

1 **Genetic factors underlie the association between anxiety, attitudes and performance in**  
2 **mathematics**

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21 sense.

22  
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27

28

29 **Abstract**

30

31 Students struggling with mathematics anxiety (MA) tend to show lower levels of mathematics self-efficacy  
32 and interest as well as lower performance. The current study addresses: (1) how MA relates to different  
33 aspects of mathematics attitudes (self-efficacy and interest), ability (understanding numbers, problem-  
34 solving ability, and approximate number sense) and achievement (exam scores); (2) to what extent these  
35 observed relations are explained by overlapping genetic and environmental factors; and (3) the role of  
36 general anxiety in accounting for these associations. The sample comprised 3,410 twin pairs aged 16-21  
37 years, from the Twins Early Development Study. Negative associations of comparable strength emerged  
38 between MA and the two measures of mathematics attitudes, phenotypically (~ -.45) and genetically (~ -  
39 .70). Moderate negative phenotypic (~ -.35) and strong genetic (~ -.70) associations were observed between  
40 MA and measures of mathematics performance. The only exception was approximate number sense whose  
41 phenotypic (-.10) and genetic (-.31) relation with MA was weaker. Multivariate quantitative genetic  
42 analyses indicated that all mathematics related measures combined accounted for ~75% of the genetic  
43 variance in MA and ~20% of its environmental variance. Genetic effects were largely shared across all  
44 measures of mathematics anxiety, attitudes, abilities and achievement, with the exception of approximate  
45 number sense. This genetic overlap was not accounted for by general anxiety. These results have important  
46 implications for future genetic research concerned with identifying the genetic underpinnings of individual  
47 variation in mathematics-related traits, as well as for developmental research into how children select and  
48 modify their mathematics-related experiences partly based on their genetic predispositions.

49

50 **Introduction**

51 Mathematics anxiety (MA) has been consistently linked to lower levels of engagement and  
52 motivation and poorer performance in mathematics (1,2). MA is a widespread phenomenon: a recent large-  
53 scale investigation of 15-year-olds found that 30% of students across multiple countries part of the  
54 Organization for Economic Cooperation and Development (OECD) reported feeling anxious or incapable  
55 when solving a mathematics problem (3). Due to the high incidence and hindering consequences for  
56 mathematics learning outcomes and experiences (4), it is important to understand the etiology of the  
57 association between MA and the attitudinal and performance components of learning mathematics.

58 The current study investigates the extent to which overlapping genetic and environmental factors  
59 underlie the associations between MA, attitudes towards mathematics, cognition and achievement. This work  
60 provides a foundation for the search of genetic variants linked to individual differences in MA, and  
61 mathematical learning. This study can also inform developmental research into how students select and  
62 modify their mathematics-related experiences, partly depending on their genetic predispositions. Moreover,  
63 identifying which aspects of performance and attitudes, if any, are more closely associated with anxiety, and  
64 the etiologies of these associations, will likely inform the focus of future interventions aimed at reducing MA  
65 and fostering mathematics learning.

66 *Mathematics anxiety and attitudes towards mathematics: self-efficacy and interest*

67 Research has indicated a moderate negative association between MA and mathematics motivation  
68 and attitudes, including lower perseverance to learn and practice mathematics (5). Moderate to strong negative  
69 associations between mathematics attitudes and anxiety are observed in student populations, as well as in  
70 samples of pre-service teachers -trainees working towards obtaining mathematics teaching qualifications-  
71 cross culturally (6). The tendency to avoid situations involving mathematics, which covaries with MA is in  
72 line with observations of avoidance behavior associated with general anxiety (5,7), and might be related to  
73 holding negative beliefs about competence in the subject (8,9). In line with this hypothesis, research found  
74 that mathematics self-efficacy, which describes individuals' perception of their own competency (10),  
75 mediated the negative association between MA and performance in high school students (11). Students who  
76 achieved higher grades at the start of high school developed higher mathematics self-efficacy, which resulted  
77 in lower levels of MA at a two-year follow-up (11). Additionally, self-efficacy was found to mediate the  
78 negative association between self-reported self-regulatory behavior and MA: A greater capacity for self-  
79 regulation was positively associated with self-efficacy which was in turn negatively linked to MA in an  
80 adolescent sample (12).

81 The expectancy-value theory of motivated behavior (13) proposes that, as well as beliefs and  
82 expectancies, subjective task value is a crucial construct characterizing motivated behavior. However, few  
83 studies have focused on investigating the association between MA and other aspects of attitudes towards  
84 mathematics, beyond self-efficacy. One study found that MA relates to a similar degree to self-efficacy,  
85 interest, and importance attributed to mathematics (-.41, -.33, -.30) (14). Similar results were obtained by two  
86 previous studies that examined the association between MA and mathematics importance, interest and usefulness  
87 (15) and between MA and mathematics confidence, interest and importance in a sample of young children  
88 (16). Yet, it remains unclear whether the same or distinct genetic and environmental influences underly the  
89 relations between MA and mathematics attitudes, such as self-efficacy and interest. The first goal of the present  
90 study is to address this gap in the literature.

91 *Mathematics anxiety and achievement*

92 Students experience MA across the entire distribution of mathematics ability (17). A recent investigation  
93 found that, although children with developmental dyscalculia were more likely to show high levels of MA  
94 than neurotypical controls, 77% of children presenting with high levels of MA showed average or high  
95 performance in mathematics (18). Nevertheless, research has found that students experiencing higher levels  
96 of MA on average show weaker mathematical performance. This negative association between MA and  
97 mathematics achievement remains significant and moderate after accounting for variation in general cognitive  
98 ability (7). The association between MA and achievement has been observed at several developmental stages,  
99 from as early as primary school (19,20).

100 Longitudinal research in an adolescent sample has suggested that the stability of MA increases from  
101 moderate to strong during the course of adolescence (21). This observed increase in the stability of MA is  
102 partly explained by stable levels of low achievement in mathematics, as achievement was found to drive the  
103 development of subsequent MA (21). These results point to the role of negative performance feedback in  
104 reinforcing the development of increasingly pervasive levels of MA in adolescence. However, another  
105 longitudinal study found reciprocal longitudinal links between negative emotions, including MA, and  
106 achievement in mathematics in a sample of secondary school students (22). This is in line with the observation  
107 of reciprocal longitudinal links between MA and performance in a sample of primary school students, although  
108 effect sizes were observed to be greater for the link from earlier achievement to subsequent anxiety (23). A  
109 further longitudinal investigation explored the emergence of the association between mathematics anxiety and  
110 achievement in a primary school sample (24). The study found that while no direct longitudinal links between  
111 MA and achievement emerged, both constructs were associated with mathematics self-evaluation, suggesting  
112 a potential role of attitudes towards mathematics, and particularly self-efficacy, in the development of the link  
113 between MA and mathematics achievement (24).

114 A further line of investigation has explored the possibility that a deficit in lower-level numerical  
115 processing may be related to MA via its negative association with mathematics achievement (25). Supporting  
116 this hypothesis, two studies have found that high levels of MA were associated with deficits in areas of basic  
117 numerical processing such as counting (25) and a simple visual enumeration (26). On the other hand, another  
118 investigation (27) failed to find an association between MA and basic numerosity – the ability to discriminate  
119 between symbolic and non-symbolic numerical quantities at a first glance (28). Using latent profile analysis,  
120 Hart et al. clustered students into different groups, based on their profile in MA, achievement and numerosity.  
121 They found that the link between MA and numerosity was weak across all identified groups (27).

122 Despite the large number of studies on the phenotypic association between MA and mathematics  
123 cognition, at present, only one study has explored the association between MA and performance applying a  
124 genetically informative design (29). This investigation, conducted in a twin sample, found that the association  
125 between MA and performance (measured as mathematics problem-solving ability) was mostly explained by  
126 common genetic influences. The second goal of the current study is to extend this research to explore the  
127 genetic and environmental overlap between MA and aspects of mathematics attitudes and performance.

