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Math Abilities Among Children with Neurodevelopmental Difficulties: Understanding Cognitive Factors and Evaluating a Pilot Intervention

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Abstract

Math development in children relies on several underlying cognitive functions, including executive functions (EF), working memory (WM), and visual-motor abilities, such as visual-motor integration (VMI). Understanding how these cognitive factors contribute to children's math performance is critical to supporting math learning and long-term math success. The present quasi-experimental waitlist control study ($N = 28$) aimed to (a) examine the unique contributions of EF, WM, and VMI to math abilities among children ages 5–8 years old with neurodevelopmental difficulties; (b) determine whether a math intervention (the Mathematics Interactive Learning Experience; MILE) that supports these cognitive processes was effective when modified to be delivered to small groups in a school setting, and (c) examine whether any participant characteristics, such as age or IQ, were correlated with post-intervention math score changes. At baseline, participants' math scores were significantly below the normative mean in all math content areas ($ps < .01$). EF, WM, and VMI were highly correlated

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with math ability; however, verbal WM was the only unique predictor of math ability in regressions analysis. Compared to a waitlist control group, children in the immediate MILE intervention group achieved significantly greater math gains overall. When all children who ultimately completed the intervention were considered together, significant improvement was observed in more than half of math content areas. Furthermore, at the individual level, 85.7% of participants showed reliable change in at least one math content area. Implications for supporting math learning in children with neurodevelopmental difficulties are discussed.

Keywords

assessment of interventions/outcomes, educational psychology, mathematics, disciplines & subjects, Elementary school, participants

Math competence is crucial for success in many areas of life. Important daily living skills, such as budgeting and time management, rely on an adequate ability to understand and work with numbers. Individuals with low math competence are more likely to be unemployed, earn lower wages, report poorer mental and physical health, and encounter more trouble with the law even than those with other academic challenges, such as low literacy skills (Geary, 2011; Parsons & Bynner, 2005). Math education is cumulative, and children who demonstrate low math competence early on are likely to continue to perform poorly in math throughout their schooling (Duncan et al., 2007; Geary et al., 2013; Mazzocco & Myers, 2003). Consequently, early intervention in math is very important; however, determining how to best support children struggling with math learning can be challenging as the cognitive factors that contribute to math difficulties are varied (Geary & Moore, 2016). For best practices in math intervention, an understanding of the cognitive processes involved in math learning, such as executive functions (EF) and attention, working memory (WM), and visual-motor integration (VMI), is thus fundamental.

Cognitive Processes Involved in Math

EF refers to a range of higher-order cognitive processes such as attention, planning, initiation, cognitive flexibility, and self-regulation which are involved in goal-oriented behavior (Anderson, 2002). In relation to math, EF helps maintain focus, assists with problem solving, and allows for flexible thinking (Cragg & Gilmore, 2014). EF is a significant predictor of math performance in children with (Bull et al., 2008; Bull & Scerif, 2001) and without math difficulties (Cragg & Gilmore, 2014).

According to Baddeley (2000), WM is a four-component cognitive system responsible for temporarily storing and manipulating information. WM is particularly important for math learning in children (Peng et al., 2016; Rasmussen & Bisanz, 2005), including those with neurodevelopmental disorders (Rasmussen & Bisanz, 2011), and predicts future math difficulties in young students (Toll et al., 2011). Three of the four proposed components of WM have been associated with math performance in children: verbal WM (Alloway & Alloway, 2010; Swanson & Jerman, 2006), visual-spatial WM (Bull et al., 2008), and the central executive (De Smedt et al., 2009). Some research points to developmental changes in which visual-spatial WM is predictive of math performance in earlier grades and verbal WM becomes more important for math achievement in later elementary (Van de Weijer-Bergsma et al., 2015); however, the evidence is mixed.

VMI involves the coordination of both visual-spatial and motor abilities (e.g., hand-eye coordination; Beery & Beery, 2010). Children with VMI challenges often experience difficulties in math (Kim et al., 2018). Activities such as copying a figure and writing legibly, which require visual-spatial and motor skills, are foundational to math learning (Kulp, 1999; Pieters et al., 2012). VMI skills are associated with EF, and both are predictive of math performance among typically developing children (Sulik et al., 2018) and children with neurodevelopmental difficulties (Memisevic & Sinanovic, 2013). In a study by Verdine et al. (2014), 70% of math skill variance in preschool children was found to be predicted by EF and VMI performance together, and 27% of math skill variance was predicted by VMI abilities alone.

Math Interactive Learning Experience (MILE)

The Math Interactive Learning Experience (MILE program) was developed to improve math abilities in children with prenatal alcohol exposure (Kable et al., 2007). MILE teaches math skills directly while also supporting the underlying cognitive processes (EF, WM, and visual-spatial abilities) involved in math learning. An important component of MILE is "FAR" (Focus/Plan, Act, and Reflect), a teaching methodology used to support self-regulation and cognitive control (i.e., EF) which was adapted from the High-Scope Perry Preschool Project's (HSPPP's) "plan-do-review" methodology (Kable et al., 2015). FAR uses metacognitive questioning, scaffolded prompting, and specific praise to teach children how to better regulate their attentional focus and mental effort during learning while also helping them become more aware of their own thinking and more reflective about their problem-solving strategies (Kable et al., 2015). Other cognitive processes, such as WM and visual-spatial abilities, are supported by strategies such as using tangible manipulatives to help learners acquire mental representations of mathematical concepts (e.g., numeracy, sorting, ordering), an approach to improving math-related skills corroborated by the results of other intervention studies (Hawes et al., 2017; Mix et al., 2020).

