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LONGITUDINAL EVALUATION OF MATHEMATICS ACHIEVEMENT IN CHILDREN AND ADOLESCENTS WITH FETAL ALCOHOL SPECTRUM DISORDER

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ABSTRACT

Background and Objectives

Mathematics achievement as a particular area of difficulty for individuals with fetal alcohol spectrum disorder (FASD) has been a robust finding in the literature. However, existing longitudinal data are outdated and do not consider mathematics performance across time during critical periods of transition such as adolescence. Longitudinal data on the developmental trajectory of mathematics and factors that may influence outcomes can inform the development of effective educational intervention strategies for youth with prenatal alcohol exposure (PAE)/FASD to promote academic success in the area of mathematics. In the present study, we aimed to add to the existing literature through the examination of mathematics performance at two time-points at both the group and individual levels. We also examined the impact of various demographic and environmental factors on mathematics skills over time.

Materials and Methods

Fifteen children and youth with PAE/FASD were assessed at time 1 (M age = 13.0 years, range 9–17 years), and at time 2 approximately 5 years later (M age = 18.5 years, range 15–23 years) using a standardized measure of math achievement.

Results

At the group level, mean normative math achievement scores significantly decreased over time. At the individual level, reliable change indices indicated that 13.3% (n = 2) of participants' scores demonstrated clinically significant change across time. No demographic or environmental factor variables were correlated with changes in scores across time.

Conclusion

With recognition that the results need to be considered in the context of the limited power and generalizability that our small sample size offers, our results highlight the importance of considering both group and individual change. Without such information, there is the potential to overgeneralize the extent to which mathematics scores for individuals with PAE/FASD are decreasing across time. Our descriptive findings acknowledge the critical need for adolescent mathematics interventions which consider the complexity and diversity of the deficits present in PAE/FASD because existing services may be buffering some difficulties in the area of mathematics, but are not necessarily promoting longer-term impacts.

Keywords: FASD; Mathematics; Longitudinal Outcomes; Education

INTRODUCTION

Prenatal alcohol exposure (PAE) can result in lifelong primary deficits to critical central nervous system (CNS) functions. Fetal alcohol spectrum disorder (FASD) refers to individuals with physical, mental, behavioral, and learning disabilities related to PAE.[1] Individuals with FASD often present with neurobehavioral impairments in domains such as intelligence, attention, language, visual perception, learning and memory, achievement, behavior, and executive functioning.[2–4]

Children and youth with FASD often require access to special education services to meet their unique learning needs. However, because of the complexity of presenting neurobehavioral profiles, many traditional educational interventions and services do not optimize individuals' academic outcomes and functioning in educational settings. Consequently, children and youth with FASD are at a higher risk of adverse educational outcomes such as disrupted school experiences (i.e., suspension, expulsion, and drop-out).[5] In order to develop and tailor academic interventions to fit the needs of children and youth with PAE/FASD and to improve success in educational settings, we first need to understand the unique developmental course of their academic skillset.

Mathematics and FASD

Mathematics knowledge begins to develop in a child's early years, and it is fundamental to future achievement in the subject area[6] as well as a wide array of adult outcomes including college degree attainment, higher reported income, and health care choices.[7–8] Individuals with PAE have more difficulty with mathematics compared to other academic domains.[9] For example, deficits in mathematics are more highly correlated with the amount of prenatal alcohol exposure than other academic and cognitive skills including reading, spelling, and mathematics.[10,11] In addition, these mathematics difficulties are associated with reduced processing speed, working memory, and visuospatial abilities.[12–15] Alterations in brain structure and function, including decreased function in the parietal region, are also associated with mathematics deficits among individuals with FASD.[16–18]

To date, the most compelling evidence in support of the persistence of mathematics deficits in individuals with FASD comes from longitudinal work conducted by Streissguth and colleagues.[11] Children with FASD were tested on standardized measures of academic achievement and cognition at ages 4, 7, 11, and 14 years. Mathematics scores were the most highly correlated with PAE at each time point above other academic skills such as reading and spelling, and the effects were dose dependent.[19–22] The association between PAE and math difficulties has been replicated in other studies,[10,23] which provides compelling evidence in support of both the sensitivity and stability of deficient mathematics performance in children and adolescents affected by PAE.