## 128 *Associations between Mathematics and General Anxiety*

129 Mathematics anxiety and general anxiety partly overlap in their physiological manifestations, which  
130 include increased heartbeat, rapid pulse and nervous stomach (30), as well as in cognitive and brain networks  
131 (3,9,31). However, the two anxieties are only moderately correlated (.35) (5), suggesting that they may be  
132 separate constructs. This is consistent with a number of studies that have observed an association between  
133 MA and performance beyond general anxiety (32–34). In line with this, a recent twin study has shown that  
134 the genetic and environmental etiology of MA only partly overlap with that of general anxiety (35). Crucially,

135 Wang et al. reported that the partial etiological overlap between MA and general anxiety was independent  
136 from the etiology of the overlap between MA and mathematics performance in a problem verification task  
137 (29). The third aim of the current study is to examine the extent to which individual differences in general  
138 anxiety account for the links between MA and mathematics attitudes, cognition and achievement.

139  
140 **Methods**

141 **Participants**

142 Participants were members of the Twins Early Development Study (TEDS), a longitudinal study of  
143 twins born in the United Kingdom between 1994 and 1996. The families in TEDS are representative of the  
144 British population in their socio-economic distribution, ethnicity and parental occupation. Informed consent  
145 was obtained from the twins prior to each collection wave. See Haworth et al. (36) for additional  
146 information on the TEDS sample. The TEDS study received ethical approval from the King's College  
147 London Ethics Committee. The present study focuses on data collected in a subsample of TEDS twins over  
148 two waves: age 16 and age 18-21.

149  
150 At **age 16**, TEDS twins contributed data on mathematics ability and achievement ( $N = 3,410$  pairs,  
151 6,820 twins; MZ = 2,612; DZ = 4,508; 56% females) and mathematics self-efficacy and interest ( $N = 2,505$   
152 pairs, 5,010 twins; MZ = 1,954; DZ = 3,270; 61.2% females). At **age 18-21**, the twins contributed data on  
153 mathematics anxiety and general anxiety ( $N = 1,506$  pairs, 3,012 twins; MZ = 1,172; DZ = 1,846; 63.9%  
154 females). All individuals with major medical, genetic or neurodevelopmental disorders were excluded from  
155 the dataset.

156  
157 **Measures**

158 *Mathematics Anxiety*

159  
160 A modified version of the Abbreviated Math Anxiety Scale (AMAS) (37) was administered to  
161 assess mathematics anxiety. The AMAS asks participants to rate how anxious they would feel when facing  
162 several mathematics-related situations. The measure includes nine items that are rated on a 5-point scale,  
163 ranging from 'not nervous at all' to 'very nervous'. Two items were adapted from the original version to  
164 make them age appropriate for the current sample (35), these are: '*Listening to a math's lecture*' and  
165 '*Reading a math's book*'. The AMAS showed excellent internal validity ( $\alpha = .94$ ) and test-retest reliability ( $r$   
166 = .85) (37).

167  
168 *Mathematics attitudes: self-efficacy and interest*

169  
170 Two scales, adapted from the OECD Program for International Student Assessment, measure  
171 mathematics self-efficacy and interest. The **mathematics self-efficacy** scale asked participants: '*How*  
172 *confident do you feel about having to do the following mathematics tasks?*' The scale included eight items  
173 that participants had to rate on a 4-point scale, from 0 = not at all confident to 3 = very confident. Examples  
174 of items are: '*Understanding graphs presented in newspapers*', and '*Solving an equation like  $3x + 5 = 17$* '.  
175 The scale showed good internal validity ( $\alpha = .90$ ). The **mathematics interest** scale included three items that  
176 participants had to rate on a 4-point scale, from 1 = strongly disagree to 4 = strongly agree. The items were:  
177 '*I look forward to my mathematics lessons*'; '*I do mathematics because I enjoy it*'; and '*I am interested in*  
178 *the things I learn in mathematics*'. The scale showed good internal validity ( $\alpha = .93$ ).

181  
182 *Mathematics performance*

183 The General Certificate of Secondary Education (GCSE) grades provided a measure of **mathematics**  
184 **exam grade**. The GCSE exams are taken nationwide at the end of the compulsory education, usually when  
185 students are 16-years-old. As mathematics is one of the core subjects in the UK educational curriculum,  
186 taking the mathematics GCSE exam is a compulsory requirement for all students. Mathematics GCSE scores  
187 were collected by questionnaires sent to the twins or their parents by post, via email, or through a phone  
188 interview. The GCSE grades, which are given in letters from A\* (similar to A+) to G, were re-coded on a  
189 scale from 11, corresponding to the highest grade (A\*) to 4 corresponding the lowest pass grade (G). No  
190 information about ungraded or unclassified results was available. However, these constitute a small  
191 proportion of all pupils in the UK (e.g. 1.5% of all exams in 2017; [https://www.jcq.org.uk/examination-](https://www.jcq.org.uk/examination-results/gcses/2017/gcse-full-course-results-summer-2017)  
192 [results/gcses/2017/gcse-full-course-results-summer-2017](https://www.jcq.org.uk/examination-results/gcses/2017/gcse-full-course-results-summer-2017)) and therefore unlikely to constitute a bias in the  
193 current study. For 7,367 twins, self- and parent-reported GCSE results were verified using data obtained  
194 from the National Pupil database (NPD;  
195 [www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/251184/](http://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251184/SFR40_2013_FINALv2.pdf)  
196 SFR40\_2013\_FINALv2.pdf), yielding correlations of 0.98 for English, 0.99 for mathematics, and >0.95 for  
197 all sciences between self- and parent-reported grades and exam results obtained from NPD (38).

198  
199 An online test battery assessed mathematics performance with three tests: understanding numbers,  
200 problem verification and approximate number sense.

201  
202 The **understanding numbers** test (39) was developed to specifically assess the ability to understand  
203 and solve problems which included numbers and was based on the NFER-Nelson Mathematics 5-14 Series,  
204 closely linked to the curriculum requirements in the UK. The items included in the measure were taken from  
205 the National Foundation for Education Research (NFER) booklets 8 to 14. The test asked participants to  
206 solve 18 mathematics problems arranged in ascending level of difficulty. Questions were presented in  
207 multiple formats, ranging from equations to problems. Participants were asked either to type a numerical  
208 response into a box or to select one or multiple correct responses out of a set of possible options. An  
209 example of one of the difficult items is '*Denise has thought of two numbers. The numbers added together  
210 make 23. The smaller number subtracted from twice the larger number makes 22. What are Denise's  
211 numbers?*' with numbers 8 and 15 being correct. Each correct answer was allocated 1 point, resulting in a  
212 maximum score of 18. The test showed good reliability in the present sample ( $\alpha = 0.90$ ).

213  
214 The **problem verification test** (PVT) (40) presented participants with a series of mathematics  
215 equations appearing for 10 seconds on a computer screen. Participants responded to each equation (correct,  
216 incorrect, don't know), by pressing the corresponding keys on the computer keyboard. If they timed out,  
217 they were automatically redirected to the following equation. The PVT included 48 items. Examples of  
218 items are ' $32 - 16 = 14$ '; and ' $2/6 = 3/9$ '. Each correct response was allocated the score of 1 and other  
219 responses and non-responses the score of 0, for a maximum score of 48. The test showed good reliability in  
220 the current sample ( $\alpha = 0.85$ ).