Previous research conducted in the US found that MILE led to immediate improvements in both math skills and behavioral functioning in children with PAE (Kable et al., 2007) which were maintained at 6-month follow-up (Coles et al., 2009). No association between IQ and math improvement was found; however, younger children were more likely to achieve treatment gains. Kable et al. (2015) further demonstrated that MILE was effective for children with PAE when delivered by trained laypeople (e.g., teachers, college students) in a community-based setting. More recently, in a study replicating and extending the MILE program in Canada, MILE was again found to be effective at improving basic math skills among children with PAE (Kully-Martens et al., 2018). In contrast to prior findings, older age and lower IQ (verbal and overall) were associated with greater math improvements in this study.

Despite the positive outcomes of MILE, however, the potential for the intervention to have a wider-reaching impact has thus far been constrained by the program's individual administration and out-of-school delivery. Moreover, because the teaching practices involved in MILE support cognitive processes that can be impacted in other neurodevelopmental disorders, it is likely that MILE would benefit children struggling with math learning who do not have PAE, as well. Thus, a critical next step in MILE research is to determine if the program is effective when delivered to small groups of children with other neurodevelopmental difficulties in a school setting.

Study Objectives

The objectives of this study were threefold. The first objective was to examine the *unique* contributions of EF (selective and sustained attention, initiation, cognitive flexibility, and planning), WM (verbal and visual), and VMI (design copy) to math abilities among children with neurodevelopmental difficulties. Although previous research has independently demonstrated that math ability is related to these underlying cognitive processes, there is little research examining their unique associations, particularly among children with neurodevelopmental difficulties. The second objective of this study was to determine whether the MILE program led to math improvement when modified and extended to be delivered more broadly to small groups of children with neurodevelopmental difficulties in a school setting. Finally, the third objective was to examine whether any participant characteristics, such as age or IQ, were associated with math score changes following participation in the modified MILE program as these findings were mixed in previous MILE studies.

Methods

Participants

Children were recruited (N=28; 5–8 years old) through a local school district (Table 1). Students were eligible to participate in the study if they (a) had been diagnosed with a neurodevelopmental difficulty that has impacted their learning, and/or (b) had been identified by their kindergarten teacher as experiencing some or significant difficulty in at least one of the following domains on the Early Years Evaluation–Teacher Assessment (EYE-TA) developmental screening tool: Awareness of Self and Environment; Social Skills and Approaches to Learning; and/or Cognitive Skills. The EYE-TA is an informal assessment and observational tool used by educators to evaluate children's school readiness (The Learning Bar, 2019). The most commonly reported neurodevelopmental difficulties of the sample included diagnoses of Attention-Deficit/Hyperactivity Disorder (37.0%), Oppositional Defiant Disorder (18.5%), Learning Disorder (11.1%), and Anxiety (7.4%). Other diagnoses reported included Adjustment

Table 1. Full Sample Participant Demographic Information.

Variable	Full sample $N = 28$
Age in years (*M* [range])	6.3 (5.0–8.0)
Sex (*n* male [%])	18 (64.3%)
WRIT General IQ (*M* [*SD*])	93.4 (10.7)
Annual household income >$50 k (*n* [%])	18 (69.2%)[a]
Neurodevelopmental difficulties (*n* [%])	
Attention-deficit/hyperactivity disorder	10 (37.0%)[b]
Oppositional defiant disorder	5 (18.5%)[b]
Learning disorder	3 (11.1%)[b]
Anxiety	2 (7.4%)[b]
Adjustment disorder	1 (3.7%)[b]
Autism spectrum disorder	1 (3.7%)[b]
Cerebral palsy	1 (3.7%)[b]
Depression	1 (3.7%)[b]
Fetal alcohol spectrum disorder	1 (3.7%)[b]
Speech delay	1 (3.7%)[b]
Classroom learning environment (*n* [%])	
Behavioral and Learning Assistance	13 (46.4%)
Regular classroom	15 (53.6%)

Note. Household income data was not provided for two participants. Neurodevelopmental diagnoses information was not provided for one participant.
[a]$N = 26$. [b]$N = 27$.

Disorder, Autism Spectrum Disorder, Cerebral Palsy, Depression, Fetal Alcohol Spectrum Disorder, and Speech Delay (3.7% each).

For the MILE pilot analysis, 14 of the originally recruited 28 children completed the intervention and were included. Attrition occurred because some students withdrew (e.g., moved away or changed schools), and because some educators were either unexpectedly unable to administer the program (i.e., required a leave of absence) or elected not to participate in the intervention after pre-testing. Of the 14 participants who completed the intervention, six children from two schools were assigned to an "immediate intervention" group, and eight children from a third school were assigned to a "waitlist control" group (Table 2). This quasi-experimental study design was chosen to allow for the formation of an untreated comparison group while also ensuring all students were able to receive the intervention regardless of initial treatment condition. To minimize disruption to teachers and classrooms, all children participating from the same school were allocated to the same treatment group. The immediate intervention group included children from two schools, two thirds of whom were in a regular classroom and one third of whom were in a Behavioral and Learning Assistance classroom. All children in the waitlist control group were in a Behavioral and Learning Assistance classroom.

Table 2. MILE Pilot Sample Participant Demographic Information.

