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Original Article

# Mathematics anxiety in deaf, hard of hearing, and hearing college students

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**While mathematics anxiety (MA) has been widely researched in recent decades, this study addresses significant gaps: namely, research that explores the relationship between MA and self-reported mathematics experiences; samples adults with a range of MA levels; and controls for general anxiety. Additionally, the study sampled deaf and hard of hearing (DHH) students, whose diverse life and educational experiences often differ from hearing students'. We investigated whether DHH students' experiences with mathematics (i.e., parental behaviors, school environment, and mathematics feelings) and demographic variables (i.e., hearing status, age, and gender) predict their MA, and whether these relationships differ from those in hearing students. Self-report questionnaires were completed by 296 DHH and hearing college students. Linear regression analyses controlling for general anxiety led to the following inference: DHH students who reported more positive attitudes toward mathematics and school environments demonstrated higher MA. Also, the relationships between mathematics feelings, parental behaviors, and MA differed between DHH and hearing students. Logistic regression analyses showed no contribution of MA to students' likelihood of pursuing STEM degrees in either DHH or between DHH and hearing groups. Overall, this work breaks new ground in the study of MA in DHH students and challenges standard views of the relationships between MA and individual experiences.**

**Keywords:** deaf/hard of hearing; mathematics anxiety; college students; mathematics experiences; STEM

## Introduction

Mathematics anxiety (MA), a negative emotional response that surfaces when one is confronted with mathematics or numbers, can interfere with mathematics performance in both formal and everyday situations.[1] Consequences of MA range from mild to severe[1] and can induce physiological changes, such as increased heart rate and upset stomach.[2] MA can arise in early childhood and last well into adulthood.[3] About 93% of adults in the United States experience MA,[2] and 17% report severe MA.[1] Furthermore, MA is a global phenomenon; one in three 15-year-old students across 65 countries feel helpless when solving mathematics problems.[4]

Researchers have connected certain demographic variables and social factors to MA. However, these studies fall short methodologically in several ways. Here, we address these shortcomings (e.g., not controlling for general anxiety) while also extending the generalizability of MA research by examining an understudied population: deaf and hard of hearing (DHH) college students. DHH individuals share some characteristics due to facing similar systemic challenges (e.g., later access to language,

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stereotypes, and inconsistent access to appropriate educational resources), but they are still a diverse group given the large variability in their lived experiences. Our results suggest that the unique and shared experiences of DHH college students impact the relationships between the predictors examined in this study and MA; in other words, MA development is experience specific.

### *The effects of MA on mathematics performance and STEM engagement*

Data across multiple countries have consistently shown an inverse relationship between MA and mathematics performance.[4,5] From elementary school through college, individuals with high MA demonstrate lower mathematics performance than their less math-anxious peers.[6] MA hinders many aspects of mathematics achievement, such as performance on mathematics examinations and numerical processing,[7,8] and a recent meta-analysis ($n = 747$) also found a significant negative correlation.[9]

MA adversely impacts learning behaviors and choices, such as eliciting an avoidance of mathematics. Individuals high in MA tend to take fewer mathematics classes throughout high school and college, learn less in those classes, and shy away from careers requiring mathematics knowledge.[3,10–12] Mathematics avoidance leads to higher MA; students who encounter mathematics less frequently (e.g., by not majoring in science, technology, engineering, and mathematics (STEM) fields) are more likely to be math-anxious. Accordingly, first-semester college students with higher MA were more likely to have lower STEM grades and to have taken fewer STEM courses.[13] Adults with STEM careers had significantly lower levels of MA than those who did not.[14] Research investigating MA levels in college students with different majors is inconsistent. One study showed significant differences (i.e., lowest MA levels reported in physical sciences majors),[15] whereas another found that MA did not vary by major.[16] It is generally accepted that STEM majors are the least math-anxious (e.g., a meta-analysis showed that college students majoring in STEM had the lowest MA levels).[17]

The potential for MA to impede STEM engagement threatens advancements in these fields.[6,17] Tobias interviewed 600 college students and found that most have the necessary "cognitive equipment" to succeed in mathematics, but their anxieties impede them from continually engaging with the subject.[18] Poor mathematics skills are associated with low individual social status and incur significant costs for the general public.[19] Given these pervasive consequences, it is critical to understand the factors associated with MA and work to alleviate its negative impact.

### *Factors that affect MA*

**Gender.** One of the most studied correlates of MA is gender.[20] Numerous studies report that women are more math-anxious than men across different age groups,[14,17,20–23] even in studies that find no gender difference in mathematics performance.[24,25] One common explanation for this difference is women's exposure to the stereotype that men surpass women in mathematics,[26] which is supported by a study examining the social determinants of adolescents' MA.[27] These and other gender-specific associations with MA may be ingrained with social experience over time.

Two other explanations are the sex-role socialization and math experiences hypotheses. With limited support, the former claims that women have been socialized to think that they are less competent in mathematics than men, which leads to worse opinions of, less experience with, and more anxiety toward mathematics.[28,29] In contrast, the math experiences hypothesis posits that MA is unrelated to gender, and instead arises from poor preparation in mathematics.[29] The results of Hunsley and Flessati[29] support the math experiences hypothesis; college women reported more MA than men yet had comparable ratings of mathematics abilities and performance. Individuals with the highest levels of MA also had the least experience with, most negative beliefs about, and lowest grades pertaining to mathematics. Still, the literature regarding the relationship between gender and MA is notoriously inconsistent.[20] Gender differences in MA are rarely found in elementary-aged children;[30,31] and were not found in a study of 120 undergraduate students.[16] Despite receiving extensive coverage, this relationship warrants further investigation.

**Age.** Students' changing experiences with mathematics over time and their consequently evolving attitudes about mathematics have been cited as reasons that MA often increases with age.[26] Studies of MA in college populations have found significant age effects, with older students having higher MA.[20,32] Still, this literature lacks consensus.[20]

**General anxiety.** Prior literature has indicated that MA may be less related to measures of academic ability and more related to other measures of anxiety,[17,33] such as general anxiety.[34] Though research has confirmed that MA and general anxiety overlap to an extent, they are still separate constructs; indeed, measures of MA correlate more highly with one another than they do with measures of general anxiety.[35] Thus, it is critical to control for general anxiety. Failing to do so would result in the inability to discern whether only MA (and not anxiety in general) is affected.

**Mathematics feelings.** Prior literature has also looked at the relationship between MA and attitudes toward mathematics. A meta-analysis of 151 studies sampling both school-aged children and college students found that positive attitudes toward mathematics were consistently related to lower MA.[17] Similarly, Olango assessed freshmen college students' MA and mathematics self-efficacy, which included mathematics problem-solving capability self-efficacy, engagement in mathematics tasks, and career-related mathematics self-efficacy.[36] All mathematics self-efficacy variables showed significant negative relationships with MA. Consistent with prior literature, Casad *et al.* demonstrated that adolescents' higher MA levels were associated with lower mathematics self-efficacy, lower mathematics behavioral intentions, worse mathematics attitudes, and greater mathematics devaluing.[27]

**Parental behaviors.** Parents may contribute to their children's MA. Maloney and colleagues posited a mechanism for intergenerational transmission of MA: children of highly math-anxious parents learned less mathematics and developed greater MA if their parents frequently helped them with their mathematics homework (as compared to children who received less homework help from highly math-anxious parents or those whose parents were not math-anxious).[37] These results suggest that parental MA on its own may have no bearing on their children's MA and that instead, parental homework helping behaviors may mediate this perceived relationship. Ramirez *et al.* theorized that increased involvement in homework from highly math-anxious parents created more opportunities for parents to express their own negative emotions toward mathematics, thereby modeling a fear of the subject for their children.[38] Another possibility is that highly math-anxious parents provide problem-solving strategies that are inappropriate or inconsistent with what children learn in school, thereby reducing their children's mathematics competency and increasing their MA.[38]

Parents can shape their children's academic outcomes depending on how they choose to involve themselves. For instance, parents can either provide need-supportive (e.g., displaying patience and understanding) or need-thwarting methods (e.g., yelling, punishing, and inducing guilt) when helping their children with homework.[39,40] Need-supportive practices foster academic persistence,[41] whereas need-thwarting practices frustrate these demands.[42] Hembree found that school-aged children and college students with high MA had negative perceptions of their parents' attitudes toward mathematics.[17] Sixth-grade students felt they performed better in school when their parents helped them with homework, but some reported mixed feelings on how much they enjoyed parental involvement.[41] Recently, Núñez and colleagues showed that adolescents who perceived having less parental support when doing homework used more self-handicapping strategies and had worse behavioral engagement; they spent less effort on their homework, completed less homework, and procrastinated more.[43] Parents can promote beneficial educational outcomes for their children, even at the college level. Perceived parental support and involvement in college students' vocational process fostered persistence and achievement in a science curriculum.[41]

**School environment.** School environments, particularly teachers, influence students' MA.[44] First, teachers can impart their MA to their students. For instance, the more MA preschool teachers report, the lower they rate their mathematics ability, which then affects the importance they attribute to mathematics in the classroom;[45] this may subsequently influence the development of MA in their students.[46] In early elementary school, women mathematics teachers' MA levels impact their girl students' mathematics achievement and beliefs about their ability.[47] In a highly cited study, Jackson and Leffingwell surveyed 157 preservice teachers, finding that specific instructional behaviors (e.g., providing inappropriate support) elicited MA regardless of age.[48] At the college level, instructor behaviors that elicited MA included communication and language barriers (e.g., students could not understand the teacher due to poor pronunciation). When students asked questions, instructors who claimed to not have enough time to help them, refused to help, or demeaned students induced MA in college students. Only 7% of the sample reported positive experiences in mathematics classes, and negative memories were so strong that MA could persist for more than two decades. Another study of 238 preservice teachers identified lower levels of formal mathematics education and negative experiences with teachers in elementary and secondary school as two main contributors to MA.[21]