221  
222 The approximate **number sense** test (28) included 150 trials displaying arrays of yellow and blue  
223 dots, varying in size. Each trial lasted 400 ms and included a different number of blue and yellow dots  
224 presented on the screen. Participants were required to judge whether there were more yellow or blue dots on  
225 the screen for each trial (see Tosto et al., 2014 for additional information on this task) (41). Each correct  
226 answer was allocated the score of 1 and the final score was calculated as the number of correct trials. The

227 final accuracy score correlated strongly ( $r = -.931$ ,  $p < .0001$ ) with the alternative score calculated using the  
228 Weber fraction (42) for which a smaller score indicates better performance.  
229

### 230 General Anxiety

231

232 The Generalized Anxiety Disorder Scale (GAD-7) (43) assessed general anxiety. The scale includes  
233 7 items asking participants to rate on a scale from 1 = not at all to 4 = nearly every day '*How often in the*  
234 *past month have you been bothered by the following problems?*' Examples of items are '*Not being able to*  
235 *control worrying*', and '*Feeling afraid as if something awful might happen*'. As well as measuring  
236 generalized anxiety disorder, the GAD-7 has been validated and is considered a reliable measure of anxiety  
237 in the general population. The GAD-7 is characterized by good internal validity ( $\alpha = .89$ ) and test-retest  
238 reliability  $r = .64$  (43).

### 239 Analyses

240

#### 241 *Phenotypic Analyses*

242

243 Descriptive statistics and ANOVAs were conducted on data from one randomly selected twin out of  
244 each pair in order to control for sample dependency (i.e. the fact that the children in the study were twins).  
245 Measures were residualized for age and sex and standardized prior to analyses.  
246

#### 247 *Genetic Analyses – The Twin Method*

248

249 The twin method allows for the decomposition of individual differences in a trait into genetic and  
250 environmental sources of variance by capitalizing on the genetic relatedness between monozygotic twins  
251 (MZ), who share 100% of their genetic makeup, and dizygotic twins (DZ), who share on average 50% of the  
252 genes that differ between individuals. The method is further grounded in the assumption that both types of  
253 twins who are raised in the same family share their rearing environments to approximately the same extent  
254 (44). Comparing how similar MZ and DZ twins are for a given trait (intraclass correlations), it is possible to  
255 estimate the relative contribution of genes and environments to variation in that trait. Heritability, the  
256 amount of variance in a trait that can be attributed to genetic variance (A), is intuitively calculated as double  
257 the difference between the MZ and DZ twin intraclass correlations (45). The ACE model further partitions  
258 the variance into shared environment (C), which describes the extent to which twins raised in the same  
259 family resemble each other beyond their shared genetic variance, and non-shared environment (E), which  
260 describes environmental variance that does not contribute to similarities between twin pairs.  
261

262 An alternative to the ACE model is the ADE model, which partitions the variance into additive  
263 genetic (A), non-additive (or dominant) genetic (D) and non-shared environmental (E) effects. This model is  
264 fitted in cases when intraclass correlations for DZ twins are below 50% of the MZ intraclass correlation –  
265 indicating non additive genetic influences (46). While additive genetic factors (A) are the sum of the effects  
266 of all alleles at all loci contributing to the variation in a trait or to the co-variation between traits, non-  
267 additive genetic effects (D) describe interactions between alleles at the same locus (dominance) and at  
268 different loci (epistasis). The classic twin design, comparing MZ and DZ twins does not allow to estimate all  
269 four sources of influence (A, D, C and E) within one univariate model, as it only includes two coefficients of  
270 relatedness (47). Therefore, with the classic twin design it is possible to partition the variance into three  
271 sources of influences: A, E, and either C or D.  
272

273 ACE models were fitted for mathematics GCSE, understanding numbers, and mathematics problems  
274 verification test. For these measures, intraclass correlations for DZ pairs were more than half of those for  
275 MZ pairs, suggesting that environmental factors contributed to the similarity between twins beyond their  
276 genetic similarity.  
277

278 ADE models were fitted for MA, general anxiety, mathematics interest, mathematics self-efficacy,  
279 and number sense. For these measures, the DZ intraclass correlation were less than half that of MZ,  
280 indicating non additive genetic effects.  
281

282 The twin method can be extended to the exploration of the covariance between two or more traits  
283 (*multivariate genetic analysis*). Multivariate genetic analysis allows for the decomposition of the covariance  
284 between multiple traits into genetic and environmental sources of variance, by modelling the cross-twin  
285 cross-trait covariances. Cross-twin cross-trait covariances describe the association between two variables,  
286 with twin 1 score on variable 1 correlated with twin 2 score on variable 2, which are calculated separately  
287 for MZ and DZ twins.  
288

289 One way of partitioning the genetic and environmental covariation between two or more traits is to  
290 conduct a *multivariate Cholesky decomposition*. The Cholesky decomposition allows to examine the  
291 overlapping and independent genetic (A), shared (C) (or non-additive D), and non-shared (E) environmental  
292 effects on the variance in two or more traits (48). A Cholesky decomposition can be interpreted similarly to  
293 a hierarchical regression analysis, as the independent contribution of a predictor variable to the dependent  
294 variable is estimated after accounting for the variance it shares with other predictors previously entered in  
295 the model. The current study applies Cholesky decompositions to the investigation of the genetic and  
296 environmental overlap between MA, mathematics motivation and performance.  
297

## 298 Results

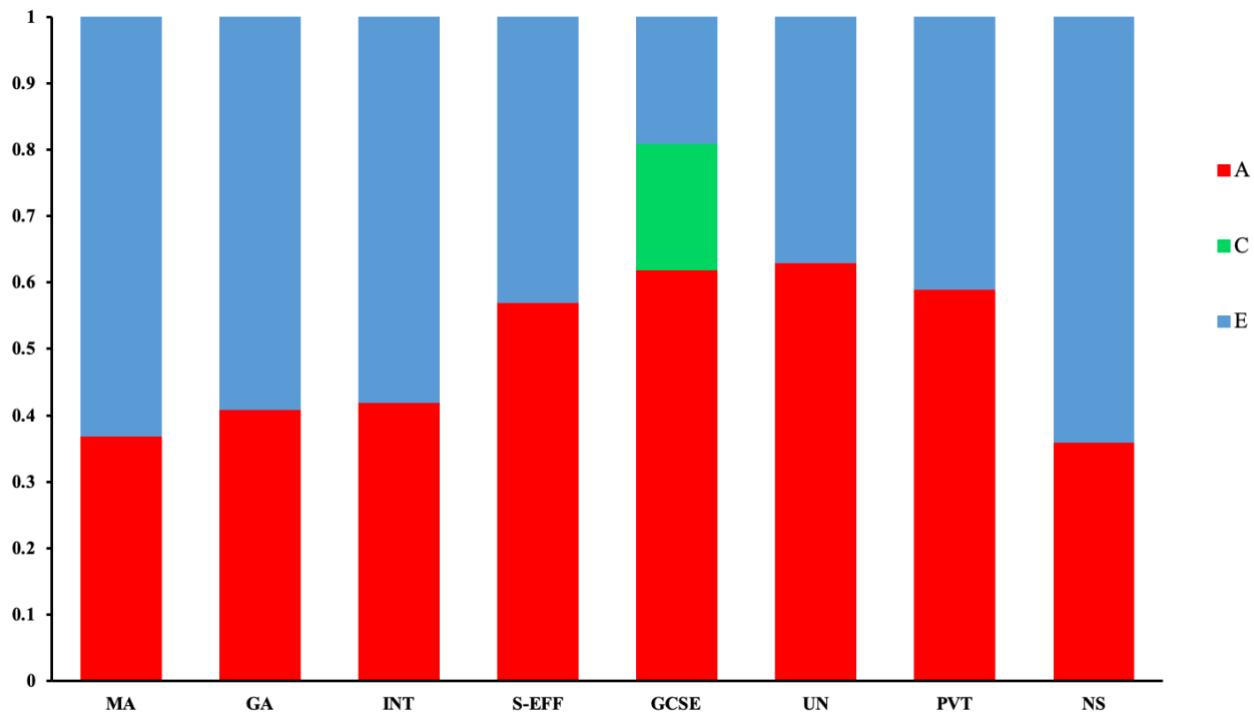
### 300 Descriptive statistics and sex differences