Mathematics Performance and Contributing Factors

Academic performance, in any domain and for any individual, can also be influenced by a variety of personal and environmental factors. Factors of particular importance to the academic context can include comorbid diagnoses, access to educational services to support and ameliorate academic challenges, disrupted school experiences, and caregiver status.[24]

Children and youth with PAE/FASD often present with comorbid psychiatric conditions. For example, Attention Deficit Hyperactivity Disorder (ADHD) commonly occurs in children with PAE/FASD with researchers documenting rates ranging from 63% to 95% in their studies.[25–26] Comorbid conditions, such as ADHD, can further complicate learning challenges for individuals with PAE/FASD because specific disorders may have their own comorbidities including Specific Learning Disorders with comorbidity prevalence estimates of 25–40.[27–28] Comorbid diagnoses are important information to gather when developing an understanding of mathematics performance across time because of the added potential influence these diagnoses may have on deficits in academic areas. For example, if a student cannot attend to the information being taught, they will be unable to learn or retrieve that information.

Individuals with FASD often present with a range of neurobehavioral difficulties which need to be supported by special education services to lessen their impact on academic performance in a variety of domains. Intervention programs, such as the Math Interactive Learning Experience (MILE), have been developed and found to successfully improve mathematics outcomes in children with FASD.[29–31] Thus, targeted interventions at early ages may shift the trajectory of math difficulties in individuals with FASD. To date, however, the MILE program is not readily available in school programming.

Children and youth with FASD are particularly susceptible to adverse educational outcomes and disrupted school experiences. For example, Streissguth and colleagues[5] using a large sample (n = 415, median age = 14, and range = 6–51) found that 14% of children and 61% of adolescents and adults with FASD reported having disrupted school experiences. Approximately 53% of the adolescents reported being suspended from school, 29% reported expulsion, and 25% had dropped out.[5] In a more recent study McLachlan and colleagues[31] examined patterns of school disruption and other areas of difficulty among a Canadian sample of individuals with FASD. The total sample (n = 726) consisted of adolescents, transition aged youth, and adults, with the authors reporting that adolescents had significantly higher rates of school disruption (26%) compared to adults (5%) but not transition aged youth (18%).[31] These disrupted school experiences can have detrimental effects on academic performance due to missed instructional time or disciplinary action removing them from their educational setting entirely. In addition, disrupted school experiences have the potential to majorly impact self-esteem and motivation to learn which can persist throughout the school-age years into adulthood.

Finally, caregiver status has been found to have an impact on academic achievement. For example, children and adolescents in child welfare and protective care show an increased risk on a wide range of developmental outcomes and of particular concern is their risk for lower academic achievement across multiple countries.[32] Relative to their same-age peers residing with biological families, children and adolescents in care are not only more likely to score significantly lower on standardized tests of academic achievement,[33,34] but they are also more likely to experience disrupted school experiences which may further contribute to lower academic achievement as discussed above.[35]

Present Study

Mathematics achievement is a particular area of difficulty for individuals with FASD.[9] However, there are very few longitudinal studies in this area, particularly studies that follow individuals with FASD across time during critical transition periods such as adolescence and early adulthood. We must also consider variables such as age, sex, PAE versus a formal FASD diagnosis, comorbid diagnoses, educational services received, and disrupted school experiences that have the potential to influence mathematics performance across time. In addition, past longitudinal studies have only examined group-level mean differences. For a more in-depth analysis of changes in mathematics scores across time, individual in addition to group-level change must be considered. Longitudinal data on the developmental trajectory of mathematics and factors that may influence outcomes can inform the development of effective educational intervention strategies for youth with PAE/FASD to promote academic success in the area of mathematics.

We examined the mathematics performance over time using a sample of youth with PAE/FASD. Consistent with previous research, we expected math difficulties would become more pronounced over time. We also examined the impact of various demographic variables (e.g., age, sex, FASD diagnosis, and comorbid diagnoses) and environmental factors (e.g., educational services, disrupted school experiences, and caregiver status) on the math skills over time.