Highly math-anxious college students believe their instructors hold more negative perceptions of mathematics relative to their less math-anxious peers.[18] Instructor attitudes and poor instruction were defining moments responsible for initiating college students' MA.[49] Specifically, instructors presenting themselves as unapproachable, uncaring, or detached from creating an effective and positive learning environment fostered feelings of helplessness and hopelessness in succeeding in mathematics class.[49] Correspondingly, students sought help more often with instructors who provided instructional and motivational support, and in classrooms that emphasized understanding, effort, mastery over performance, and enjoyment.[50]

### Limitations of current research

Few studies have investigated the relationship between students' own perceptions of their experiences and MA; existing studies indicate that negative experiences likely lead to MA, while positive experiences might diminish MA.[34] Furthermore, students' appraisals of their experiences with mathematics may be more important to the development of MA than the experiences themselves.[38] However, these studies only sample individuals with MA and do not control for general anxiety, two limitations addressed by the current study. Another shortcoming is the limited number of studies sampling adult participants with a range of MA levels.[29,51] Moreover, most MA research has focused on the self-reported mathematics experiences[34] and MA of preservice teachers.[21,48,52–54] As such, much of the research conducted in this area may not generalize to broader populations. Whether our current understanding of MA is specific to these populations is unclear, and thus this study tests the strength of those interpretations by investigating whether the proposed relationships also exist in DHH students, whose diverse life and educational experiences often differ from those of hearing students.

### DHH students

Most MA research has been conducted with hearing populations; more studies with marginalized and thus underrepresented groups (e.g., DHH) are needed to better understand how diverse mathematics experiences impact MA, allowing researchers to better model MA and its predictors. DHH individuals encounter vastly different experiences in life and education than their hearing counterparts; it stands to reason that their MA development would also differ. Few studies have investigated DHH MA. Furthermore, most studies with DHH participants (in this domain and others) fail to report sufficient background information, especially regarding whether participants had appropriate access to language. Because relatively few DHH children experience unimpeded access to a spoken or a signed language beginning early in their development,[55] such information is critical for appropriately interpreting their outcomes.

Prior literature has consistently reported lower levels of mathematics achievement in DHH students compared to hearing students.[56] One study demonstrated this gap prior to the start of formal schooling, in which half of DHH preschoolers struggled to understand foundational mathematics concepts.[57] DHH college students are reported to also demonstrate lower mathematics performance relative to their hearing peers.[58–60] Though many studies have identified this gap, few have considered how differences in experiences between DHH and hearing students might contribute to MA.

One experience-specific effect may be DHH individuals' variable access to language and its impact on linguistic and cognitive development.[61] DHH children of DHH parents demonstrated significantly higher mathematics abilities than DHH children with hearing parents.[62] However, only 5–10% of DHH children are born to signing parents.[63] Consequently, relatively few DHH children are guaranteed very early access to language and communication, and thus are less likely to experience similar types and levels of support from their parents as do typically hearing children.[57,64] Factors related to language experiences have been shown to be important in shaping mathematical outcomes in DHH children and adults, including: numerical reasoning,[65] early number knowledge,[62] arithmetic and geometrical reasoning,[66] cardinality,[67] elementary-level mathematics achievement,[68] and college-level word problems.[69] Importantly, American Sign Language (ASL) skills positively predict mathematics performance in DHH students aged 8–18 years[70] and in college students.[71]

Most DHH students attend mainstream educational programs that lack instruction in sign language, which along with other language barriers, may further curb their mathematics potential.[72] Hearing individuals might erroneously assume that signed languages are rudimentary compared to English and interfere with STEM learning.[73] However, instruction in sign language supports DHH students' mathematics abilities, regardless of whether sign language is their first or second language.[74] The language that mathematics teachers use is crucial to DHH students' learning, though research continues to elucidate the exact nature of this relationship.[75] Furthermore, DHH students must navigate multiple languages (e.g., academic science vocabulary in both ASL and English) in class, and science-specific ASL vocabulary remains limited.[76] DHH students struggle to solve mathematics problems when prompted in spoken language that is incomprehensible.[76] The onus falls on teachers even more because DHH children's incidental learning opportunities are limited by their parents' lack of signing abilities.[77]

DHH individuals also encounter numerous barriers in STEM educational settings specifically that impede achievement, including an unwelcoming, exclusive environment arising from colleagues who have little to no experience working with DHH individuals.[73] To complicate the issue, teachers lack adequate STEM training, an issue compounded by inadequate captioning and sign language interpretation.[78] Policy mandates can hamper, rather than benefit, STEM education for DHH students, and public schools still vary greatly in curricula, teaching approaches, and accommodations and/or early interventions.[79]

Teachers' perceptions also influence DHH students' mathematics experiences in the classroom. Mathematics teachers of DHH kindergarteners through 12th graders reported considering discrete mathematics concepts too difficult for their students, consequently excluding certain topics (e.g., matrices and probability) from their curriculum.[75] Teachers of DHH students do not provide challenging word problem-solving situations due to concerns about their students' language and reading skills.[75] Preservice teachers of DHH students experience the highest levels of MA compared to those in special education and early childhood or elementary education.[53] Around half of mathematics teachers in deaf education systems do not hold related degrees or certifications, and half lack experience with mathematics instruction.[75,80] In another study, 296 deaf education teachers reported higher efficacy beliefs in classroom management and instructional strategies than in student engagement.[81] These challenges may be amplified when students cannot identify with their mentors in STEM or connect STEM with their daily lives, which is often the case in formal classrooms.[82]

Furthermore, personal factors may influence how DHH college students experience their school environment. In one study, 437 DHH students entering college lacked confidence in preparing for classes and time management despite knowing how to access school resources. These particular students reported higher stress, lower motivation to finish college, and more negative attitudes toward teachers compared to the national average, resulting in poorer academic performance.[83]

MA is an understudied potential contributor to DHH students' mathematics performance and their severe underrepresentation in STEM disciplines: DHH scientists and engineers (either currently employed or majoring in STEM) represent only 0.6% of the workforce.[84] Four studies (the former two in Iran, and the latter two in Nigeria) have examined MA in DHH students. Alimoradi investigated the relationship between MA and mathematics motivation in DHH students ages 13–21 years and found that MA was negatively correlated with mathematics expectancy, self-efficacy, and value.[85] Comparing 126 hearing and DHH high school girls, Ariapooran found significantly lower mathematics performance and self-efficacy, and higher MA, in the DHH students.[60] In 249 DHH secondary students from Nigeria, student–teacher interactions were found to be most predictive of MA, followed by parental involvement and school environment.[86] In another study with 41 DHH students, those with the lowest MA scored the highest on their mathematics attitudes.[87] These studies sampled participants with a range of MA levels.

Relationships between various factors and MA have been extensively studied in hearing individuals. Yet, how DHH individuals' variable experiences impact their MA development differently than hearing students' remains unclear. Thus, research that includes DHH students provides a specific instantiation of considering experience-specific effects on MA.

### *Current study*

This study investigates the contributions of the following measures to MA in hearing and DHH college students: demographics (i.e., age and gender), education (e.g., STEM major/minor), general anxiety, mathematics feelings, parental behaviors with mathematics, and school environment. Data were collected from hearing and DHH students using a self-report questionnaire. The two central questions were:

*Question 1: What measures predict MA in DHH students?*

*Question 2: How do the relationships between the included measures and MA differ between DHH and hearing students?*

We also asked whether DHH students' MA influenced their likelihood of studying for a STEM degree.

Although previous work has examined the effects of various factors on MA, this work is the first to examine, in a single study, these relationships in DHH students and how they differ from those reported for hearing students. Ariapooran compared MA and certain mathematics feelings between DHH and hearing students, but did not control for general anxiety, had a significantly smaller sample consisting only of girls in secondary school, and considered fewer variables.[60] This study addresses these gaps by sampling a range of MA levels in adult participants, gathering self-reported mathematics experiences, and controlling for general anxiety in all statistical models. Also, sampling DHH students and comparing how our measures differentially impact MA in DHH and hearing students enables this study to assess whether and how diverse and unique experiences with mathematics influence MA. Many DHH students face inequities in mathematics and STEM education; over time, these distinctive challenges may socialize DHH students to feel a specific way toward the subject and STEM in general (similarly to how students may be socialized to accept flawed gendered ideas about mathematics over time). Though there are commonalities in the challenges DHH individuals face, they also have distinct experiences from one another.

The impacts of DHH students' unique experiences are evident given their severe underrepresentation in the STEM workforce as explained above. Disparities between DHH students (and students with other disabilities) and hearing students (or nondisabled students) in STEM career participation underscore the necessity to identify and examine the individual and environmental factors contributing to MA. By identifying the predictors of MA in DHH students (especially as compared to hearing students), the current study takes the first step toward removing barriers to their STEM participation. Finally, our study is the first to investigate MA in DHH students in the United States.

The first question is addressed using linear models to evaluate the contribution of our chosen measures to MA in DHH students only. In line with prior research, we hypothesize that DHH students' MA would increase with age and that women would exhibit higher MA than men. We also hypothesize that DHH students reporting worse perceptions of their experiences surrounding mathematics would demonstrate higher MA than those reporting better perceptions.

