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Mathematics intervention for children with fetal alcohol spectrum disorder: A replication and extension of the math interactive learning experience (MILE) program

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ABSTRACT

Background: Individuals with fetal alcohol spectrum disorders (FASD) experience deficits in behavior, cognition, and academic functioning resulting from prenatal alcohol exposure (PAE). Although receiving intervention for developmental disabilities is a strong protective factor against negative outcomes in FASD, intervention research in this population is in its infancy.
Aims: The purpose of this study was to replicate and extend a mathematics intervention, the Math Interactive Learning Experience (MILE) program, which was developed in the USA specifically for children with FASD.
Methods: Twenty-eight Canadian children aged 4–10 years with confirmed PAE or an FASD diagnosis were assigned to either the MILE intervention or a contrast intervention.
Results: Following a relatively brief, individualized, one-on-one intervention, children in the MILE group demonstrated significantly greater changes in math achievement compared to the contrast group. Significant changes in other cognitive functions were not observed. Older age, lower IQ, and confirmed PAE but no FASD diagnosis were associated with greater math achievement change in the MILE group.
Conclusions: The replication and extension of the math intervention appears to have significant, positive impact on mathematics achievement scores of children with PAE and FASD.

What this paper adds

Researchers and clinicians have been working together to modify and pilot existing evidence-based practices to help mitigate some of the many challenges faced by individuals prenatally exposed to alcohol; yet, intervention development for children with fetal alcohol spectrum disorder (FASD) is in its early stages. Impairment in mathematics appears to be a significant and specific area of deficit among individuals with FASD, with implications for educational, occupational, and adaptive behavioral success across the lifespan. We took an intervention which has been shown to be promising among children with FASD and modified it to examine whether we could still effect positive changes in math achievement when the intervention was adapted to enhance efficiency and ecological validity. The success of this modified intervention suggests that a math intervention designed to be considerate of both strengths and weaknesses, that accommodates for underlying cognitive impairment, that can be delivered in schools over the course

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of roughly five one-on-one hours, and that does not directly involve caregiver time commitment, can be effective in improving math achievement among children with FASD.

1. Introduction

Each year, approximately one in eight women consume alcohol while pregnant, and approximately a sixth of these women binge drink (Mattson et al., 2013). Consequently, thousands of children are born prenatally exposed to alcohol, the most widely consumed teratogen in the world (Streissguth, 1997). Approximately 1 to 5% of children have fetal alcohol spectrum disorder (FASD), an umbrella term that describes a broad spectrum of congenital neurological and physical effects resulting from alcohol-induced organic brain damage (Cook et al., 2016; May et al., 2009, 2018).

Individuals with FASD tend to exhibit significant neurobehavioral deficits, including a range of mild to severe dysfunction in executive functioning, intellectual ability, learning, achievement, memory, attention, visuospatial functioning, language, and adaptive functioning (see Mattson, Crocker, & Nguyen, 2011). These primary neurobehavioral disabilities, coupled with limited availability of appropriate and effective interventions, contribute to the multitude of adverse outcomes common in individuals with FASD. These outcomes include disrupted educational and occupational experiences, confinement (e.g., incarceration, inpatient treatment), inappropriate sexual behaviors, and alcohol and drug abuse (Streissguth, Barr, Kogan, & Bookstein, 1996). However, early diagnosis and access to services for developmental disabilities have been found to reduce negative outcomes and thus decrease the broader societal financial burden and other social-emotional impacts that this disability may have on individuals, families, and communities (Streissguth et al., 2004).

Developing appropriate services to meet the needs of individuals with FASD has been difficult for several reasons. First, the body of research addressing FASD is relatively young—approximately 45 years (Jones & Smith, 1973; Jones, Smith, Ulleland, & Streissguth, 1973; Lemoine, Harosusseau, Borteyru, & Menuet, 1968). Only more recently has understanding of cognitive, behavioral, and adaptive consequences of FASD advanced enough to begin to inform appropriate intervention. Second, individuals with FASD experience a myriad of behavioral and self-regulation problems in addition to cognitive impairments. Many also experience the systemic effects of chaotic family life and involvement in social services (Streissguth et al., 1996). This unique presentation makes it difficult to fit children with FASD neatly into existing treatment or educational intervention platforms. Fortunately, there have been several recent attempts to develop and pilot interventions targeted specifically to children with FASD. The purpose of the present study was to investigate the effectiveness of a mathematics intervention that aimed to improve math achievement, as well as underlying cognitive deficits, in young children prenatally exposed to alcohol. This project is a replication and an extension of the Math Interactive Learning Experience (MILE) program that was first conceptualized and studied in Atlanta, Georgia, USA (Coles, Kable, & Taddeo, 2009; Kable, Coles, & Taddeo, 2007).

