Cognitive and emotional math problems largely dissociate: Prevalence of developmental dyscalculia and mathematics anxiety.

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Abstract

A negative correlation between math anxiety and mathematics performance is frequently reported, thus, some may assume that very high levels of mathematics anxiety are associated with very poor mathematical understanding. However, no previous research has clearly measured the association between mathematics anxiety and mathematical learning disability. In order to fill this gap here we investigated the comorbidity of developmental dyscalculia (a selective, serious deficit in mathematical performance) and mathematics anxiety in a sample of 1757 primary (8-to 9-year-old) and secondary (12- to 13-year-old) school children. We found that children with developmental dyscalculia were twice as likely to have high mathematics anxiety as children with typical mathematics performance. More girls had comorbid mathematics anxiety and developmental dyscalculia than boys. However, 77% of children with high mathematics anxiety had typical or high mathematics performance. Our findings suggest that cognitive and emotional mathematics problems largely dissociate and call into question the assumption that mathematics anxiety is exclusively linked to poor mathematics performance. Different intervention methods need to be developed to prevent and treat emotional and cognitive blocks of mathematical development.

Keywords: Developmental dyscalculia; math anxiety; gender differences

Educational Impact and Implications Statement

This study shows that about one fifth of children meeting criteria for developmental dyscalculia are also highly anxious about mathematics. Yet, the majority of children with high mathematics anxiety have adequate or even high mathematics performance. These findings suggest that for the most part, each of these math learning problems needs to be treated separately; interventions targeted towards reducing or offloading worrying thoughts may be beneficial to children with math anxiety, whereas interventions focusing on improvement of numerical skills and working memory are more likely to be successful in the treatment of developmental dyscalculia.

Cognitive and Emotional Math Problems Largely Dissociate: Prevalence of Developmental Dyscalculia and Mathematics Anxiety.

In today's information age, mathematical skills are becoming as important for everyday life and employment as literacy. However, cross-national research has revealed that around 6% of children have problems acquiring mathematical skills (reviewed in Devine, Soltész, Nobes, Goswami, & Szűcs, 2013). Mathematical learning impairments of developmental origin are usually termed mathematical learning disability (MLD) or developmental dyscalculia (DD). Mathematics anxiety (MA), on the other hand, refers to a debilitating negative *emotional* reaction to mathematical tasks, which may occur in children and adults with and without mathematics learning disabilities (Ashcraft, 2002). Importantly, children affected by MA may come to develop negative attitudes towards mathematics, avoid or drop out of mathematics classes, or stay away from careers involving quantitative skills (Ashcraft, 2002; Ma, 1999). Much research has focused on the correlation of MA and mathematics performance across the ability spectrum, but little research has specifically investigated the association between MA and performance within mathematical disability subgroups or the prevalence of comorbidity of MA and DD. Many studies have revealed a moderate overall correlation between MA and mathematics performance (approximately r =-.30; Hembree, 1990; Ma, 1999). Thus, because MA is associated with lower mathematics performance some may assume that high MA is strongly linked to poorer mathematical skills, that is, that MA is just another term for low mathematics ability (Beilock & Willingham, 2014). However, to our knowledge, no prior research has investigated the prevalence of comorbidity of MA and DD. Furthermore, research investigating the link between MA and mathematics performance in children and adolescents with DD is sparse. Past research has tended to show that girls report higher MA than boys, particularly at the secondary school level (Devine, Fawcett, Szűcs & Dowker, 2012; Hill et al., 2016). However, it is currently unknown whether girls are also more likely to be affected by comorbid MA and DD than boys. The current study aims to fill these research gaps by jointly investigating MA and DD, and inspecting gender differences, in 1757 English primary and secondary school students.

Developmental Dyscalculia (DD)

Children with DD lag behind their peers in mathematics performance but otherwise their general cognitive ability, reading and writing skills are normal (Butterworth, 2005). The causal origins of DD are unknown but several theories exist, which suggest that DD is related to the impairment of one or many possible cognitive functions/ representations, e.g., magnitude representation, working memory, inhibition, spatial skills or phonological ability (Szűcs & Goswami, 2013). Specific criteria for clinical diagnosis of DD are provided in the Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition, (DSM-5, American Psychiatric Association, 2013) and the ICD-10 (known as 'specific disorder of arithmetical skills', World Health Organisation, 1994). These diagnostic taxonomies both stipulate that in order to be diagnosed with DD, a child's mathematics abilities (as measured by standardised tests) must be significantly below the level expected for the child's age and should not be due to general intellectual disability or inadequate educational provision. However, neither the DSM-5 or the ICD-10 criteria define a specific diagnostic threshold for low mathematics performance. Furthermore, there are some differences between the DSM-5 and ICD-10 criteria regarding the persistence and specificity of the difficulties and the sources of evidence required for diagnosis.

In any case, clinical diagnostic criteria are not consistently employed in DD research studies (Devine et al., 2013). For example, many researchers define DD operationally if individuals have lower mathematics performance than the average performance for their age, but the inclusion of a control variable (e.g. reading, spelling, IQ) varies across studies.

Moreover, the mathematics performance cut-off used for identification of DD in research varies considerably across international studies (from performance below the 3rd percentile to performance below the 25th percentile (2 *SD* to 0.68 *SD* below the mean). Other DD inclusion criteria have been employed in research, such as a discrepancy definition (e.g., between mathematics performance and performance on a control variable such as IQ or language abilities), a two-year achievement delay (i.e., performance below the mean performance of the school grade two years below), or resistance to intervention (reviewed in Devine et al., 2013). The choice of inclusion criteria necessarily impacts the sample that is selected; thus, the prevalence estimates reported for DD in previous prevalence studies range between 1.3 and 13.8% depending on the criteria used (ibid). Two studies have estimated the prevalence of DD in the United Kingdom (UK) previously. Lewis and colleagues assigned children to the DD group if their mathematics performance was below 1 *SD* below the mean, and reading and IQ performance was at or above a standardized score of 90 (slightly above 1 *SD* below the mean) and found that 1.3% of their sample met these inclusion criteria (Lewis, Hitch, & Walker, 1994). More recently, Devine et al. (2013) investigated the effects of using different DD definitions on the prevalence of DD and gender differences. When DD was defined as mathematics performance below 1 *SD* below the mean and reading performance at or above 1 *SD* below the mean, 6% of their sample met the criteria for DD.

Mathematics Anxiety (MA)

MA is broadly defined as a state of discomfort caused by performing mathematical tasks (Ma & Xu, 2004). MA can be manifested in many different ways, for example as feelings of apprehension, dislike, tension, worry, frustration, and fear (Ashcraft & Ridley, 2005; Ma & Xu, 2004; Wigfield & Meece, 1988). MA is positively correlated with anxiety elicited by testing situations (test anxiety; Hembree, 1990: $r = .52$; Kazelskis et al., 2000: $r = .50$ for males, $r = .52$ for females); however, it is considered a distinct construct (Ashcraft &

Ridley, 2005). Similar to test anxiety, MA is multidimensional. For example, Wigfield and Meece (1988) identified two dimensions which correspond to those identified for test anxiety (Liebert & Morris, 1967): a cognitive component (usually referred to as "worry") which concerns worries about performance/ failure; and an affective component ("emotionality"), which describes nervousness/ tension and associated physiological reactions felt in evaluative settings (Dowker, Sarkar, & Looi, 2016). Some MA scales separate MA elicited by testing situations from other types of MA (e.g., manipulating numbers, doing arithmetic or using mathematics in everyday life; Pletzer, Wood, Scherndl, Kerschbaum, & Nuerk, 2016). The Abbreviated Math Anxiety Scale (AMAS), for example, consists of two subscales measuring: MA felt when learning mathematics in the classroom ("Learning MA"), and MA felt in testing situations ("Evaluation MA", Hopko, Mahadevan, Bare & Hunt, 2003).

Although MA is present in younger school children (Aarnos & Perkkilä, 2012; Chiu & Henry, 1990; Newstead, 1998; Ramirez, Gunderson, Levine, & Beilock, 2013), MA and negative attitudes towards mathematics appear to increase at the secondary school level (Blatchford, 1996; Dowker, 2005) and persist into post-secondary education and adulthood (Betz, 1978; Jameson & Fusco, 2014). Nonetheless, few researchers have systematically estimated the prevalence of MA.