Variable	Immediate intervention *n* = 6	Waitlist control *n* = 8
Age in years (*M* [range])	7.2 (7.0–8.0)	6.8 (5.0–8.0)
Sex (*n* male [%])	4 (66.7%)	4 (50.0%)
WRIT General IQ (*M* [*SD*])	90.0 (9.7)	99.1 (14.9)
Annual household income >$50 k (*n* [%])	4 (66.7%)	4 (57.1%)[a]
Presence of EYE-TA difficulties (yes [%])		
Awareness of self/environment	2 (33.3%)	3 (42.9%)[a]
Cognitive skills	4 (66.7%)	5 (71.4%)[a]
Social skills/approaches to learning	4 (66.7%)	7 (100.0%)[a]
Neurodevelopmental difficulties (*n* [%])		
Attention-deficit/hyperactivity disorder	1 (16.7%)	6 (75.0%)
Oppositional defiant disorder	0 (0.0%)	4 (50.0%)
Learning disorder	1 (16.7%)	1 (12.5%)
Anxiety	1 (12.5%)	1 (12.5%)
Autism spectrum disorder	1 (16.7%)	0 (0.0%)
Fetal alcohol spectrum disorder	0 (0.0%)	1 (12.5%)
Classroom learning environment (*n* [%])		
Behavioral and learning assistance	2 (33.3%)	8 (100.0%)
Regular classroom	4 (66.7%)	0 (0.0%)

Note. Household income and EYE-TA data was not available for one participant in the waitlist control group.
[a]$n = 7$.

Procedure

All participants completed measures of math and cognitive processes at baseline (Time 1; ~1−2 hours). Children ($n = 14$) who participated in the MILE pilot then completed two additional testing sessions to examine changes in math scores over the course of the intervention or waitlist control period. All testing took place in a quiet room at the child's school. Tests were administered by a graduate student or research assistant (RA) who held a degree in psychology and who received training and supervision from a Registered Psychologist. Testing was sometimes spread across multiple days to respect teacher and classroom schedules and accommodate students who had difficulty completing the assessment in a single session. The study lasted just over 1 year; the immediate intervention group (two schools) completed all testing from March to December 2016, and the waitlist control group (one school) completed all testing from December 2016 to May 2017.

MILE Intervention

The intervention was administered to seven groups of two participants by an educator, educational assistant (EA), or RA. Initially, the program was intended to be delivered by school staff (educator or EA) only; however, a study RA agreed to administer the intervention to two groups of children when school staff were unable. All interventionists received formal training in the MILE program at the University of Alberta over the course of approximately 6 hours. Eleven educators/EAs and one RA completed this training; six (including the RA) completed the intervention with their students. Training was provided by study investigators, all of whom received training from the original MILE program developers. Training included an overview of the study, educational instruction, and videos outlining and explaining the key facets of the intervention (e.g., the FAR methodology). Time was also allotted for attendees to familiarize themselves with the materials, practice with fellow educators, and discuss any questions they had with the trainers. Interventionists received a $25 gift card for their participation in the study.

Intervention sessions took place for approximately 30–50 minutes twice a week until each participant had completed 14 sessions. The average length of the intervention was 7.7 weeks ($SD = 1.1$) for the entire sample; the length of the intervention was not significantly different between intervention groups, with a mean difference of only 0.3 weeks, $p > .05$.

For each intervention session, interventionists engaged in three steps: planning the session, teaching the session, and reflecting on the session. Planning involved choosing a goal or curriculum page to work on based on the child's pre-test math scores and the interventionist's notes from the previous session. Teaching involved carrying out the lesson plan they devised, and reflecting involved recording notes about the session and the child's progress on the skills taught or practiced.

Each individual intervention session was then carried out in three stages following FAR methodology. Sessions began by co-creating the day's schedule with participants (*Focus/Plan*). This was done on a sheet of paper with blank spaces for (a) the day's goal(s) ("Today we will _______"), (b) three possible activities that would be used to achieve these goal(s), and (c) two reminders pertinent to the participants or session. Children were encouraged to contribute their ideas to this sheet, and although the instructor created a lesson plan with the session's objectives prior to beginning, children were given as much choice as possible over how they would like to accomplish these goals (e.g., by choosing the shape and color of manipulatives used). The children then carried out activities aligned with the learning objectives (*Act*), such as using their chosen manipulatives to sort or add, as the instructor supported them and facilitated their engagement through questioning, praise, and prompting. Finally, at the end of the session, children and instructors reviewed the plan they had created together and discussed what they had learned in the day's session (*Reflect*).

Measures

Demographic questionnaire. All caregivers completed a questionnaire prior to beginning the intervention which gathered demographic information such as the participant's age, grade, sex, and pertinent medical and educational history. Family and household factors such as annual income range, caregiver's relationship to child, and caregiver's educational attainment were also obtained.

Ability (IQ). The Wide Range Intelligence Test (WRIT) was administered at baseline to obtain an estimate of participants' intellectual abilities. The WRIT is a brief, standardized test of cognitive functioning designed for use with individuals aged 4–85. The WRIT consists of four subtests that contribute to the generation of two composite scores (Verbal IQ and Visual IQ) and one overall score (General IQ; Glutting et al., 2000). WRIT scores are reported as standard composite scores (M = 100.0, *SD* = 15.0).

Math. The KeyMath-3 Diagnostic Assessment, Canadian Edition (KeyMath-3 DA; Connolly, 2008) includes 10 subtests that combine to create one Total score and three composite scores: Basic Concepts (Numeration, Algebra, Geometry, Measurement, Data Analysis and Probability), Operations (Mental Computation and Estimation, Addition and Subtraction, Multiplication and Division), and Applications of Problem Solving (Foundations of Problem Solving and Applied Problem Solving). Parallel forms of the KeyMath-3 DA were used at consecutive time points to minimize practice effects. Raw scores on the KeyMath-3 DA are converted into standard composite scores (M = 100.0, *SD* = 15.0) and scaled subtest scores (M = 10.0, *SD* = 3.0).