Using the same linear models, we address the second question by directly comparing the contribution of these measures to MA in hearing and DHH students. We hypothesize significantly different relationships between age, gender, and MA in DHH and hearing students. Particularly, MA scores may be higher in DHH students than hearing students due to the compounded effects of language inaccessibility and STEM barriers. Furthermore, we hypothesize that the relationships between MA and mathematics feelings, perceptions of parental behaviors toward mathematics, and perceptions of school environment previously reported in hearing students would remain qualitatively similar but

**Table 1. Participant demographic information**

| | DHH ($n = 136$) | Hearing ($n = 160$) | Overall ($n = 296$) |
|---|---|---|---|
| Age (years) | | | |
| Mean (SD) | 21.2 (2.11) | 19.4 (1.34) | 20.2 (1.94) |
| Median [min, max] | 21.0 [18, 30] | 19.0 [18, 24] | 20.0 [18, 30] |
| SES | | | |
| Mean (SD) | 42.3 (13.1) | 48.3 (12.0) | 45.7 (12.8) |
| Median [min, max] | 42.5 [14.0, 64.5] | 51.5 [8.00, 66.0] | 47.5 [8.00, 66.0] |
| Missing | 22 (16.2%) | 12 (7.5%) | 34 (11.5%) |
| Gender | | | |
| Women | 48 (35.3%) | 107 (66.9%) | 155 (52.4%) |
| Men | 88 (64.7%) | 50 (31.2%) | 138 (46.6%) |
| Nonbinary | 0 (0%) | 3 (1.9%) | 3 (1.0%) |
| Grade | | | |
| First year | 28 (20.6%) | 66 (41.2%) | 94 (31.8%) |
| Second year | 57 (41.9%) | 41 (25.6%) | 98 (33.1%) |
| Third year | 33 (24.3%) | 27 (16.9%) | 60 (20.3%) |
| Fourth year | 12 (8.8%) | 22 (13.8%) | 34 (11.5%) |
| Degree conferred | 4 (2.9%) | 1 (0.6%) | 5 (1.7%) |
| Missing | 1 (0.7%) | 1 (0.6%) | 2 (0.7%) |
| Other | 1 (0.7%) | 2 (1.2%) | 3 (1.0%) |
| Race | | | |
| White | 124 (91.2%) | 90 (56.2%) | 214 (72.3%) |
| American Indian/Alaska Native | 4 (2.9%) | 3 (1.9%) | 7 (2.4%) |
| Asian | 2 (1.5%) | 48 (30.0%) | 50 (16.9%) |
| Black or African American | 1 (0.7%) | 10 (6.2%) | 11 (3.7%) |
| Native Hawaiian/Pacific Islander | 0 (0%) | 1 (0.6%) | 1 (0.3%) |
| Prefer not to answer/Other | 2 (1.5%) | 6 (3.8%) | 8 (2.7%) |
| Missing | 3 (2.2%) | 2 (1.2%) | 5 (1.7%) |
| Ethnicity | | | |
| Hispanic or Latino | 7 (5.1%) | 18 (11.2%) | 25 (8.4%) |
| Not Hispanic or Latino | 125 (91.9%) | 132 (82.5%) | 257 (86.8%) |
| Unsure | 1 (0.7%) | 2 (1.2%) | 3 (1.0%) |
| Missing | 3 (2.2%) | 8 (5.0%) | 11 (3.7%) |

would be magnified in DHH students. Lastly, a logistic regression addresses whether MA influences students' likelihood of studying STEM. We hypothesize that, as in hearing students, DHH students' MA would inversely predict their likelihood of studying STEM and that this relationship would also be more pronounced.

## Methods

### *Participants*

The participants were 296 college students (155 women) aged 18–30 ($M = 20$, $SD = 2$) in the Northeastern United States (Table 1). One hundred sixty hearing participants were recruited from a large public university and via social media; 136 DHH participants were formally recruited, via email and posters on campus, from a liberal-arts university with high concentrations of DHH students; we also used social media to recruit more generally in the deaf community. The social media recruitment likely also drew participants from an institution with a high proportion of DHH students majoring in STEM fields (though we did not systematically collect information about institution). Participation was anonymous and voluntary. We applied the following exclusionary criteria to the 353 students who agreed to participate: (1) incomplete MA questionnaire (36 students excluded), (2) incomplete baseline numerical ability test (13), and (3) students who did not report their hearing status or whose hearing status did not match the version of the questionnaire they selected (8). All participants were required to

**Table 2. Demographic information related to STEM**

| | DHH ($n = 136$) | Hearing ($n = 160$) | Overall ($n = 296$) |
|---|---|---|---|
| Major/minor | | | |
| Mathematics | 30 (22.1%) | 7 (4.4%) | 37 (12.5%) |
| Psychology | 1 (0.7%) | 27 (16.9%) | 28 (9.5%) |
| Other (humanities) | 36 (26.5%) | 77 (48.1%) | 113 (38.2%) |
| Other (science) | 63 (46.3%) | 38 (23.8%) | 101 (34.1%) |
| Undeclared | 3 (2.2%) | 11 (6.9%) | 14 (4.7%) |
| Missing | 3 (2.2%) | 0 (0%) | 3 (1.0%) |
| STEM major/minor? | | | |
| Yes | 97 (71.3%) | 78 (48.8%) | 175 (59.1%) |
| No | 33 (24.3%) | 74 (46.2%) | 107 (36.1%) |
| Missing | 6 (4.4%) | 8 (5.0%) | 14 (4.7%) |
| Average STEM grade | | | |
| A | 17 (12.5%) | 74 (46.2%) | 91 (30.7%) |
| B | 72 (52.9%) | 51 (31.9%) | 123 (41.6%) |
| C | 34 (25.0%) | 12 (7.5%) | 46 (15.5%) |
| D | 8 (5.9%) | 0 (0%) | 8 (2.7%) |
| Missing | 5 (3.7%) | 23 (14.4%) | 28 (9.5%) |
| Number of STEM courses | | | |
| Mean (SD) | 2.76 (3.20) | 6.04 (7.04) | 4.53 (5.84) |
| Median [min, max] | 2.00 [0, 25] | 4.00 [0, 42] | 3.00 [0, 42] |
| Parent career in STEM? | | | |
| Yes | 42 (30.9%) | 62 (38.8%) | 104 (35.1%) |
| No | 56 (41.2%) | 64 (40.0%) | 120 (40.5%) |
| Missing | 38 (27.9%) | 34 (21.2%) | 72 (24.3%) |

complete and score at least one standard deviation below chance on a baseline numerical ability test (see below). This was to ensure that our findings were attributed to MA as opposed to atypical nonsymbolic numerical cognition that might influence their relationship with mathematics. All participants scored higher than one standard deviation below chance or answered more than 21 trials correctly out of 34 ($M = 21.1$, $SD = 3.5$, range = 13–30), so no participants were excluded on this basis.

Out of the 136 DHH participants, 72 identified as deaf (52.9%) and 64 as hard of hearing (47.1%). Although not analyzed as part of this study, additional information on participants' auditory and language experiences are provided in Table S1 (online only). Continuous demographic variables were not normally distributed; therefore, we ran unpaired, two-sample Wilcoxon tests. Socioeconomic status (SES) was calculated using Barratt's Simplified Measure of Social Status (BSMSS) based on participants' parents' education levels and occupations (range 3–66).[88] DHH students ($M = 42.3$, $SD = 13.1$) had significantly lower SES compared to hearing students ($M = 48.3$, $SD = 12.0$; $W = 6121.5$, $P < 0.001$). The sample was mostly students in their first (31.8%) or second (33.1%) years of postsecondary education. Most DHH participants were second-year students (41.9%), while most hearing participants were first-year students (41.2%). This grade difference aligns with the significant age difference between DHH ($M = 21.2$, $SD = 2.1$) and hearing students ($M = 19.4$, $SD = 1.3$; $W = 16860$, $P < 0.001$). A chi-square test showed that significantly more hearing students (38.8%) reported racial backgrounds other than white compared to DHH students (5.1%) ($\chi^2 (1, n = 283) = 46.04$, $P < 0.001$).

The majority (59.1%) of respondents reported majors or minors in STEM (Table 2). While approximately half (48.8%) of hearing students reported majoring or minoring in STEM compared to 71.3% of DHH students, DHH students reported taking significantly fewer STEM courses ($M = 2.8$, $SD = 3.2$; Hearing: $M = 6.0$, $SD = 7.0$; $W = 6828$, $P < 0.001$). Furthermore, DHH students' average STEM grades were mostly Bs (52.9%) compared to hearing students, who reported receiving mostly As (46.2%). Lastly, 31% of DHH students reported having a parent currently working in a STEM occupation compared with 38.8% of hearing students.

## Questionnaire

Two versions (Hearing and DHH) of the same questionnaire were administered online (Qualtrics, Provo, UT; full questionnaire in File S1, online only) and included seven sections: (1) baseline numerical ability test; (2) demographic information; (3) parental, educational, and occupational questions; (4) general anxiety; (5) feelings and experiences with mathematics; (6) parental behaviors; and (7) school environment. Questions in sections 5–7 addressed two different time frames: in the past (i.e., during middle school and high school) and currently (i.e., in the past month). For the purposes of this study, we only examined student responses for the current time frame. We used both pre-existing standardized measures and author-created measures. The reading grade level of the questionnaire was 4.3 (Microsoft Word).

