The origins of math anxiety and interventions

Where does math anxiety come from, and why are girls more likely to be anxious about numbers than boys?

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Theme/s:

Effective teaching / Gender and STEM education / Learning mathematics / Learning difficulties

This report arises from Science of Learning Fellowships funded by the International Brain Research Organization (IBRO) in partnership with the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IBRO/IBE-UNESCO Science of Learning Fellowship aims to support and translate key neuroscience research on learning and the brain to educators, policy makers, and governments.

Executive summary

- *Math anxiety* (MA) is distinct from cognitive mathematical learning problems.
- Girls are more prone to MA than boys.
- Several environmental and personal factors interact in the origins of MA.
- Societal stereotypes about math may play an important role in triggering the gender gap in MA.
- MA has many consequences—the most serious lifelong consequence being that affected pupils may avoid math-related careers.
- Cognitive-behavioural interventions seem the most promising in preventing and alleviating MA.

MA is distinct from cognitive mathematical learning problems

Before 2017 there has been no study on the interrelationship of cognitive mathematical learning problems and MA. A recent large study[1] explicitly addressed the question of whether a specific weakness in mathematics performance (labeled developmental dyscalculia) overlaps with MA. The study involved 1,757 primary and secondary school pupils in the United Kingdom. Overall, 99 children were identified with specific mathematics learning problems (5.6% of 1,757; see Figure 1). In these children, reading comprehension was in the normal range (within plus or minus one standard deviation of the mean on a standardized achievement test), but mathematical performance was poor (less than the mean minus one standard deviation level on a standardized achievement test).

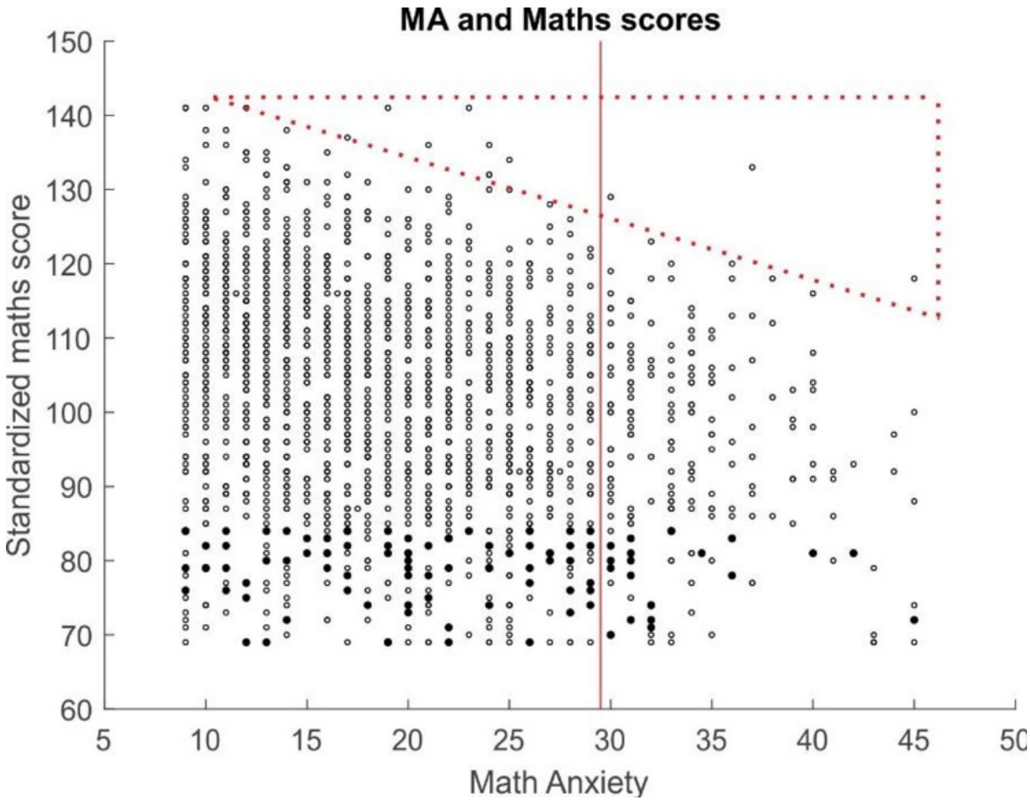

Figure 1. The bivariate distribution of MA scores (range: 0-45) and standardized math scores in a sample of 1,757 children[1]. The vertical line marks the high MA threshold (≥30) used in the study (note that we tested multiple thresholds). An approximate area of increasingly sparse observations is marked by the dotted triangle in the upper right part. Sparse observations in this area indicate that the main impact of MA may be decreasing the number of high achieving children. Children with specific mathematical learning problems are marked by bold dots (standardized reading score>85; standardized math score<86). The figure replots the data shown in Figure 2A from Ref. [1].

