Anxiety as a Predictor of Movement During a Math Task in Elementary School Children

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ABSTRACT
Anxiety can come in various forms; general anxiety is characterized by feelings of excessive anxiety impacting multiple domains of everyday life, whereas anxiety may also manifest within a single domain (*i.e.*, math anxiety). Those that present with anxiety who also have Autism Spectrum Disorder often exhibit ritualized movement as a coping mechanism for their anxiety. However, the relationship between anxiety and movement has not yet been explored within typically developing children. It is also unclear if the form of anxiety impacts the degree to which children move. In this study, we used Motion Energy Analysis to quantify the relationship between both general and math anxiety and movement during a math flashcards task. Multivariate linear regression analysis was used to determine possible relationships between anxiety and movement. General anxiety significantly contributed to models predicting movement during the math flashcards task, while math anxiety did not. Our results suggest that movement could be an indicator of general anxiety in elementary aged children.

KEYWORDS
General Anxiety; Math Anxiety; Elementary; Academics; Motion Energy Analysis; Movement; Ritualized Movement; Mathematics

INTRODUCTION

Anxiety is a psychiatric disorder impacting approximately 12.5% of the adult population in the United States. Additionally, 9.4% of children ages 3-17 years will be diagnosed with anxiety, with the proportion of children diagnosed with anxiety growing substantially over the last decade.[1–3] In addition to affecting day-to-day experiences, anxiety can have detrimental effects in academic and educational settings.[4] Anxiety in students has been associated with reduced thriving and academic achievement in students at multiple ages.[5–6] Importantly, the negative impacts of general anxiety are not subject specific, having measurable negative impact across academic subject areas.[7] Additionally, student anxiety scores have been shown to increase as students' progress from elementary to middle to high school, which furthers the impact of anxiety on academic performance.[8] The growing impact of anxiety on students motivates the need to determine how anxiety might manifest in students of all ages.

In some cases, anxiety can be associated with a specific academic subject, such as math-specific anxiety, which affects approximately 17% of the U.S. student population. Importantly, unlike general anxiety which has measurable impacts across academic subject areas[7], math anxiety negatively influences math-specific skills, grades in math classes, and general attitudes towards math.[4, 9, 10] Math anxiety is also known to impact student choices and behavior, as students with math anxiety tend to avoid taking math-related classes altogether.[11] While both general and math anxiety have similar impacts on academic performance, the relationship between the anxiety types is complicated. While those with math anxiety are much more likely to also exhibit general anxiety symptoms,[9] presence of general anxiety by itself has not been shown to predict math performance.[12] As a result, while individuals with math anxiety may be more likely to have generalized anxiety, general anxiety alone often does not lead to anxiety-related math deficits. This complicated relationship implores the need for research into how these different anxiety types manifest within students and impact their behavior.

One behavior that may be differentially impacted by generalized vs. subject-specific anxiety is soothing behavior, which is the variety of behaviors individuals dealing with anxiety turn to in order to soothe their anxious emotions. Ritualized movements, often referred to as stimming, are known to strongly correlate with anxiety symptoms within individuals diagnosed with Autism Spectrum Disorder (ASD).[13] Additionally, placing individuals with ASD into scenarios that often trigger anxiety, such as public speaking, has been shown to cause ritualized movement behavior.[14] However, it is unclear whether ritualized movements are

uncontrolled responses to anxiety, or are instead self-regulatory behavior to sooth anxiety symptoms.[14-16] In fact, individuals with ASD of various ages report that ritualized movements provide emotional regulation support, despite the behavior not consistently being deemed socially acceptable.[17-20]

The current body of knowledge surrounding the relationship between movement and anxiety is mostly centered around individuals with ASD. As a result, it is unknown if movement might also have important relationships with anxiety in typically developing children, with anxiety leading to increased movement. Additionally, no current literature has explored whether various anxiety types have differing predictive contributions to movement. The current study aims to fill these gaps in understanding. We quantified movement in typically developing children ages 6-11 years with motion energy analysis (MEA) while the subjects completed a math flashcards task. Our results examine the independent and overlapping effects of general and math anxiety on movement to determine whether anxiety contributes to movement and explore whether one form of anxiety contributes to movement more than the other. Overall, this research aims to broaden the understanding of how anxiety impacts behavior during elementary school age.