**Individual measures.** *Baseline numerical ability test*. To confirm typical numerical estimation ability, participants completed the Panamath task.[89] On each trial, two arrays of colored dots were presented simultaneously (one yellow and one blue) on each side of the screen for 500 ms; participants clicked to indicate which side had more dots (Table S2, online only).

*Demographic information*. Participants provided their age, gender, race, ethnicity, and hearing status. DHH participants were prompted with additional questions about assistive hearing device use, language use, and preferred language(s) in home and school contexts.

*Parental, educational, and occupational questions*. Participants provided information on their class standing, major and/or minor, cumulative GPA, number of STEM courses taken, and their average grade. Questions about their parents included their hearing status, highest degree obtained, and field of study and occupation. Participants then responded to three open-ended questions reporting the career they themselves currently wanted to pursue, which occupation they aspired to when they were children, and if their responses to those two questions differed, they were asked to explain what changed.

*General anxiety*. The General Anxiety Disorder-7 (GAD-7) is a seven-item questionnaire that assesses an individual's general anxiety level.[90] Items include questions, such as how often over the past 2 weeks participants have been bothered by various problems (e.g., "trouble relaxing," "feeling nervous, anxious, or on edge"). Participants rated their levels of anxiety on a 4-point Likert scale from 0 = "not at all" to 3 = "nearly every day" (range = 0–21). As with most clinical assessments, the GAD-7 has not been validated for use with DHH college students.

*Short Mathematics Anxiety Rating scale (sMARS)*[91] The sMARS was our measure for MA. The sMARS presents 25 mathematics-related situations (in academic and nonacademic contexts) and participants rated the levels of anxiety prompted by those situations on a 5-point Likert scale (1 = "not at all" to 5 = "very much," range = 25–125). Examples include: "Studying for a math test," "Reading a cash register receipt after your purchase," and "Buying a math textbook." Because our primary goal is to compare DHH students to previously studied hearing students, and not to investigate the factors underlying MA, we used the overall sMARS score to compare these groups.[1,13,92] The sMARS has not been validated for use with DHH college students.

*Mathematics feelings*. Because no mathematics feelings measures have been validated for use with DHH participants of any age, we developed a scale in which participants rated their perceptions of their mathematics skills and the usefulness and importance of mathematics in their lives. Participants responded to six 5-point Likert scale questions. Sample items included "I felt/feel math should be a part of my future career" (1 = "strongly disagree" to 5 = "strongly agree") and "I felt/feel that my performance in math was…" (1 = "far below standards" to 5 = "far above standards"). Students with higher scores on this measure held more positive perceptions of their mathematics skills and the importance of mathematics. All six items were retained as one factor, referred to as "mathematics feelings" (range = 6–30). The third item was a candidate for elimination due to its low pattern coefficient from the exploratory factor analysis (EFA) (0.38) and its relatively small item–total correlation ($r = 0.33$). However, we decided not to eliminate this item because students' perceptions of their mathematics performance have been found to relate to their MA.[93]

**Table 3. Pearson correlations and descriptive statistics**

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Age | | | | | | |
| 2. General anxiety | **0.15**** (−0.01, 0.14) | | | | | |
| 3. Mathematics feelings | −0.06 (**−0.30*****, −0.12) | 0.01 (0.04, −0.09) | | | | |
| 4. Parental behaviors | 0.15 (−0.14, 0.40*) | **0.34***** (0.12, 0.31) | **0.43***** (**0.43*****, −0.07) | | | |
| 5. School environment | **−0.18**** (**−0.34*****, 0.05) | 0.02 (−0.05, 0.10) | **0.32***** (**0.48*****, **0.29*****) | 0.18* (0.20*, −0.02) | | |
| 6. MA | **0.22***** (−0.12, 0.10) | **0.36***** (0.14, **0.36*****) | 0.07 (**0.25****, **−0.23****) | **0.51***** (**0.23****, **0.64*****) | 0.04 (**0.24****, 0.05) | |
| No. of items | 1 | 7 | 6 | 8 | 7 | 25 |
| $M^a$ | **20.24 (21.19, 19.43)***** | **8.59 (9.82, 7.54)***** | **22.10 (23.20, 21.15)***** | **25.19 (27.13, 15.62)***** | 27.18 (26.73, 27.60)* | **70.70 (81.23, 60.54)***** |
| *SD* | 1.94 (2.11, 1.34) | 5.54 (4.49, 6.11) | 4.02 (3.61, 4.13) | 7.63 (6.03, 7.58) | 3.87 (3.49, 4.16) | 21.52 (15.72, 21.51) |
| *n* | 296 (136, 160) | 292 (134, 158) | 293 (136, 157) | 148 (123, 25) | 277 (132, 145) | 273 (134, 139) |
| Skewness | 1.71 (1.88, 0.72) | 0.23 (0.23, 0.47) | −0.65 (−0.99,−0.38) | −0.52 (−0.26, 0.68) | −0.44 (−0.13, −0.70) | −0.25 (−0.49, 0.34) |
| Kurtosis | 5.94 (5.75, −0.21) | −0.81 (−0.66, −0.88) | 0.88 (2.37, 0.45) | −0.33 (−0.51, −0.52) | 1.78 (0.30, 2.51) | −0.41 (2.55, −0.60) |
| α | — | 0.88 (0.77, 0.93) | 0.73 (0.69, 0.72) | 0.89 (0.85, 0.93) | 0.73 (0.55, 0.83) | 0.95 (0.91, 0.95) |

NOTE: Correlation coefficients are reported for the overall sample, followed by the values for DHH and Hearing subgroups in parentheses: (DHH, Hearing).
[a] Significance level indicates difference in means between DHH and hearing students.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$. Bold font indicates statistical significance.

*Parental behaviors*. Participants rated their perceptions of and feelings about their parents' homework helping behaviors using a series of thirteen 5-point Likert scale questions. Sample items included "While helping me with my math homework, my parent/legal guardian raised/raises their voice in anger" (1 = "never" to 5 = "always") and "While helping me with my math homework, my parent/legal guardian was…" (1 = "not at all stressed" to 5 = "extremely stressed"). Students with higher scores perceived their parental mathematics experiences more negatively. Only 8 of the 13 Likert scale items were retained as one factor, referred to as "parental behaviors" (range = 8–40) (eliminated items in Table S3, online only). We also asked "How many parents help you with your math homework" (response options: 0, 1, or 2).

*School environment*. Participants rated their perceptions of their school's STEM emphasis, STEM faculty, and STEM resources by indicating their level of agreement with seven 5-point Likert scale statements. Sample items included "My school provided/provides resources in STEM in the languages that I prefer," "My school provided/provides resources outside of the classroom to help with STEM homework/assignments," and "My professors in STEM provided/provide instruction in the languages I prefer" (1 = "strongly disagree" to 5 = "strongly agree"). Higher scores reflected more perceived STEM emphasis and better support and accessibility. All seven items were retained as one factor, referred to as "school environment" (range = 7–35).

**Scoring.** The questionnaire used a forced choice format; however, all questions included the response options "Prefer not to answer" and "Not applicable," which were treated as missing data. For participants who provided responses on at least half the measures, missing data were replaced with the mean value of their existing responses to calculate summary scores. Changes to proration with a 50% threshold were applied to calculate subscale summary scores.[94] Each summary measure was a summation to keep scoring methods consistent with the existing standardized measures (i.e., GAD-7 and sMARS).

Table 3 provides descriptive statistics and reliability for the included measures. Confirmatory factor analysis (CFA) was performed on the GAD-7 and the sMARS to examine the relationships between items. Results from the CFA on the GAD-7 yielded adequate fit (CFI = 0.991, TLI = 0.986, RMSEA = 0.073, RMSEA 90% CI = (0.043, 0.103), SRMR = 0.035). Results from the CFA on the sMARS yielded a poor fit (CFI = 0.719, TLI = 0.694, RMSEA = 0.130, RMSEA 90% CI = (0.122, 0.138), SRMR = 0.115). An EFA was used to investigate the factor structure of the author-created measures and the results suggested a three-factor model.[88,95–98] For these measures, items were candidates for elimination if they met any of the following criteria: had a factor loading greater than 0.3 for two or more factors; did not have a factor loading greater than 0.4 on any factor; had a factor loading less than 0.5 on one factor and greater than 0.2 on another; or if they did not have a 5-point Likert response scale. See the

**Table 4. Measures predicting MA in DHH students only and the difference in relationship between DHH and hearing students**

| | DHH students only *B (SE)* | DHH and hearing students *B (SE)* |
|---|---|---|
| Age | –0.91 (0.79) | 2.10 (1.43) |
| Gender | 2.29 (3.34) | –9.67 (4.76)* |
| Mathematics feelings | **1.27 (0.46)**** | **–2.31 (0.59)***** |
| Parental behaviors | 0.42 (0.22) | **1.49 (0.46)**** |
| School environment | **1.28 (0.45)**** | –1.26 (0.58)* |

NOTE: Table results are based on linear regression analyses.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ after controlling for general anxiety. Bold font indicates statistical significance.

individual measure section below for further details on the factor analysis results, see Table S4 (online only) for the items not evaluated here, and see the OSF link (osf.io/2utjq) for data and analysis codes.