It is important to note that academic anxieties such as MA are not considered clinical anxiety disorders (e.g., specific phobia), nor are academic anxieties currently recognised in the DSM-5 or ICD-10 (American Psychiatric Association, 2013; World Health Organisation, 1994). Questionnaires alone cannot be used to diagnose specific phobia (ibid); however, they are used extensively in educational and psychological research for identifying MA and test anxiety in children and adults.

Many different self-report questionnaires have been developed over the years to measure trait-like MA. The most frequently used scale is the Mathematics Anxiety Rating Scale (MARS) which has 98 items (Richardson & Suinn, 1972). However, with such a large number of items, the MARS is time consuming to administer. Thus, several shorter questionnaires have been developed, including scales specifically for use with primary school children (see Dowker et al., 2016 for a review). Although these other child-friendly scales have reported good reliability, they are typically only suitable for use with a specific age range and often validated only with American samples (Carey, Hill, Devine & Szűcs, 2017). Devine et al. (2012) and Zirk-Sadowski, Lamptey, Devine, Haggard, & Szűcs (2014) recently modified Hopko and colleagues' 9-item AMAS (Hopko, et al.,, 2003) for use with British primary and early secondary school students. With only nine items, the modified AMAS (hereafter: mAMAS), is suitable for administration with younger school children, yet, has good reliability and construct validity (Carey et al., 2017; Zirk-Sadowski et al., 2014).

Similar to DD research, MA researchers utilize different definitions of high MA. Ashcraft and colleagues defined high MA as scores falling above 1 *SD* above the mean MA level (Ashcraft, Krause, & Hopko, 2007); assuming MA scores are normally distributed, a cut-off at 1 *SD* above the mean would indicate that approximately 17% of the population would meet the criteria for being highly math anxious. Yet, the distribution of MA scores is often not reported making the use of a *SD* definition of high MA questionable. According to other definitions, the prevalence of high MA could be much lower. Chinn defined high MA as scores at or above a score of 60 on Chinn's mathematics anxiety survey which corresponded to 'often anxious' in mathematics situations, and found that between 2 and 6% of secondary school students were affected by high anxiety (Chinn, 2009).

Gender differences in DD and MA

Although boys are overrepresented in some developmental disorders such as reading disability, dyslexia, ADHD and autistic spectrum disorder (Bauermeister et al., 2007; Rutter et al., 2004; Scott, Baron-Cohen, Bolton, & Brayne, 2002), the gender ratio reported in past studies of DD is not consistent. Some studies have reported that DD is more prevalent in girls (e.g., Dirks, Spyer, van Lieshout, & de Sonneville, 2008; Hein, Bzufka & Neumärker, 2000; Lambert & Spinath, 2014; Landerl & Moll, 2010) or boys (e.g., Barahmand, 2008; Reigosa-Crespo et al., 2011; von Aster, 2000), yet UK studies have reported that DD is equally prevalent in both genders (Devine et al., 2013; Lewis et al., 1994). Studies have shown that secondary school girls and adult females tend to report higher levels of MA than secondary school boys and adult males (e.g., Chang & Cho, 2013; Devine et al., 2012; Else-Quest, Hyde & Lynn, 2010; Ferguson, Malony, Fuselgang, & Risko, 2015; Frenzel, Pekrun & Goetz, 2007; Goetz, Bieg, Lüdtke, Pekrun & Hall, 2013; Primi, Busdraghi, Tomasetto, Morsanyi, & Chiesi, 2014). However, MA gender differences are less consistent at the primary school level (see Hill et al., 2016 for a review). Thus, there appears to be some inconsistency across studies with regard to gender differences in DD prevalence and MA gender differences at the primary school level. Several factors could explain these conflicting findings, including variation in the selection criteria employed, the measures of both mathematics performance and MA used as well as the socio-cultural context of the samples under study (see Birgin, Baloğlu, Çatlıoğlu, & Gürbüz, 2010; Devine et al., 2012; 2013; Else-Quest et al., 2010 for discussion of these issues).

Relation between MA and performance/ DD

As mentioned above, studies have revealed moderate negative correlations between MA and performance (approximately r = -.30; Hembree, 1990, Ma, 1999) and meta-analytic research confirms this negative association exists across many nations and cultures (Lee, 2009). Many studies have focussed on the direction of this relationship, with the aim of determining whether MA has debilitating effects on performance or whether prior poor performance leads to the development of MA (Carey et al., 2016). The former direction has been labelled the Debilitating Anxiety model, whereas the latter is referred to as the Deficit Theory (ibid). The Deficit Theory claims that anxiety emerges a result of an awareness of poor mathematics performance in the past (Tobias, 1986). In contrast, the Debilitating Anxiety Model posits that high levels of anxiety interfere with performance due to a disruption in pre-processing, processing and retrieval of information (Carey et al., 2016; Tobias, 1986; Wine, 1980). This model also argues that "MA may influence learning by disposing individuals to avoid mathematics-related situations" (Carey et al., 2016, p.2; Chinn, 2009; Hembree, 1990).

The Deficit Theory is supported by research showing that children with MLD show higher levels of MA than children with typical mathematics performance (Lai, Zhu, Chen, & Li, 2015; Passolunghi, 2011; Wu, Willcutt, Escovar, & Menon, 2013). Moreover, research has suggested that the association between MA and arithmetic problem solving is stronger in children with DD than in children without DD (Rubinsten & Tannock, 2010). Children’s mathematics performance has been shown to predict their MA levels in subsequent school years (Ma & Xu, 2004), providing further support for the Deficit Theory. Other research has revealed deficits in basic numerical processing in highly math-anxious adults (Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010), however, it is unclear whether these deficits are a cause or are a consequence of MA. That is, highly math-anxious adults' basic numerical abilities may be impaired because they have avoided mathematical tasks throughout their education and adulthood due to their high levels of MA, which would be more in line with the Debilitating Anxiety Model (Carey et al., 2016).

Support for the Debilitating Anxiety model comes from studies which have shown that adults and adolescents with high MA tend to avoid math-related situations, avoid enrolling in mathematics classes or taking up careers involving mathematics (Hembree, 1990). Adults with high MA have been shown to have decreased reaction times and increased error rates (Ashcraft & Faust, 1994) and decreased cognitive reflection during mathematical problem solving (Morsanyi, Busdraghi, & Primi, 2014), suggesting that math anxious adults tend to avoid processing mathematical problems. Further support for the Debilitating Anxiety model comes from studies indicating that processing resources used for mathematics problem solving are taxed by MA. For example, negative relationships have been found between MA and working memory span (Ashcraft & Kirk, 2001), and the effects of high MA on performance appear to be more marked for math problems with a high working memory load (Ashcraft & Krause, 2007). The Debilitating Anxiety model is also supported by studies which have shown that performance is affected when MA is manipulated (e.g., Park, Ramirez, & Beilock, 2014) or that the association between MA and performance is reduced when tests are administered in a more relaxed format (Faust, Ashcraft, & Fleck, 1996). Additional support for the Debilitating Anxiety model comes from studies that have manipulated stereotype threat (thought to increase anxiety in girls and females) and found effects on performance, and neuroimaging studies which suggest links between MA, performance, and different brain regions involved in both numerical and emotional processing (e.g., Beilock, Rydell & McConnell 2007; Lyons & Beilock, 2012; Pletzer, Kronbichler, Nuerk, and Kerschbaum, 2015; but also see Carey et al., 2016, for a detailed review).

Thus, the evidence supporting the two models is in conflict. The purported mechanisms proposed by each model may contribute to this conflict (Carey et al., 2016). That is, longitudinal studies may be more likely to support the Deficit Theory because knowledge of poor performance is likely to lead to increased anxiety over time, whereas the mechanisms thought to be involved in the Debilitating Anxiety Model are likely to impact performance in the short term, and thus, are more likely to be supported by experimental studies. Therefore, the two models may, in fact, operate simultaneously (ibid). Alternatively, in some individuals, experiences of failure or negative evaluations in mathematics may lead to an increase in MA, possibly resulting in a vicious circle, which also leads to an ever- increasing MA/performance relationship (Carey et al., 2016; Devine, et al., 2012; Jansen et al., 2013). This bidirectional relationship between MA and performance has been labelled the Reciprocal Theory (Carey et al., 2016). Indeed, longitudinal data suggest that the MA and math performance relationship functions reciprocally. Luo and colleagues found that MA levels were linked to a student's prior achievement and that MA, in turn, was linked to future performance (Luo et al., 2014). Similarly, Cargnelutti and colleagues found similar evidence for a bidirectional relationship between MA and performance in young children (Cargnelutti, Tomasetto, & Passolunghi, 2016).