302 Descriptive statistics for all variables, which were normally distributed, are presented in the  
303 supplementary Table S1. Due to previously reported sex differences in mathematics anxiety (49) and  
304 performance (50), we firstly tested for sex differences in all measures using univariate ANOVAs (Table S2).  
305 Males showed significantly higher levels of mathematics self-efficacy, interest and performance across all  
306 measures, and lower levels of mathematics and general anxiety. Sex explained a relatively small portion of  
307 the variance in all measures (0-7%). Previous genetically informative work on these same measures (35,51)  
308 did not find support for the existence of qualitative differences in the etiology of mathematics anxiety and  
309 performance between males and females. Consequently, these analyses were not repeated. Table S3 reports  
310 the twin correlations separately for same-sex (DZss) and opposite-sex (Dzos) dizygotic pairs. As can be seen  
311 in Table S3, the twin correlations for DZss and Dzos are similar for all variables, suggesting no qualitative  
312 or quantitative sex differences in ACE estimates.  
313

### 314 Genetic and environmental variation in mathematics related traits

316 Eight univariate models were conducted in order to partition individual differences in all  
317 mathematics-related traits. Figure 1 reports the results of these univariate analyses. (Table S4 reports  
318 intraclass correlations and 95% confidence intervals for these univariate analyses.) With the exception of  
319 GCSE exam scores (for which significant C was found), the AE model was found to be the best fit for the

320 data for all traits. Dropping the C or D paths did not significantly decrease the goodness of fit of the  
321 univariate models (see Table S5). Estimates of heritability ranged between 36% and 63%, and the remaining  
322 variance was explained by non-shared environmental factors, which also include measurement error. Shared  
323 environmental factors accounted for 18% of the variance in GCSE exam scores.



324  
325 **Figure 1.** Univariate genetic (A), shared environmental (C) and non-shared environmental (E) estimates for all mathematics  
326 related measures; MA = mathematics anxiety; GA = general anxiety; INT = interest; S-EFF = self-efficacy; GCSE = mathematics  
327 GCSE exam score; UN = understanding numbers; PVT = problem verification test; NS = number sense.  
328  
329

330 *Phenotypic and genetic correlations across all mathematics related traits*  
331

332 Figure 2 presents the phenotypic (observed) and genetic correlations between all mathematics related  
333 traits. Moderate negative phenotypic correlations ( $r$  ranging between -.31 and -.45) and strong negative  
334 genetic correlations ( $r_A$  ranging between -.67 and -.75) were observed between MA and all other  
335 mathematics related variables. The only exception was the association between MA and approximate  
336 number sense, which was weak phenotypically ( $r = -.10$ ) and modest genetically ( $r_A = -.31$ ). Measures of  
337 mathematics attitudes shared a positive moderate to strong phenotypic association ( $r$  ranging between .38  
338 and .56) and strong genetic association ( $r_A$  ranging between .57 and .82) with measures of mathematics  
339 performance. Phenotypic and genetic correlations across measures of mathematics performance were strong.  
340 Again, an exception was approximate number sense, which was only moderately related to other  
341 mathematical measures.  
342

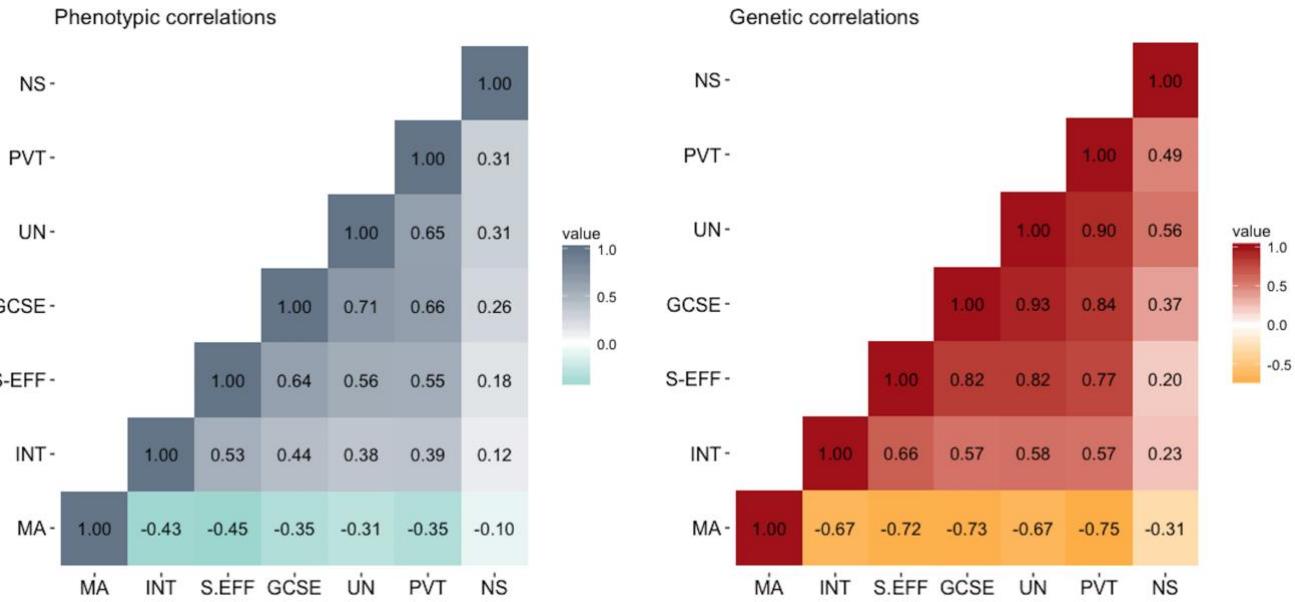
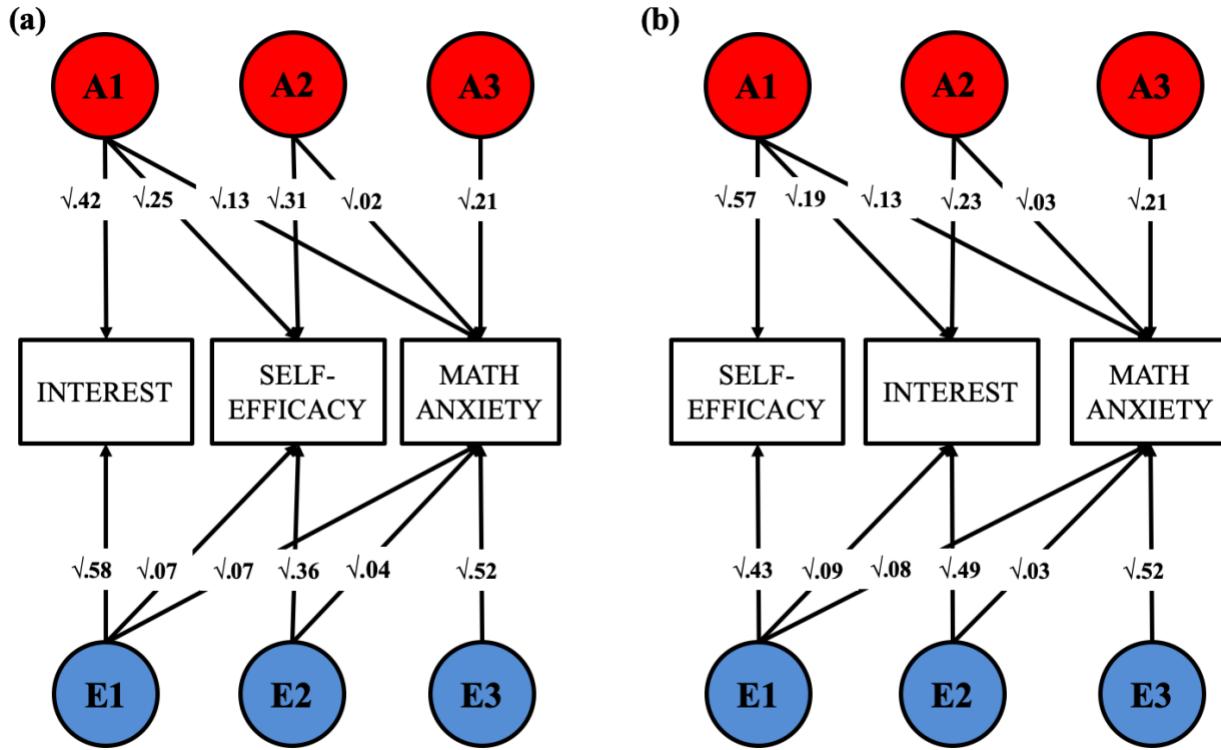


Figure 2. Phenotypic and genetic correlations across all mathematics related measures; MA = mathematics anxiety; INT = interest; S-EFF = self-efficacy; GCSE = mathematics GCSE exam score; UN = understanding numbers; PVT = problem verification test; NS = number sense.