1.1. Mathematics and FASD

Mathematics impairments in individuals with FASD have been a robust finding cross-sectionally and longitudinally, even after controlling for many variables (e.g., maternal drug use/nutrition/education, socioeconomic status, IQ; see Rasmussen & Bisanz, 2009). Evidence for a specific deficit in mathematics in individuals with FASD is supported by research indicating that individuals with FASD have more difficulty with mathematics than other cognitive domains (Coles et al., 1991; Howell, Lynch, Platzman, Smith, & Coles, 2006; Kerns, Audrey, Mateer, & Streissguth, 1997; Streissguth et al., 1991), and that mathematics impairment is more highly correlated with amount of prenatal alcohol exposure than are other cognitive skills such as reading and spelling (Goldschmidt, Richardson, Stoffer, Geva, & Day, 1996; Streissguth, Barr, Sampson, & Bookstein, 1994). Furthermore, attempts to create a characteristic FASD neurobehavioral profile have consistently identified math deficiency as a key component (e.g., McLachlan et al., in review; Nash et al., 2013). Functional deficits in mathematics persist from childhood (age four) to adulthood (Streissguth et al., 1994). In fact, Streissguth et al. (1991) found that adolescents and adults with FASD scored at a grade two level for arithmetic. Individuals with FASD have also been found to be impaired on tests of number processing, including measures of cognitive estimation, proximity judgment, and calculation (Kopera-Frye, Dehaene, & Streissguth, 1996).

Deficiencies in several underlying areas of neurobehavioral functioning may contribute to mathematics impairment. Understanding these features is key to implementing effective educational intervention strategies (Millians, 2015). For example, children with prenatal alcohol exposure exhibit *slower processing speed* and a specific processing efficiency deficit on number processing tasks (Burden, Jacobson, Sokol, & Jacobson, 2005). Additionally, researchers have shown that *working memory* is important for mathematics performance among typically developing children (Rasmussen & Bisanz, 2005) and that working memory deficits are linked to math disabilities in children (McLean & Hitch, 1999). Rasmussen and Bisanz (2010) found that among young children with FASD, impairment on tests of quantitative concepts and problem solving were highly correlated with working memory abilities. Many children prenatally exposed to alcohol also experience difficulty with *visual-spatial processing*, which has been linked to lowered math achievement. For example, Crocker, Riley, and Mattson (2015) found that spatial working memory and spatial recognition memory significantly predicted math achievement among alcohol-exposed children. Finally, deficits in fine motor function such as *graphomotor skills* (e.g., Kalberg et al., 2006) may also contribute to math difficulties. Damage to neural centers responsible for movement may affect the ability of children with FASD to learn and remember muscle movement sequences needed to write numbers (Lebel, Roussotte, & Sowell, 2011). Consequently, the cognitive burden of writing may actually interfere with academic learning (Kable et al., 2007).

1.2. Creating a math intervention for FASD

Improved mathematical cognition can greatly impact educational and occupational success as well as daily functioning. Previous literature on intervention for children with brain damage suggests that interventions should target underlying neurocognitive factors of functionally relevant skills within the context of those functional skills (Laugeson et al., 2007; Ylvisaker, 1998). Therefore, a mathematics intervention should focus on developing math skills while accommodating and attempting to remediate underlying problems with neurocognition (e.g., processing speed, visual-spatial skills, working memory, graphomotor control), rather than repeating tasks aimed solely to improve cognition with the hope that improvements will generalize to achievement (Kable et al., 2007). This theory forms the basis of the Math Interactive Learning Experience (MILE) program, which was developed by Kable et al. (2007). MILE was first piloted with 61 children with fetal alcohol syndrome (FAS) and partial FAS (pFAS) aged 3–10 years; 31 participants were randomly assigned to the MILE group, and 30 were assigned to a non-intervention contrast group (n = 30). Participants in the MILE group received six weeks of individualized one-on-one tutoring, and their caregivers received training regarding how to support math learning at home. Post-intervention, the MILE group demonstrated significantly greater gains in math achievement, which were maintained six months later (Coles et al., 2009). In the MILE group, those who made the greatest treatment gains were more likely to be younger. Among the entire sample, those who made gains had higher levels of alcohol-related dysmorphia. Gender, IQ, and SES did not appear to have an impact on treatment outcome.

1.3. Present study

Although it is clear that FASD occurs frequently and leads to challenging neurodevelopmental difficulties, there has been limited attention to developing methods to improve child outcomes. Math achievement, in particular, appears to be significantly negatively affected in children with FASD. These difficulties tend to persist across the lifespan, likely contributing to a host of behavioral and independent living problems.

The original MILE study provided an important first step in better understanding math difficulties in alcohol-affected children, as well as hope that these challenges can be addressed. We sought to replicate and *extend* the MILE study with a sample of Canadian children prenatally exposed to alcohol by making several changes to the original MILE study design. First, the design of the original MILE project did not allow the authors to determine which aspects of the program (i.e., one-on-one instruction, parent training) were more or less responsible for the treatment effect. Understanding the relative contributions of various aspects of treatment is important to determine how MILE can be streamlined to ensure ease of community translation, efficiency, and cost-effectiveness. Therefore, we eliminated the significant parental component and utilized child tutoring only. Second, we conducted all interventions in a typical ecological setting (i.e., child's school or home). Third, we also investigated whether underlying cognitive abilities (EF, working memory, visuospatial functioning) improved as a result of MILE. Fourth, instead of using a 'sham' intervention contrast group, we used a behavioral comparison intervention. Finally, we included children with diagnoses across the fetal alcohol spectrum (referred to as 'FASD'), as well as alcohol-exposed children without a clinical diagnosis (referred to as 'PAE').