### *Procedure*

Participants completed an anonymous, online questionnaire that required ~30 minutes. The versions differed only in the language(s) offered, based on hearing status. All participants were offered the questionnaire in written English; DHH participants also had the option to see each question signed in ASL by a fluent deaf signer. All participants completed the questionnaire on computers. Participants recruited from the large public university with predominantly hearing students received course credit, while DHH respondents were compensated $15. Consent was obtained by asking participants to check "Yes, I would like to participate" before starting the questionnaire; the questionnaire concluded with a debrief form. This study was reviewed and approved by the relevant institutional review boards.

## Results and discussion

The current study aimed to test relationships among various measures previously identified as possible contributors to MA. Including a large group of DHH students, whose mathematics experiences differ from those of hearing students, provides the ability to explore experience-specific effects on MA. We asked which factors predict MA in DHH students, and whether the relationships between various self-reported measures and MA differed between DHH and hearing college students. Due to multiple tests and sample size restrictions, a significance level of 0.01 was used. The same linear regressions that controlled for general anxiety were used to answer our two central questions. For each measure, regression coefficients were estimated from a model in which MA was predicted by the measure, hearing status, general anxiety, the interaction between the measure and hearing status, and the interaction between general anxiety and hearing status.

### *Question 1: Which measures predict MA in DHH students?*

We hypothesized that older female DHH students who had worse perceptions of their mathematics feelings, parental behaviors, and school environment would have higher MA. Surprisingly, however, these hypotheses were not supported. When controlling for general anxiety, mathematics feelings and school environment significantly predicted DHH students' MA, while age, gender, and parental behaviors did not (Table 4). DHH students who reported higher MA gave higher ratings to the following predictors: their mathematics skills, the importance of mathematics, their school's emphasis on STEM, school support, and resources.

A nonsignificant age effect may have been due to the limited range of ages in the sample ($M = 21.2$, $SD = 2.11$, range = 18–30). The nonsignificant and unexpected finding for gender may be explained by the intersectional dynamics of identity (i.e., hearing status and gender) in DHH students at play in their connection to STEM.[82] Regarding parental behaviors, previous studies have found a relationship between sign language skills and mathematics performance in DHH students (with parental hearing status as a moderator).[70] Our models did not consider the potential moderating effects of parental hearing status or parent–student

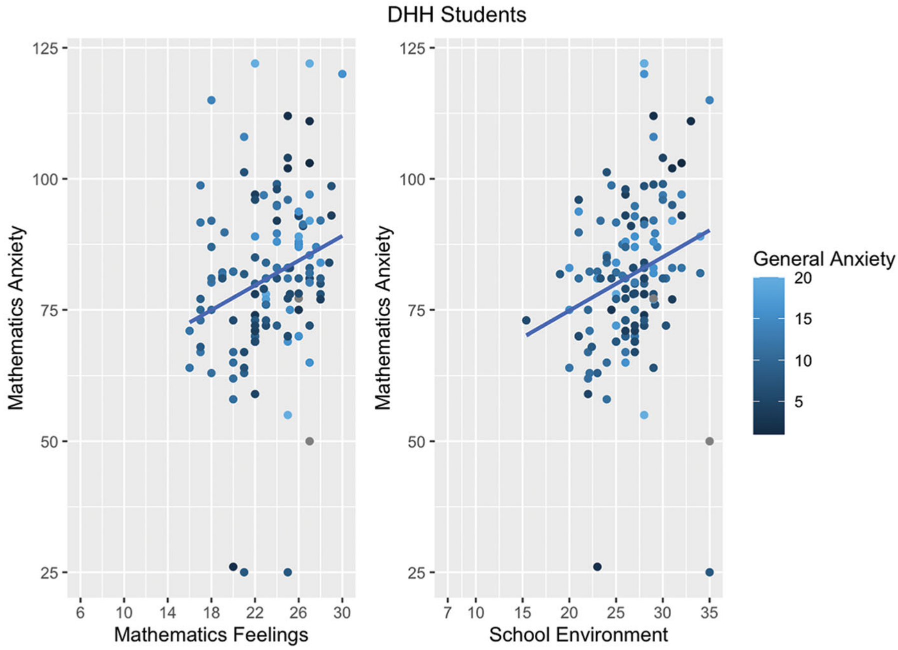


**Figure 1.** As mathematics feelings (left panel) and school environment (right panel) ratings increased (reflecting more positive perceptions), DHH students reported higher levels of MA (controlling for general anxiety).

communication on MA, which may explain the lack of significance for parental behaviors in MA.

DHH students' mathematics feelings and perceptions of their school environments showed the *opposite* direction of influence on MA than expected (Fig. 1). This novel finding may be attributed to the consequences of DHH individuals' extreme underrepresentation in STEM. For DHH respondents reporting higher school environment and mathematics feelings scores (reflecting an increased desire to succeed in STEM), MA might increase due to a perceived high risk of failure.[26] Not only might highly math-anxious DHH students be even more afraid of performing poorly in mathematics, they may also expect to fail due to knowing they are underrepresented, or because they are unable to learn from mentors with whom they can identify.[74] This interpretation can account for the failure of increases in mathematics feelings and school environment to attenuate MA, and entrenched expectations of failure arising from a dearth of role models for DHH students in STEM.[78]

DHH MA levels may additionally remain high due to other barriers this community faces, overshadowing any potential influences of positive experiences on MA. We also explored whether any specific item contributed to the unexpected findings. However, each item in the mathematics feelings and school environment measures positively correlated with MA. A disconnect between DHH students' perceptions and their actual experiences may also be responsible, such that, despite negative mathematics-related experiences, they still report positive perceptions. We tried to anticipate any issues that may arise with exploring these relationships in DHH students; however, we were limited based on scarce prior research, which highlights the need for further investigation.

### *Question 2: How do the relationships between the included measures and MA differ between DHH and hearing students?*

For all measures, we hypothesized that DHH and hearing students' mathematics experiences would exhibit significantly different relationships with MA. Specifically, it was posited that DHH students' MA would be significantly higher than hearing students' as the DHH students' perceptions grew more negative. When controlling for general anxiety, the relationships between MA and age, gender,

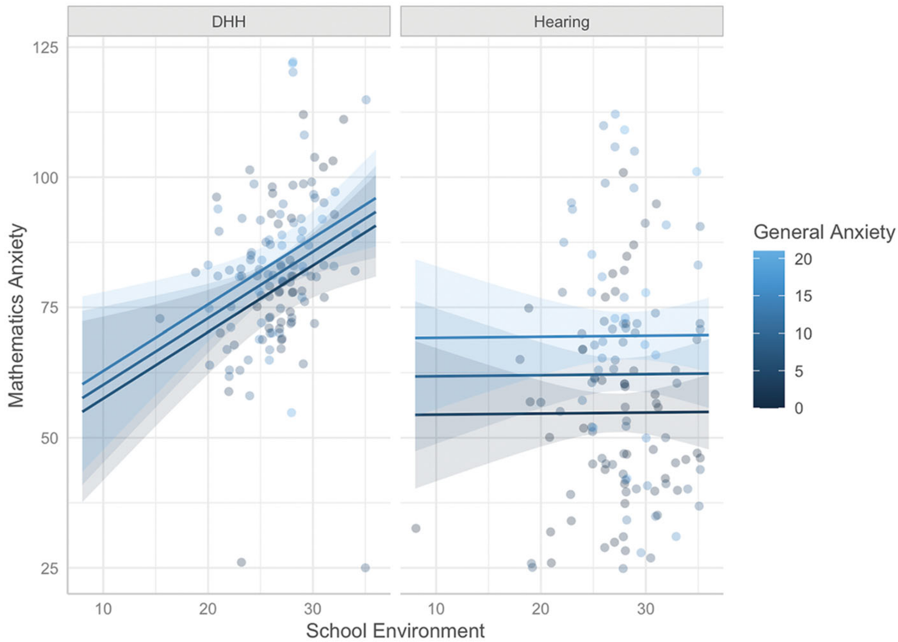


**Figure 2.** **The relationship between school environment and mathematics anxiety (controlling for general anxiety) did not differ between DHH (left panel) and hearing (right panel) students.**

and school environment were not significantly different between DHH and hearing students, while the relationships with mathematics feelings and parental behaviors were, partially supporting our hypotheses (Table 4).

Again, the limited age range in our study could have contributed to the nonsignificant age effect. As explained previously, the nonsignificant difference in the effect of gender between DHH and hearing students may arise from the intersectionality of multiple underrepresented identities.[82] One of the potential confounds of previous studies is that they do not control for general anxiety. Since women often display higher levels of general anxiety, previous findings that demonstrated that women have higher MA than men may have conflated the two (MA and general anxiety). These findings also align with the inconsistency of findings relating gender to MA.

The majority of the participants likely came from one of two institutions in the United States that have high proportions of DHH students. Thus, the lack of heterogeneity of institutions in our sample may explain the nonsignificant difference between groups for school environment (Fig. 2). Contrary to our hypothesis, DHH and hearing students showed opposite patterns in the relationship between mathematics feelings and MA. Aligned with previous work, hearing students' mathematics feelings were inversely related to MA. In contrast, positive mathematics feelings positively predicted MA in DHH students (Fig. 3). This unexpected finding may be due to an increased fear of failure for DHH students;[26] however, why DHH students show a different pattern from hearing students remains unclear.