Executive functioning and attention. Children completed two subtests from the NEPSY-II (Korkman et al., 2007): Auditory Attention (measuring selective and sustained attention) and Design Fluency (measuring initiation, cognitive flexibility, and planning). The Auditory Attention subtest requires children to listen to an audio recording and point to the corresponding colors in the stimulus booklet. Design Fluency involves drawing novel designs by connecting two or more dots in structured and unstructured arrays. The NEPSY-II yields scaled scores (M = 10.0, *SD* = 3.0).

Working Memory. The Automated Working Memory Assessment (AWMA) is a computer-based assessment used to measure verbal and visual-spatial WM (Alloway, 2007). The AWMA short form was administered as it is recommended for individuals with suspected memory difficulties. The following four subtests were administered: Digit Recall (verbal short-term memory), Listening Recall (verbal WM), Dot Matrix (visual-spatial short-term memory) and Spatial Recall (visual-spatial WM). The AWMA yields standard composite scores (M = 100.0, *SD* = 15.0).

Visual-motor integration. The Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th edition (Beery VMI) is an assessment used to evaluate the integration of visual perception and motor abilities (Beery & Beery, 2010). The Beery VMI has 30 items designed for individuals of all ages and involves the copying of geometric forms using paper and pencil. The test yields standard scores (M = 100.0, *SD* = 15.0).

Program fidelity. To ensure that the MILE program was being delivered as intended, a 15-point fidelity to intervention checklist (Kable et al., 2015) was completed by a research assistant familiar with the program at two time points for each interventionist over the course of the study. The interventionists were scored *yes* (2 points), *sometimes/partial* (1 point) or *no* (0 points) on the presence of important MILE teaching methodology, such as "the instructor allowed the child to choose some aspect of the math fun work," as well as on logistical details, such as "the instructor's materials were readily available." The fidelity scores ranged from 26 to 30 out of 30, with an average score of 27.4 out of 30. Only three instances of *no* were recorded, each for separate instructors. Two of these occurred because the interventionist did not co-create the lesson plan with the children at the beginning of the session; in these cases, the interventionists reported that they had made the day's plan prior to the session and reviewed it with the participants before beginning to preserve instructional time. The third instance was scored when the instructor did not discuss breaks or behavioral contracts with participants.

Data Analysis

Data was analyzed using IBM SPSS 25. Although it would not be unusual to detect outliers in a small sample size of children with neurodevelopmental difficulties, the Shapiro–Wilk test was first conducted on the most summative outcome variables of interest at baseline (i.e., the KeyMath-3 DA Total composite, the two NEPSY-II subtests, the four AWMA subtests, and the Beery VMI) and the WRIT General IQ score in order to estimate the distribution of the data. Other descriptive statistics were also calculated to characterize the sample.

To address objective one, we compared performance on the measures of math, EF, WM, and VMI to the normative means using one-sample t-tests to determine areas of relative difficulty. Then, Pearson correlations were conducted to examine the associations between standardized baseline math scores and scores on measures of EF, WM, and VMI. Finally, all predictive measures were added to a forward selection linear regression to determine the unique associations of cognitive processes to math ability.

For objective two, we conducted independent sample t-tests to compare math score changes from Time 1 to Time 2 between the immediate intervention and waitlist control groups. Then, after all participants had completed the intervention, the immediate intervention and waitlist control groups were combined and paired sample t-tests were used to compare math score changes from pre- to post-intervention for the entire sample. As in previous MILE studies, raw score performance was examined in these analyses because it is more sensitive to change at the individual level over a short period of time (Kully-Martens et al., 2018).

Next, Reliable Change Index (RCI) analyses were conducted to determine whether the individual math scores of children who received MILE improved more than would be expected due to factors such as practice effects and measurement error (Duff, 2012; Jacobson & Truax, 1991). RCI is often used to test for individual-level changes in small sample sizes. For this analysis, we used an extension of the original RCI formula (Jacobson & Truax, 1991) proposed by Iverson (2001) which uses test-retest correlations, means, and standard deviations to account for the effects of measurement error and prior experience with the assessment materials on participant score changes. Six-month follow-up data was also collected for those in the immediate intervention group; however, as the number of participants available for testing was limited, formal analyses were not conducted on this data. Finally, for objective three, biserial and point-biserial Pearson correlations were calculated between demographic variables, such as age and IQ, and raw math score changes at the composite level.

Missing values. Two participants in our sample did not provide information regarding household income. A small amount of outcome data (e.g., NEPSY-II and KeyMath-3 DA scores) also was not obtainable for various reasons, including age/norming constraints and behavioral challenges during testing. Sample size and any missing data details are noted below each table.

Results

Sample Characteristics

No outcome variable standard scores were found to depart significantly from normality in the full sample (ps > .05, N = 28) except the KeyMath-3 DA Total composite (p = .031), where visual analysis of the histogram indicated that a high number of lower scores were found. However, as this intervention was aimed at children with math difficulties, such skewness was expected. Tables 1 and 2 provide details about participant characteristics for the full sample and by group (i.e., immediate intervention and waitlist control). There were no significant differences between the intervention and waitlist groups on age, sex, IQ, or household income, ps > .05.

Associations Between Math Performance and EF, WM, and VMI Scores

Across the full sample at baseline, mean KeyMath-3 DA composite scores were all significantly below the normative mean (ps < .01), with performance being the highest on Operations and lowest on Applications (Table 3). Mean subtest scores were also all significantly below the normative mean (ps < .01), with children scoring highest on Addition/Subtraction and Geometry and lowest on Measurement and Applied Problem Solving (Figure 1). The sample performed significantly below the normative mean (ps < .01) on all subtests of NEPSY-II, AWMA, and Beery VMI, with the exception of the AWMA Spatial Recall subtest (p = .31; Table 3), as well.