In spite of this large body of literature investigating the relationship between MA and performance, crucially, no prior research has investigated the prevalence of comorbidity of MA and DD. Previous studies have compared MA levels in different mathematics achievement groups (e.g., Lai et al., Passolunghi, 2011; Wu, Willcut, Escovar, & Menon, 2013); or have compared the working memory profiles of children with MA and DD (e.g., Mammarella, Hill, Devine, Caviola, Szűcs, 2015); however, the prevalence of children with comorbid DD and high MA was not reported, nor was the correlation between MA and mathematics performance reported separately in the different achievement groups. Prior investigations of DD prevalence in UK samples did not also measure MA (e.g., Devine et al., 2013; Lewis et al., 1994), thus, it is not currently clear what percentage of children are affected by these mathematics learning problems in combination; moreover, the gender ratio of comorbid DD and MA is unknown. The current study aimed to fill these research gaps by measuring the comorbidity of MA and DD in a very large sample of primary and secondary school children. This study is the first phase of a larger investigation of the early experiences of MA in British school children. In the current analysis, we first estimated the prevalence of DD, MA, and the comorbidity of DD and MA. We used an absolute threshold definition of DD used in a recent UK study by Devine et al. (2013) and, thus expected to replicate the prevalence rate of 6% reported there. However, we had no a priori definition of high MA and thus derived our estimate of high MA prevalence and prevalence of MA and DD comorbidity from observation of the MA score distribution. Furthermore, we compared the proportion of high MA children falling in different mathematics performance groups (those with typical mathematics performance, DD, and comorbid mathematics and reading difficulties). Informed by previous research (Lai et al., 2015; Passolunghi, 2011; Wu et al., 2013), we expected that children with DD would be more likely to have high MA than children with typical mathematics performance. We also inspected gender differences in MA, DD and co-occurring DD and MA. In line with previous UK studies (Devine et al., 2013; Lewis et al., 1994), we expected to find no gender difference in DD prevalence. However, we had no hypothesis regarding gender differences in the prevalence of comorbidity of MA and DD, due to the lack of prior research investigating this.

Method

Participants

The sample consisted of 1757 children and adolescents attending primary and secondary schools in south east England. The primary school sample (N = 830) consisted of 408 girls and 422 boys from Year 4 (mean age =109.4 months *SD* = 3.73). The secondary school sample (N = 927) consisted of 340 girls and 349 boys from Year 7 (mean age = 146.93 months; *SD* = 3.54) and 120 girls and 118 boys from Year 8 (mean age = 151.26 months; *SD* = 3.45). School demographics varied widely, with locations being both urban and rural. A school's percentage of students receiving Free School Meals (FSM) can be used as an indicator of Socio-Economic Status (SES), since consistent economic criteria are used nationwide to determine a child's entitlement to FSM (Gorard, 2012). Schools in this sample varied from 2.9% to 36.5% receiving FSM (Department for Education, 2015b), with schools falling both above and below the national average (calculated as 20.9% of 11 year olds in 2014, from figures in (Department for Education, 2015a). Schools also varied widely in the percentage of students with special educational needs (SEN) and who had English as an additional language (EAL). Students were not excluded on the basis of SEN or EAL, in order to increase the representativeness of the sample. Parental consent was received for all children before testing. The study received ethical permission from the psychology research ethics committee of the University of Cambridge. The study was carried out in accordance with the approved guidelines of the ethics committee.

Materials

Math Anxiety

Math anxiety was measured using a modified version of the AMAS (Hopko et al., 2003); a self-report questionnaire with a total of 9 items. Although it is a short scale, research indicates that the AMAS is as effective as the longer MARS (Hopko, 2003) (e.g. internal consistency: Cronbach's $\alpha = .90$; two-week test-retest reliability: $r = .85$; convergent validity of AMAS and MARS-R: r = .85). Participants use a 5-point Likert scale to indicate how anxious they would feel during certain situations involving math (e.g. 1 = low anxiety; 5 = high anxiety). The maximum score is 45.

The modified version used in the current study, (hereafter: mAMAS), was used previously with a large sample of British primary school children (Zirk-Sadowski et al., 2014). Further research determined that the mAMAS retains the factor structure of the original scale (Carey et al., 2017). The modifications involved minor adjustments to British

English and terminology and the replacement of items as some of the AMAS items referred to advanced topics which would not be meaningful to primary or lower secondary school children (Ashcraft & Moore, 2009). For example, “Checking the tables in the back of a textbook” was changed to “Completing a worksheet by yourself”. See Results for reliability estimates of the mAMAS in the current sample. The mAMAS can be found in the Appendix.

Mathematics performance

Students’ math performance was assessed using the Mathematics Assessment for Learning and Teaching tests (MaLT; Williams, 2005). These group-administered pencil and paper tests were developed in line with the National Curriculum and National Numeracy Strategy for England and Wales. Items cover a range of mathematical content such as counting and understanding number, knowing and using number facts, calculating, understanding shape, measurement, and handling data. In accordance with their schooling level, Year 4 students completed the MaLT 9, Year 7 students completed the MaLT 12 and Year 8 students completed the MaLT 13. Students had 45 minutes to complete the tests. The tests were age-standardized using a nationally-representative sample of 12,591 children from 120 schools across England and Wales and all show good internal consistency (MaLT 9: α = .93, MaLT 12: α = .92, MaLT 13: α = .93).

Reading performance

The Hodder Group Reading Tests II (HGRT-II; Vincent & Crumpler, 2007) were used to assess students' reading performance. The written tests include multi-choice items which assess children’s ability to read and understand words, sentences and passages. Each test has two parallel versions and we used these to discourage students from copying each other. In accordance with their schooling level, Year 4 students completed HGRT level 2 and Year 7 and 8 students completed HGRT level 3. Students had 30 minutes to complete the tests. The tests were standardized in 2005 with children from 111 schools across England and Wales (HGRT level 2: α = .95, HGRT level 3: α = .94).

Procedure

Researchers went to schools to administer the tests and questionnaires. Children were assessed in group settings (either as a class or whole year group) with sessions lasting approximately 2 hours. The order in which the mAMAS, MaLT and HGRT were administered was counterbalanced between schools.

Given the young age of the primary students, we made sure to present the testing material in a child-friendly and accessible manner. We presented practice questionnaire items (e.g., "Rate how anxious you would feel climbing a tree") alongside a colorful PowerPoint slide-show. Furthermore, we defined or explained any difficult words or terms (e.g. “anxiety” was defined as "nervousness" and "worry") and researchers checked that children understood how to complete the practice items before proceeding with the mAMAS. All mAMAS items were read out loud. The questionnaire was formatted so that it was more readable for young children and included sad and happy emoticons at the end points of the Likert-scale to aid students in their responses (see Appendix). However, the researchers emphasized that the questionnaire was assessing anxiety, and that the faces in this context were meant to indicate feeling less and more anxious, not happiness and sadness.

Grouping of children

When we use the term 'all children' we are referring to the whole sample. In line with Devine et al. (2013), DD was defined as mathematics performance below 1 *SD* below the mean and reading performance above 1 *SD* below the mean. Comorbid mathematics and reading difficulties (hereafter: DD+RD), was defined as mathematics and reading performance below 1 *SD* below the mean. Children with typical mathematics performance (TM) had mathematics performance at or above 1 *SD* below the mean.

Data analysis

Although the mAMAS consists of separate "Learning MA" and "Evaluation MA" components, in the current study, we focussed only on total MA scores. The normality of the distribution of MA scores for all children was tested using the Shapiro-Wilk test. Chi-square analysis was used to compare the frequency of girls and boys with DD, the frequency of DD in the three year groups, and the frequency of girls and boys with high MA and DD.