In both groups, as perceptions of parental behavior grew more negative, MA also increased (Fig. 4), with this relationship significantly weaker in DHH students. However, this result should be interpreted with caution because far more DHH students ($n = 123$, 90.4%) responded compared with hearing students ($n = 25$; 15.6%; Table 3). Response rates were comparable for all other measures. Furthermore, significantly more DHH students (71%) indicated receiving help from their parents compared to only 6% of hearing students (Wilcoxon signed-rank test: $W = 17{,}510$, $P < 0.001$). This discrepancy could reflect DHH students' greater reliance on parents to compensate for the barriers and inequities they face in education. Despite DHH students reporting receiving more help with homework than hearing

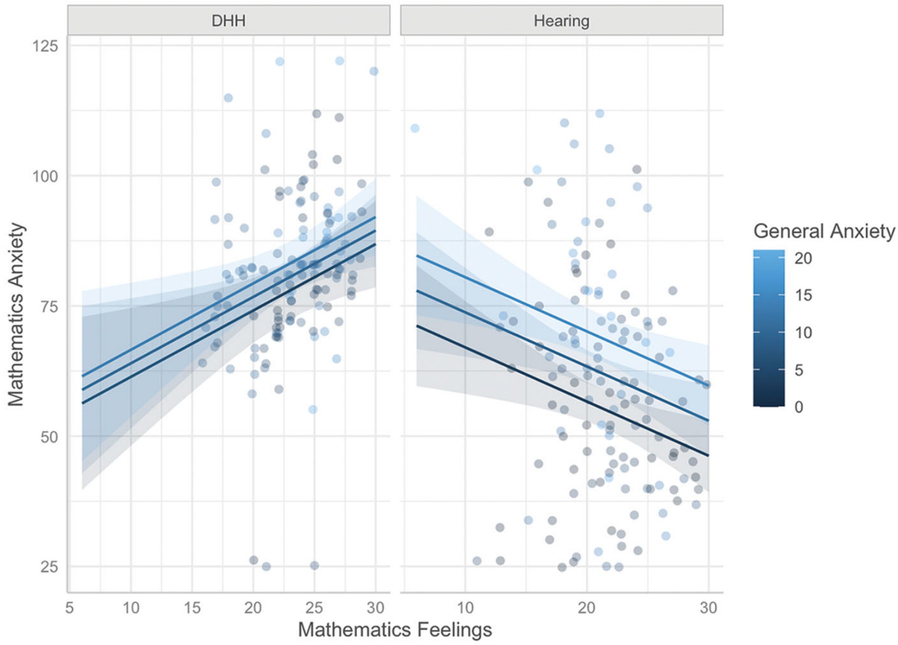


**Figure 3.** **The relationship between mathematics feelings and mathematics anxiety (controlling for general anxiety) differed between DHH (left panel) and hearing (right panel) students.**

students, parental homework involvement may not be valuable for DHH youth.[64] This could be due to most parents of DHH children not being DHH themselves, and as a result, not providing effective methods of homework support compared to what hearing students receive. It is also worth noting that both DHH and hearing participants likely live on campus at their respective institutions, so the differences noted above are likely not attributable to living situation.

### *Additional question: Does students' MA influence their likelihood of studying a STEM field?*

A logistic regression which also controlled for general anxiety assessed the relationship between MA and studying for degrees in STEM fields. DHH students' MA did not predict the likelihood of studying a STEM field ($B = -0.03$, $SE = 0.01$, $P = 0.05$). This relationship was not significantly different between DHH and hearing students ($B = 0.02$, $SE = 0.02$, $P = 0.27$). It was hypothesized that DHH students' MA would predict their likelihood of choosing STEM fields and that this relationship would differ between DHH and hearing students. Therefore, neither of these hypotheses was supported. However, MA may not have varied by STEM field due to our sample, which consisted largely (59%) of students pursuing STEM degrees. This lack of association and explanation accords with the findings of Helal and colleagues.[16]

### *Limitations*

The lack of variability in and differences between DHH and hearing students' ages, SES, and races may restrict the generalizability of these findings. Most participants were white 18- to 22-year olds with high-SES parents. While the literature notes SES and race as possible contributors to MA, consensus on specific relationships is lacking.[26,99] We did not collect information on early educational experiences (e.g., age entered school and language of instruction). Such educational experiences are known to vastly differ for DHH students and may relate to their MA later in life. Future research should examine how the diversity of students' backgrounds may impact not only MA levels, but also their experiences of mathematics. Lastly, only the sMARS and the GAD-7 were standardized for hearing college students and displayed poor to adequate model fit in our sample, while remaining measures were formulated by the authors. No part of the

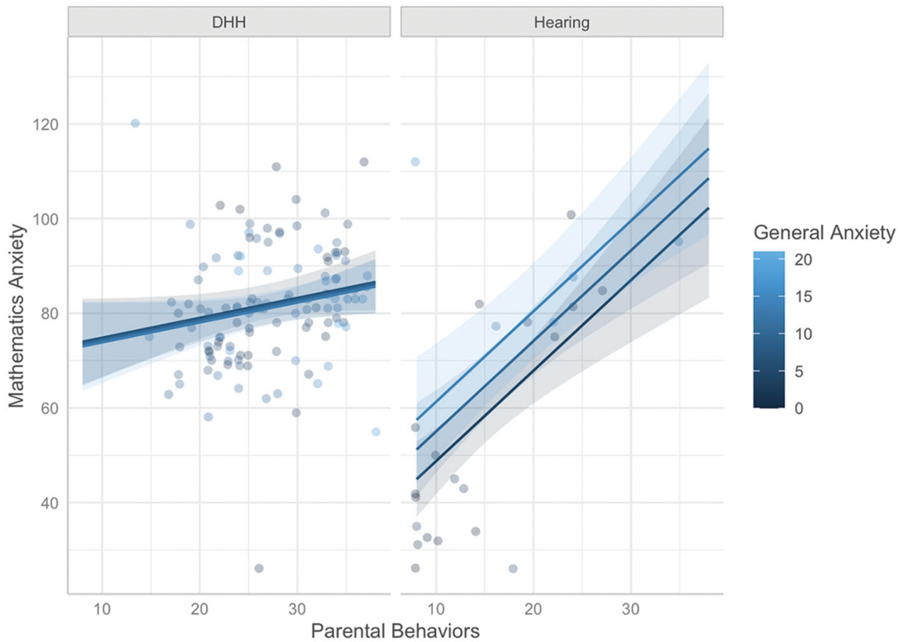


**Figure 4.** The relationship between parental behaviors and mathematics anxiety (controlling for general anxiety) differed between DHH (left panel) and hearing (right panel) students.

questionnaire, in fact, was standardized for DHH college students. Thus, we cannot be certain that our results stem from existing differences in DHH students rather than poor measurement of constructs of interest. Future research should carry out a more thorough empirical validation of the use of these or similar measures in DHH college students.

## Conclusions

This study expands previous studies of MA by controlling for general anxiety, sampling adults with a range of MA levels, and collecting self-reported experiences with mathematics along three dimensions: mathematics feelings, parental behaviors, and school environment. One of our primary goals was to identify experience-specific effects on MA by examining DHH college students and comparing them to hearing students. We hypothesized that the factors known to impact MA for hearing students would also impact DHH students, albeit at different rates. We have shown that contributors to MA in hearing students do not necessarily operate the same way in DHH students. Indeed, opposite and unexpected effects were observed in the DHH population (i.e., more positive feelings toward mathematics predicted higher MA). We propose that relationships between various factors and MA in hearing students do not necessarily apply to all populations, and that unique experiences may influence MA more than was previously thought. Here we aimed to provide an overview and preliminary analysis of MA in DHH college students, a severely understudied population. Additional collected information will be analyzed in a subsequent paper, such as the effects on MA of participants' use of hearing devices and experiences with signed and spoken language.

DHH individuals are massively underrepresented in STEM careers, often facing discrimination and stereotypes that hinder their success. They also struggle to access appropriate resources in STEM education, leading to lower reported performance in mathematics and related areas. Information that can diminish or eradicate these barriers is valuable. In particular, this study indicates that interventions for reducing MA in DHH based on results with hearing populations may be ineffective or counterproductive. If MA development is specific to experience, then proposals to reduce MA must accommodate DHH students' unique challenges. To this end, instruments measuring MA and mathematics experiences need to be validated for use with DHH populations. Such findings could direct resources toward MA interventions that benefit DHH students; based on our findings, interventions targeting parents (e.g., improving parents' confidence in assisting with mathematics) may be effective. Identifying and understanding how parents and schools contribute to children's anxieties and attitudes toward mathematics is the first step to countering widespread negative attitudes and allaying MA. We also highlight the contribution of this work with a specific population, DHH students, to increasing attention to individuals' specific experiences with mathematics and their impact on MA. Given the national call to broaden participation in STEM, and the detrimental impact of MA on students' pursuit of STEM careers, such solutions are critical, especially for underrepresented groups like DHH students.

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## Author contributions

Co-first authors A.M. and K.W. substantially and equally contributed to all stages of this project, B.O. was the primary data analyst and assisted in manuscript editing, and C.L. and M.C. helped with conception and design of the questionnaire and manuscript editing. K.W. and B.O. accept responsibility for the integrity of data analyzed.

## Supporting information

Additional supporting information may be found in the online version of this article.

**Files S1.** Full questionnaire (DHH version).

**Table S1.** Participants' auditory and language experiences.

**Table S2.** Trial information for the baseline numerical ability task.

**Table S3.** Items that were eliminated from the "Parental Behaviors" measure.

**Table S4.** List of measures noting which items were not evaluated for this study.

## Competing interests

The authors declare no competing interests.