METHOD

Participants

Data were collected as part of a larger study on neurobehavioral outcomes in children and adolescents with PAE/FASD at a clinic in Western Canada. Of the 67 participants who participated in the previous study, 24% (n = 16) completed participation, 30% (n = 20) did not return phone calls or were not interested in participating, and 46% (n = 3 1) of the participants had an outdated phone number or had moved. Of the 16 remaining participants, only 15 completed the standardized measure of mathematics achievement at two time points. Therefore, the remaining longitudinal sample was 15 children and adolescents with FASD/PAE. Fifteen children and youth with PAE/FASD were assessed at time 1 (*M* age = 13.0 years, range 10–17 years), and again ~6 years later at time 2 (*M* age = 19.8 years, range 15–20 years). Participant characteristics and demographic information for the full sample (n = 52) and the longitudinal sample (n = 15) are listed in Table 1.

TABLE 1 Participant Characteristics.

	Full Sample (n = 52)	**Longitudinal Sample (n = 15)**	***p***
Variable			
% Sex [male (n)]	44% (23)	53.3% (8)	0.53[b]
Age in years at time 1 (M [range])	11.38 (6–17)	13.8 (10–17)	0.06[a]
Age in years at time 2 (M [range])	-	19.8 (15–20)	-
Diagnosis [% FASD (n); % PAE (n)]	51.9% (27); 48.1% (25)	80% (12); 20% (3)	0.05[b]
Stability [% (n) ≤ 3 living situations]	57.7% (30)	53.3% (8)	0.95[b]
Annual Household Income [% (n) < $50, 000]	65.3% (34)	80% (12)	0.07[b]
Disrupted school experiences prior to time 1			
% Suspended (n)	19% (10)	20% (3)	0.66[b]
% Expelled (n)	0.04% (2)	0% (0)	0.74[b]
% Dropped out (n)	0.04% (2)	0.01% (1)	0.56[b]
Disrupted school experiences prior to time 2			
% Suspended (n)	-	33.3% (5)	-
% Expelled (n)	-	20% (3)	-
% Dropped out (n)	-	20% (3)	-

Note. [a]*Analyzed with ANOVA;* [b]*analyzed with chi-square; *p < 0.05.*

PROCEDURE

Data collection

All processes and procedures for this project received ethics approval prior to the commencement of data collection. Child and adolescent participants were administered standardized measures of mathematics achievement at time 1 and time 2. Research assistants were trained in the administration of these measures. Given the length of time between data collection time points, the research assistants differed across time points. At time 1, caregivers took part in a structured interview and completed demographic and behavioral questionnaires at time 1 and time 2. Time 1 data were collected between 2010 and 2011. Time 2 data were collected between 2016 and 2017.

MEASURES

Demographic Questionnaire

This questionnaire was completed by caregivers and gathered information regarding the child's age, grade, placement history, and current living situation. Caregivers were also required to provide their own information regarding marital status, highest level of education, occupation, and annual household income.

Structured Interview

A structured caregiver interview on service delivery was completed with caregivers. The interview consisted of questions from the *Services for Children and Adolescents – Parent Interview (SCAPI).* [36] In particular, we looked at the variables pertaining to receiving educational services. Caregivers indicated whether or not their child had received the following educational supports: individual program plan (IPP), tutoring, extra help in class, and other specialized programming.

Mathematics Achievement

Participants completed the Quantitative Concepts subtest from the *Woodcock-Johnson-III Tests of Achievement.*[37] The *WJ-III ACH* is an individually administered measure of academic achievement for individuals aged two years to adulthood. Quantitative concepts require knowledge of mathematical concepts, symbols, and vocabulary. The subtest comprises two subtests, Concepts and Number Series, and yields a standard score (M = 100, SD = 15). Extensive research documents the reliability and construct validity evidence of scores on the *WJ-III ACH.*[38]

Data Analysis

The first phase of our data analysis included analyzing the various demographic and environmental characteristics of both the full and longitudinal samples. We calculated the descriptive statistics (i.e., mean, range, and frequency; see Tables 1 and 2). We compared the two groups for any differences in variables (e.g., sex, age, diagnosis, living situations, annual household income, and disrupted school experiences prior to time 1). Analysis of variance (ANOVA) was used for continuous data and chi-square for categorical data. We chose to create a number of living situations variable coded as ≤ 3 living situations and > 3 living situations in an effort to create a *stability* variable given that the caregiver status of our participants is rather homogenous.