We endeavored to answer three main research questions:

1. Do children with PAE/FASD in a modified MILE intervention program improve in mathematics compared to children with PAE/FASD in a different intervention both immediately post-intervention as well as six months post-intervention? We hypothesized that children with PAE/FASD in the modified MILE intervention program would show greater improvements in mathematics compared to children with PAE/FASD in a different intervention, and that these improvements would be maintained six months post-intervention.
2. Is receiving the MILE intervention related to improvement in other cognitive abilities (EF, working memory, visuospatial functioning) both immediately post-intervention as well as six months post-intervention? We suspected that children in the MILE intervention would show improvements in other cognitive skills from pre- to post-test when compared to children in the contrast intervention, and that these improvements would be maintained over time.
3. Are there any specific participant characteristics that seem to influence treatment outcomes? Based on the findings of Coles et al. (2009), we hypothesized that younger children would show greater change than older children, as will children with a diagnosis of FASD compared to those with just PAE. We also believed that gender, IQ, and SES would be unrelated to any observed treatment effects.

2. Method

2.1. Participants

Twenty-eight children age 10 years with PAE and FASD participated: 15 in the MILE intervention and 13 in the contrast intervention. The groups did not differ significantly on any demographic variables (see Table 1). Participants were recruited via convenience sampling through a hospital-based FASD clinic, an FASD respite program, and various schools within two local school districts. Interested participants contacted the researchers, who then contacted the potential participants' educators to determine if in-school tutoring was feasible.

After obtaining consent, it was confirmed if children had a diagnosis of FASD in accordance with the Canadian Guidelines for FASD diagnosis (Chudley et al., 2005). Children without diagnoses established within the Canadian guidelines but with prenatal

Table 1
Participant Characteristics.

Demographic Characteristic	MILE Group (n = 15)	Contrast Group (n = 13)	*p*
Age in years (M [range])	7.5 (4–10)	7.4 (5–10)	0.88[a]
Sex [n male (%)]	7 (47.7%)	6 (46.2%)	0.98[b]
Diagnosis [n FASD (%)]	6 (40.0%)	4 (30.8%)	0.61[b]
Full-Scale IQ [M (SD)]	87.3 (12.6)	96 (17.1)	0.14[a]
Length of intervention (days) [M (range)]	37.5 (32–6)	37.7 (33–44)	0.94[a]
Time from pre-test to post-test (days) [M (range)]	66.6 (49–85)	66.3 (53–89)	0.97[a]
Current living arrangement [N (%)]			0.62[b]
Adoptive parents	< 9 (60.0%)	9 (69.2%)	
Foster care	6 (40.0%)	4 (30.8%)	
Lifetime number of living situations [M (range)]	2.7 (1–6)	3.4 (1–6)	0.33[a]
Current caregiver characteristics			
SES [M (SD)]	43.4 (9.5)	38.5 (8.7)	0.19[a]
Annual income [N (%) > than $50,000]	13 (86.7%)	11 (84.6%)	0.13[b]
Education [N (%) one parent graduated high school]	14 (93.3%)	13 (100%)	0.34[b]

Note. SES was obtained from the primary caregiver using the Hollingshead Four Factor Index of Social Status. Possible scores range from 8 to 66. Full-Scale IQ reported as a standard score using the Wide Range Intelligence Test (WRIT).
[a] Analyzed with ANOVA.
[b] Analyzed with chi-square.

alcohol exposure (confirmed through affidavit) were labeled as 'PAE.' It is common for children prenatally exposed to alcohol to exhibit other diagnostic comorbidities, particularly attention deficit/hyperactivity disorder (for a review, see Pei, Denys, Hughes, & Rasmussen, 2011). Thus, participants with common mental health comorbidities were included.

2.2. Procedure

Participants completed a three-hour pre-test battery that included assessment of IQ, math achievement, and other cognitive abilities. Following pre-testing, children were matched to the two intervention groups, first based on age, then diagnosis (FASD or PAE), math achievement score, full scale IQ, and then gender where possible.

Both the mathematics and contrast interventions were individualized based on pre-test performance. Intervention sessions began within four weeks of pre-testing, and were delivered by a graduate student or a trained research assistant. Interventionists were kept consistent for each child, with the exception of one participant. Intervention sessions were scheduled once or twice a week for a total of 10 thirty-minute sessions over 6–8 weeks. Post-testing occurred within 10 days of the last intervention, on average (range 2–21 days). The same measures were used at post-test, with the exception of IQ testing and demographic information. Post-testing was conducted by a research assistant who was blind to the child's intervention condition (Fig. 1).

