Wass et al., 2012) given its importance for learning as well as its central role in the development of other abilities, such as working memory, that support learning (Rothbart & Posner, 2001). Thus, the present study examines the individual and synergistic effects of an intensive math and attention training intervention on the math and cognitive outcomes for young at-risk children.

Research Questions:

The primary questions addressed in this presentation are: 1) Does an intensive early math intervention significantly improve the mathematical knowledge of low-performing pre-k children as compared to a business-as-usual Control condition? 2) Does attention training significantly improve the attention abilities of low-performing pre-k children as compared to the Math Only and Control conditions? 3) Does attention training combined with an intensive early math intervention provide additional support for mathematical learning in low-performing pre-k children as compared to the Math Only condition?
Interventions:

Mathematics. We employed a tutor-based intervention, *Pre-K Mathematics Tutorial* (PKMT), in which one tutor works with groups of two children 4 days per week outside of the classroom. *PKMT* consists of 20 math activities, with one activity delivered per week in sessions ranging from 10-20 minutes (80 sessions). In addition, 4 review weeks were scheduled over the course of the intervention to make up missed dosages due to school absences and to ensure that children mastered the targeted mathematical concepts.

*PKMT* is adapted from an effective Tier 1 mathematics curriculum, *Pre-K Mathematics* (Klein & Starkey, 2004). The *PKMT* provides intensive math instruction on a core set of foundational concepts and skills using concrete materials to help low-performing preschool children develop a strong foundation of informal mathematical knowledge. In keeping with the recommendations of the National Council of Teachers of Mathematics Focal Points (2006), more than half of the math activities in *PKMT* focus on learning concepts and skills related to Number and Operations, with a secondary emphasis on Geometry and Space. The mathematical content of these activities is based on cognitive developmental research about the nature and extent of early mathematical knowledge (see Geary, 1994; Ginsburg et al., 1998; and Bisanz et al., 2005). The *PKMT* intervention starts with basic Foundational math activities in order to accommodate the children’s very low levels of mathematical knowledge and moves progressively to more advanced *Pre-K* versions of these math activities. *PKMT* increases the intensity of instruction in mathematics in addition to Tier 1 instruction; provides explicit, systematic instruction; provides opportunities for cumulative review; teaches mathematical concepts to mastery; provides tutor scaffolding for learning as well as emotional support; and differentiates instruction by providing a downward (less-challenging) extension for children who are not ready for the core math activity, and an upward extension for children who succeed on the core activity.

Fidelity of implementation was measured for tutors 5-6 times per year for *PKMT*. Mean fidelity scores for the *PKMT* intervention were .98 in Texas and .99 in California.

Attention Training. We employed an attention training program based on Posner’s attention networks model and used in previous preschool attention training studies (Rueda et al., 2004). Children in the Math + Attention Training condition received 16 8-minute attention training sessions one day per week during the last 16 weeks of the math intervention. Children in the Math Only condition listened to books on tape for the same amount of time.

The computer-based activities use animated animal characters, and attention abilities are challenged by the adaptive nature of the programs. One game “trains” *Alerting* attention (establish and maintain vigilance in order to react to stimuli) and the other “trains” *Executive Attention* (control goal-directed behavior involved in detecting targets and errors, resolving conflicts, and inhibiting automatic responses). The *Alerting* game requires the child to wait and remain in a ready-to-respond state for an extended period of time, in order to rapidly respond to an infrequent and very brief event, such as waiting for a fly to exit a jar before hitting a button to *catch* the fly. The *Conflict* game trains *Executive Control/Attention* using rule change items that conflict with the stated rule and recently reinforced, but currently inappropriate, decisions. For example, there is a rule for what the monsters like to eat and it changes. During the day the red monster likes to eat red food and the blue monster likes to eat blue food, but at night one monster likes to eat flowers and the other likes to eat trucks. Various combinations of the two colors and objects along with the rule change produces response interference or conflict.
Both PKMT and Attention Training (as well as the Books on Tape control activity) were delivered in the child’s primary language (English or Spanish).

**Setting and Participants:**

The study took place in 3 pre-k programs in California and in one large pre-k program in Texas. All pre-k programs at both sites served low-income children. Each site collected data on 2 cohorts of children over two consecutive years. Approximately 40% of the children from the Texas site and 62% of the children from the California site had Spanish as their primary language. The sample was 53% male. On average, children were 4.5 years of age at pre-intervention assessment, and all children had to be 4 years of age at the start of the intervention.

Across two years and two sites 542 children (266 for cohort 1 and 276 for cohort 2) were recruited based on very low performance on a screening measure of mathematical knowledge at the beginning of the pre-k year (Child Math Assessment Screener). We chose a cut-point on this pre-k screening measure associated with kindergarten performance below the 25th percentile on the TEMA measure of math achievement, and also balanced false positives and negatives. All pre-k children from recruited classrooms were screened (1700 students). Children with severe developmental disability, autism, or severe behavioral disorder were excluded from the study.

Cohort 1 children have received the intervention(s), been pre- and post-tested in pre-k, and tested in kindergarten. Cohort 2 children have completed pre-testing and the intervention and post-testing will be completed in May 2014. The retention rate for cohort 1 at pre-k post-test and kindergarten follow-up was over 90% for both sites with similar attrition across conditions.