The association between MA and performance in the whole sample and in students with DD was measured using Spearman's rank correlation. In order to further assess the robustness of correlations, we also constructed bias corrected and accelerated 95% bootstrap confidence intervals for correlations (hereafter: BcaCI).

The normality of the MA distribution in DD children was tested using the Shapiro-Wilk test and the distributions for each gender were compared using the Mann-Whitney U test. Internal consistency was estimated using Cronbach’s alpha coefficient and ordinal Alpha coefficients. MA raw scores were sorted into 5 bins. Where distributions differed, the cell counts of girls and boys with DD were compared using Chi-square analyses. In comparisons with sample sizes of less than 5, Fisher’s exact *p* is reported. Chi-square analyses were also used to compare the frequency of children with high MA in different mathematics ability groups. Effect sizes for Chi-square analyses are reported (φ). Analyses were done in MATLAB (R2015a) and in R (R Core Team, 2016) using the "GPArotation", "psych" and "Rcmdr" packages (Bernaards, 2005; Fox, 2005; Revelle, 2014). Power calculations were done in G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009).

Results

Prevalence of high MA

We inspected the distribution of raw MA scores in order to determine whether a statistical definition of high MA could be used, such as the definition used by Ashcraft et al (2007) of MA scores greater than 1 *SD* above the mean. As shown in Figure 1A, the distribution of mAMAS scores in the current study was significantly different from normal (N=1757, $W = .95$, $p < .001$, skewness =.70; Kurtosis = -.006, see Supplementary Information for further details about non-normality of the mAMAS). However, none of the subsequent analyses required normality of MA scores. We defined high MA as scores at or above the 90th percentile, which corresponded to raw scores of 30 and above (an average score above 'Moderate amount of anxiety' on the scale). Figure 1B shows the empirical cumulative distribution function with the score corresponding to the 90th percentile marked. The percentiles corresponding to each raw score are also provided in tabular format in the Supplementary Information. We note that the actual percentage of children identified as having high MA was 11% of the whole sample, as the precise location of the 90^{th} percentile fell within a group of several children with scores of 30. Rather than arbitrarily selecting some of the children with scores of 30 in order to get a high MA group of exactly 10% of the sample, we included all children with scores of 30 in the high MA group and thus, the final percentage was 11%.

Cronbach's alpha for the mAMAS was .85 (primary sample $\alpha = .85$; secondary sample $\alpha = .86$) and split-half reliability was .84 (primary sample .85; secondary sample .86). Cronbach's alpha tends to underestimate reliability in cases where data are not continuous (e.g., Likert-type scales), when there are few items in a scale, and when scores are not normally distributed (these issues are discussed in (Cipora, Szczygiel, Willmes, & Nuerk, 2015). Therefore, in line with Cipora et al (2015) we estimated the reliability of the mAMAS further using ordinal Alpha coefficients (Gadermann, Guhn, & Zumbo, 2012). Ordinal Alpha for the mAMAS was 0.89 (0.89 for primary students and 0.89 for secondary students). Ordinal alpha did not increase if any item was dropped. Thus, the mAMAS demonstrated good reliability at both school levels.

Insert Figure 1 about here

Prevalence of DD

In order to determine the prevalence of comorbidity of DD and MA, we first inspected the prevalence of DD in the sample. Using the absolute threshold definition of DD used by Devine et al (2013), 99 children (5.6%) were included in the group of children with DD. The number and percentage of children in the DD group by gender and year group are presented in Table 1. Chi-square analysis confirmed that the number of girls and boys in the DD group was not significantly different ($\chi^2 = 1.82$, p =.18; two-tailed; $\varphi = .032$). There were more children with DD in Year 4 than in Year 7 ($\chi^2 = 6.52$, p =.012; two-tailed; $\varphi = .065$); however the number of children with DD was not significantly different between Year 4 and Year 8 ($\chi^2 = .046$, p =.831; two-tailed; $\varphi = .007$), nor between Year 7 and Year 8 ($\chi^2 = 4.54$, p =.033; two-tailed; $\varphi = .069$) after correction for multiple comparisons (p-value of .05; divided by the number of comparisons: 3 comparisons).

Insert Table 1 about here

Relation between DD and MA

In the whole sample of 1757 children, MA was significantly and negatively correlated with mathematics performance ($r_s = -.30$, $p < .001$, BcaCI: -.34, -.25). The correlation between MA and mathematics performance is shown in Figure 2A. The correlation between MA and mathematics performance in the TM group was also significant (r_s = -.28, p < .001, BcaCI: -.33, -.24). In contrast, the correlation between MA and mathematics performance within the DD group was not significant (r_s = -.09, p = .38; n = 99; BcaCI: -.29, .12), nor was the correlation significant within the DD+RD group (r_s = -.02, p = .79; n = 140; BcaCI: -.19, .14). Note that the lack of correlation in these sub-samples was not due to lack of power as the power to detect a correlation of r_s = -.30 in these groups was .93-.95; the lack of correlation in such sub-samples can be expected because of the narrow range of mathematics scores in the DD and DD+RD groups. The DD group amongst the whole sample is also shown in Figure 2A and the lack of correlation between MA and mathematics performance in this group can be seen. Note that the spread of MA scores has about the same range in the DD group as in the whole sample.

Insert Figure 2 about here

Prevalence of comorbidity of DD and high MA

Table 2A shows the percentage of students with high MA in the different mathematics performance groups. When using a threshold of high MA at or above the 90th percentile, 10% of students with typical mathematics performance had high MA; however, 22% percent of students in the DD group had high MA. Note that this percentage is of the children who met the DD criteria, not the percentage of all children with math scores falling below 1 *SD* below the mean. The frequency of children with high MA was significantly different between the DD group and the TM group (χ^2 = 14.42, p < 001; two-tailed, φ = .094). The frequency of children with high MA was also significantly different between the children with comorbid reading and math difficulties (DD+RD) and the TM group (χ^2 = 6.86, p =.008; two-tailed, φ =

.064); however, the frequency of children with high MA was not significantly different between the DD group and DD+RD (χ^2 = .96, p =.32, two-tailed, φ = .063).

Figure 2B confirms that only a relatively small proportion of DD children can be categorized as having high MA independent of the DD and MA definitions used. When DD is defined as math performance below 1.5 *SD* below the mean (and reading performance within or above the average range), the percentage with high MA is 25%, which is slightly higher than the mean–1 *SD* definition (note that this percentage is calculated out of the total number of DD children meeting the mean–1.5 *SD* criterion: 32 children). It is important to highlight that the more conservative definition of DD depicted in Figure 2B approximates clinical diagnostic criteria for DD (mathematics performance substantially below the average performance for a child's age, with a discrepancy between mathematics performance and language abilities). However, the definition of DD did not make a notable difference to the prevalence of co-occurrence of MA and DD, thus, the remainder of our analyses refer to the original DD and high MA definitions.

Importantly, of the students with high MA across the whole sample, only 11% fell in the DD group and 12% had below average math performance but did not meet criteria for DD (i.e. had comorbid reading difficulty). Thus, the majority of students with high MA (77%) had average or above average mathematics performance (see Table 2A). The proportion of typically performing and high performing children with different MA scores is also illustrated in Supplementary Figure S3 in the Supplementary Information. Table 2B shows the median MA scores and BcaCI for median MA scores.

The distributions of MA scores in the DD group by gender are shown in Figure 3. This distribution (collapsed across gender) was significantly different from normal (n = 99; W = 0.97; p =.03; skewness = 0.23; kurtosis = 2.47). The Mann-Whitney U test confirmed that

MA levels of DD girls and DD boys were different from one another (Z = -2.50, *p* =.013; girls' mean = 24.15, BcaCI: 22.12; 26.15; boys' mean = 20.19; BcaCI: 17.86; 22.78, Cohen's *d* = 0.5). Chi-square analysis confirmed that there were more girls with high MA (18) than boys with high MA (4) in the DD group (Fisher's exact *p* = .013; two-tailed). The distribution of MA scores in the DD group for each school level is shown in Supplementary Figure S4 in the Supplementary Information.

Insert Figure 3 about here

Discussion

The current study aimed to investigate the association between MA and math performance, and the prevalence of co-occurrence of MA and DD. We also examined gender differences in DD, MA and comorbid DD and MA. To our knowledge, we are the first to estimate the prevalence of comorbidity of DD and MA in a large representative cohort of primary and secondary school children.