Second, we used a paired samples *t*-test to determine whether there was a significant difference in mean quantitative concepts measured between time 1

TABLE 2 Educational Services Received at Time 1 and Time 2.

Variable	Time 1 n (%)	Time 2 n (%)
Receiving Educational Services	14 (93.3)	12 (80)
Individual Program Plan (IPP)	13 (86.7)	9 (60)
Tutoring	3 (20)	3 (20)
Extra Help in Class	12 (80)	9 (60)
Special School Programming	6 (40)	8 (53.3)
Special Testing	5 (33.3)	6 (40)

and time 2 (see Table 3). We then calculated difference scores (i.e., individual changes in standard scores from time 1 to time 2) on quantitative concept scores, to determine the percentage of participants increasing or decreasing in terms of standard deviation (*SD*) units relative to their same-age peers.

Third, Reliable Change Index (*RCI*) was calculated to examine individual changes using Jacobson and Truax's[39] method (see Table 4). For change to be considered statistically reliable, we must consider measurement error. Errors are normally distributed and, therefore, all properties of the normal curve apply to error distributions. The *RCI* formula calculates the difference between time 1 and time 2 scores at the individual level divided by the standard error (SE) of the difference score. If the calculated *RCI* value is ≥ 1.64 for educational measures, a difference of this magnitude falls in the 5% tail of the error distribution.[38] Therefore, the resulting change is reliable and is not likely due to measurement error.

Fourth, we aimed to examine whether group differences remained after removing the two participants who showed reliable change based on our RCI calculations. We used a paired-samples *t*-test to determine if there was a significant difference in mean quantitative concepts measured between time 1 and time 2.

Finally, we examined the association between age, sex, PAE or FASD diagnosis, comorbid diagnoses, disrupted school experiences, and number of living situations with the magnitude of the observed change in scores over time using Pearson correlations for nondichotomous variables and Point Biserial correlations for dichotomous variables (see Table 5). It is important to note that we excluded educational services from our correlational analyses given that we had limited variability as the majority of participants (n = 14) were receiving educational services at time 1.

RESULTS

Sample Characteristics

Using ANOVA for continuous data and chi-square for categorical data, we compared the full and longitudinal samples for any group differences in variables (e.g., sex, age, diagnosis, living situations, annual household income, and disrupted school experiences prior to time 1). The groups did not significantly differ on any variables (see Table 1).

Mathematics Achievement

Preliminary assumptions testing was conducted with no violations observed. The paired samples *t*-test showed that there was a statistically significant decrease in mean Quantitative Concepts standard scores from time 1 to time 2; $t\ (14) = 2.66$, $p = 0.0001$.

TABLE 3 Results of t-test and Descriptive Statistics for WJ-III Quantitative Concepts Scores from Time 1 to Time 2.

	Time 1		Time 2				
Outcome	**M**	**SD**	**M**	**SD**	**n**	**t**	**df**
Quantitative Concepts	83.27	13.43	78.60	15.34	15	2.66*	14

*Notes. Standard scores based on M = 100, SD = 15; WJ-III = Woodcock-Johnson-III * p < 0.001.*

TABLE 4 Reliable Change Indices for Quantitative Concepts Scores from Time 1 to Time 2.

	% (n) Decreased	% (n) Increased	% (n) No Change	% (n) Reliable Change
Quantitative Concepts	80% (12)	13.3% (2)	6.7% (1)	13.3% (2)*

*Note. * significant at p < 0.05.*

TABLE 5 Correlations between Participant Characteristics and Mathematics Change Scores.

	Correlation	***p***
Sex	0.25	−0.32
Age	0.35	0.21
PAE or FASD Diagnosis	0.23	0.41
Other diagnoses at time 1		
ADHD	−0.02	0.96
Anxiety	0.03	0.90
Depression	0.38	0.16
Disrupted school experiences prior to time 2		
Suspended	−0.01	0.98
Expelled	0.21	0.45
Dropped out	0.13	0.65

When examining individual changes in standard scores, we found that 80% of the participants showed a decrease in their standard scores. Specifically, 60% decreased by >0 to 0.5 *SD*, and 20% decreased by >0.5 *SD*. The remaining participants either showed no change (6.7%) or increased (13.3%) by >0–0.5 *SD*. Figure 1 depicts participants' individual quantitative concept scores presented according to time points.