METHODS AND PROCEDURES

Sample

Parent-child dyads were both indirectly and directly recruited from the greater Charlottesville-Albemarle County Area for study participation. Families either responded to flyers posted around the community or were contacted by research personnel using a University of Virginia-managed database of families who had previously noted interest in research participation. Parents completed an eligibility questionnaire which they populated with family demographic information and child medical history. Inclusion criteria included child age between 6-11 years, indication of the child's ability to communicate verbally, and no diagnosis of a neurodevelopmental disorder. Parents were required to be 18 years of age or older. Parents provided written informed consent while the child provided verbal assent unless over the age of seven, in which case written assent was obtained. Dyads were excluded from the final sample if the child's Intelligence Quotient (IQ) was less than 85, the child could not complete the experimental session due to behavioral issues or discomfort with equipment, or if there was not a complete dataset for the dyad (*e.g.*, missing scores for a cognitive assessment subset). The final sample consisted of dyads of 15 typically developing children (aged 9.33 $\pm$ 1.64 years, 8 male) and one parent per child (4 male parents).

Procedure

All recruitment and protocol procedures were approved by the University of Virginia Social and Behavioral Sciences Institutional Review Board (SBS-2174). The data utilized here is a subset of a larger study that included children with Autism Spectrum Disorder in addition to the typically developing sample. At the Sheila Johnson Center for Clinical Services at the University of Virginia, participants completed two separate sessions as part of this study: a cognitive assessments session and an experimental task session which occurred on two separate days.

During cognitive assessment sessions, a trained clinician administered a battery of assessments to pediatric participants while parents waited in a separate room. The Woodcock-Johnson IV (WJ-IV) was used to assess children's cognitive abilities and the Differential Ability Scales Version 2 (DAS-II) was used to assess child IQ (*e.g.*, quantitative, verbal, and nonverbal reasoning). Of interest to this analysis is the math facts fluency subtest of the WJ-IV. In this subtest, participants are presented with a series of simple addition, subtraction, and multiplication questions. Participants are instructed to complete as many facts as possible within the three-minute time limit, and their performance is scored based on the number of correct answers and a qualitative observation of their rate of performance compared to their peers. To assess children's math anxiety, the Single Item Math Anxiety (SIMA) scale was administered.[10] In this assessment, children were asked the following question: "On a scale of one to 10, how math anxious are you?" Math anxiety was described to child participants as feelings of anxiety or stress that occur when learning or doing math, with the scale depicting a score of one as "not anxious" and a 10 as "very anxious." Children also provided an analogous general anxiety measure by answering the question: "On a scale of one to 10, how anxious are you?" using the same scale. Children also completed a math excitement questionnaire. Participants were presented with a scale of five drawings of faces depicting varying levels of excitement, labeled "not at all excited", "not very excited", "just a little excited", "very excited", or "very, very excited". Each drawing was given a score between zero and four, with higher scores indicating greater excitement. Participants were instructed to mark a line through the face that best described their response to the following questions: "How excited do you feel when your teacher talks about numbers and math," "How excited do you feel when you have to do number and math work at school," and "How excited do you feel when you are asked to practice numbers and math at home?". The sum of the scores for each question served as total math excitement score, with possible values ranging from zero to 12.

During experimental sessions, children and their parents performed a variety of tasks designed to elicit varying types of interaction while sitting across from each other at a table. This analysis focuses specifically on a math flashcards task, where parents were instructed to quiz their child using arithmetic flashcards. The task mandated that parents quiz the child (not vice versa) and that

they proceeded through the cards in a specified order. Parents were allowed to provide as much or as little help as they deemed appropriate. Parents were provided with three flashcard decks, each consisting of 25 cards, and instructed to proceed through them in order of ascending difficulty. Stacks one and two contained single-digit and double-digit addition and subtraction problems, while stack three contained single-digit multiplication problems. The cards of each deck were numbered in a way such that all dyads answered the same cards in the same order. The task lasted approximately five minutes, and participants were instructed to complete as many cards as possible in that time frame. If a child finished answering all three decks of flashcards within the time limit, the participants were instructed to start again from the beginning to ensure five minutes of recorded data for all dyads.