We estimated the prevalence of DD using the definition used previously by Devine et al. (2013). When DD was defined as mathematics performance at least 1 *SD* below the mean and reading performance above 1 *SD* below the mean, 5.6% of the sample met the criteria for DD. This prevalence estimate is very similar to international estimates reported previously (Gross-Tsur, Manor, & Shalev, 1996; Koumoula et al., 2004). This estimate is also similar to that found in UK students previously using these same criteria (Devine et al., 2013).

In the whole sample, MA and mathematics performance were moderately negatively correlated (r_s = -.30; 95% confidence interval: -0.34 to -0.25) which is about the same effect size as that reported in previous meta-analyses (Hembree, 1990; Ma, 1999). The similarity between the current data and results from the 1990s is remarkable: MA seems to be a highly persistent factor in mathematical development. Due to the cross-sectional design of the current study, we could not determine the direction of this association. However, inspecting the prevalence of comorbidity of MA and DD allows us to draw some conclusions about the relationship between MA and DD which add to the general literature on the MA–performance relationship.

Most notably, children with DD had as wide range of MA levels as typically developing children and 78% of DD children did not have high MA. While 11% of our whole sample had high MA, 22% of the DD group had high MA. Hence, high MA appears to be twice as likely in children with DD as in children with mathematics performance at or above the average range. On the one hand this finding supports previous studies which have shown higher levels of MA in children with DD/MLD (Lai, Zhu, Chen, & Li, 2015; Passolunghi, 2011; Wu, Willcutt, Escovar, & Menon, 2013) and potentially lends further support to the Deficit Theory. However, on the other hand, of the students with high MA across the whole sample, only 11% fell in the DD group and 12% were in the DD+RD group. Thus, the majority of students with high MA (77%) had average or above average mathematics performance, demonstrating that high MA is not exclusive to children with MLD or DD.

In contrast to the idea that MA may simply equate to low math ability (Beilock & Willingham, 2014), the results of the current study suggest that many children with DD do not report high levels of MA. It is not clear why many children with DD are not highly anxious about mathematics, but it may be related to expectations or the value attached to mathematics (Eccles, 1994). That is, MA may be related to children's worries about not meeting their own or their socialisers' expectations (Ho et al., 2000; Wigfield & Meece, 1988). Children with DD may not have high expectations of themselves with regard to their mathematics performance (or their socialisers may not have high expectations of them), therefore, some DD children may not develop anxiety towards mathematics. Similarly, mathematics may not be viewed as important by children with DD (and/or their parents/peers), thus, they may not get anxious about poor performance in the subject (Wigfield & Meece, 1988).

However, an alternative explanation could be that some children with DD may not possess the metacognitive skills necessary to accurately evaluate their mathematics abilities and consequently, they may not perceive mathematics as anxiety inducing. Past research has revealed metacognitive deficits in MLD. More specifically, younger children with MLD are less accurate than typically achieving children in evaluating and predicting their mathematical performance (Garrett, Mazzocco, & Baker, 2010) and adolescents with learning disabilities are more likely to overestimate their mathematics performance compared to typically achieving children (Heath, Roberts, & Toste, 2011). Therefore it is possible that the link between MA and mathematics performance may be moderated by DD children's self-perceptions of their mathematics performance/ability. However, children's self-perceptions were not measured in the current work, so we could not test these relationships. Yet, research has suggested that the relationship between mathematics self-ratings and performance may develop prior to the relationship between MA and performance in primary school children (Dowker, Bennett & Smith, 2012); thus, mathematics self-ratings are important to consider. Further research is needed to investigate the link between self-perceptions of mathematics ability and MA in children with DD.

We found an equal prevalence of boys and girls with DD, which is also in line with the findings of Devine et al. (2013) and several other studies (Gross-Tsur et al., 1996; Koumoula et al., 2004; Lewis et al., 1994). However, there were more girls than boys in the DD group with comorbid MA, which is in line with the many studies that have shown that girls have higher levels of MA than boys (reviewed in Devine et al., 2012 and Hill et al., 2016).

It is not clear why females frequently report higher MA than males but several explanations have been put forward. Biological links to MA have been suggested by the study of MA in monozygotic and same-sex dizygotic twins by Wang et al (2014) which revealed that around 40% of the variation in MA could be explained by genetic factors. Nonetheless, environmental and social factors may play crucial roles in the development of MA gender differences. For example, gender differences in socialisation during childhood, particularly the introduction of gender stereotypes about mathematics, may differentially affect situational anxiety experienced by girls and boys, and their mathematics performance (Bander & Betz, 1981; Fennema & Sherman, 1976). Mathematics gender stereotypes do have detrimental effects on girls' performance (Appel, Kronberger, & Aronson, 2011; Flore & Wicherts, 2014) and other work has suggested that parents' and teachers' gender-stereotyped beliefs influence children's attainment, and indirectly affect children's academic choices (Eccles, 1994; Gunderson, Ramirez, Levine & Beilock, 2011).

It is important to note that females are also more likely to report higher levels of both TA and GA than males (Hembree, 1988; Wren & Benson, 2004; Vesga-Lopez et al., 2008); thus, it is possible that females' general propensity for anxiety may contribute to girls' higher levels of MA. However, there are other variables that may contribute to the gender difference in MA, such as mathematics confidence/self-concept and mathematics self-efficacy; for example, several studies have shown that boys report greater confidence in mathematics and higher mathematics self-efficacy than girls (Pajares, 2005; Huang, 2013; Wigfield, Eccles, MacIver, Reuman, & Midgley, 1991). Mathematics self-efficacy has been shown to be related to MA (Meece, Wigfield, & Eccles, 1990; Jain & Dowson, 2009), thus, mathematics competence beliefs may indeed contribute to MA gender differences.

We have shown that approximately one fifth of children with DD have comorbid MA, with girls being overrepresented in this group compared to boys. These findings suggest that some students, particularly girls, may be more susceptible to negative affective reactions to mathematics alongside performance deficits in the subject. As children's mathematics performance is likely to be influenced by anxiety during assessment (Ashcraft et al., 2007; Ashcraft & Ridley, 2005), there is the possibility that highly math-anxious children may have the potential to improve their mathematics performance, if they are able to combat their MA. Indeed, research has shown that interventions which specifically address MA (rather than mathematics knowledge) have resulted in mathematics performance benefits (Hembree, 1990; Ramirez & Beilock, 2011). For example, Hembree (1990) reported that interventions which focussed on systematic desensitisation or cognitive restructuring resulted in improvements in mathematics performance. More recently, Ramirez and Beilock (2011) also found performance benefits when participants wrote about their anxieties before an examination. The authors theorised that writing about one's anxieties before a test reduces the need to worry during the test, which decreases rumination and frees up working memory resources, thereby improving test performance. Collectively, these results suggest that test performance can indeed be improved via the alleviation of MA and/or TA, thus, some of the DD children with comorbid high MA may be able to improve their performance by overcoming or reducing MA, to the point that they may no longer meet DD inclusion criteria. Therefore, we believe that identifying MA in the classroom is essential so that children can be equipped with appropriate coping strategies for dealing with anxious reactions towards mathematics, particularly around assessment.

Our findings challenge the suggestion that deficits in basic numerical processing underlie MA (Maloney et al., 2010; 2011), as here we show that although there is some degree of overlap between them, MA and numerical deficits (characteristic of DD) are dissociable. Our results suggest that cognitive deficits (DD) mostly exist in the absence of emotional problems (MA) and vice-versa and likely require quite different types of interventions. Children affected by MA, or co-occurring MA and DD are likely to benefit from the types of interventions outlined above, rather than interventions focusing on the improvement of mathematical skills. Indeed, Hembree's (1990) meta-analysis of MA studies revealed that interventions for MA that focus on the cognitive aspects of anxiety were more effective than interventions that attempted to reduce MA through mathematics tuition or curricular changes. Moreover, the abovementioned interventions which focussed on relieving the cognitive symptoms of anxiety, particularly those which are purported to free up working memory resources, have shown promising results for the relief of anxiety, and improvement of performance (Hembree, 1990; Ramirez & Beilock, 2011). On the other hand, children with DD who do not have negative emotional reactions towards mathematics are likely to benefit from interventions that target the development of mathematical skills, working memory and visuo-spatial processing (Holmes & Dowker, 2013; Holmes, Gathercole & Dunning, 2009; Lambert & Spinath, 2014; Wißmann, Heine, Handl, & Jacobs, 2013). Nonetheless, children with DD are also likely to benefit from the encouragement of positive attitudes towards mathematics, which may, for example foster engagement with mathematics, encourage persistence in spite of difficulty with the subject, and may mitigate the development of anxiety towards mathematics in the future. Indeed, longitudinal research suggests that characteristics such as conscientiousness, self-control, grit (that is, persistence towards long term goals; Duckworth, Peterson, Matthews & Kelly, 2007) and growth mindset (i.e., the belief that academic ability can be improved with effort, Dweck, 2006), are associated with mathematics performance gains during middle school (West, Kraft, Finn, Martin & Duckworth, 2016).