2.3. Interventions

2.3.1. Interventionists

Two trained research assistants and one graduate student ('interventionists') performed the pre- and post-testing, as well as the intervention sessions. To minimize bias, one interventionist would perform a child's pre-testing and intervention, and a different interventionist would conduct the child's post-testing. The interventionists were trained by Dr. Julie Kable and Dr. Elles Taddeo, co-creators of MILE. The MILE Fidelity Checklist (Kable, Taddeo, Strickland, & Coles, 2015) was used to monitor fidelity to treatment by the interventionists and was completed roughly every three sessions.

2.3.2. Math intervention

MILE is premised on the idea that intervention should focus on accommodating and habilitating the underlying neurodevelopmental deficits that contribute to the math difficulties within the context of math tutoring. For example, each intervention session incorporated a slow pace of instruction and an interactive method of teaching to compensate for deficits in EF and working memory and to ensure that math concepts (e.g., size, quantity, time, operations) could be fully processed and integrated. Working memory was additionally supported through use of small pieces of information, cues, repetition, and practice, and giving ample time for recall. Visuospatial processing deficits were accommodated by use of manipulatives and tools (e.g., a vertical number line).

Since certain preliminary skills need to be in place to support higher-order math, MILE focuses on slowly building a solid foundation of basic math skills. As an illustration, a child needs to be able to recognize the size and shape of an object before skills like sorting and categorization (conceptual precedents for skills such as addition, subtraction, multiplication, division, and eventually algebra and geometry) can develop. Therefore, interventionists worked with children at their respective developmental level, not necessarily their grade level. Problem-solving skills, understanding key concepts, and 'filling in skill gaps' were prioritized over math fact drills. This is because children with neurodevelopmental disorders typically do not learn optimally through rote memorization. In addition, they are prone to forgetting and memory retrieval problems, so performance will be unstable and children may experience

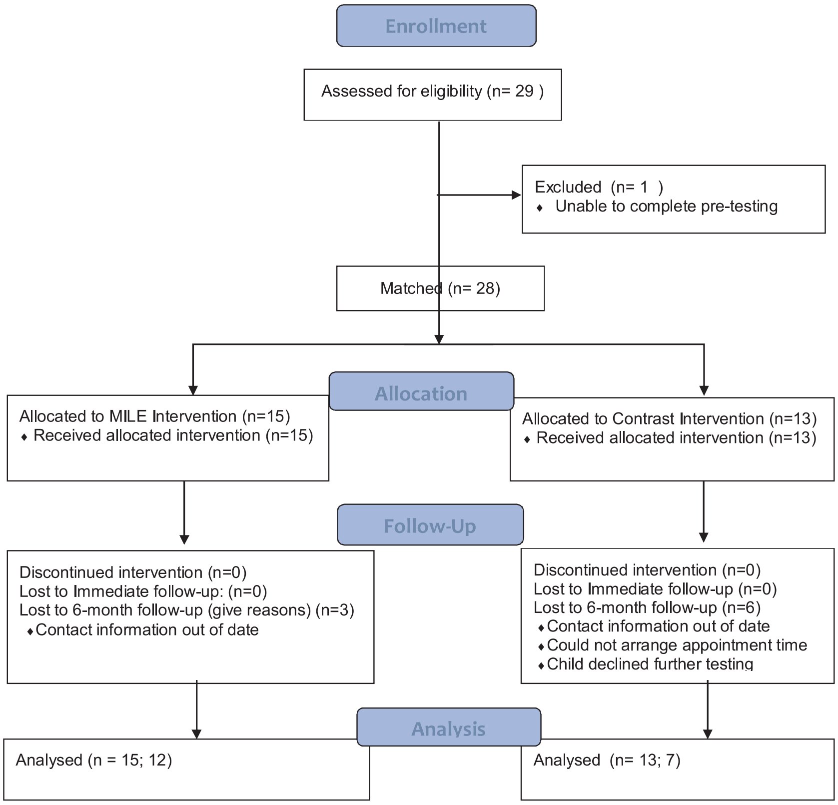

Fig. 1. Flow Diagram of Intervention Study.

difficulty with acquiring future skills that require an understanding of 'lower level' skills.

2.3.3. *Contrast intervention*

Many individuals with PAE and FASD experience difficulties with various aspects of social behavior (see Kully-Martens, Denys, Treit, Tamana, & Rasmussen, 2012). In addition, the skills targeted in social skills remediation efforts do not generally overlap with mathematics. For these reasons, we selected a social skills intervention as our comparison. We employed the companion intervention guide to the Social Skills Intervention System rating scale (SSIS; Gresham & Elliott, 2010). Based on a profile of needs and strengths generated by the SSIS (not reported in this paper), each child in the contrast group received an individualized intervention that focused on key areas of social skills and behavioral difficulties that often manifest in school settings (e.g., communication, co-operation, responsibility, empathy, self-control).

2.4. *Measures*

2.4.1. *Demographic questionnaire*

Caregivers completed a brief questionnaire regarding the child's age, grade, placement history, current living situation, and caregiver factors such as marital status, highest level of education, occupation, and household income bracket.