**Research Design:**

Children who met screening criteria within a classroom were randomly assigned to one of three conditions: (1) the Math + ATT condition, in which children received the PKMT intervention four times per week and attention training (ATT) once per week during the pre-k year; (2) the Math Only condition, in which children received the PKMT four times per week and the Books on Tape control activity once per week; and (3) a business-as-usual Control condition.

**Data Collection and Analysis:**

These children underwent extensive pre- and post-intervention assessments of mathematics knowledge (Child Math Assessment, TEMA-3), attention (Child Attention Networks Test, Preschool Continuous Performance Task), number acuity (Panamath), working memory (Visual-spatial working memory test) and phonological/early literacy abilities (TOPEL or SPELA at pre-test and WJ-III Letter Word Identification at post-test). KBIT Matrices at pre-test assessed nonverbal cognition. Mathematics and attention skills were assessed in a long-term follow-up in kindergarten. Assessment data were collected by trained and certified assessors and double-scored prior to data scanning of teleforms. Attention measures were collected via computer. Multi-level modeling of mathematics and attention outcomes are reported below for Cohort 1. Cohort 2 data will be added to the models for the presentation. Both raw and transformed data were used in the analyses yielding similar findings. Data reported are based on the intent-to-treat sample.

**Findings / Outcomes:**

**Impact on Mathematics Outcomes.** The CMA data were analyzed using a multi-level, repeated measures ANOVA for mean proportion correct. There were significant main effects for
condition and wave, and a significant wave by condition interaction (p < .004). The Math + ATT and Math Only conditions significantly outperformed the Control condition at wave 2 in both states. Effect sizes were .59, and .96 for the Texas and California samples, respectively. Change in CMA scores by condition and wave (controlling for pre-test age) is in Figure 1 (Appendix B).

The Test of Early Mathematics Ability-3 (TEMA-3) data were analyzed using a multi-level, repeated measures ANOVA on raw scores. For the TEMA raw score, there were significant main effects for state and wave, and a significant state by wave by condition interaction (p < .042). In California, the effect for condition was significant at wave 2 (p < .016), with an effect size of .47 for the Math + ATT and Math Only conditions compared to the Control condition. However, in Texas, there was no significant effect of condition at wave 2 though all conditions improved from wave 1 to wave 2. In addition, there was a main effect of state with scores being higher overall in Texas than in California. Change in TEMA raw scores by condition and wave (controlling for pre-test age) is in Figure 2 (Appendix B).

**Attention Outcomes.** Child ANT data were analyzed using a multi-level, repeated measures ANOVA for median response times and accuracy. There were significant effects from pre-test to post-test representing developmental change, such that children were faster and more accurate at post-test. For accuracy, there was a wave (pre-test/post-test) by condition interaction such that the difference between pre-test and post-test differed by condition (Appendix B, Fig 3). Specifically, the difference was greater for the Math + ATT condition over the average of the other two condition (p = 0.0050) and the Math + ATT condition had a larger difference between pre-test and post-test than either the Math Only condition (p = 0.0396) or the Control condition (p =0.0052). However, accuracy for the Math + ATT condition at post-test is not higher than for the other groups at p < .05. For response time, there was no differential effect of condition; however, children improved more (i.e., response times decreased) on congruent than incongruent trials and on cued than non-cued trials from pre-test to post-test.

**Conclusions:**

Based on the data from the first cohort, there is evidence for an impact of the intervention on a broad measure of informal mathematics knowledge and for one site on a standardized test of mathematics achievement. These findings suggest that an intensive mathematics intervention for very low performing preschoolers can be effective, in keeping with what is known about tutorial-based interventions for school-age students with mathematics difficulties (Bryant et al., 2008; Fuchs et al., 2004). There is also evidence for effects of the attention training on the primary attention outcome measure. Despite these impacts of the intensive mathematics instruction on mathematics knowledge and of attention training on attention performance, there is currently no evidence that attention training of the type employed in this study provides additional support for mathematical learning for these children who begin pre-k with very low mathematics knowledge. Even though a combined intervention approach was used in one condition, the findings are consistent with a recent meta-analysis of working memory training that found no transfer of cognitive skills training to academic achievement (Melby-Lervag & Hulme, 2012). Possible limitations of the study for drawing strong inferences will be discussed, including the intensity of attention training as well as issues related to definitions of combined interventions. We will also explore reasons for some of the differences between sites, particularly with reference to our classroom assessments of Tier 1 mathematics instruction.
Appendix A. References


Appendix B. Figures

**CMA by Condition and Wave**

![CMA by Condition and Wave](image)

*Figure 1. CMA Proportion Correct Score by Site and Condition (Condition 1 = Math + Attention; Condition 2 = Math Only; Condition 3 = Business as Usual)*

**TEMA by Condition and Wave**

![TEMA by Condition and Wave](image)

*Figure 2. TEMA-3 Raw Score Results by State and Condition (Condition 1 = Math + Attention; Condition 2 = Math Only; Condition 3 = Business as Usual; State 1 = Texas, State 2 = California)*
Figure 3. Cohort 1 Findings for the Child-ANT. Condition 1 = Math + Attention Training, Condition 2 = Math Only, Condition 3 = Business as Usual