Motion Energy Analysis (MEA)

Experimental sessions were recorded on video and analyzed post-hoc for total amount of child movement during the task using the Motion Energy Analysis (MEA) software. MEA is a software that quantifies the degree of change in pixilation between frames in a user-defined area of interest, which can be used as a proxy for movement within a specific region of interest.[21] Video recordings provided three angles of the subjects during the task. For this analysis, a front-facing view of the child participant was used, with the region of interest defined to capture as much of the child's full-body motion as possible. An MEA time series was produced for each child participant for this specific math flashcards task condition. The threshold for movement detection was changed from the default value of "20" to "seven." This value was identified during initial processing to be the most appropriate threshold for the quality of our recorded videos in distinguishing noise from legitimate, finer movements in the video. This identification was accomplished using the "frame-differenced movie" preview of the MEA software, following recommendations of choosing a threshold that yields a clear white outline around the participant of interest and minimal noise elsewhere in the video.

Statistical Analysis

Data was uploaded into SPSS for statistical analysis. Multivariate linear regression models were used to determine which components of anxiety produced better predictive models of child movement. Median child MEA scores were used as the dependent variable. Median values were used as opposed to mean values to better account for periods of no movement at the very beginning and the very end of the task. Independent variables of interest included: age, sex, IQ, WJ-IV math facts fluency, and reported excitement related to math. Three separate models were run: (1) general anxiety scores were added as an additional independent variable, (2) math-specific anxiety scores were added as an independent variable, and (3) both general and math anxiety scores were added as independent variables. The variables were removed from the model using a backwards approach with criteria of probability of $F > 0.1$, meaning any variables in the model that have a p-value greater than 0.1 were removed one at a time until all variables contributed to the predictive power of the model at a threshold of $p \leq 0.1$. As a result, only variables with relevant predictive effects were included in the final models. We determined the most successful model to be that which had the highest adjusted R^2 and had a p-value of < 0.05.

RESULTS

Group Characteristics

The final study sample consisted of seven female and eight male children with an average age of 9.33 (SD=1.64) years. The children had an average full-scale IQ of 116.4 (SD=12.81) and math facts fluency score of 95.47 (SD=9.478). General anxiety scores of children ranged from one to nine, with an average of 4.4 (SD=3.22). Math anxiety scores of children ranged from one to eight with an average of 4.8 (SD=2.21). There was no significant difference between male and female subjects' scores on general anxiety or math anxiety questionnaires, or between math facts fluency score or IQ scores as determined by unpaired T-Tests. Median MEA value across all subjects was 397 (SD=352) pixels/frame. Complete characteristics for all variables are included in Table 1.

	Mean	SD	Range	Skew	Kurtosis	n
Age (years)	9.33	1.64	6.3-11.7	-0.481178	-0.774209	15
IQ	116.4	12.81	101-136	0.674416	-0.708996	15
Math Facts Fluency	95.47	9.748	75-108	-0.874916	0.644223	15
General Anxiety	4.4	3.22	1-9	0.217035	-1.868782	15
Math Anxiety	4.8	2.21	1-8	0.428603	-0.72397	15
Math Excitement	6.067	2.79	3-12	0.536207	0.03595	15
Median MEA (pixels)	397.13	352.015	8-1236	1.161488	0.973373	15

Table 1. Characteristics of Included Variables

Anxiety Contributions to Movement During Task

Math Anxiety Model

Linear Regression Models were used to examine the relationship between math anxiety and child movement. Predictors included in the models were age, sex, IQ, math facts fluency score, math excitement and math anxiety. None of these models were significant in predicting movement during the math task (**Supplementary Table 1**).