#### Multivariate associations between MA and mathematics attitudes

We conducted two Cholesky decomposition analyses to explore the unique genetic and environmental overlap between each measure of mathematics self-efficacy and interest and MA. Following the rationale of hierarchical regression, in order to explore the unique genetic and environmental variance shared between self-efficacy and MA after accounting for interest, we entered interest as the first variable in the model, followed by self-efficacy and MA (Figure 3a). The attitudes variables were then inverted in a second model (Figure 3b), which explored the unique association between interest and MA after accounting for self-efficacy. Both models found that MA shared ~35% of its genetic variance with mathematics attitudes, and these shared genetic effects were common across both measures of mathematics attitudes. The percentage of genetic variance in MA that overlaps with self-efficacy and interest can be calculated dividing the effect size of the standardize  $a_{1,3}$  paths in Figure 3a and 3b (.13) by the total heritability of MA (.37). Specific genetic associations between each attitude construct and MA were smaller in magnitude, accounting for between 5% and 8% of additional genetic variance in MA.

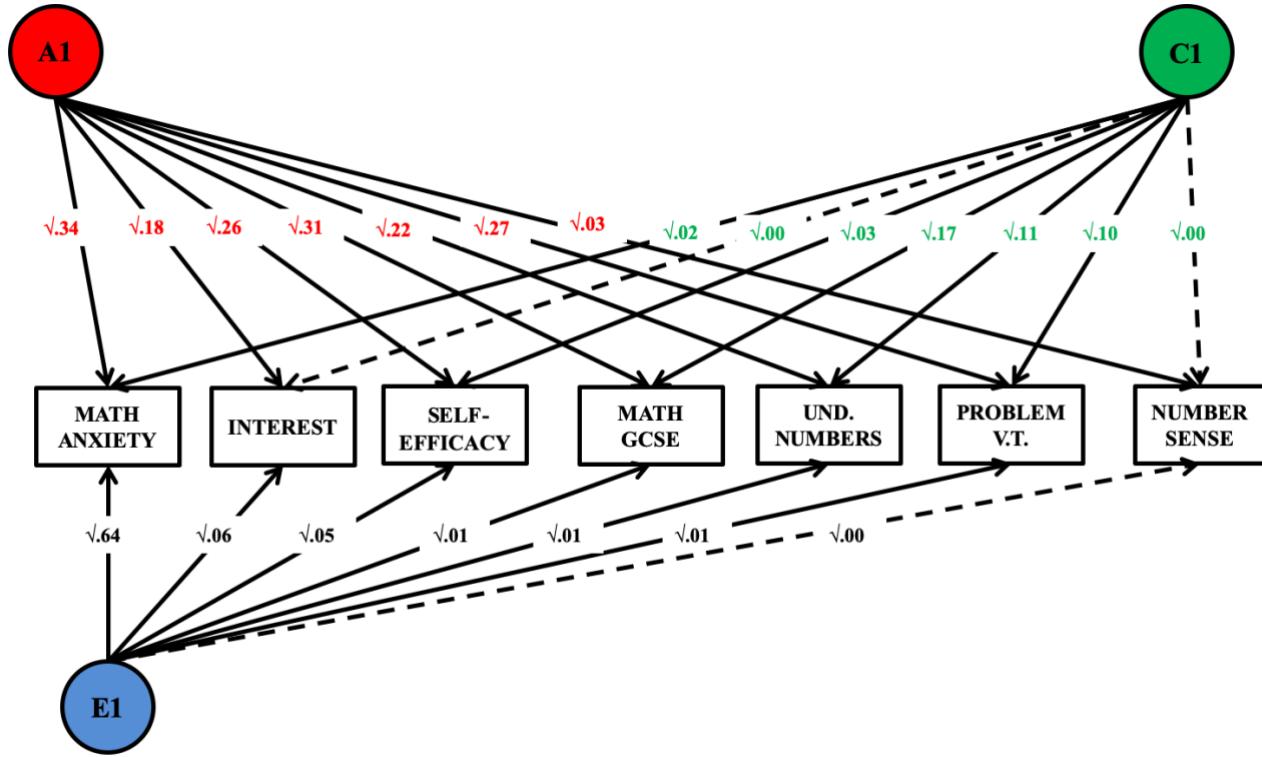
A degree of specificity was observed in the non-shared environmental overlap between the measures, as ~10% of the non-shared environmental variance in MA overlapped with self-efficacy independently of the other ~10% of the variance it shared with interest. These can be calculated diving the effect size of the standardized  $e_{1,2}$  and  $e_{1,3}$  paths linking self-efficacy and interest to MA (.09 and .08, respectively) by the total non-shared environmental variance in MA (.63).



370  
371 **Figure 3.** Trivariate Cholesky decompositions exploring the unique genetic and non-shared environmental overlap between MA  
372 and mathematics self-efficacy (2a), and MA and mathematics interest (2b) - after accounting for the other measure of motivation,  
373 entered at the first stage in the model.

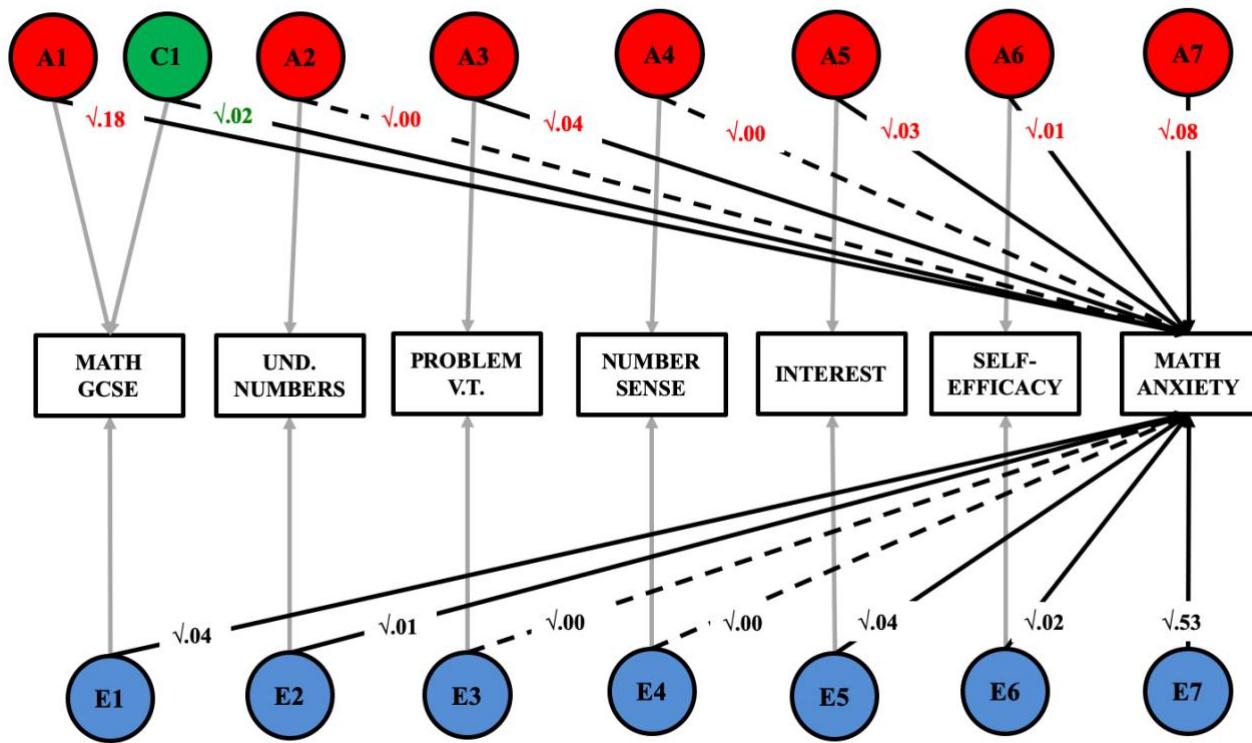
374  
375  
376 *Genetic and environmental variance common to MA, mathematics attitudes and performance*