Table 4 outlines the correlations between cognitive measures and math scores. Listening Recall (verbal WM), Spatial Recall (visual-spatial WM), and Design Fluency were highly correlated with performance on all math composites, ps < .05; Auditory Attention (EF) was correlated with the Basic Concepts and Total math composites; and the Beery VMI was correlated with the Applications of Problem Solving and Total math composites, ps < .05. We then conducted a linear regression analysis using a forward selection method to examine the *unique* contributions of the AWMA, NEPSY-II Auditory Attention and Design Fluency subtests, and Beery VMI to the Total math composite score. The model accounted for 54.7% of total math ability R^2 = .55, F(1, 23) = 26.56, p < .01, with Listening Recall (verbal WM) being the only significant predictor (t = 5.15, r = .74, p < .01).

Table 3. Standard/Scaled Scores on Mathematics and Cognitive Measures for the Full Sample at Baseline.

Measure	*M* (*SD*) *N* = 28	*p*	% in clinically significant range
KeyMath-3 DA			
Basic concepts	78.6 (17.1)	<.01**	67.9
Operations	86.0 (14.2)	<.01**	50.0
Applications of problem solving	76.4 (15.2)	<.01**	64.3
Total	78.1 (16.0)	<.01**	67.9
NEPSY-II			
Auditory attention[a]	7.8 (3.7)	<.01**	54.2
Design fluency	7.9 (3.5)	<.01**	46.4
AWMA			
Digit recall	93.5 (13.8)	<.01**	35.7
Listening recall	90.2 (15.8)	<.01**	46.4
Dot matrix	87.2 (14.7)	<.01**	42.9
Spatial recall	96.8 (16.3)	.31	35.7
Beery VMI	89.6 (14.1)	<.01**	42.9

Note. Clinically significant range refers to scores >1 *SD* below the measure's normative mean. NEPSY-II Auditory Attention scores were not available for four participants.
[a]*N* = 24.
***p* < .01.

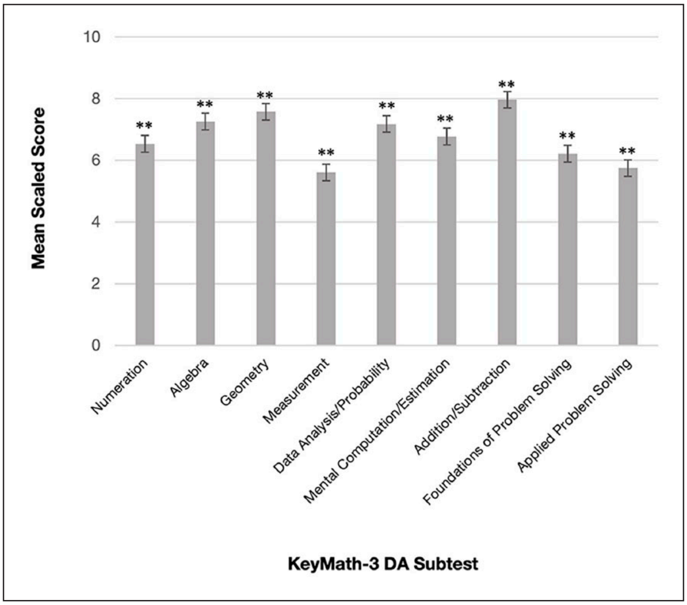

Figure 1. KeyMath-3 DA subtest scores for the full sample at baseline.

Table 4. Correlations Between KeyMath-3 DA Math Composite Standard Scores and Cognitive Measures for the Full Sample at Baseline.

	Basic concepts	Operations	Applications of problem solving	Total
Digit recall	.29	.38*	.42*	.34
Listening recall	.70**	.69**	.68**	.74**
Dot matrix	.42*	.42*	.36	.47*
Spatial recall	.51**	.41*	.55**	.52**
Auditory attention	.50*	.40	.30	.48*
Design fluency	.51**	.46*	.40*	.52**
Beery VMI	.37	.29	.38*	.39*

Note. All correlations include 28 participants except for NEPSY-II Auditory Attention ($N=24$).
*$p<.05$. **$p<.01$.

MILE Intervention Effects

There were no significant differences between the immediate intervention group and waitlist control group on any of the math composites at baseline, ps > .05. Following the intervention, children in the immediate intervention group achieved significantly greater raw score gains on the KeyMath-3 DA Total index ($M=10.5$, $SD=4.1$) than the waitlist control group ($M=3.3$, $SD=3.3$), $t(10)=3.33$, $p=0.008$, but not on other composites, ps > .05. When all children who received the intervention were included in analyses (i.e., those who received the intervention immediately and those who received it following the waitlist control period), statistically significant raw score growth was found to have occurred on more than half of the KeyMath-3 DA subtests and composites (Basic Concepts, Algebra, Measurement, Data Analysis and Probability, Applications of Problem Solving, Foundations of Problem Solving, Applied Problem Solving, and the Total index; Table 5).

At the individual level, 12 out of 14 (85.7%) of participants were found to have demonstrated reliable change on at least one KeyMath-3 DA composite or subtest (using a .70 CI). Additionally, 8 out of 14 participants (57.1%) showed reliable improvement in two or more areas, 6 out of 14 participants (42.9%) showed reliable improvement in three or more areas, and one participant (7.1%) showed reliable change in four content areas. Because only five participants in the immediate intervention group were available for the 6-month follow up, we did not conduct any statistical analyses due to limited power. However, mean scores on the Total composite were comparable at post-intervention ($M=71.4$) and 6-month follow up ($M=72.6$).