General Anxiety Model

To examine the relationship between movement and general anxiety, the same predictors above were used, but math anxiety was replaced with general anxiety. The best-fitting linear model included general anxiety, age, math excitement, and IQ as predictor variables for child movement (adjusted $R^2 = 0.539$, $p = 0.017$) (**Table 2**). Within this model, unit increases in age ($p = 0.039$), math excitement ($p = 0.049$), and general anxiety ($p = 0.005$) were found to have significant impacts on child movement. Age was negatively associated with movement (B=-128.334), whereas math excitement (B=77.507) and general anxiety (B=69.001) were positively associated with movement. IQ was also positively associated with movement, although not significantly (B=6.199, p=0.278) (**Table 4**).

Model	R	R Square	Adjusted R Square	F	p-value
1	.825[a]	.680	.440	2.836	.087
2	.823[b]	.677	.498	3.775	.040
3	**.819[c]**	**.670**	**.539**	**5.085**	**.017**
4	.792[d]	.627	.525	6.165	.010

a. Predictors: (Constant), Math Facts Fluency, General Anx, Age, Math Excitement, Sex, IQ
b. Predictors: (Constant), Math Facts Fluency, General Anx, Age, Math Excitement, IQ
c. Predictors: (Constant), General Anx, Age, Math Excitement, IQ
d. Predictors: (Constant), General Anx, Age, Math Excitement

Table 2. Modeling movement using general anxiety

Math Anxiety and General Anxiety Model

We then determined whether movement could be better modeled using a combination of math and general anxiety using the same modeling structure and predictors but including both math and general anxiety. The best-fitting linear model for movement included general anxiety, age, math excitement, and math anxiety as predictor variables (adjusted $R^2 = 0.640$, $p = 0.005$) (**Table 3**). Within this model, unit increases in general anxiety ($p = 0.007$), math excitement ($p = 0.007$), and age ($p = 0.008$) were again found to significantly impact child movement. General anxiety and math excitement were again both positively associated with movement and age was negatively associated, reflecting the findings from the general anxiety model. Math anxiety ($B = 41.703$, $p = 0.141$) did not have a significant effect within the model (**Table 4**). Therefore, while the addition of math as a predictor led to increased fit for our model predicting movement (meaning this model had a larger adjusted R^2 compared to the model including only general anxiety), math anxiety itself was not a significant variable within this model. Conversely, general anxiety was a significant predictor in both models, as were math excitement and age.

Model	R	R Square	Adjusted R Square	F	p-value
1	.871[a]	.758	.516	3.130	.078
2	.867[b]	.752	.565	4.034	.037
3	.864[c]	.747	.606	5.302	.015
4	**.862[d]**	**.743**	**.640**	**7.212**	**.005**

a. Predictors: (Constant), Gen Anx, IQ, Age, Sex, Math Excitement, Math Anx, Math Facts Fluency
b. Predictors: (Constant), Gen Anx, Age, Sex, Math Excitement, Math Anx, Math Facts Fluency
c. Predictors: (Constant), Gen Anx, Age, Sex, Math Excitement, Math Anx
d. Predictors: (Constant), Gen Anx, Age, Math Excitement, Math Anx

Table 3. Modeling movement using both general and math anxiety.

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	p-value
General Anxiety[a]	(Constant)	-121.971	738.288		-.165	.872
	General Anxiety	**80.355**	22.124	.736	3.632	**.005**
	MathExcitement	**62.173**	27.759	.493	2.240	**.049**
	Age	**-99.983**	42.139	-.466	-2.373	**.039**
	IQ	6.199	5.405	.226	1.147	.278
General & Math Anxiety[a]	(Constant)	589.006	335.363		1.756	.110
	Age	**-128.334**	37.461	-.598	-3.426	**.006**
	Math Anxiety	61.100	28.838	.384	2.119	.060
	Math Excitement	**77.507**	22.797	.614	3.400	**.007**
	General Anxiety	**69.001**	20.599	.632	3.350	**.007**

a. Dependent Variable: MEA

Table 4. Coefficients for best-fitting significant models.