High MA was defined as scoring at least 30 (equal to or beyond the 90[th] percentile on the MA score distribution; see **Brief 4**). Hence, in the whole sample, by definition, about 11% of children had high MA. In contrast, 22% of children with specific mathematics learning problems had levels of MA. That is, the proportion of children with high MA was about twice as high amongst children who were performing weakly specifically in mathematics than in other children. Notably, in line with the gender gap in MA, 18 of the 22 children with specific mathematics learning problems and high MA were girls, and 4 were boys. However, overall this group of high MA children only constituted about 11% of all the 198 children with high MA. In fact, 78% of children with specific mathematics learning problems did not have high MA. Moreover, **77% of children with high MA had normal to high mathematics achievement**. That is, while the proportion of high MA pupils seems to be somewhat larger in children with specific mathematics learning problems than in normally achieving children[2-3], most children with high MA are at least normally achieving.

The above data strongly suggest that cognitively based specific mathematics learning problems and MA strongly **dissociate**, and they represent **very different phenomena**. First, *many low achievers did not have high MA*. This may happen because they or their parents/carers do not value mathematics highly[4] or they may simply lack the metacognitive abilities to see their performance in context or they may misjudge their performance level[5]. Importantly, the findings also mean that it is unlikely that MA is causally linked to any kind of low-level mathematical impairment[1]. If this were the case, most children with high MA would also have low levels of mathematics achievement.

The second important point is that **most children with high MA are actually normal to high achievers on mathematics tests**. A point related to this is that, as discussed previously in **Brief 2**, the working memory interference caused by MA may primarily negatively impact performance on more difficult rather than easier problems[6]. Hence, better math ability children with high MA may experience larger *relative* (relative to their abilities) performance decrement due to MA than poorer ability children. This is because poorer math ability children may genuinely be unable to solve some difficult math problems, whereas better ability children may actually be able to solve them were it not for the debilitating effect of their MA on their measured achievement levels. For example, some children achieving normally in test situations may actually be propelled to be high achievers if their MA were alleviated.

Overall, it is very important to consider that normal to high math ability children may be in danger of being completely neglected from the point of view of MA. In fact, these children may constitute the group who are in **most danger** of avoiding elective math classes and avoiding math-related careers. Considering the potentially life-long impact of MA (through career choices), it would be imperative to monitor MA levels in schools and intervene to alleviate MA in normal to high achieving children.

The gender gap in math anxiety and its potential causes

A consistent characteristic of MA is a relatively large gender gap: Girls/women typically show notably higher MA levels than boys/males in many countries from different cultures[7]. The gender gap has been shown to be present already in grade 2 of primary school[8] and is highly expressed in grades 3-5[8]. The early presence of the gender gap suggests that it may be related to extracurricular causes (family) or the very early impact of the school environment.

The gender gap in MA may appear for various reasons. *First*, many studies have shown that girls typically achieve at the **same** levels as boys in mathematics[1,7,8,9-10]. Hence, it is unlikely that gender discrepancy in objective perception of performance results in gender difference in MA. This suggests that the deficit theory is unlikely to explain gender differences in MA. *Second*, girls also seem to report higher levels of test anxiety and general anxiety than boys[10]. Hence, it may be that they are **generally more anxious** than boys and, therefore, also more likely to develop higher levels of specific MA. If this is so, considering the observation that anxiety forms and their relation to performance may become more specific during schooling[11], we could expect that girls differentiate more pronouncedly than boys into two separate groups from primary to secondary school: one with general anxiety issues and another with well-expressed MA.

Third, mathematics (and science-related) **gender stereotypes** are very prevalent in many societies[12], and both teachers' and parents' gender stereotypes are known to affect math performance and MA levels in pupils[13]. That is, girls may feel less confident and more anxious in fields stereotypically considered alien and difficult for girls. For example, experimental evidence shows that if girls experience *stereotype threat* that negatively affects their mathematics performance[13]. (Stereotype threat is when a person is in such a situation that s/he feels to be at risk of confirming negative stereotypes about their social group.) *Fourth*, several studies have shown that girls report lower levels of **confidence** and self-efficacy in mathematics than boys[14-16]. As mathematics self-efficacy and mathematics competence beliefs have been shown to be related to MA[16], girls' lower confidence levels may result in higher MA levels than in boys. Obviously, low confidence levels may result from negative gender stereotypes about mathematics.

Fifth, girls may also have higher levels of metacognitive readiness[7] and therefore may be able to **report** on their own anxiety perceptions more accurately than boys. *Sixth*, girls may also be more **willing to admit** their own anxieties than boys, as boys in many cultures are expected to suppress their emotions more than girls[7]. It is notable that even if different reported anxiety levels may partly be due to differing self-report accuracy and willingness to admit anxiety, such differences may still be highly significant: if girls perceive themselves as much more anxious than boys, that will probably impact their performance in some form.