Although it is likely that MA is triggered by past poor performance in some cases (for example, potentially in the children with DD and high MA), our results suggest that the Deficit Theory may only explain the MA–performance relationship in a small proportion of children. Furthermore, our research shows that a much greater proportion of children with high MA have typical mathematical performance. This is also apparent in the observation that the most conspicuous feature of the correlation between MA and mathematics performance seems to be a drop in the number of mathematically high achieving children with increasing MA levels rather than an increase in the number of very poor achievers (note the lack of observations in the upper right ‘triangular part’ of Figure 2A). Our findings suggest that many children who are performing adequately in math may in fact be struggling with MA. These children may “slip under the radar” if teachers and parents/caregivers rely on mathematics achievement as a measure of children’s mathematical wellbeing. Competent mathematicians with high MA still run the risk of developing further negative attitudes towards mathematics, potentially leading to mathematics avoidance and drop-out from elective mathematics classes in the future (Ashcraft, 2002; Hembree, 1990; Ma, 1999). Collectively, the MA literature suggests that the MA–performance association may function reciprocally or as a vicious circle (Carey et al., 2016). Thus, even if students with high MA are performing within the average range at one time point, MA may lead to poorer educational outcomes in the future probably mainly because of the avoidance of higher-level elective mathematics classes. Our findings therefore emphasize the importance of identifying MA in children of all ability levels and we suggest that attendance to children’s affective reactions during mathematics learning should be considered an essential element of educational provision.

Taken together, our results suggest that cognitive and emotional mathematics problems largely dissociate and call into question the idea that MA is exclusively linked to poor mathematics ability. Different intervention methods need to be developed to prevent and treat emotional and cognitive blocks of mathematical development.

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Table 1

Number and percentage of children in DD group by gender and year group.

	Girls		Boys		Total	
	N	%	N	%	N	%
Year 4	31	7.6	25	5.9	56	6.7
Year 7	17	5.0	9	2.6	26	3.8
Year 8	9	7.5	8	6.7	17	7.1
Total	57	**6.5**	42	**4.7**	99	**5.6**

Table 2.

Math anxiety scores in different groups. (A) Number and percentage of children with high MA falling within different mathematics achievement groups (DD: Developmental Dyscalculia; DD+RD: DD with Reading Deficit; TM: Typical Math). Row 1 shows the proportions of high MA children in a group relative to the number of children in that group (e.g. there were 198 high MA children in the whole sample of 1757 children). Row 2 shows proportions relative to all 198 children with high MA (198 = 24+22+152). (B) Median MA scores and 95% bootstrap bias corrected and accelerated confidence intervals (BcaCI) for medians in different groups.

A.	DD+RD		DD		TM		Whole sample	
	N	%	N	%	N	%	N	%
Proportion with high MA in each group	24/140	17	22/99	22	152/1518	10	**198**/1757	11
Proportion relative to all high MA children	24/**198**	12	22/**198**	11	152/**198**	77	-	-
B.	**DD+RD**		**DD**		**TM**		**Whole sample**	
	Mdn	BcaCI	*Mdn*	BcaCI	*Mdn*	BcaCI	*Mdn*	BcaCI

	23	21/24	*22*	20/26	*18*	17/18.67	*18*	18/19

Figure Captions

Figure 1. The distribution of raw MA scores (1A) and the cumulative distribution function of MA scores (1B). The 90th percentile (denoting high MA cut-off) is shown by the dashed line.

Figure 2. The correlation between MA and mathematics performance in the whole sample (A). Filled circles show children in the DD group (mean-1 *SD* definition). (B) The percentage of DD children with high MA using different DD inclusion criteria (math performance below 1 *SD* below the mean vs. 1.5 *SD* below the mean; note both criteria include average reading performance) and different MA cut-offs (raw scores between 27 and 45: the maximum MA raw score).

Figure 3. Distribution of MA scores for the DD group by gender.

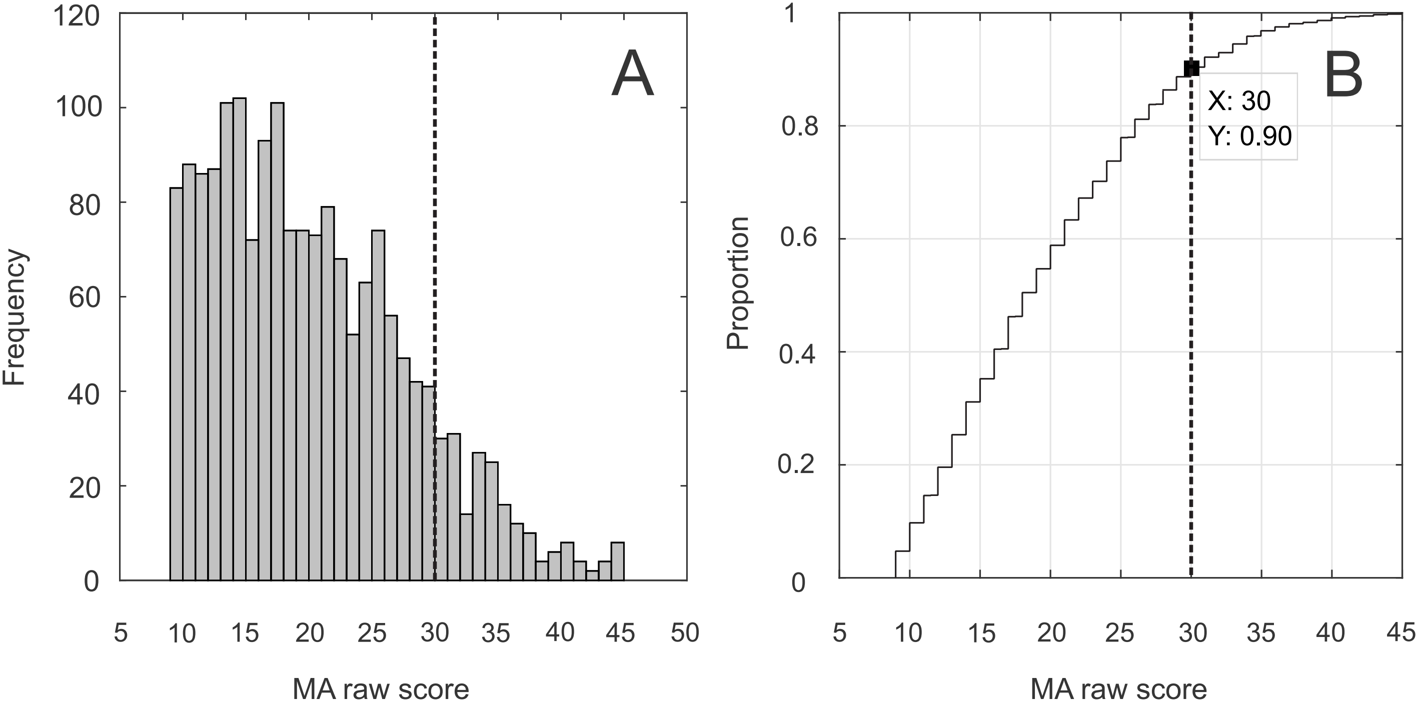
Appendix. *mAMAS*

A modified version of the Abbreviated Math Anxiety Scale (Hopko, Mahadevan, Bare, & Hunt, 2003).