377  
378 Two additional Cholesky decompositions explored association between mathematics anxiety and all  
379 mathematics-related traits. The first decomposition (Figure 4) explored the genetic and environmental  
380 variance that MA shared with each of the other mathematics related measure – with MA entered first in the  
381 analysis. Results of this first decomposition indicated that the heritability of MA accounted for between 35%  
382 and 50% of the genetic variance in the mathematics related measures, with the exception of approximate  
383 number sense, for which only 8% of the genetic variance overlapped with MA. The weak shared  
384 environmental variance, which could not be dropped from this multivariate analysis (see Table S6) was  
385 shared with other mathematics-related traits. In contrast, the non-shared environmental variance in MA  
386 accounted for a small proportion of non-shared environmental variance in all other mathematics related  
387 measures (between 0 and 10%). Full results for this multivariate model are reported in Table S7.



391  
392 **Figure 4.** Proportion of genetic and environmental variance shared between MA and all other measures of mathematics  
393 motivation and performance. For ease of reading and interpretation, the current figure shows only the A1 genetic paths and C1  
394 and E1 environmental paths. These standardized and squared path estimates were derived from a full Cholesky decomposition  
395 (see results Table S7).

396 The second multivariate model (Figure 5) included the same seven variables but entered in a  
397 different order - providing a different perspective on examining the genetic and environmental overlap  
398 between MA, attitudes and performance in mathematics. This second analysis tested how much of the  
399 genetic and environmental variance in MA was accounted for by all the other variables previously entered in  
400 the model, and how much remained specific to MA. In order to explore whether there was specificity in the  
401 genetic and environmental variance shared between measures of mathematics affect after accounting for  
402 performance, all measures of mathematics performance were entered first in the model, followed by  
403 measures of attitudes and, lastly, MA. The results (see Table S8 for the results of the full Cholesky  
404 decomposition) indicated that 76% of the genetic variance in MA was shared with the other mathematics  
405 related measures, and that the majority of this substantial genetic overlap was common to measures of  
406 performance and attitudes. The two mathematics attitudes measures accounted for an additional 10% of this  
407 shared genetic variance. The small shared environmental variance in MA was entirely shared with  
408 mathematics performance (GCSE exam scores). In contrast, most (83%) of the non-shared environmental  
409 variance was specific to MA, with 8% in common with measures of mathematics performance and 9% in  
410 common with measures of attitudes.  
411  
412  
413



414  
415 **Figure 5.** Proportion of genetic and environmental variance in MA accounted for by all other mathematics-related measures. For  
416 ease of reading and interpretation, the current figure shows only the standardized and squared path estimates linking each  
417 predictor to variation in MA - derived from a full Cholesky decomposition (see full results Table S8). The results of this  
418 decomposition can be interpreted as those of a hierarchical regression: the effect of each predictor is estimated after accounting for  
419 the variance explained by each other predictor previously entered in the model.

420  
421 *The role of general anxiety in the MA-attitudes-performance association*

422  
423 The Cholesky decomposition presented in Figure 4 was repeated including general anxiety, in order  
424 to test whether the observed genetic and environmental associations between MA and mathematics attitudes  
425 and performance could be accounted for by general anxiety. Results (Table S9) indicated that general  
426 anxiety accounted for 22% of the genetic variance and 4% of the environmental variance in MA. However,  
427 after accounting for general anxiety, the genetic and environmental associations between MA, attitudes and  
428 performance remained mostly unchanged.

429  
430 **Discussion**

431  
432 The present investigation was the first to adopt a genetically informative framework to explore the  
433 genetic and environmental overlap between anxiety, self-efficacy, interest and performance in the domain of  
434 mathematics, and the role of general anxiety in accounting for the observed associations. The results showed  
435 a substantial genetic overlap between all mathematics related traits. This shared genetic variance was largely  
436 independent from general anxiety.

437  
438 The first aim of the study was to explore whether MA was similarly associated with different  
439 measures of mathematics attitudes. Results indicated that similar effect size characterized the negative  
440 associations between MA and mathematics self-efficacy and interest. More than one third of the genetic  
441 variance in MA overlapped with mathematics self-efficacy and interest. In contrast, environmental effects  
442 across MA, and attitudes towards mathematics were mostly specific to each measure.

443 These results show that a high degree of generality characterizes the genetic overlap between  
444 mathematics anxiety, interest and self-efficacy, as largely overlapping genetic effects were found to  
445 contribute to variation in all constructs. On the other hand, the environmental links between mathematics  
446 anxiety and interest and self-efficacy were found to be largely specific to each construct, and to include  
447 individual-specific, or stochastic processes (including measurement error), which are encompassed by non-  
448 shared environmental variance, rather than family-wide characteristics which are subsumed under shared  
449 environmental effects. In fact, the majority of the non-shared environmental links were specific to the  
450 pairwise associations between MA and self-efficacy and MA and interest, and not shared across the three  
451 constructs.

452  
453 Different environmental experiences, such as different classrooms, teachers, peers, life events, or  
454 perception of parental involvement and socio-economic status, could all play a role in explaining these  
455 observed non-shared environmental associations. Evidence of an overlap between environmental factors  
456 across measures of mathematics attitudes and anxiety is consistent with research showing that the classroom  
457 learning environment is similarly associated with both MA and mathematics self-efficacy (52). Future  
458 research is needed to identify the environmental factors that link MA to self-efficacy but not interest, and  
459 vice versa.

460  
461 The second aim of the study was to explore the common genetic and environmental variance across  
462 MA and multiple measures of mathematics attitudes and performance. Common genetic factors were  
463 observed to characterize the etiology of all mathematics-related traits. MA accounted for more than one  
464 third of the genetic variance in mathematics attitudes and between one third and half of the genetic variance  
465 in mathematics performance. In turn, measures of mathematics performance accounted for three quarters of  
466 the genetic variance in MA. These differences in the proportion of heritability accounted for by MA and  
467 mathematics performance likely reflect the difference in heritability between the measures. MA, as it is  
468 often observed for self-reported constructs (53,54), is moderately heritable, while the heritability of  
469 mathematics performance is more substantial. Longitudinal studies in genetically informative samples (e.g.  
470 51) are needed to investigate causal directions between constructs.

471  
472 A significant genetic association between mathematics attitudes, particularly self-efficacy, and  
473 performance beyond MA was observed. The only exception was approximate number sense, which shared a  
474 very small proportion of its genetic variance with all measures of mathematics affect. The negligible  
475 association between approximate number sense and MA is in line with previous evidence (27). Moreover,  
476 our findings suggest that MA is particularly linked to numerical tasks that involve learned symbolic  
477 representations of discrete quantitates, rather than approximate representations (41). The lack of a shared  
478 genetic etiology between measures of mathematics affect and approximate number sense suggests that basic  
479 approximate numerical skills are unlikely to function as a cognitive precursor of the negative association  
480 observed between MA and performance.