Importantly, the gender gap of MA has about the **same effect size** today in 2018 as it had in the 1990s[1,10]. Nevertheless, it is rather surprising that the gender gap in MA and in other forms of anxiety has not decreased at all during the past 30 years. This is contrary to the fact that many countries in Europe (including the United Kingdom, where most European studies have been done) have devoted a considerable amount of attention to increasing gender equality. Hence, it would merit further investigation of why gender discrepancy has not decreased in MA and in other anxiety forms, as well as whether there are factors that could contribute to decreasing gender discrepancy in anxiety levels.

The origins of math anxiety

It is still unclear what *typical emotional and other events* may result in the development of MA[17]. Nevertheless, a number of potential triggers can roughly be categorized into environmental and personal characteristics.

Environmental factors

In terms of environmental factors, we can identify **negative experiences** in mathematics classes, some teacher characteristics **disliked** by students, and **transmission** of anxieties from teachers and parents/guardians to pupils [see Ref. [18] for review]. First, it has been known for a long time that trainee primary school **teachers** (who are often females) are likely to show high levels of MA[10]. The reasons for this perhaps odd-looking observation may be manifold and country-specific (most observations are coming from the United States). Nevertheless, it is easy to imagine that mathematics may be a relatively alien subject to many who choose primary school teaching careers. This may be more and more so as most graduates with high levels of mathematics skills are eagerly sought after by industry. Hence, it is plausible to assume that many trainee primary school teachers may actually feel uncertain in their subject knowledge and may nurse strong (overt or covert) gender stereotypes about mathematics.

Transmitting **gender stereotypes** to pupils and the inducing stereotype threats may be a particularly pervasive way of generating MA. In a particularly interesting study, first and second grade US pupils were asked to draw pictures of pupils who were good or bad in mathematics[19]. Pupils who draw a boy for the pupil who was good in mathematics were considered to confirm gender stereotypes. Pupils who draw a girl for the pupil who was good in mathematics were considered *not* to confirm gender stereotypes. The analysis of end-of-school-year mathematics scores showed that the boys who confirmed gender stereotypes performed better than the boys who did not confirm gender stereotypes. In contrast, girls who confirmed gender stereotypes performed worse than the girls who did not confirm gender stereotypes. Moreover, the study also provided evidence that gender math ability beliefs and MA of the teachers of the pupils in the study had a direct influence on girls' math achievement. Other studies provide evidence that **parental stereotypes** and **gender ability beliefs** may also play a substantial role in triggering MA[20-21].

Personal factors

Several personal factors may shape MA. Children may genuinely differ in **intellectual** ability, and in some cases, MA may be the consequence of perceived low (relative) math ability as discussed in relation to the deficit theory of MA. Further, **self-esteem, self-confidence,** and perceived **self-efficacy** in mathematics also have strong relations with MA[10] and they strongly depend on **gender**[16]. Finally, basic **attitudes** towards math will also vary from individual to individual[10].

Interplay between environment and personal factors

It is very important to emphasize that **environmental and personal factors** do not act in isolation, and they likely

continuously interact. For example, many girls may be more predisposed to anxiety to start with[11]. Anxieties may then further be amplified by gender stereotypes about mathematics transmitted from the environment[19-21]. Stereotypes may lead to avoiding extra math tuition, negatively impacting self-perceived math performance (for example, relative to the best mathematician boys in the school class taking extra math tuition) that may justify anxieties and poor self-confidence in mathematics. Clearly, researchers and practitioners must **consider various environmental and personal factors together**.

Subjective experience of math anxiety

While MA is typically researched by quantitative questionnaires, there is a shortage of data on the qualitative experience of MA. Nevertheless, it is important to understand this experience so that (1) researchers can better understand the causes of MA, and that (2) they can help to generate emerging theories from qualitative data. Additionally, the first-hand understanding of pupil perspectives on learning is also important because subjective perceptions can strongly influence achievement behaviour[16]. Following the above rationale, a recent study in the United Kingdom has analysed a large volume of interview data from primary school pupils with MA[22].

Many children noted that they *did not prefer* mathematics as a subject. Quite a few children pointed to *specific experiences* or incidents that led to them feeling anxious or nervous about math lessons. Most children with MA noted that they *lacked confidence* in math, and they thought that they were unable to learn as well as they should or were doing poorer in tests *than they should*. Several children mentioned *panicking* in math class and *getting stuck* on questions due to *stress*. Some children mentioned that they feel nervous because they think they are *not good enough* in math, while girls noted that math is often perceived as a *boyish* domain. Some also noted the negative impact of having to move to poorer *ability groups*. Somewhat fewer children noted that they were anxious because they disliked the *nature* of mathematics (for example noting that they thought they were "not good with patterns," whereas "math is about patterns"). Some were not happy about how specific aspects of mathematics were *taught*, particularly when the subject was taught by *different teachers*, which led to *confusion* in class. A few children described *peers mocking* them about their math which made them feel MA, and others mentioned *unfavorable comparisons* to siblings. Overall, it is striking that the qualitative data from children's self-reflection confirms the many factors discussed in this document about the potential causes of MA.