2.4.2. *Mathematics*

The Key Math 3 Diagnostic Assessment—Canadian Edition (KeyMath 3 DA; Connolly, 2007), a standardized measure of essential mathematical skills and concepts for children ages 4–21 years, was administered to participants at pre- and post-testing. Individual pre-test standard scores were used to determine the course of each MILE participant's intervention. The battery included 10 subtests measuring basic concepts (i.e., early numeration, algebra, geometry, measurement, probability awareness), operations (i.e., mental computation, estimation, written computation), and problem solving. Two parallel forms of the KeyMath 3 DA were used from pre- to post-test in order to minimize practice effects.

2.4.3. *Executive functioning*

Executive functioning (EF) was measured pre- and post-test with the Auditory Attention/Response Set subtests from the NEPSY–II (Davis & Matthews, 2010), which is a standardized neuropsychological battery for children ages 3–16 years. The Auditory Attention task measures auditory selective and sustained attention by asking a child to point to stimuli based on orally presented instructions.

Response Set involves a similar set of stimuli as the Auditory Attention task, but shifting and inhibition of previous rules from the Auditory Attention task are required.

2.4.4. Working memory

The Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), appropriate for children ages 5–15 years, was administered at pre- and post-test. One measure each of the phonological loop (Digit Recall) and the visuospatial sketchpad (Block Recall), as well as two measures of the central executive (Backward Digit Recall, Counting Recall) were used.

2.4.5. Visuospatial functioning

Two tools were used to assess visuospatial functioning at pre- and post-test. First, the Block Construction subtest from the NEPSY-II was employed to assess visuospatial construction skills. Second, the Rey Complex Figure Test (RCFT; Meyers & Meyers, 1995) was administered at pre- and post-testing as a measure of visuospatial processing, and visuospatial memory.

2.4.6. Intelligence

The Wide Range Intelligence Test (WRIT; Glutting, Adams, & Shelow, 2000) was used at pre-test only as a brief measure of verbal and nonverbal cognitive abilities. The WRIT provides verbal (crystallized) IQ and visual (fluid) IQ scores, which together yield a measure of general IQ for individuals aged 4–85 years. Though brief, the WRIT provides a good estimate of general cognitive ability; it has been highly correlated with lengthier IQ tests such as the WISC-III.

2.5. Data analysis

The initial phase of data analysis included analyzing the various demographic features of our sample. We compared the two groups for any demographic differences (e.g., age, sex, diagnosis, IQ, SES, number of living arrangements, current living arrangement) by using ANOVA for continuous data and chi-square for categorical data.

Research questions 1 and 2 were addressed by calculating the difference between pre- and post-test raw scores ('change scores') for each of the relevant measures and subtests. Raw scores were used because they tend to be more sensitive to change over a short period of time than standard scores. Change scores (i.e., changes in raw score over time) were used because there was a significant difference between the group pre-test scores. To investigate whether math performance improved immediately after intervention as well as after six months, we analyzed the KeyMath outcome variables with a step-down procedure. We first analyzed the total KeyMath composite and the three sub-composites (Basic Concepts, Operations, Applications of Problem Solving) separately using four univariate analysis of variance (ANOVA) procedures. If significant group differences were found on any of the three composites, we entered the subtests comprising the composite into a multivariate analysis of variance (MANOVA). Further tests were not performed on composites in which no significant group differences were found. For the cognitive data, we performed an exploratory analysis by conducting separate *t*-tests for raw change scores. Multiple tests were required due to the nature of how scores are derived for these measures. As such, these analyses should be taken as descriptive and exploratory.

To answer the third and final research question, we examined how particular demographic variables related to the magnitude of the observed math treatment effect. For each intervention group, correlations were conducted between the KeyMath total score and the three KeyMath sub-composites and various predictor variables: age, sex, diagnosis, IQ, and SES. Pearson correlations were conducted for non-dichotomous variables (e.g., age, IQ, SES) and Point Biserial correlations were conducted for dichotomous variables (e.g., sex, diagnosis).

3. Results

As hypothesized, from pre- to post-test, children in the MILE intervention significantly increased their total KeyMath score by an average of 11.93 raw points, compared to a 3.15 point increase observed in the contrast group, $F(1, 27) = 5.89$, $p < 0.05$, $\eta^2 = 0.19$ (see Table 2). On the Basic Concepts composite, the MILE group demonstrated a significant gain of 7.07 raw points compared to the contrast group, who gained an average of 2.31 points, $F(1, 27) = 4.98$, $p < 0.05$, $\eta^2 = 0.16$. Represented another way, 37.5% of participants in the MILE group improved their math standard scores by half a standard deviation or more on both the Total Math composite and the Basic Concepts composite compared to 7.7% of participants in the contrast group. The overall MANOVA for the five subtests of the Basic Concepts composite was not significant, $F(5, 27) = 2.01$, $p > 0.05$. The MILE group did not gain significantly more raw points than the contrast group from pre- to post-test on either of the remaining two composites (Operations and Applications of Problem Solving).

Data for six month follow-up were collected for 19 children. Six-month follow-up appointments were not able to be arranged for nine children for various reasons, including out-of-date contact information and inability to find a mutually-agreeable time for follow-up appointment. There were no significant demographic differences between the two groups at 6-month follow-up. Children who participated in the six month follow-up had significantly higher SES than those who were unavailable for follow-up. After a six month delay, children who had received the MILE intervention showed greater increases in total math achievement than those in the contrast intervention; those in the MILE group demonstrated a 25 point increase from pre-test to 6-months follow-up post-test, compared to a 13.7 point increase in the contrast group, $F(1, 18) = 5.47$, $p < 0.05$, $\eta^2 = 0.24$.