Associations Between Participant Characteristics and MILE Intervention Effects

Younger age was associated with more math gains on the Basic Concepts composite, $r(11)=-.76$, $p<.01$. Additionally, higher scores on the Verbal IQ composite were

Table 5. Raw Score Changes Pre- and Post-Intervention for All MILE Participants.

KeyMath-3 DA content area	*M* (*SD*) Pre	Post	Change	*p*	Effect size
Basic concepts	42.5 (19.3)	51.3 (20.9)	8.8 (6.8)	.001**	1.28
Numeration	10.9 (6.4)	11.4 (4.8)	0.5 (4.4)	.680	0.11
Algebra	5.6 (3.8)	7.5 (3.8)	1.9 (2.5)	.016*	0.74
Geometry	11.6 (3.9)	12.6 (4.8)	1.1 (2.7)	.158	0.40
Measurement	5.8 (3.5)	8.5 (5.2)	2.8 (2.9)	.004**	0.97
Data analysis/probability	7.5 (3.9)	10.00 (4.6)	2.5 (1.8)	<.001***	1.44
Operations	11.2 (3.3)	13.2 (6.2)	2.0 (4.5)	.155	0.44
Mental computation/estimation	4.8 (1.5)	6.4 (4.0)	1.5 (3.4)	.129	0.45
Addition/subtraction	6.8 (2.5)	7.5 (2.7)	0.7 (2.0)	.239	0.34
Applications of problem solving	11.5 (5.3)	15.8 (6.3)	4.2 (2.3)	<.001***	1.83
Foundations of problem solving	5.7 (2.4)	7.4 (2.4)	1.7 (1.3)	.001**	1.29
Applied problem solving	5.8 (3.4)	8.4 (4.3)	2.5 (2.4)	.003**	1.04
Total	61.4 (22.8)	76.3 (29.1)	14.9 (9.4)	<.001***	1.58

Note. Effect size calculated using Cohen's $d = t/\sqrt{N}$. All $n = 12$–14.
*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

associated with more gains on the Applied Problem Solving composite, $r(11) = .65$, $p < .05$, and higher scores on the Visual IQ and General IQ composites were associated with more gains on the Total index, $r(10) = .63$, $p < .05$ and $r(10) = .61$, $p < .05$, respectively. No other correlations between participant characteristics and math score changes were significant.

Discussion

The objectives of this study were: (a) to examine the unique contributions of underlying cognitive abilities (EF, WM, and VMI) to math performance among children with neurodevelopmental difficulties; (b) to examine whether a pilot math intervention (MILE) that targets these underlying abilities was effective when administered to small groups of children with neurodevelopmental difficulties in a school setting; and (c) to examine whether any participant characteristics were correlated with post-intervention math score changes. Such information is important to better understanding the factors that contribute to math challenges for children with neurodevelopmental difficulties, and to understanding how to best support and remediate these challenges in an effective manner.

Our sample of young children with neurodevelopmental difficulties demonstrated low math achievement overall, displaying mean baseline scores that were significantly below the norm on all math composites and subtests. Study participants scored highest on math operations subtests (addition and subtraction) and lowest on math problem solving and measurement subtests, which is typical among children with math difficulties (Swanson & Beebe-Frankenberger, 2004). Aside from participants' performance on a spatial recall task, mean EF, WM, and VMI scores were also below the norm in our sample. Measures of EF, WM, and VMI were found to be highly correlated with math ability in this study. However, in the regression analysis, verbal WM was the only *unique* predictor of math ability. This finding is supported by previous research indicating that the role of verbal WM in math achievement tends to increase over time relative to visual-spatial WM (Van de Weijer-Bergsma et al., 2015). Given these associations, this study suggests that interventions that target EF, WM (particularly verbal WM), and VMI may be particularly beneficial for children with math learning difficulties.

Children who received the MILE intervention showed greater math improvement than those in a waitlist control group. Significant math gains were also observed at the group level in several domains, and at the individual level, 85.7% of participants were found to have demonstrated improvements in at least one math content area (using RCI) that were greater than what would be expected based on other factors, such as practice effects or measurement error, alone. Taken together, these findings provide promising evidence that MILE remains effective when modified and extended to increase accessibility to the program.

Determining for whom programs are most effective is important when developing and implementing academic interventions. Previous MILE studies have reported mixed findings about the relationship between participant characteristics and changes in math scores following completion of the MILE program. For example, Coles et al. (2009) reported that younger age was associated with greater math gains, while Kully-Martens et al. (2018) found that older age was associated with greater gains. We found that younger age was associated with greater improvements on the Basic Concepts composite. This finding may reflect that younger children are less likely than their older peers to have mastered the foundational abilities captured by this index, suggesting that they may have had more "room to grow" in this area and may have spent more time building the skills measured by this composite throughout the course of the intervention. In addition, we found that children with higher baseline Verbal IQ scores improved more on the Applications of Problem Solving composite, and children with higher Visual and General IQ scores improved more on the Total math index, indicating that children with stronger baseline cognitive abilities achieved greater math gains. Although Coles et al. (2009) did not find any significant associations between IQ and math improvements in their study, Kully-Martens et al. (2018) found that children with lower verbal and general IQ scores achieved greater math gains. Thus, further research with larger samples sizes is needed to clarify the associations between age, IQ, and math improvements.