Consequences of math anxiety

MA has short-, medium-, and long-term consequences. Regarding *short-term* consequences, as discussed in the author's brief "Mathematics anxiety and mathematics performance," MA is negatively correlated with mathematics **performance**. Hence, high MA at a certain time point in life may decrease the math performance of an otherwise capable child. MA has *very strong negative correlations* with self-confidence in mathematics, enjoyment of mathematics, and even self-confidence with computers[10]. Hence, in the *medium-term,* pupils with high MA may avoid choosing elective math classes, and therefore may miss out on **optional mathematics education**. This is a particularly pressing problem because, as shown previously, 77% of children with high MA are average to high math achievers who, in principle, may be able to take optional further mathematics education. As mathematics is a highly hierarchical subject, avoiding elective math classes may strongly restrict pupils' realistic later **career choices**. In addition, missing out on elective mathematics classes may further decrease these children's perceived mathematical self-efficacy when comparing themselves to their peers taking elective math classes. Lower perceived mathematical self-efficacy may then further increase MA levels that may again lead to the avoidance of elective math classes. In the *long-term*, the main danger seems to be that pupils with high MA will avoid choosing **careers** strongly relying on mathematics. This may particularly be a problem in the case of **girls/women** who tend to show higher MA than boys/men. In fact, the avoidance of math-related careers due to MA may be a factor behind the stubborn gender gap in STEM subjects in many countries.

Potential interventions for math anxiety

There are various reasons to run early interventions for MA: (1) As discussed, there is an about $r = -0.3$ correlation between MA and mathematics performance. 22% of children with specific mathematical problems experience high MA, and 78% of average-to-high achievers experience high MA[1]. If the debilitating anxiety model is indeed in effect at least in some children, then we could expect that interventions could improve the pupils' mathematics performance. This would mean that at least some low achieving children's **performance may improve** enough to become normally achieving. (2) Alleviating MA may increase the **well-being** and **quality of life** of pupils who may experience daily anxiety in math classes. (3) As discussed, MA may result in avoiding elective math classes and may lead to the avoidance of math-related careers, especially in girls/women. Hence, alleviating MA may increase the proportion of pupils aiming for math-related **careers** and may lead to more equal gender balance in STEM fields at universities. (4) As shown before (see author's brief "Mathematics anxiety and mathematics performance"), MA seems to increase with time during primary/secondary schooling[23], and a specific relation of MA and poor math performance is becoming more engraved[8,11]. Hence, early identification of MA would enable support programmes to be put in place sooner, which would be in the pupils' best interests. Consequently, an important objective of cutting-edge research is to identify prevention and intervention programmes that could preempt and alleviate MA.

Hembree[10] has identified various potential avenues for alleviating MA. These include: (1) *Classroom interventions* that work with whole classes. For example, these could include a more play-based math curriculum in earlier years and a focus on motivating mathematics learning rather than mechanistic problem-solving. Small-group rather than large group-based approaches and collaborative rather than competitive groups of children working together may also be potential avenues for intervention. (2) *Cognitive-behavioural treatments* of MA could reduce the negative emotionality attached to mathematics and thereby eliminate the 'worry' component linked to MA. Solutions in this category could include relaxation (e.g., mindfulness exercises) and related systematic desensitization where the anxiety response elicited by mathematics is gradually overcome. Cognitive restructuring of belief systems is also a possibility, but this may be more difficult with young children who may lack necessary metacognitive abilities and may live in an environment where belief restructuring may be difficult (e.g., may experience strong recurrent gender stereotypes in the family). Overall, at least in adults, systematic desensitization, relaxation training, and belief restructuring seemed the most effective strategies for interventions, but clearly, much more evidence is needed for firm conclusions[10].

Most recently, *expressing worries* in the form of *writing about anxieties* surrounding mathematics has been suggested as a potential intervention for MA[24-25]. The proposed mechanism would be that writing about worries before the test would reduce worries and worry-related ruminations during the test. This would then free up working memory resources during testing resulting in better test performance. However, contrary to the initial promising outcomes, a recent large study could not replicate the initial results[26]. Hence, it is currently unclear whether expressive writing can alleviate MA.

Clearly, the most important goal of current MA research is to identify effective, easy-to-upscale, and cost-effective prevention and intervention techniques for MA. This would serve both individual quality of life and well-being and enhance economic competitiveness by moving more pupils towards STEM fields.

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