Next, we explored whether there were changes in EF following the intervention. by examining raw change scores for Auditory Attention and Response set (total correct as well as changes in error patterns). No significant differences were observed in raw change

Table 2
Changes in Raw KeyMath Scores by Group.

KeyMath	Pretest to Immediate Follow-Up			Pretest to 6-Month Follow-Up		
	MILE (n = 15)	Contrast (n = 13)	*p*	MILE (n = 12)	Contrast (n = 7)	*p*
Basic Concepts	7.01	2.31	0.04[a]	15.67	11.14	0.21[a]
Numeration	1.40	0.8	0.07[b]	2.50	3.28	
Algebra	0.60	0.85	0.75[b]	2.25	1.00	
Geometry	1.13	0.77	0.77[b]	2.83	4.14	
Measurement	2.67	0.31	0.01[b]	4.00	1.86	
Data Analysis/Probability	1.27	0.08	0.17[b]	3.67	1.00	
Operations	2.13	−0.08	0.07[a]	5.08	2.43	0.23[a]
Mental Computation	0.73	−0.08		1.91	0.00	
Addition/Subtraction	1.07	0.31		2.83	1.43	
Multiplication/Division	0.20	−0.31		0.25	1.00	
Applications of Problem Solving (PS)	2.07	0.92	0.32[a]	4.50	3.00	0.11[a]
Foundations of PS	2.40	0.85		2.50	1.00	
Applied PS	0.73	0.08		2.25	2.00	
Total	11.93	3.15	0.02[a]	25.00	13.71	0.03[a]

Note.
[a] Analyzed with ANOVA.
[b] Analyzed with MANOVA.

scores on the Auditory Attention and Response set (total correct as well as changes in error patterns) from pre- to post-test (see Table 3). However, descriptively, children in the MILE group trended toward demonstrating larger gains in total correct raw points for both Auditory Attention (a gain of 5.33 raw points versus 0.46 points in the Contrast group) and Response Set (a gain of 9.63 raw points versus 3.14). Children in the MILE group also trended toward greater decreases in Omission errors than the Contrast group across both subtests, although significant differences were not observed. No significant changes were observed in working memory or visuospatial skills, and, from a descriptive standpoint, the groups performed comparatively from pre- to post-test. Since no significant changes were observed in any of the cognitive domains assessed from pre- to post-test, we did not examine change in cognitive functioning further at the six month follow-up.

Finally, we examined whether specific participant characteristics such as age, sex, or IQ were related to any observed math treatment effects (see Table 4). Within the MILE group, older age was associated with higher KeyMath Total and Operations raw change scores. Sex was not significantly related to KeyMath Total raw change score in either the MILE group or the Contrast group. Within the MILE group, a PAE ‘diagnosis’ was strongly associated with greater raw point gains in Operations, Problem Solving, and Total Score, but not in the Contrast group. Within the MILE group, a lower Verbal IQ was associated with greater change in KeyMath

Table 3
Cognitive Measures Raw Change Scores by Group.

	Pretest to Immediate Follow-Up		
	MILE	Contrast	*p*
Executive Functioning (NEPSY-II)			
Auditory Attention			
Total Correct	5.33	0.46	0.18
Omission Errors	−6.73	−0.46	0.67
Commission Errors	−3.23	−2.67	0.89
Inhibition Errors	1.6	−1.46	0.41
Response Set			
Total Correct	9.63	3.14	0.13
Omission Errors	−9.63	−3.14	0.13
Commission Errors	−3.38	−2.00	0.55
Inhibition Errors	−0.5	−1.13	0.58
Working Memory (WMTB-C)			
Digit Span	−1.5	0.46	0.38
Block Recall	−0.73	0.38	0.59
Counting Recall	2.27	0.08	0.12
Backward Digit Recall	1.13	0.54	0.67
Visuospatial (RCFT)			
Copy	0.93	−0.35	0.67
Immediate Recall	0.10	1.04	0.34
Delayed Recall	0.03	0.31	0.76
Recognition Recall	1.27	1.15	0.91

Note. For error indices, a negative change score represents a decrease in the number of errors from pre to post test.

Table 4
Correlations Between Demographic Characteristics and Changes in Math Achievement.