DISCUSSION

Our study explored the relationship between movement and anxiety in a cohort of typically developing elementary aged children. Using linear regression models with math anxiety, general anxiety, or both as predictors, we were able to determine how each anxiety type differentially relates to movement. Our results show that general anxiety had significantly positive effects on child movement during a math flashcards task, while our models including math anxiety as a predictor did not reveal any significant relationships between math anxiety and median child movement. However, the model including both forms of anxiety had the best predictive power of movement during the task, indicating both anxiety forms may distinctly contribute to movement. In all significant models, the magnitude of effect of general anxiety on movement was significantly positive, meaning that higher general anxiety scores were related to increased movement during the task. Interestingly, math excitement also had significant positive effects, meaning children who reported being more excited by math also moved more during the task. The effect of age on movement was significantly negative in our models, suggesting older children move less throughout the task. The effect of math anxiety on movement was insignificant in all models.

Our findings provide additional insight into the relationship between anxiety and movement in a group of typically developing elementary-aged children, which is an under-researched age group within anxiety research. Our results indicate a role for general anxiety, but not math-specific anxiety, in movement during a math flash cards task. While movement is a well-known manifestation of anxiety in individuals with ASD,[14] these findings provide evidence that movement may also be an expression of anxiety in typically developing children. Moreover, the elicited movements may also be a means of managing feelings of anxiety, as ritualized movement has been shown to be beneficial in managing anxiety in ASD populations.[14-16] While ritualized movements have yet to be studied as a mitigator of anxiety in typically developing cohorts, other forms of movement are known to be beneficial for reducing anxiety. In elementary students, self-reported anxiety levels decrease following moderate exercise.[22] In fact, multiple studies across age groups report that in some cases, movement and exercise may be equally as beneficial as medications in managing anxiety symptoms.[23] As a result, the relationship between general anxiety and movement within our cohort may reflect that movement could also be a mechanism of managing anxiety symptoms during an anxiety-inducing activity. However, further work is needed to better understand how movement relates to anxiety and determine whether movement is simply an expression of anxiety, versus a potential soothing response mechanism in typically developing cohorts.

Our findings also highlight the exciting applications for motion-analysis software for further understanding the relationships between movement and mental states. The use of novel technology to analyze movements will allow for further subdivision and understanding of movement and its relationship to anxiety. MEA has shown promise in using movement analysis to identify individuals at higher risk for psychiatric disease,[24] or understanding how social interactions are physically altered among individuals with ASD.[25] Movement-analyzing technology also allows researchers to better understand more detailed aspects of movement, such as the rigidity or repetitiveness of specific actions, further expanding the aspects of motion that researchers are able to explore.[15] As this technology is easily adaptable to various research methodologies, the application of MEA or similar technology will allow better informed exploration into the relationships between movement and anxiety in diverse populations.

While our work provides substantial insight into the relationships between anxiety forms and movement, there are multiple limitations that should be addressed in future work expanding upon this topic**.** The current study focused on a small cohort of predominately Caucasian typically developing children within the Charlottesville-Albemarle County Area. Future work should aim to include a larger sample with greater racial diversity. Further research should expand upon the relationship between general and math anxiety in a larger cohort to further understand the unique contributions of general and subject-specific anxiety to movement. This additional exploration should include potential age-dependent changes in the relationship between math anxiety and movement. Additionally, understanding whether increased movement in response to anxiety is compensatory, leading to better behavioral outcomes, will create applications for the classroom and other academic environments.

CONCLUSIONS

Overall, our study demonstrates how various forms of anxiety differentially manifest in elementary aged children in relation to movement. Our results show that general anxiety, but not math-specific anxiety, has important impacts on movement during a math task. These findings suggest that movement may be an indicator of anxiety in elementary aged students and raise the question as to whether movement may be a potential coping mechanism in response to general anxiety. Moreover, our findings highlight the exciting possibilities provided by Motion Energy Analysis in the examination of the relationships between movement and anxiety within students of all ages.

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PRESS SUMMARY

Anxiety is present in the everyday life of many students and can come in different forms, such as general anxiety and math anxiety. Individuals with Autism Spectrum Disorder report that movement can be soothing for anxiety, but the relationship between anxiety and movement has not yet been explored within typically developing children. In this study, we explored how both general and math-specific anxiety relate to movement during a math flashcard task in elementary school children. We found that general anxiety uniquely contributes to the amount of movement during the task. Our results have relevance to suggesting a possible predictive relationship between movement and anxiety in typically developing children and demonstrate the possibility of movement being a coping mechanism for anxiety in these children.