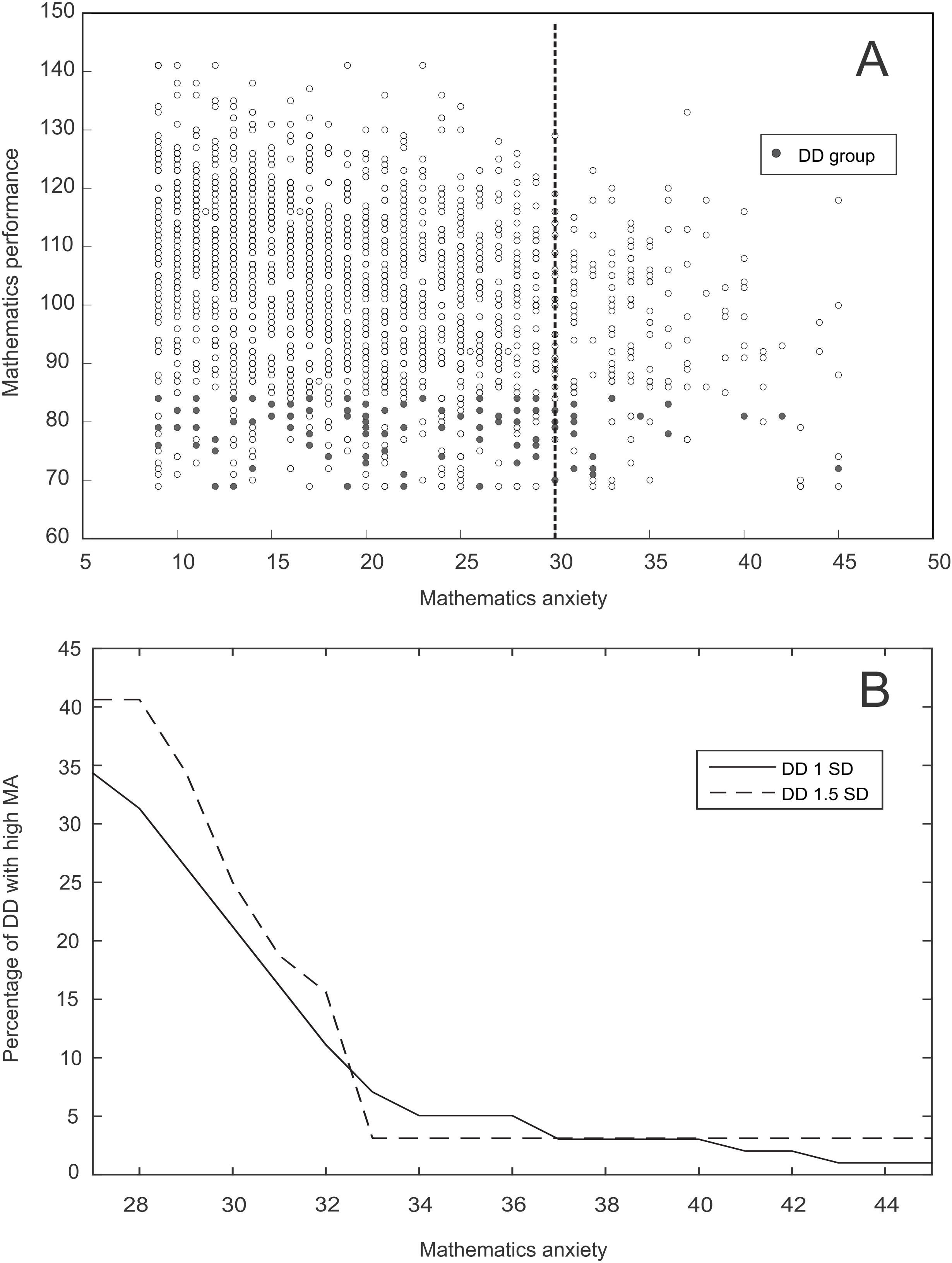
Instructions:

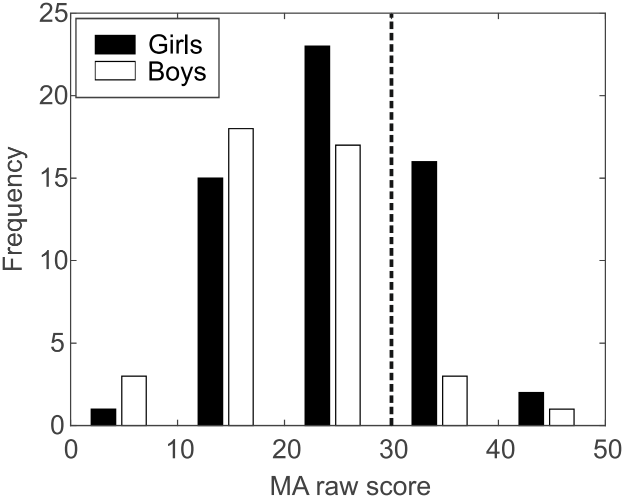
Please give each sentence a score in terms of how anxious you would feel during each situation. Use the scale at the right side and circle the number which you think best describes how you feel.

	☺				☹
	Low anxiety	Some anxiety	Moderate anxiety	Quite a bit of anxiety	High anxiety
1. Having to complete a worksheet by yourself.	1	2	3	4	5
2. Thinking about a maths test the day before you take it.	1	2	3	4	5
3. Watching the teacher work out a maths problem on the board.	1	2	3	4	5
4. Taking a maths test.	1	2	3	4	5
5. Being given maths homework with lots of difficult questions that you have to hand in the next day.	1	2	3	4	5
6. Listening to the teacher talk for a long time in maths.	1	2	3	4	5
7. Listening to another child in your class explain a maths problem.	1	2	3	4	5
8. Finding out you are going to have a surprise maths quiz when you start your maths lesson.	1	2	3	4	5
9. Starting a new topic in maths.	1	2	3	4	5



A
Frequency
MA raw score
0
20
40
60
80
100
120
5
10
15
20
25
30
35
40
45
50
B
Proportion
MA raw score
X: 30
Y: 0.90
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
40
45


A
DD group
Mathematics performance
Mathematics anxiety
B
DD 1 SD
DD 1.5 SD
Percentage of DD with high MA
Mathematics anxiety



Girls
Boys
Frequency
MA raw score
0
5
10
15
20
25
0
10
20
30
40
50

Supplementary Information

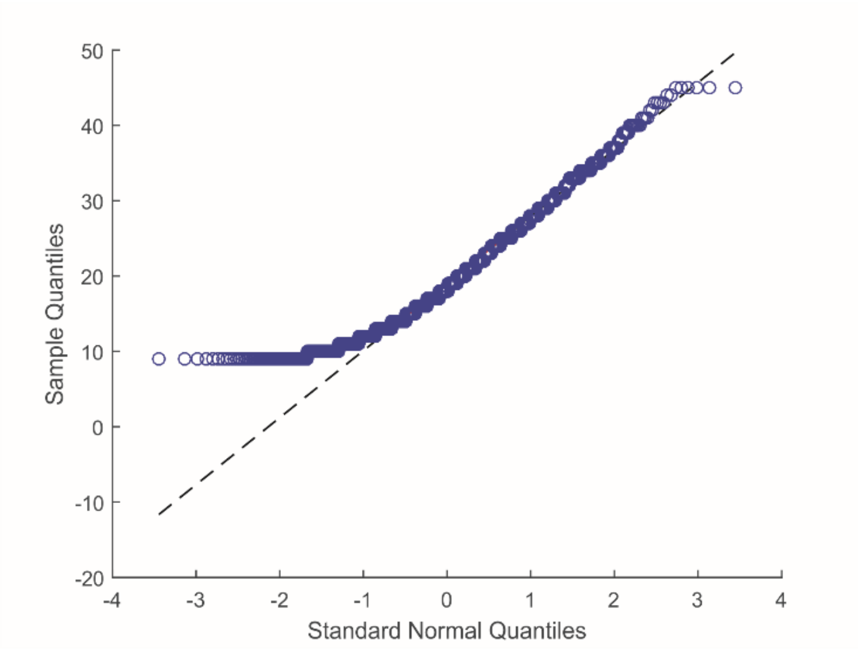
Cognitive and emotional math problems largely dissociate: Prevalence of developmental dyscalculia and mathematics anxiety.