481  
482 The third aim of the present study was to explore whether the association between mathematics  
483 anxiety, attitudes and performance was domain specific, or whether general anxiety accounted for part of  
484 their association. Although general anxiety and MA shared ~20% of their genetic variance, general anxiety  
485 did not account for the association between MA and measures of mathematics attitudes and performance; in  
486 fact, it was mostly unrelated to variation in mathematics interest, self-efficacy and performance.  
487 These findings extend the line of evidence provided by Wang et al. (2014) and suggest that the common  
488 etiology of the association between MA, self-efficacy, interest and cognition may be partly specific to the  
489 domain of mathematics. Our results are consistent with evidence showing genetic and environmental

490 specificity for general anxiety and measures of anxiety in the mathematics and spatial domains (35).  
491 Research integrating measures of anxiety and performance in other domains, such as for example second  
492 language learning, will be able to further test the hypothesis of domain-specific factors linking affect and  
493 cognition in the field of mathematics.

494  
495 The current investigation presents some limitations. As well as relying on the methodological  
496 assumptions of twin design (see Rijdsdijk & Sham, 2002 for a detailed description) (47), the models  
497 employed in the current investigation do not specifically account for gene–environment interplay. One  
498 possibility is that the observed genetic association between MA, attitudes and performance may operate via  
499 environmental effects that are correlated or interact with genetic predisposition. For example, children with  
500 a genetic predisposition towards experiencing difficulties with mathematics may develop a greater  
501 vulnerability to negative social influences in the context of mathematics, such as negative feedback received  
502 from teachers or parents on their effort and performance, which in turn may lead to greater feelings of  
503 anxiety towards mathematics (56). This has the potential to generate a negative feedback loop (7) between  
504 performance, motivation and anxiety - that is potentially a product of interacting inherited and  
505 environmental factors. The present investigation, including one time point for each measure of mathematics  
506 anxiety, attitudes and performance does not allow us to establish the direction of causality between the  
507 observed associations. Longitudinal genetically informative studies, integrating multiple measures of  
508 mathematics attitudes, anxiety and performance are therefore needed.

509  
510 A further limitation of the present investigation is that the measure of MA was not collected at the  
511 same time as the measures of mathematics performance and motivation. However, longitudinal  
512 investigations found moderate to strong phenotypic and genetic stability of MA (21), attitudes and  
513 performance (57), which suggests that the links between this two-year time lapse capture the majority of the  
514 processes involved.

## 515 **Conclusions**

516 The present investigation was the first to examine the genetic and environmental overlap between MA  
517 and several aspects of mathematics attitudes and performance. Our findings of a shared, likely domain-  
518 specific, etiology between these mathematics-related traits provide a seminal step for future genetic research  
519 aimed at identifying the specific genes implicated in variation in the cognitive and non-cognitive factors of  
520 mathematics. Our results suggest that the majority of genetic variants implicated in individual differences  
521 across mathematics anxiety, attitudes and performance are unlikely to be implicated in variation in general  
522 anxiety. The current findings also provide a starting ground for developmental research to delve deeper into  
523 the observed common genetic links, examining how the experiential processes through which children select,  
524 shape and modify their mathematical experiences interact with genetic predispositions to produce variation in  
525 mathematics anxiety, attitudes and performance.

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541

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543

## 544 References

1. Devine A, Fawcett K, Szűcs D, Dowker A. Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. *Behav Brain Funct.* 2012 Jan;8(1):33.
2. Eden C, Heine A, Jacobs AM. Mathematics Anxiety and Its Development in the Course of Formal Schooling—A Review. *Psychology* [Internet]. 2013;04(06):27–35.
3. Suárez-Pellicioni, Macarena, Núñez-Peña, María Isabel, & Colomé À. Math anxiety: A review of its cognitive consequences, psychophysiological correlates, and brain bases. *Cogn Affect Behav Neurosci.* 2016
4. Carey E, Hill F, Devine A, Szűcs D. The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. *Front Psychol.* 2016;6(JAN):1–6.
5. Hembree R. The Nature , Effects , and Relief of Mathematics Anxiety. *J Res Math Educ.* 1990;21(1):33–46.
6. Hoffman B. “I think I can, but I’m afraid to try”: The role of self-efficacy beliefs and mathematics anxiety in mathematics problem-solving efficiency. *Learn Individ Differ.* 2010 Jun;20(3):276–83.
7. Ashcraft MH, Moore AM. Mathematic Anxiety and the Effective Drop in Performance. *J Psychoeducational Assess.* 2009;27(3):197–205.
8. Ashcraft MH. Math Anxiety : Personal , Educational , and Cognitive Consequences. *Curr Dir Psychol Sci.* 2002;11(5):181–5.
9. Ashcraft MH, Kirk EP. The relationships among working memory, math anxiety, and performance. *J Exp Psychol Gen.* 2001;130(2):224–37.
10. Bandura A. Self-efficacy: Toward a Unifying Theory of Behavioral Change. *Psychol Rev Univ* [Internet]. 1977;Vol. 84(No. 2):191–215.
11. Meece JL, Wigfield A, Eccles JS. Predictors of math anxiety and its influence on young adolescents' course enrollment intentions and performance in mathematics. *J Educ Psychol.* 1990;82(1):60–70.
12. Jain S, Dowson M. Mathematics anxiety as a function of multidimensional self-regulation and self-efficacy. *Contemp Educ Psychol.* 2009;34(3):240–9.
13. Wigfield A, Eccles JS. Expectancy-Value Theory of Achievamanr Motivation. *Contemp Educ Psychol.* 2000;25(1):68–81.
14. Wang Z, Shakeshaft N, Schofield K, Malanchini M. Anxiety is not enough to drive me away: A latent profile analysis on math anxiety and math motivation. *PLoS One.* 2018;13(2).
15. Wigfield A, Meece JL. Math Anxiety in Elementary and Secondary School Students. *J Educ Psychol.* 1988;80(2):210–6.
16. Ganley CM, McGraw AL. The development and validation of a revised version of the math anxiety scale for young children. *Front Psychol.* 2016;7(AUG).
17. Ashcraft MH, Krause JA. Working memory, math performance, and math anxiety. *Psychon Bull Rev* [Internet]. 2007;14(2):243–8.
18. Devine A, Hill F, Carey E, Szűcs D. Cognitive and emotional math problems largely dissociate:

582 Prevalence of developmental dyscalculia and mathematics anxiety. *J Educ Psychol.* 2018;110(3):431–  
583 44.

584 19. Ramirez G, Gunderson EA, Levine SC, Beilock SL. Math Anxiety, Working Memory, and Math  
585 Achievement in Early Elementary School. *J Cogn Dev.* 2013;14(2):187–202.

586 20. Vukovic RK, Kieffer MJ, Bailey SP, Harari RR. Mathematics anxiety in young children: Concurrent  
587 and longitudinal associations with mathematical performance. *Contemp Educ Psychol* [Internet].  
588 2013;38(1):1–10.

589 21. Ma X, Xu J, Xu J. The causal ordering of mathematics anxiety and mathematics achievement: a  
590 longitudinal panel analysis. *J Adolesc.* 2004 Apr;27(2):165–79.

591 22. Pekrun R, Lichtenfeld S, Marsh HW, Murayama K, Goetz T. Achievement Emotions and Academic  
592 Performance: Longitudinal Models of Reciprocal Effects. *Child Dev.* 2017;88(5):1653–70.

593 23. Gunderson EA, Park D, Maloney EA, Beilock SL, Levine SC. Reciprocal relations among  
594 motivational frameworks, math anxiety, and math achievement in early elementary school. *J Cogn*  
595 *Dev* [Internet]. 2018;19(1):21–46.