	Math Composite							
	Basic Concepts		Operations		Problem Solving		Total Math	
	MILE	Contrast	MILE	Contrast	MILE	Contrast	MILE	Contrast
Age	0.52[a]	0.32	0.77[b]	−0.09	0.38	−0.03	0.48	0.18
Sex	0.01	0.32	0.04	−0.46	−0.21	−0.08	0.02	0.14
Diagnosis	−0.48	0.08	−0.68[b]	0.18	−0.64[a]	−0.07	−0.58[a]	0.09
IQ								
Verbal IQ	−0.33	0.11	−0.60[a]	−0.10	−0.59[a]	0.75[a]	−0.46	0.36
Visual IQ	−0.18	0.20	−0.18	0.01	−0.34	0.79[b]	−0.17	0.49
General IQ	−0.29	0.18	−0.47	−0.05	−0.54[a]	0.85[b]	−0.38	0.47
SES	−0.15	0.52	−0.31	−0.49	−0.07	0.21	−0.12	0.28

Note. Correlations based on raw change scores.
[a] Correlation significant at 0.05 level (2-tailed).
[b] Correlation significant at 0.01 level (2-tailed).

Operations and Problem Solving raw scores. However, among participants in the Contrast group, a higher Verbal and Visual IQ was associated with more raw changes in Problem Solving. Finally, a strong negative relationship was observed between overall IQ and KeyMath Problem Solving raw change score in the MILE group, $r(13) = -0.54, p < 0.05$. In comparison, IQ was strongly positively related to KeyMath Problem Solving raw change score in the Contrast group, $r(11) = 0.85$, $p < 0.01$. SES was not significantly correlated with changes math achievement within either group.

4. Discussion

This study replicated and extended a mathematics intervention ('MILE'), which was developed for children with FASD. Centrally, we sought to determine if MILE could still effect significant improvements in math achievement when it was delivered without parent training and in an ecological setting. We also wanted to determine if receiving MILE supported any changes in related cognitive domains such as EF, working memory, and visuospatial skills. Finally, we assessed the relationship between various demographic variables and the magnitude of the math treatment effect in order to help identify qualities of participants who may benefit more from MILE.

4.1. Mathematics outcomes

The math outcomes observed in this study suggest that a targeted psychoeducational program that focuses on the alcohol-related neurodevelopmental difficulties related to poor math achievement may help to ameliorate some of the deficits associated with prenatal alcohol exposure. Although the intervention was conducted over a relatively short time period, we still observed significant gains in math achievement performance in our MILE group relative to our contrast group. Effectively, after a two month period, children in the MILE group were able to demonstrate knowledge of close to 12 new basic math concepts, compared to 3 in the contrast group. Improvements were most evident in the domain of Basic Concepts (i.e., geometry, measurement, and basic estimation), which is commensurate with the focus of the majority of the individualized MILE intervention plans delivered. The significant difference in achievement acquisition was sustained over time. Indeed, the MILE group successfully demonstrated understanding of more new math concepts (i.e., acquisition of more raw score points) than the contrast group six months after the intervention ceased, with an increase of 13.07 points since the immediate post-test compared to 10.56 in the contrast group.

A promising outcome of this study is that we were able to observe a significant change in math achievement by using an intervention that totaled to approximately five hours of direct child instruction. By contrast, the original MILE study, which utilized parent training and child tutoring, equated to roughly 20 h of direct instruction for both children and caregivers combined (Coles et al., 2009). Our results suggest that parental support of mathematics learning may be an ideal—but perhaps not wholly necessary—factor in improving math achievement within the context of this intervention, which is important for children who may not come from stable home environments.

4.2. Other cognitive outcomes

The MILE program was designed not only to strengthen math skills in children with FASD, but to also accommodate deficits in underlying cognitions related to math, such as EF, working memory, and visuospatial functioning. Given the putative role of these processes in supporting math achievement, and the observed relationships between these cognitions and math in our sample, we felt it was reasonable to expect that if we saw changes in math achievement we may also see a transfer effect to other cognitions. Broadly speaking, children in both groups exhibited marginal gains on the cognitive measures from pre- to post-test. Descriptively, we observed a trend toward greater change on tests of EF among participants in the MILE group compared to those in the contrast group, although none of our comparisons were significant.

Based on the literature, it is not necessarily unusual for an intervention focused on achievement to not show generalized gains to other cognitive domains. For instance, Jansen, De Lang, and Van der Molen (2013) studied the effect of a computerized math training program in adolescents with mild to borderline intellectual disability. They found that although adolescents improved in math skill, there was no transfer effect to EF, working memory, or visuospatial processes. However, a study by Van der Molen, Van Luit, Van der Molen, Klugkist, and Jongmans (2010) approached treatment of math difficulties inversely, and found that training visuospatial working memory led to improvements in mathematics in children with mild to borderline intellectual disability. This suggests that it may be fruitful to incorporate direct training of various cognitive skills to enhance generalization to math achievement.

It is important to note that although our contrast intervention, which targeted social skills, was not believed to have any overlap with mathematics, the ability to successfully deploy social skills does require the operation of cognitive abilities such as EFs (see Kully-Martens, Treit, Pei, & Rasmussen, 2013). Thus, it is possible that the MILE intervention did contribute to improvements in EFs, but perhaps not uniquely from another intervention.

4.3. Factors related to math treatment effect

Among participants who received the MILE intervention, those who made greater math achievement gains immediately post-intervention were older, with lower verbal and full-scale IQ, and were alcohol-exposed but undiagnosed (‘PAE’). Conversely, those in the contrast group who made greatest changes in math performance tended to have higher IQ.