## Peer review

The peer review history for this article is available at: https://publons.com/publon/10.1111/nyas.14773

## References

1. Ashcraft, M.H. & A.M. Moore. 2009. Mathematics anxiety and the affective drop in performance. *J. Psychoeduc. Assess.* **27:** 197–205.
2. Blazer, C. 2011. Strategies for reducing math anxiety. *Res. Serv.* **1102:** 1–8.
3. Maloney, E.A. & S.L. Beilock. 2012. Math anxiety: who has it, why it develops, and how to guard against it. *Trends Cogn. Sci.* **16:** 404–406.
4. OECD. 2013. PISA 2012 results: ready to learn (volume III): students' engagement, drive and self-beliefs. OECD Publishing.
5. Foley, A.E., J.B. Herts, F. Borgonovi, *et al.* 2017. The math anxiety–performance link: a global phenomenon. *Curr. Dir. Psychol. Sci.* **26:** 52–58.
6. Luttenberger, S., S. Wimmer & M. Paechter. 2018. Spotlight on math anxiety. *Psychol. Res. Behav. Manag.* **11:** 311–322.
7. Betz, N.E. 1978. Prevalence, distribution, and correlates of math anxiety in college students. *J. Counsel. Psychol.* **25:** 441–448.
8. Maloney, E.A., D. Ansari & J.A. Fugelsang. 2011. Rapid communication: the effect of mathematics anxiety on the processing of numerical magnitude. *Q. J. Exp. Psychol.* **64:** 10–16.
9. Barroso, C., C.M. Ganley, A.L. McGraw, *et al.* 2021. A meta-analysis of the relation between math anxiety and math achievement. *Psychol. Bull.* **147:** 134–168.
10. Ashcraft, M.H. 2002. Math anxiety: personal, educational, and cognitive consequences. *Curr. Dir. Psychol. Sci.* **11:** 181–185.
11. Akinsola, M.K., A. Tella & A. Tella. 2007. Correlates of academic procrastination and mathematics achievement of university undergraduate students. *Eurasia J. Math.* **3:** 363–370.
12. Brown, M., P. Brown & T. Bibby. 2008. "I would rather die": reasons given by 16-year-olds for not continuing their study of mathematics. *Res. Math. Educ.* **10:** 3–18.
13. Daker, R.J., S.U. Gattas, H.M. Sokolowski, *et al.* 2021. First-year students' math anxiety predicts STEM avoidance and underperformance throughout university, independently of math ability. *Npj Sci. Learn.* **6:** 1–13.
14. Hart, S.A. & C.M. Ganley. 2019. The nature of math anxiety in adults: prevalence and correlates. *J. Numer. Cogn.* **5:** 122–139.

15. Brush, L.R. 1978. A validation study of the Mathematics Anxiety Rating Scale (MARS). *Educ. Psychol. Meas.* **38:** 485–499.
16. Helal, A., E.A. Hamza & F. Hagstrom. 2011. Math anxiety in college students across majors. *Int. J. Arts Sci.* **4:** 211–221.
17. Hembree, R. 1990. The nature, effects, and relief of mathematics anxiety. *J. Res. Math. Educ.* **21:** 33–46.
18. Tobias, S. 1991. Math mental health: going beyond math anxiety. *Coll. Teach.* **39:** 91–93.
19. Szczygieł, M. 2021. The relationship between math anxiety and math achievement in young children is mediated through working memory, not by number sense, and it is not direct. *Contemp. Educ. Psychol.* **65:** 1–14.
20. Baloğlu, M. & R. Koçak. 2006. A multivariate investigation of the differences in mathematics anxiety. *Pers. Individ. Differ.* **40:** 1325–1335.
21. Brady, P. & A. Bowd. 2005. Mathematics anxiety, prior experience and confidence to teach mathematics among preservice education students. *Teach. Teach.* **11:** 37–46.
22. Else-Quest, N.M., J.S. Hyde & M.C. Linn. 2010. Cross-national patterns of gender differences in mathematics: a meta-analysis. *Psychol. Bull.* **136:** 103–127.
23. Hill, F., I.C. Mammarella, A. Devine, *et al.* 2016. Maths anxiety in primary and secondary school students: gender differences, developmental changes and anxiety specificity. *Learn. Individ. Differ.* **48:** 45–53.
24. Karimi, A & S. Venkatesan. 2009. Mathematics anxiety, mathematics performance and overall academic performance in high school students. *J. Indian Acad. Appl. Psychol.* **34:** 147–150.
25. Devine, A., K. Fawcett, D. Szucs, *et al.* 2012. Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. *Behav. Brain Funct.* **8:** 1–9.
26. Dowker, A., A. Sarkar & C.Y. Looi. 2016. Mathematics anxiety: what have we learned in 60 years? *Front. Psychol.* **7:** 508.
27. Casad, B.J., P. Hale & F.L. Wachs. 2015. Parent–child math anxiety and math-gender stereotypes predict adolescents' math education outcomes. *Front. Psychol.* **6:** 1597.
28. Bander, R.S. & N.E. Betz. 1981. The relationship of sex and sex role to trait and situationally specific anxiety types. *J. Res. Pers.* **15:** 312–322.
29. Hunsley, J. & S.L. Flessati. 1988. Gender and mathematics anxiety: the role of math-related experiences and opinions. *Anxiety Res.* **1:** 215–224.
30. Jameson, M.M. & B.R. Fusco. 2014. Math anxiety, math self-concept, and math self-efficacy in adult learners compared to traditional undergraduate students. *Adult Educ. Q.* **64:** 306–322.
31. Van Mier, H.I., T.M.J. Schleepen & F.C.G. Van den Berg. 2019. Gender differences regarding the impact of math anxiety on arithmetic performance in second and fourth graders. *Front. Psychol.* **9:** 2690.
32. Wigfield, A. & J.L. Meece. 1988. Math anxiety in elementary and secondary school students. *J. Educ. Psychol.* **80:** 210–216.
33. Ashcraft, M.H., E.P. Kirk & D. Hopko. 1998. On the cognitive consequences of mathematics anxiety. In *The Development of Mathematical Skills*. C. Donlan, Ed.: 175–196. Hove: Psychology Press.
34. O'Leary, K., C.L. Fitzpatrick & D. Hallett. 2017. Math anxiety is related to some, but not all, experiences with math. *Front. Psychol.* **8:** 2067.
35. Ashcraft, M.H. & K.S. Ridley. 2005. Math anxiety and its cognitive consequences: a tutorial review. In *Handbook in Mathematical Cognition*. J.I.D. Campbell, Ed.: 315–330. Hove: Psychology Press.
36. Olango, M. 2016. Mathematics anxiety factors as predictors of mathematics self-efficacy and achievement among freshmen science and engineering students. *Afr. Educ. Res. J.* **4:** 109–123.
37. Maloney, E.A., G. Ramirez, E.A. Gunderson, *et al.* 2015. Intergenerational effects of parents' math anxiety on children's math achievement and anxiety. *Psychol. Sci.* **26:** 1480–1488.
38. Ramirez, G., S.T. Shaw & E.A. Maloney. 2018. Math anxiety: past research, promising interventions, and a new interpretation framework. *Educ. Psychol.* **53:** 145–164.
39. Reeve, J. 2009. Why teachers adopt a controlling motivating style toward students and how they can become more autonomy supportive. *Educ. Psychol.* **44:** 159–175.
40. Ryan, R.M. & E.L. Deci. 2000. Seld-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Am. Psychol.* **55:** 68–78.
41. Ratelle, C.F., S. Larose, F. Guay, *et al.* 2005. Perceptions of parental involvement and support as predictors of college students' persistence in a science curriculum. *J. Fam. Psychol.* **19:** 286–293.
42. Moè, A., I. Katz, R. Cohen, *et al.* 2020. Reducing homework stress by increasing adoption of need-supportive practices: effects of an intervention with parents. *Learn. Individ. Differ.* **82:** 1–11.
43. Núñez, J.C., C. Freire, M. Ferradás, *et al.* 2021. Perceived parental involvement and student engagement with homework in secondary school: the mediating role of self-handicapping. *Curr. Psychol.* https://doi.org/10.1007/s12144-021-01791-8
44. Radišić, J., M. Videnović & A. Baucal. 2015. Math anxiety—contributing school and individual level factors. *Eur. Psychol. Educ.* **30:** 1–20.
45. Geist, E. 2015. Math anxiety and the "math gap": how attitudes toward mathematics disadvantages students as early as preschool. *Education* **135:** 328–336.
46. Bush, W.S. 1989. Mathematics anxiety in upper elementary school teachers. *Sch. Sci. Math.* **89:** 499–509.
47. Beilock, S.L., E.A. Gunderson, G. Ramirez, *et al.* 2010. Female teachers' math anxiety affects girls' math achievement. *Proc. Natl. Acad. Sci. USA* **107:** 1860–1863.
48. Jackson, C.D. & R.J. Leffingwell. 1999. The role of instructors in creating math anxiety in students from kindergarten through college. *Math. Teach.* **92:** 583–586.
49. Quan-Lorey, S. 2017. Roots of mathematics anxiety in college students. *J. Math. Educ. Teach. Coll.* **8:** 19–30.
50. Turner, J.C., C. Midgley, D.K. Meyer, *et al.* 2002. The classroom environment and students' reports of avoidance strategies in mathematics: a multimethod study. *J. Educ. Psychol.* **94:** 88–106.