Group Differences between Time 1 and Longitudinal Samples

A one-way ANOVA revealed that there was not a statistically significant difference in time 1 quantitative concepts scores between the original and longitudinal samples, F(1, 27) = 0.49, $p = 0.49$.

Individual-Level Change

The *RCI*[38] was used to determine how many participants' scores from time 1 to time 2 were reliable and were not due to measurement error. Table 4 presents the total percentage of participants' scores that increased, decreased, showed no change, and showed reliable change. Calculated *RCI* values indicate that 13.3% (n = 2) of participants' scores were ≥ 1.64 or statistically significant at $p < 0.05$.

Group Differences for Participants without Reliable Change

We examined whether group differences remained significant after removing the two participants who showed reliable change based on our RCI calculations. Preliminary assumptions testing was conducted with no violations observed. The paired samples *t*-test showed there was a statistically significant decrease in mean Quantitative Concepts standard scores from time 1 ($M = 82.77$, $SD = 12.77$) to time 2 ($M = 80.38$, $SD = 14.36$), $t(12) = 2.54$, $p < 0.001$.

Participant Characteristics

There were no significant correlations between demographic variables (i.e., age, PAE/FASD, sex, comorbid diagnoses, disrupted school experiences, and number of living situations) and mathematics change scores (see Table 5).

DISCUSSION

In the present study, we first aimed to determine whether mathematics achievement scores changed over time among individuals with PAE/FASD at both the group and individual levels. We also correlated changes in mathematics scores across time with factors including age, sex, comorbid diagnoses, disrupted school experiences, and number of living situations. These variables were identified as having the potential to influence academic performance across time, regardless of domain, and thus were included for correlational analyses in the present study.

Mathematics Achievement

In our sample, participants' mean mathematics achievement scores significantly decreased over time, demonstrating group-level changes in quantitative concepts skills relative to participants' same-age peers. Our results differ from past longitudinal work given that our results show a decline in mean scores across time rather than stability in a mathematics deficit.[10,11,23] This pattern of decline, with deficits becoming more pronounced with age, has been observed in other domains including executive functioning,[40] social skills,[40–41] and adaptive skills[40,42] for individuals with FASD. It is important to note that decreases in scores over time do not reflect a loss of skills, but rather a reduced rate of skill acquisition relative to same-age peers. Thus, among individuals with FASD, math difficulties were more pronounced with increasing age, indicating that they were falling further behind the normative population with age. There were also participant and methodological differences between our study and the most compelling longitudinal study to date completed by Streissguth and colleagues.[11] Our study assessed 15 children and youth with PAE/FASD at time 1 (*M* age = 13.0 years, range 10–17 years), and again ~6 years later at time 2 (*M* age = 19.8 years, range 15–20 years). Streissguth and colleagues[11] tested children with FASD on standardized measures of academic achievement and cognition at ages 4, 7, 11, and 14 years.

Mathematics is a subject which requires building on previously learned material to demonstrate progress. Thus, deficits in mathematics skills may tend to accumulate over time, which may be reflected in the longer-term differences, or decrease in scores, as we observed in mathematics achievement across time. Furthermore, mean quantitative concepts scores at both time points fell below the 25th percentile, which is commonly used to identify those individuals at risk for severe difficulties in mathematics.[43,44] When examining individual scores, 80% showed a decrease in their standard score over time. Therefore, our results identify a mathematics deficit in individuals with PAE/FASD that persists across time. Our findings add to the literature on this particular academic deficit by identifying and providing a rationale to support students with PAE/FASD at an earlier time in their academic trajectory to prevent further decline in their mathematics skillset.

Although we observed group-level statistically significant changes in mean mathematics scores across two time points, we also considered individual-level change. In our sample, *RCI* values calculated indicated that 13.3% (n = 2) of participants' scores changed (decreased) at a level that is regarded as statistically significant or psychometrically reliable as per Jacobson and Truax's[38] guidelines. The inclusion of *RCI* in our study alongside mean group-level comparisons allowed us to add a further dimension to our findings such that we can conclude, based on our results, that the majority of our participants' change across two time points was not above what would be expected due to measurement error. We cannot unpack these results in the context of past longitudinal studies given that researchers did not examine individual-level change using *RCI* and instead only reported group-level differences.[10,11,23]