Limitations

Sample size is the most notable limitation of this study because it restricted statistical power. Additionally, for a variety of scheduling reasons, participants in the waitlist control group and immediate intervention groups did not receive their interventions at the same time of year. This makes direct comparisons somewhat less straightforward than if the programs had been run at the exact same time, though the impact of this difference should be minimized by the individualized nature of the intervention sessions; the use of standardized, age-normed testing materials in many analyses; and the examination of individual-level changes using RCI. Disruptions related to behavioral challenges may have also impacted the testing (and learning) process for some participants, and it is possible that teacher- or classroom-specific effects may have had an impact on intervention outcomes. However, random assignment to different groups was not logistically feasible for this study, and the sample size did not allow for comparisons between such groups. Accordingly, these differences were considered and controlled for as much as possible by using standardized interventionist training and fidelity monitoring. Finally, we had a relatively high attrition rate because only 14 of the 28 originally recruited children completed the intervention. Reasons for this high attrition rate included both student factors (e.g., student moved schools) and teacher factors (e.g., teacher was unable to administer the program during the study timeframe). Thus, our final intervention sample may not be generalizable to the entire school population.

Relevance to the Practice of School Psychology

Improving mathematics in young children with neurodevelopmental difficulties who are struggling with math learning is of critical importance to their short- and long-term educational outcomes. Effective early intervention is particularly imperative given the cumulative nature of math education and the association between early math abilities and later math performance. As such, the results of this study have significant educational implications for children with neurodevelopmental difficulties and the professionals working with them. Many promising and efficacious interventions do not have the intended impact due to barriers translating research to practice (Hicks et al., 2014). Fortunately, school psychologists are well-positioned to facilitate the implementation of MILE given their training and their role in identifying students who have neurodevelopmental difficulties. For example, because they would be aware of the students who may be well-suited for this intervention, they could take steps to advocating for its incorporation into individualized education plans. Moreover, because school psychologists possess in-depth knowledge of the cognitive processes relevant to this intervention, they would be uniquely situated to explain the influence of these processes on math learning to teachers, which should contribute to implementing this intervention with even greater fidelity. Further work is now needed to determine how to best train educators on the MILE program and support their use of MILE in the classroom.

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References

Alloway, T. P. (2007). *Automated working memory assessment*. Pearson.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*(1), 20–29. https://doi.org/10.1016/j.jecp.2009.11.003

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*(2), 71–82. https://doi.org/10.1076/chin.8.2.71.8724

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, *4*, 417–423. https://doi.org/10.1016/S1364-6613(00)01538-2

Beery, K. E., & Beery, N. A. (2010). *The Beery-Buktenica developmental test of visual-motor integration with supplemental developmental test of visual perception and motor coordination for children and adults and stepping stones age norms from birth to age six: Administration, scoring and teaching manual* (6th ed.). Pearson.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*(3), 205–228. https://doi.org/10.1080/87565640801982312

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*(3), 273–293. https://doi.org/10.1207/S15326942DN1903_3

Coles, C., Kable, J., & Taddeo, E. (2009). Math performance and behavior problems in children affected by prenatal alcohol exposure: Intervention and follow-up. *Journal of Developmental and Behavioral Pediatrics*, *30*(1), 7–15. https://doi.org/10.1097/DBP.0b013e3181966780

Connolly, A. (2008). *KeyMath-3 diagnostic assessment: Manual forms A and B*. Pearson.

Cragg, L., & Gilmore, C. (2014). Skills underlying mathematics: The role of executive function in the development of mathematics proficiency. *Trends in Neuroscience and Education*, *3*(2), 63–68. https://doi.org/10.1016/j.tine.2013.12.001

De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology*, *103*(2), 186–201. https://doi.org/10.1016/j.jecp.2009.01.004

Duff, K. (2012). Evidence-based indicators of neuropsychological change in the individual patient: Relevant concepts and methods. *Archives of Clinical Neuropsychology*, *27*(3), 248–261. https://doi.org/10.1093/arclin/acr120

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., Pagani, L. S., Feinstein, L., Engel, M., Brooks-Gunn, J., Sexton, H., Duckworth, K., & Japel, C.

(2007). School readiness and later achievement. *Developmental Psychology*, *43*(6), 1428–1466. https://doi.org/10.1037/0012-1649.43.6.1428

Geary, D. C. (2011). Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics. *Journal of Developmental and Behavioral Pediatrics*, *32*(3), 250–263. https://doi.org/10.1097/DBP.0b013e318209edef

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2013). Adolescents' functional numeracy is predicted by their school entry number system knowledge. *PLoS ONE*, *8*(1), e54651. https://doi.org/10.1371/journal.pone.0054651

Geary, D. C., & Moore, A. M. (2016). Cognitive and brain systems underlying early mathematical development. *Progress in Brain Research*, *227*, 75–103. https://doi.org/10.1016/bs.pbr.2016.03.008

Glutting, J., Adams, W., & Shelow, D. (2000). *Wide range intelligence test*. Psychological Assessment Resources Inc.