51. Flessati, S.L. & J. Jamieson. 1991. Gender differences in mathematics anxiety: an artifact of response bias? *Anxiety Res.* **3:** 303–312.
52. Harper, N.W. & C.J. Daane. 1998. Causes and reduction of math anxiety in preservice elementary teachers. *Action Teach. Educ.* **19:** 29–38.
53. Johnson, B. & S. vanderSandt. 2011. "Math makes me sweat": the impact of pre-service courses on mathematics anxiety. *IUMPST* **5:** 1–8.
54. Haciomeroglu, G. 2013. Mathematics anxiety and mathematical beliefs: what is the relationship in elementary preservice teachers? *IUMPST* **5:** 1–9.
55. Hall, W.C., L. Levin & M.L. Anderson. 2017. Language deprivation syndrome: a possible neurodevelopmental disorder with sociocultural origins. *Soc. Psychiatry Psychiatr. Epidemiol.* **52:** 761–776.
56. Gottardis, L., T. Nunes & I. Lunt. 2011. A synthesis of research on deaf and hearing children's mathematical achievement. *Deaf. Educ. Int.* **13:** 131–150.
57. Pagliaro, C.M. & K.L. Kritzer. 2013. The math gap: a description of the mathematics performance of preschool-aged deaf/hard-of-hearing children. *J. Deaf Stud. Deaf Educ.* **18:** 139–160.
58. Bull, R., M. Marschark, P. Sapere, *et al.* 2011. Numerical estimation in deaf and hearing adults. *Learn. Individ. Differ.* **21:** 453–457.
59. Blatto-Vallee, G., R.R. Kelly, M.G. Gaustad, *et al*. 2007. Visual spatial representation in mathematical problem solving by deaf and hearing students. *J. Deaf Stud. Deaf Educ.* **12:** 432–448.
60. Ariapooran, S. 2017. Mathematics motivation, anxiety, and performance in female deaf/hard-of-hearing and hearing students. *Commun. Disord. Q.* **38:** 172–178.
61. Langdon, C., C. Kurz & M. Coppola. 2020. The importance of early number concepts for learning mathematics in deaf and hard of hearing children. *Early Child. Psychol. Educ.* **5:** 125–156.
62. Kritzer, K.L. 2009. Barely started and already left behind: a descriptive analysis of the mathematics ability demonstrated by young deaf children. *J. Deaf Stud. Deaf Educ.* **14:** 409–421.
63. Mitchell, R.E. & M.A. Karchmer. 2004. Chasing the mythical ten percent: parental hearing status of deaf and hard of hearing students in the United States. *Sign Lang. Stud.* **4:** 138–163.
64. Cawthon, S.W., C.L. Garberoglio, J.M. Caemmerer, *et al.* 2015. Effect of parent involvement and parent expectations on postsecondary outcomes for individuals who are d/deaf or hard of hearing. *Exceptionality* **23:** 73–99.
65. Bandurski, M. & T. Galkowski. 2004. The development of analogical reasoning in deaf children and their parents' communication mode. *J. Deaf Stud. Deaf Educ.* **9:** 153–175.
66. Edwards, A., L. Edwards & D. Langdon. 2013. The mathematical abilities of children with cochlear implants. *Child Neuropsychol.* **19:** 127–142.
67. Pitt, B., E. Gibson & S.T. Piantadosi. 2022. Exact number concepts are limited to the verbal count range. *Psychol. Sci.* **33:** 371–381.
68. van der Straaten, T.F.K., J.J. Briaire, E. Dirks, *et al.* 2021. The school career of children with hearing loss in different primary educational settings—a large longitudinal nationwide study. *J. Deaf Stud. Deaf Educ.* **26:** 405–416.
69. Kelly, R.R., H.G. Lang, K. Mousley & S.M. Davis. 2003. Deaf college students' comprehension of relational language in arithmetic compare problems. *J. Deaf Stud. Deaf Educ.* **8:** 120–132.
70. Henner, J., C. Pagliaro, S. Sullivan, *et al.* 2021. Counting differently: assessing mathematics achievement in signing deaf and hard of hearing children through a unique lens. *Am. Ann. Deaf* **166:** 318–341.
71. Kelly, R.R. & M.G. Gaustad. 2007. Deaf college students' mathematical skills relative to morphological knowledge, reading level, and language proficiency. *J. Deaf Stud. Deaf Educ.* **12:** 25–37.
72. 2013. Regional and national summary report of data from the 2011–2012 Annual Survey of Deaf and Hard of Hearing Children and Youth. Washington, DC: GRI, Gallaudet University.
73. Braun, D.C., M.D. Clark, A.E. Marchut, *et al.* 2018. Welcoming deaf students into STEM: recommendations for university science education. *CBE—Life Sci. Educ.* **17:** es10.
74. Kurz, C. & C.M. Pagliaro. 2019. Using L1 sign language to teach mathematics. In *The Routledge Handbook of Sign Language Pedagogy*. R.S. Rosen, Ed.: 85–99. New York: Routledge.
75. Kelly, R.R., H.G. Lang & C.M. Pagliaro. 2003. Mathematics word problem solving for deaf students: a survey of practices in grades 6–12. *J. Deaf Stud. Deaf Educ.* **8:** 104–119.
76. Enderle, P., S. Cohen & J. Scott. 2020. Communicating about science and engineering practices and the nature of science: an exploration of American Sign Language resources. *J. Res. Sci. Teach.* **57:** 968–995.
77. Nunes, T. & C. Moreno. 1998. Is hearing impairment a cause of difficulties in learning mathematics? In *The Development of Mathematical Skills: Studies in Developmental Psychology*. C. Donlan, Ed.: 227–254. Hove: Psychology Press.
78. Ladner, R., H. Lang & R. Kushalnagar. 2012. Workshop for emerging deaf and hard of hearing scientists: chapter 5: technical resources available for STEM students. Gallaudet University, Washington, DC.
79. Horn, V. 2019. Impact of education policies on STEM education for deaf/hard of hearing students. MS thesis. Rochester Institute of Technology, Rochester.
80. Pagliaro, C.M. 1998. Mathematics preparation and professional development of deaf education teachers. *Am. Ann. Deaf* **143:** 373–379.
81. Garberoglio, C.L., M.E. Gobble & S.W. Cawthon. 2012. A national perspective on teachers' efficacy beliefs in deaf education. *J. Deaf Stud. Deaf Educ.* **17:** 367–383.
82. Renken, M., J. Scott, P. Enderle, *et al*. 2021. "It's not a deaf thing, it's not a black thing; it's a deaf black thing": a study of the intersection of adolescents' deaf, race, and STEM identities. *Cult. Stud. Sci. Educ.* **16:** 1105–1136.
83. Albertini, J.A., R.R. Kelly & M.K. Matchett. 2012. Personal factors that influence deaf college students' academic success. *J. Deaf Stud. Deaf Educ.* **17:** 85–101.
84. Milan, L. 2019. National Survey of College Graduates. National Science Foundation (US), Alexandria, VA.

85. Alimoradi, F. 2014. Relationship between mathematics motivation and math anxiety in deaf students of Arak and Qom in 2013–2014 academic years. *Indian J. Fund. Appl. Life Sci.* **4:** 351–357.
86. Adigun, O.T. & U.M. Iheme. 2020. Mathematics anxiety among deaf learners: an analysis of predictive factors. *Int. J. Sci. Math. Technol. Learn.* **28:** 1–13.
87. Olaoluwa, S.A. & C.A. Ayantoye. 2016. Impact of brain-based instructional strategy on academic performance of deaf students in mathematics in Oyo school of handicapped, Nigeria. *World J. Educ. Res.* **3:** 447–459.
88. Humphreys, L.G. & D.R. Ilgen. 1969. Note on a criterion for the number of common factors. *Educ. Psychol. Meas.* **29:** 571–578.
89. Halberda, J., M.M.M. Mazzocco & L. Feigenson. 2008. Individual differences in non-verbal number acuity correlate with maths achievement. *Nature* **455:** 665–668.
90. Spitzer, R.L., K. Kroenke, J.B.W. Williams, *et al*. 2006. A brief measure for assessing generalized anxiety disorder: the GAD-7. *Arch. Intern. Med.* **166:** 1092–1097.
91. Alexander, L. & C. Martray. 1989. The development of an abbreviated version of the Mathematics Anxiety Rating Scale. *Meas. Eval. Counsel. Dev.* **22:** 143–150.
92. Necka, E.A., H.M. Sokolowski & I.M. Lyons. 2015. The role of self-math overlap in understanding math anxiety and the relation between math anxiety and performance. *Front. Psychol.* **6:** 1543.
93. Ahmed, W., A. Minnaert, H. Kuyper, *et al.* 2012. Reciprocal relationships between math self-concept and math anxiety. *Learn. Individ. Differ.* **22:** 385–389.
94. Wu, W., F. Gu & S. Fukui. 2021. Combining proration and full information maximum likelihood in handling missing data in Likert scale items: a hybrid approach. *Behav. Res. Methods*. https://doi.org/10.3758/s13428-021-01671-w
95. Horn, J.L. 1965. A rationale and test for the number of factors in factor analysis. *Psychometrika* **30:** 179–185.
96. Velicer, W.F. 1976. Determining the number of components from the matrix of partial correlations. *Psychometrika* **41:** 321–327.
97. Schwarz, G. 1978. Estimating the dimension of a model. *Ann. Statist.* **6:** 461–464.
98. McCoach, D.B., R.K. Gable & J.P. Madura. 2013. *Instrument Development in the Affective Domain*. New York: Springer.
99. Ahmed, W. 2018. Developmental trajectories of math anxiety during adolescence: associations with STEM career choice. *J. Adolescence* **67:** 158–166.