Amy Devine, Francesca Hill, Emma Carey & Dénes Szűcs.

Supplementary note - Non-normality of mAMAS scale

Whereas Hopko et al. (2003) reported that AMAS scores were normally distributed in their scale development study (N= 815, Shapiro-Wilk W = .98, p = ns; skewnesss = .32; kurtosis = –.31), we found that scores on the mAMAS were not normally distributed (N=1757, W = .95, p <.001, skewness =.70; Kurtosis = -.006). However, it is important to note that the report of Hopko et al. (2003) is inconsistent in that at N = 815, W = 0.98 is a statistically significant finding, i.e., the distribution would be significantly different from a normal distribution, because the critical value for N = 815 at α = 0.05 is W = 0.9963. That is, relying on the W value reported by Hopko et al. one could argue that the original AMAS scores were not normally distributed, either. The non-normality of the mAMAS is also illustrated in the q-q plot shown below in Supplementary Fig. S1. The distribution of scores was also significantly different from normal when tested separately for primary (N=830, W = .93, p <.001) and secondary students (N=927, W = .95, p <.001). Importantly, none of the analyses conducted in the current study required normality of MA. That is, rather than defining high MA using a cut-off such as 1 *SD* above the mean (as used by Ashcraft et al., 2007), we defined high MA as raw mAMAS scores at or above the 90th percentile (raw scores of 30 and above). This is lower than the 17% proposed by Ashcraft *et al.* which would result from using a cut-off of 1 *SD* above the mean score of a normal distribution, however, as scores on the mAMAS were not normally distributed it was not appropriate to use a *SD* definition of high MA, and thus, the high MA prevalence estimate was lower using our more conservative definition.

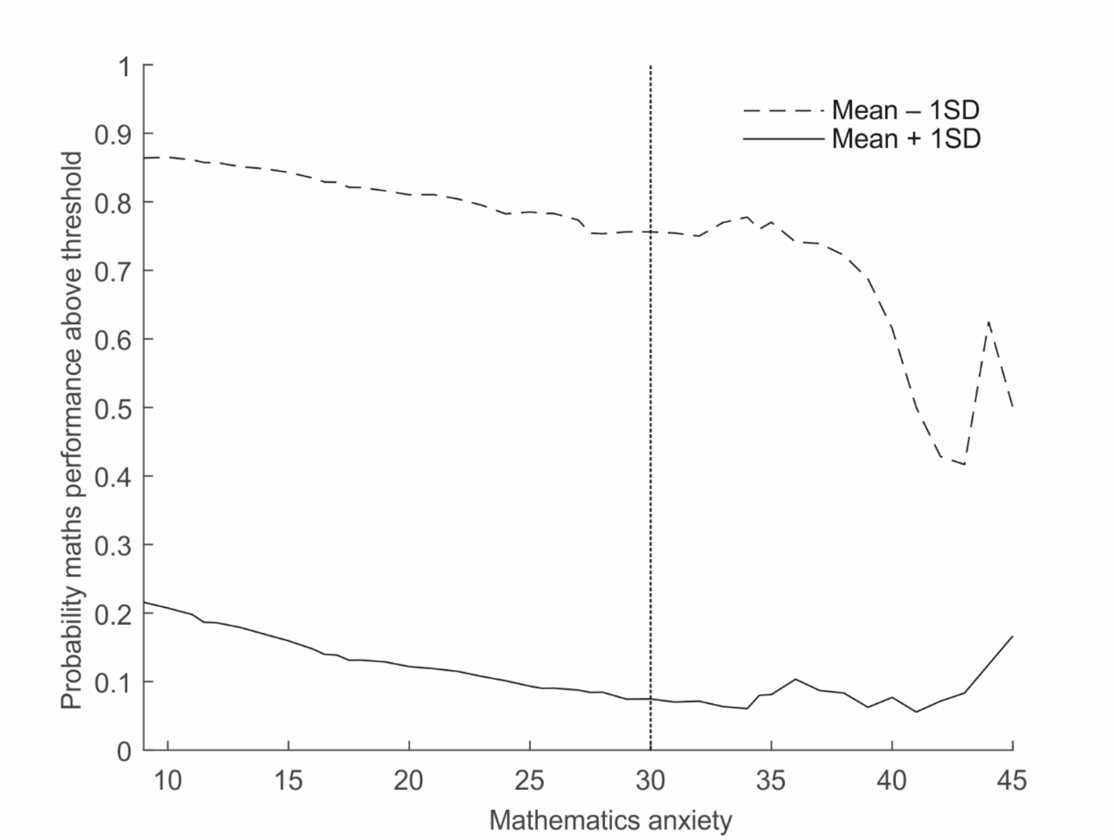
We note that other recent studies employing translated versions of the AMAS have shown that MA scores were not normally distributed as well. For example, Cipora *et al.* found that total scores on their Polish translation of the AMAS, and scores on two AMAS subscales were significantly different from normal (Cipora, Szczygiel, Willmes, & Nuerk, 2015). Likewise, Primi et al. (2014) found that some items of their Italian translation of the AMAS did not satisfy normality criteria when administered on samples of adults and secondary school students. Using another shortened version of the MARS (the MARS30-brief), Pletzer et al. (2016) found that neither the total score, nor the items of the scale were normally distributed in adults. It is possible that the positive skew of the MA distribution in our study is because our sample included children rather than adults, however, as mentioned above, recent studies did not find MA was normally distributed in adults and high school students either.



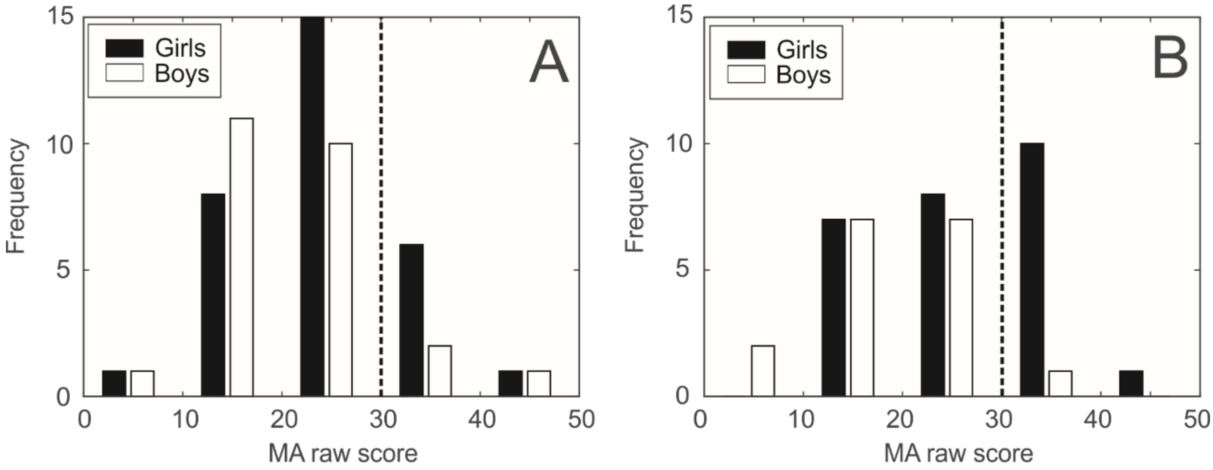
Supplementary Figure S1. A normal q-q plot of the mAMAS data, showing the deviation from a normal distribution.

Supplementary Table S2. *Percentiles for each raw score of the mAMAS.*

MA raw score	Percentile	MA raw score	Percentile
9	4.7	29	88.6
10	9.7	30	90.2
11	14.6	31	92.0
12	19.9	32	92.8
13	25.3	33	94.4
14	31.1	34	95.8
15	35.2	35	96.7
16	40.5	36	97.4
17	46.2	37	97.9
18	50.5	38	98.2
19	54.7	39	98.5
20	58.9	40	99.0
21	63.4	41	99.2
22	67.2	42	99.3
23	70.2	43	99.5
24	73.8	44	99.7
25	77.9	45	100
26	81.2		
27	83.8		
28	86.2		



Supplementary Figure S3. The probability of having mathematics performance above a certain threshold with different math anxiety scores.



Supplementary Figure S4. Distribution of MA scores for the DD group in primary (A) and secondary students (B), by gender.