Hawes, Z., Moss, J., Caswell, B., Naqvi, S., & MacKinnon, S. (2017). Enhancing children's spatial and numerical skills through a dynamic spatial approach to early geometry instruction: Effects of a 32-week intervention. *Cognition and Instruction*, *35*(3), 236–264. https://doi.org/10.1080/07370008.2017.1323902

Hicks, T. B., Shahidullah, J. D., Carlson, J. S., & Palejwala, M. H. (2014). Nationally Certified School Psychologists' use and reported barriers to using evidence-based interventions in schools: The influence of graduate program training and education. *School Psychology Quarterly*, *29*(4), 469–487. https://doi.org/10.1037/spq0000059

Iverson, G. L. (2001). Interpreting change on the WAIS-III/WMS-III in clinical samples. *Archives of Clinical Neuropsychology*, *16*(2), 183–191. https://doi.org/10.1016/S0887-6177(00)00060-3

Jacobson, N. S., & Truax, P. (1991). Clinical significance: A statistical approach to defining meaningful change in psychotherapy research. *Journal of Consulting & Clinical Psychology*, *59*(1), 12–19. https://doi.org/10.1037/0022-006X.59.1.12

Kable, J. A., Taddeo, E., Strickland, D., & Coles, C. D. (2015). Community translation of the Math Interactive Learning Experience Program for children with FASD. *Research in Developmental Disabilities*, *39*, 1–11. https://doi.org/10.1016/j.ridd.2014.12.031

Kable, J. A., Coles, C., & Taddeo, E. (2007). Socio-cognitive habilitation using the math interactive learning experience program for alcohol-affected children. *Alcoholism: Clinical and Experimental Research*, *31*(8), 1425–1434. https://doi.org/10.1111/j.1530-0277.2007.00431.x

Kim, H., Duran, C. A. K., Cameron, C. E., & Grissmer, D. (2018). Developmental relations among motor and cognitive processes and mathematics skills. *Child Development*, *89*(2), 476–494. https://doi.org/10.1111/cdev.12752

Korkman, M., Kirk, U., & Kemp, S. (2007). *NEPSY-II: Clinical and interpretive manual*. PsychCorp.

Kully-Martens, K., Pei, J., Kable, J., Coles, C. D., Andrew, G., & Rasmussen, C. (2018). Mathematics intervention for children with fetal alcohol spectrum disorder: A replication and extension of the math interactive learning experience (MILE) program. *Research in Developmental Disabilities*, *78*, 55–65. https://doi.org/10.1016/j.ridd.2018.04.018

Kulp, M. T. (1999). Relationship between visual motor integration skill and academic performance in kindergarten through third grade. *Optometry and Vision Science*, *76*(3), 159–163. https://doi.org/10.1097/00006324-199903000-00015

The Learning Bar. (2019). Early Years Evaluation: Teacher Assessment (EYE-TA). https://thelearningbar.com/early-years-evaluation-kindergarten-readiness/

Mazzocco, M. M., & Myers, G. F. (2003). Complexities in identifying and defining mathematics learning disability in the primary school-age years. *Annals of Dyslexia*, *53*(1), 218–253. https://doi.org/10.1007/s11881-003-0011-7

Memisevic, H., & Sinanovic, O. (2013). Executive functions as predictors of visual-motor integration in children with intellectual disability. *Perceptual and Motor Skills*, *117*(3), 913–922. https://doi.org/10.2466/15.25.PMS.117x25z4

Mix, K. S., Levine, S. C., Cheng, Y. L., Stockton, J. D., & Bower, C. (2020). Effects of spatial training on mathematics in first and sixth grade children. *Journal of Educational Psychology*, *113*(2), 304–314. https://doi.org/10.1037/edu0000494

Parsons, S., & Bynner, J. (2005). *Does numeracy matter more?* National Research and Development Centre for Adult Literacy. https://nrdc.org.uk/wp-content/uploads/2005/01/Does-numeracy-matter-more.pdf

Peng, P., Barnes, M., & Namkung, J. (2016). A meta-analysis of mathematics and working memory: Moderating effects of working memory domain, type of mathematics skill, and sample characteristics. *Journal of Educational Psychology*, *108*(4), 455–473. https://doi.org/10.1037/edu0000079

Pieters, S., Desoete, A., Roeyers, H., Vanderswalmen, R., & Van Waelvelde, H. (2012). Behind mathematical learning disabilities: What about visual perception and motor skills? *Learning and Individual Differences*, *22*(4), 498–504. https://doi.org/10.1016/j.lindif.2012.03.014

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of Experimental Child Psychology*, *91*(2), 137–157. https://doi.org/10.1016/j.jecp.2005.01.004

Rasmussen, C., & Bisanz, J. (2011). The relation between mathematics and working memory in young children with Fetal Alcohol Spectrum Disorders. *The Journal of Special Education*, *45*(3), 184–191. https://doi.org/10.1177/0022466909356110

Sulik, M. J., Haft, S. L., & Obradović, J. (2018). Visual-motor integration, executive functions, and academic achievement: Concurrent and longitudinal relations in late elementary school. *Early Education and Development*, *29*(7), 956–970. https://doi.org/10.1080/10409289.2018.1442097

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology*, *96*(3), 471–491. https://doi.org/10.1037/0022-0663.96.3.471

Swanson, H. L., & Jerman, O. (2006). Math disabilities: A selective meta-analysis of the literature. *Review of Educational Research*, *76*(2), 249–274. https://doi.org/10.3102/00346543076002249

Toll, S. W. M., van der Ven, S. H. G, Kroesbergen, E. H., & van Luit, J. E. H. (2011). Executive functions as predictors of math learning disabilities. *Journal of Learning Disabilities*, *44*(6), 521–532. https://doi.org/10.1177/0022219410387302

Van de Weijer-Bergsma, E., Kroesbergen, E. H., & Van Luit, J. E. (2015). Verbal and visual-spatial working memory and mathematical ability in different domains throughout primary school. *Memory & Cognition*, *43*(3), 367–378. https://doi.org/10.3758/s13421-014-0480-4

Verdine, B. N., Irwin, C. M., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Contributions of executive function and spatial skills to preschool mathematics achievement. *Journal of Experimental Child Psychology*, *126*, 37–51. https://doi.org/10.1016/j.jecp.2014.02.012

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