Past longitudinal studies have also demonstrated the sensitivity of mathematics performance to PAE and the stability of the deficit over time. Our results, at the individual level, provide an alternative lens to changes over time because they indicate that not all participants who demonstrated decreases in mathematics scores relative to same-age peers across time are exhibiting changes that are substantial enough and go beyond what would be expected at random due to measurement error. These results highlight the importance of including both group- and individual-level analyses in studies examining academic performance, in any domain, across time. Consideration of measurement error is critical in studies of this nature because, without such analysis, we may overestimate the extent to which the majority of participants' scores are decreasing across time. Including *RCI* data in our study allowed us to determine that not all participants' scores were decreasing to an extent that would be considered meaningful. Without such information, we may have overgeneralized the extent to which mathematics scores for individuals with PAE/FASD are declining across time to the point in which they are considered to fall outside of the normal score distribution as recognized by the standard error of measurement.

Participant Characteristics

Correlational analyses revealed that no variables were found to be associated with change scores at the group level; however, our sample size was very small and may have restricted our power to detect relationships. Our descriptive analysis revealed that the majority of participants (n = 14; 93.3%) were receiving at least one type of educational service at time 1. Given that we did note group-level changes in quantitative scores across time despite the majority of participants receiving services, it could be that the supports were potentially buffering some difficulties in the area of mathematics but were not necessarily promoting longer-term impacts such as the development of age-appropriate mathematics skills over time. This descriptive finding is not surprising given that educational services appropriate for the majority of struggling students do not typically account for the complexity and diversity of deficits present in individuals with FASD. For example, receiving the support of an Individualized Program Plan (IPP) is a service that is provided to a multitude of students presenting with varying levels of difficulty and disabilities. The IPP is an overarching document structured to identify several areas students may require support in that it does not necessarily consider the intraindividual variability in neurobehavioral profiles observed in individuals with FASD. Furthermore, our descriptive analysis revealed that for those participants who demonstrated a reliable change in their mathematics scores across the two time points (n = 2; 13.3%), both participants had an IPP in place at time 1. This descriptive finding adds to our understanding that perhaps the IPP is not supporting the academic needs of students with FASD in the domain of mathematics given that these participants, even with the IPP in place, demonstrated a reliable decline in their mathematics scores relative to their same-age peers above what would be expected given the standard error of measurement.

It is also important to note that the number of individuals receiving services did slightly decrease from time 1 (n = 14) to time 2 (n = 12) which perhaps suggests that participants' scores were also decreasing due to lack of consistent support for their learning needs. This descriptive finding perhaps highlights the importance of implementing consistent, ongoing, and long-term support for individuals with FASDs' learning needs. If steps are taken to ensure that supports are not withdrawn and instead adapted as learning needs change, or transitions take place, we may not observe a decline in performance if services are removed.

Strengths and Implications

Our study built on past longitudinal work in several ways. First, previous longitudinal studies included standardized measures of intelligence and academic achievement, which targeted arithmetic and working memory-based skills (i.e., digit span). These standardized tests typically examine only accuracy on a small range of problems that do not necessarily account for the applied nature of mathematics instruction in the classroom. In our study, we used the quantitative concepts subtest from the *WJ-III ACH*,[36] which measured aspects of mathematics knowledge and quantitative reasoning. Thus, we used a measure which considered the application of two subskill areas of mathematics. Second, samples used in past longitudinal work collected data up until age 14.[11] We used a sample of adolescents with PAE/FASD with a mean age range of 13.8–19.8 years from time 1 to time 2. Third, as mentioned previously, we considered individual-level change across time using calculated RCIs. Finally, to the authors' knowledge, this study is the only longitudinal study using a Canadian sample of individuals with PAE/FASD. Overall, our results make a unique and novel contribution to the literature by providing evidence that supports an understanding of mathematics performance in adolescents with PAE/FASD through an examination of how specific and applied mathematics skills develop over time at the group and individual level during a critical transition period (i.e., adolescence) and in a Canadian sample.