Both the present study and the work of Coles et al. (2009) found that gender and SES were not related to the treatment outcome. However, contrary to the findings of the present study, Coles and colleagues reported that IQ did not appear to have a significant impact on treatment outcome, and that children with greater math achievement gains were more likely to be

younger and have greater alcohol-related dysmorphia (i.e., a more severe diagnosis on the fetal alcohol spectrum). It is possible that the differences found between these two studies may be due to different sample compositions and outcome measures. For example, Kable et al. (2007) and Coles et al. (2009) utilized a younger sample than the present study, and employed additional measures that specifically sampled math skills in younger age groups (e.g., Test of Early Math Achievement). In contrast, the KeyMath includes fewer items appropriate for younger children. We used the KeyMath for all our participants, even for those whose current age fell slightly below the recommended age for use. During individual testing sessions it generally did not appear to be an issue; however, it could be argued that this test was less sensitive to change in lower level math skills, particularly in younger children. Thus, correlations of math achievement with age could be overestimated. In addition, the sample in Kable et al. (2007) was larger ($n = 61$), a lower-income, largely African American sample of predominately clinically-referred children diagnosed with the most severe forms of FASD (i.e., FAS, pFAS). In contrast, the present study utilized a more moderate-income, older, predominately Caucasian and Aboriginal sample with a wider spectrum of clinical diagnoses. Finally, different measures were used to assess IQ in the two studies.

4.4. Limitations and future directions

Although our results are promising, several questions remain unanswered, and several limitations exist pertaining to both the study design and program implementation. First, we do not know the long-term implications of this intervention beyond six months. Future investigations may also want to manipulate the length of treatment to ascertain the treatment duration that is most associated with both short and long-term gains.

We attempted to enhance the generalizability of this program to a greater variety of alcohol-affected children by including all children on the fetal alcohol spectrum, as well as those who were undiagnosed. To better understand the specificity of the intervention, trials with children who present with overlapping areas of neurodevelopmental challenge (e.g., ADHD, specific learning disorder) should be explored. Similarly, although the MILE program was designed to use specific strategies and supportive educational tools to help support alcohol-related neurodevelopmental difficulties, our study could not determine if these strategies were necessary to the treatment effect or if the model was valid. Future studies may want to compare MILE to other one-on-one, individualized math interventions to determine which aspects are integral to the treatment effect.

There are also some limitations inherent to our sample. For example, children in the ‘undiagnosed’ PAE group may indeed meet criteria for an FASD diagnosis at a later assessment. It is also difficult to control for individual participant factors that may contribute to potential treatment effects, such as qualities related to an individual participant’s teachers, classroom, programming, school, and family, or unique subjective life history factors.

As this is a pilot study, our sample size was very small and may have restricted our power to detect group differences. However, we were still able to demonstrate large effect sizes even with a limited sample. Further, due to these design limitations, we still are not certain which participant characteristics may be most integral to a math treatment effect. Decreased power to detect group differences was also compounded by calculating change scores instead of using a repeated-measure design. However, because groups were very different at pre-test (despite matching), a repeated-measure design would likely have cloaked any treatment effects. Because this is an exploratory pilot study, we did not adjust alpha for multiple comparisons.

There are also issues related to testing and measurement. Although we were able to provide an alternate parallel form of the KeyMath to participants at post-test, we did not have different forms of the measures we used to assess EF, working memory, and visuospatial functioning. It is possible that the lack of group differences observed could be due to a practice effect in both groups on these measures. Furthermore, the MILE group had lower math scores at pre-test than the Contrast group, which may be more subject to effect of regression to the mean.

4.5. Implications

Our results suggest that using individualized and targeted teaching methods can foster learning in alcohol-affected children. The results of this study coupled with findings from other intervention studies conducted with this population should help to dispel the belief that individuals with alcohol-related brain damage are resistant to habilitation. In turn, this should generate further interest and study in designing and implementing models and methods of service delivery for individuals with PAE and FASD. Although one-on-one instruction with children does require time, we were able to effect changes in math achievement with an intervention that totaled to only five hours of direct instruction with a child and no significant contact with a teacher or parent. This sort of investment should certainly be feasible to conduct in both clinical and educational settings.

The benefit of learning math concepts is not limited to the traditional math curriculum or the school setting. Over the course of development, math constructs such as sorting, classifying, patterning, adding, and subtracting become integrated into our everyday adaptive life skills and problem-solving behaviors, allowing us to move about successfully in the world, predicting the outcomes of our behavior, the outcomes of others' behavior, and the environmental events that influence us. For example, understanding concepts such as units of time (e.g., minute, hour) and the repetition of days in a calendar can permit a sense of predictability and focus in work, school, and personal lives. Poor understanding of the relationship between time, events, objects, and other people, including event sequencing which is necessary for appropriate causal attribution and accepting time frames and delays in reference to activities and preferred items can contribute to frustration and lead to behavioral problems commonly observed in alcohol-affected individuals (Kable et al., 2007). Accordingly, a mathematic psychoeducational intervention may not just enhance the academic skills that lead to improved educational and occupational outcomes, but enhanced problem-solving skills that will impact everyday functioning.

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