596 24. Krinzinger H, Kaufmann L, Willmes K. Math Anxiety and Math Ability in Early Primary School  
597 Years. *J Psychoeduc Assess* [Internet]. 2010;27(3):206–25.

598 25. Maloney EA, Ansari D, Fugelsang JA. Rapid Communication. The effect of mathematics anxiety on  
599 the processing of numerical magnitude. *Q J Exp Psychol.* 2011;64(1):10–6.

600 26. Maloney EA, Risko EF, Ansari D, Fugelsang J. Mathematics anxiety affects counting but not  
601 subitizing during visual enumeration. *Cognition.* 2010;114(2):293–7.

602 27. Hart S, Logan JAR, Thompson LA, Kovas Y, McCloud G, Petrill S. A latent profile analysis of  
603 math achievement, numerosity, and math anxiety in twins. *Florida State Univ Libr.* 2015;Faculty  
604 Pu:1–48.

605 28. Halberda J, Ly R, Wilmer JB, Naiman DQ, Germine L. Number sense across the lifespan as revealed  
606 by a massive Internet-based sample. *Proc Natl Acad Sci U S A.* 2012 Jul;109(28):11116–20.

607 29. Wang Z, Hart SA, Kovas Y, Lukowski S, Soden B, Thompson L a, et al. Who is afraid of math? Two  
608 sources of genetic variance for mathematical anxiety. *J Child Psychol Psychiatry.* 2014 Mar;1–9.

609 30. Adams C. Overcoming math anxiety. *Math Intell.* 2001;23:49–50.

610 31. Wu SS, Barth M, Amin H, Malcarne V, Menon V. Math anxiety in second and third graders and its  
611 relation to mathematics achievement. *Front Psychol.* 2012;3(June):1–11.

612 32. Cargnelutti E, Tomasetto C, Passolunghi MC. How is anxiety related to math performance in young  
613 students? A longitudinal study of Grade 2 to Grade 3 children. *Cogn Emot.* 2017;31(4):755–64.

614 33. Wu SS, Willcutt EG, Escobar E, Menon V. Mathematics Achievement and Anxiety and Their  
615 Relation to Internalizing and Externalizing Behaviors. *J Learn Disabil.* 2014;47(6):503–14.

616 34. Hill F, Mammarella IC, Devine A, Caviola S, Passolunghi MC, Szucs D. Maths anxiety in primary  
617 and secondary school students: Gender differences, developmental changes and anxiety specificity.  
618 *Learn Individ Differ.* 2016;48:45–53.

619 35. Malanchini M, Rimfeld K, Shakeshaft NG, Rodic M, Schofield K, Selzam S, et al. The genetic and  
620 environmental aetiology of spatial, mathematics and general anxiety. *Sci Rep.* 2017;7(42218).

621 36. Haworth CMA, Davis OSP, Plomin R. Twins Early Development Study (TEDS): A Genetically  
622 Sensitive Investigation of Cognitive and Behavioral Development From Childhood to Young  
623 Adulthood. *Twin Res Hum Genet* [Internet]. 2013;16(01):117–25.

624 37. Hopko DR, Mahadevan R, Bare RL, Hunt MK. The abbreviated math anxiety scale (AMAS).  
625 Assessment. 2003;10(2):178–82.

626 38. Krapohl E, Rimfeld K, Shakeshaft NG, Trzaskowski M, McMillan A, Pingault J-BJ-B, et al. The high  
627 heritability of educational achievement reflects many genetically influenced traits, not just  
628 intelligence. *Proc Natl Acad Sci* [Internet]. 2014;111(42):15273–8.

629 39. Tosto MG, Asbury K, Mazzocco MMM, Petrill SA, Kovas Y. From classroom environment to  
630 mathematics achievement: The mediating role of self-perceived ability and subject interest. *Learn  
631 Individ Differ* [Internet]. 2016;50:260–9.

632 40. Murphy MM, Mazzocco MMM. Mathematics Learning Disabilities in Girls With Fragile X or Turner  
633 ... *J Learn Disabil.* 2008;29–46.

634 41. Tosto MG, Petrill SA, Halberda J, Trzaskowski M, Tikhomirova TN, Bogdanova OY, et al. Why do  
635 we differ in number sense? Evidence from a genetically sensitive investigation. *Intelligence.*  
636 2014;43(1):35–46.

637 42. Halberda J, Mazzocco MMM, Feigenson L. Individual differences in non-verbal number acuity  
638 correlate with maths achievement. *Nature* [Internet]. 2008 Sep 7;455:665.

639 43. Löwe B, Decker O, Müller S, Brähler E, Schellberg D, Herzog W, et al. Validation and  
640 Standardization of the Generalized Anxiety Disorder Screener (GAD-7) in the General Population.  
641 *Med Care* [Internet]. 2008;46(3):266–74.

642 44. Kendler KS, Neale MC, Kessler RC, Heath AC, Eaves L. A twin study of recent life events and  
643 difficulties. *Arch Gen Psychiatry.* 1993;50:789–96.

644 45. Martin NG, Eaves LJ. Stages ; the First To Determine the Genetical and Environmental Model. *Most.*  
645 1977;38:79–95.

646 46. Eaves LJ, Silberg JL, Meyer JM, Maes HH, Simonoff E, Pickles A, et al. Genetics and  
647 Developmental Psychopathology: 2. The Main Effects of Genes and Environment on Behavioral  
648 Problems in the Virginia Twin Study of Adolescent Behavioral Development. *J Child Psychol  
649 Psychiatry.* 1997;38(8):965–80.

650 47. Rijsdijk F V, Sham PC. Analytic approaches to twin data using structural equation models. *Brief  
651 Bioinform* [Internet]. 2002;3(2):119–33.

652 48. Neale MC, Boker SM, Bergeman CS, Maes HH. The Utility of Genetically Informative Data in the  
653 Study of Development. 2005;1–58.

654 49. Goetz T, Bieg M, Lüdtke O, Pekrun R, Hall NC. Do Girls Really Experience More Anxiety in  
655 Mathematics? *Psychol Sci.* 2013 Aug.

656 50. Reilly D, Neumann DL, Andrews G. Sex differences in mathematics and science achievement: A  
657 meta-analysis of National Assessment of Educational Progress assessments. *J Educ Psychol  
658* [Internet]. 2015;107(3):645–62.

659 51. Tosto MG, Hanscombe KB, Haworth CMA, Davis OSP, Petrill SA, Dale PS, et al. Why do spatial  
660 abilities predict mathematical performance? *Dev Sci.* 2014;17(3):462–70.

661 52. Taylor BA, Fraser BJ. Relationships between learning environment and mathematics anxiety. *Learn  
662 Environ Res.* 2013;16(2):297–313.

663 53. Malanchini M, Engelhardt LE, Grotzinger AD, Harden KP, Tucker-drob EM. “ Same But Different ”:  
664 Associations Between Multiple Aspects of Self-Regulation, Cognition and Academic Abilities. *J Pers  
665 Soc Psychol* [Internet]. 2018;advance on.

666 54. Briley DA, Tucker-Drob EM. Genetic and environmental continuity in personality development: A  
667 meta-analysis. Vol. 140, *Psychological Bulletin*; 2014. p. 1303–31.

668 55. Malanchini M, Wang Z, Voronin I, Schenker VJ, Plomin R, Petrill SA, et al. Reading self-perceived  
669 ability, enjoyment and achievement: A genetically informative study of their reciprocal links over  
670 time. *Dev Psychol.* 2017;53(4).

671 56. Beilock SL, Maloney E a. Math anxiety: a factor in math achievement not to be ignored. *Policy  
672 Insights from Behavioral Brain Sci.* 2015;2(1):4–12.

673 57. Luo YLL, Kovas Y, Haworth CMA, Plomin R. The etiology of mathematical self-evaluation and  
674 mathematics achievement: Understanding the relationship using a cross-lagged twin study from ages  
675 9 to 12. *Learn Individ Differ* [Internet]. 2011;21(6):710–8.