Our results indicate that applied mathematics skills (i.e., quantitative concepts) are particularly difficult for individuals with FASD, and that this difficulty persisted or became more pronounced over time. Quantitative concepts are one particular skill that could be the target point of mathematics interventions. Interventions should target this skill while simultaneously attempting to accommodate for underlying cognitive deficits specific to mathematics (i.e., working memory). Accounting for these underlying cognitive deficits could be accomplished by including intervention components that have demonstrated success in previously developed interventions. For example, MILE[28–30] employs metacognitive strategies and involves multisensory stimulation exercises in fostering the development of mathematics skills. These core intervention components can be tailored to be developmentally appropriate for later elementary and secondary levels of education and have the potential to demonstrate similar success to that observed in the younger sample MILE was developed for (i.e., ages 3–10).

We also targeted a critical educational transition period in our study by focusing on adolescence to early adulthood. This transition is a particularly vulnerable period of change for youth, not just for those with FASD. Adolescents who are already struggling in a specific academic domain may fall further behind their peers because of increased academic demands and hence the need for substantial autonomy and self-management skills. It is crucial to assess children in mathematics before this transition to identify specific skill areas that are underdeveloped relative to their same-age peers and may require the implementation of effective educational intervention strategies. In addition, mathematics competency is important for key daily living adult functions, such as money and time management, which may impact independence. Therefore, early math interventions that target developmental-level and underlying cognitive factors specific to mathematics such as working memory and visual spatial skills, like MILE, are critical to promote the development of mathematics skills required throughout adolescence and into adulthood.

Limitations and Directions for Future Research

Although we yielded valuable information regarding age-related changes in adolescent mathematics outcomes, it is critical to consider our study's limitations to inform directions for future research. First, we recruited our participants from a previous study that collected data 6 years prior to the beginning of our recruitment process. The majority of participants from the previous study could not be located for recruitment and we were only able to maintain 24% of our original sample, resulting in a high attrition rate and very small sample size (n = 15). The small sample of our study substantially limits the power and generalizability of the results, and thus any conclusions made are to be interpreted carefully and tentatively. Indeed, our attrition rate is much higher than Streissguth and colleagues'[11] longitudinal work given that they were able to successfully maintain 82% of the original cohort that was examined. The authors cite consistent and extensive contact tracing which contributed to maintaining the majority of their original cohort.[11] Small sample sizes frequently occur in research with children and adolescents with PAE/FASD[15] given that it is often challenging recruiting participants with confirmed PAE or a formal diagnosis, which was a requirement for participation in this study. This recruitment challenge may be reflective of the caregiving situation, which shifts in late adolescence, especially if the individual is living in group care or not with a significant guardian to help them navigate systems of care and receive a formal diagnosis. Despite our small sample size, we found significant group-level changes in mathematics. However, further studies are needed to validate the current findings.

Second, we only tested participants in one area of mathematics: quantitative concepts. This approach limits our ability to comment on the developmental trajectory of mathematics achievement in other applied areas of mathematics, such as problem-solving. Third, we measured mathematics achievement at two time-points, whereas adding additional time points may have added specificity and yielded a true developmental trajectory over time. Finally, given the length of time between time 1 and time 2 data collection (i.e., ~6 years), the examiners differed which could have impacted performance. Future research should attempt to recruit a larger sample size, including multiple applied areas of mathematics, and include more than two time-points with consistent examiners when evaluating age-related changes in mathematics achievement.

It may also be beneficial for future studies to include both group- and individual-level analyses. The added benefit of determining whether or not individual participants' change scores are clinically significant allows us to determine whether or not group-level results are consistent with how participants are performing at the individual level. Finally, future research would benefit from including a more in-depth examination of those participants who did not show significant decreasing scores across time and what factors (i.e., demographic and environmental variables) influenced these participants' outcomes across time. Looking at individuals who had better outcomes may help identify supports and interventions that are more effective.

CONCLUSION

With recognition that the results need to be considered in the context of the limited power and generalizability that our small sample size offers, our results highlight the importance of considering both group and individual changes. Without such information, there is the potential to overgeneralize the extent to which mathematics scores for individuals with PAE/FASD are decreasing across time. Our descriptive findings acknowledge the critical need for adolescent mathematics interventions which consider both the complexity and diversity of the deficits present in PAE/FASD because existing services may be buffering some difficulties in the area of mathematics but are not necessarily promoting longer-term impacts. In addition, it is critical that when supports are put into place that they are monitored, adapted as needed, and maintained across transition periods.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest for this study.

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