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Do implicitly measured math–anxiety associations play a role in math behavior?

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A B S T R A C T

The current study examined the role of implicitly measured associations (henceforth referred to as *associations*) between math and anxiety in adolescents' math anxiety. Previous research has shown that associations predicted behavior independent of explicit measures. In this study, it was investigated whether math–anxiety associations would be related to math anxiety and whether they predicted math behavior as well as state math anxiety independent of explicitly measured math anxiety. In addition, the domain specificity of math–anxiety associations for predicting math behavior was investigated. Adolescents' anxiety associations and self-reported anxiety were assessed for three domains: math anxiety, foreign language (English) anxiety, and trait anxiety. A sample of 189 secondary school students performed three single-target implicit association tests, performed a math problem solving task, and filled out questionnaires. Overall, adolescents showed stronger math–anxiety associations in comparison with math–calmness associations. In contrast to our hypotheses, math–anxiety associations were not related and did not uniquely or specifically predict math behavior and state math anxiety. Explicit anxiety measures demonstrated specificity in predicting math and English grades as

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well as state math anxiety. The innovative aspects of this study are the investigation of implicitly measured math–anxiety associations and the relation to math anxiety and math behavior. Further research is needed to develop tasks that are better able to capture the most relevant math–threat associations and to investigate which math behavior might be most strongly influenced by these associations.

Introduction

Math anxiety can be defined as a negative emotional response that is evoked by (the prospect of) math situations in ordinary life and diverse academic settings (Richardson & Suinn, 1972; Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). Math anxiety has consistently shown to be negatively related to math achievement such as math school grades (see Ashcraft & Krause, 2007; Ma, 1999). It has been proposed that math anxiety causes a drop in performance, which is independent of an individual's competence in math (Ashcraft & Moore, 2009). Math anxiety has also been related to avoidance behavior such as avoidance of math courses and careers as well as avoidance of cognitive involvement in math tasks (Ashcraft & Faust, 1994; Trezise & Reeve, 2014a). Finally, math anxiety develops from childhood (Vukovic, Kieffer, Bailey, & Harari, 2013) and might become especially harmful during adolescence because this is a crucial period for math performance at school as well as for making first career choices (Beilock & Ramirez, 2011; Hembree, 1990).

Models on cognitive vulnerability to anxiety stress the importance of schema-based biased information processing (Beck & Clark, 1997; Mathews & MacLeod, 2005). An integrative multiprocess model proposed a distinction between associative and rule-based information processing systems (Ouimet, Gawronski, & Dozois, 2009). Associative processing is characterized by rapid activation of associated concepts via spreading activation, whereas rule-based processing involves rational analysis of factual relations between concepts. Behavior is proposed to be jointly influenced by these systems. The model assumes that encountering a given stimulus would activate corresponding concepts and associated threat-related concepts in the associative system. Differences in the strength of associations between a stimulus and threat-related concepts would explain individual differences in anxiety and behavior (Ouimet et al., 2009). Math anxiety, however, is often measured with self-report questionnaires (Hopko, Mahadevan, Bare, & Hunt, 2003; Richardson & Suinn, 1972), which are limited in capturing these rapidly activated associations (Egloff & Schmukle, 2002; Mathews & MacLeod, 2005). We hypothesized that math behavior, like other types of anxiety behavior, is the result of a combination of both associative and rule-based processing. Therefore, to fully understand math anxiety, indirect or implicit measures are crucial to capture associative processing and to predict math behavior next to explicit measures.

The strength of associations has most often been assessed with varieties of the Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998); implicitly measured associations using variants of the IAT (henceforth referred to *associations*). The IAT is easy to administer, produces large and robust effects, and has been shown to provide reliable and valid implicit measures of cognitions and attitudes in a wide range of topics (e.g., Greenwald, Poehlman, Uhlmann, & Banaji, 2009; Nosek, Greenwald, & Banaji, 2005). The IAT measures the relative strengths of associations between target categories (e.g., "self" or "other") and evaluative attributes (e.g., "anxiety" or "calmness"). Participants classify stimuli (often words) in separate blocks, where a target is subsequently paired with two different evaluative attributes (e.g., anxiety vs. calmness). The underlying logic is that it should be easier to classify stimuli when two concepts that are strongly associated for the individual (e.g., anxiety and self) require the same response than when they require a different response. For example, stronger trait anxiety is indicated by faster responses in the anxiety + self (vs. calmness + other) combination block than in the calmness + self (vs. anxiety + other) combination block (Egloff & Schmukle, 2002). Previous research has shown that the strength of anxiety associations is sensitive to differences in state and trait anxiety, supporting the relevance of these associations (Gamer, Schmukle, Luka-Krausgrill, & Egloff, 2008; Glashouwer, de Jong, & Penninx, 2012; Westberg, Lundh, & Jönsson, 2007).

Theoretical models (Ouimet et al., 2009) postulate that implicit and explicit measures of anxiety capture different processes and that they independently contribute to the explanation of behavior. Indeed, previous studies have shown that implicit and explicit measures of anxiety were low or not significantly correlated (Egloff & Schmukle, 2002; Salemink, Friese, Drake, Mackintosh, & Hoppitt, 2013). A systematic review indicated that for some anxiety disorders associations showed results that were consistent with explicit reports, whereas for other anxiety disorders results were mixed or inconsistent (Roefs et al., 2011). More important, it has been shown that anxiety associations predicted changes in anxious expressions and behavior, as well as changes in performance, above and beyond self-reported anxiety (Egloff & Schmukle, 2002). These findings suggest that anxiety associations are involved in anxiety behavior independent of explicitly reported anxiety and that they contribute to our understanding of anxiety behavior.

In the current study, it was expected that math–anxiety associations would be related to math behavior (e.g., performance) independent of explicit math anxiety. Previously, associations between math (as well as related subjects) and various concepts such as valence, identity/self, gender, and difficulty have been investigated—however, not the association between math and anxiety (Kessels, Rau, & Hannover, 2006; Nosek, Banaji, & Greenwald, 2002a, 2002b). Research has supported the relevance of implicitly measured associations with math. In general, IAT results showed that math was more strongly associated with negative evaluations (unpleasant or bad) than language or arts, women showed stronger negativity toward math than men, and math was more strongly associated with male gender than female gender (Nosek et al., 2002a, 2002b). Similarly, in elementary school-aged children, stronger associations between boys and math (vs. girls and reading) were found, and boys showed a stronger association between self and math, in comparison with reading, than girls (Cvencek, Meltzoff, & Greenwald, 2011). More important, even though implicit and explicit measures were related, support was found for the unique and independent predictive value of implicit and explicit measures of math attitudes, as well as stereotypes, when predicting performance (Nosek et al., 2002b). These results demonstrate that math associations are involved in math behavior and develop from a young age. It can be expected that math–anxiety associations play a key role in math anxiety and math behavior as well. Surprisingly, research on math associations in relation to math anxiety is lacking.

Further research has pointed to the domain specificity of anxiety and associations. That is, explicitly reported anxiety for different school domains was found to be weakly correlated (Goetz, Frenzel, Pekrun, & Hall, 2006; Goetz, Frenzel, Pekrun, Hall, & Lüdtke, 2007). In addition, anxiety behavior has shown to be best predicted by implicit and explicit measures corresponding to that specific type of anxiety, in contrast to anxiety in a different or broader domain (i.e., trait anxiety; Gschwendner, Hofmann, & Schmitt, 2008). Together, these findings suggest that anxiety associations might be specific for different school domains; however, research is lacking.

In sum, previous research has shown that math and anxiety associations explained variance in (math) behavior and performance and predicted additional variance that was not accounted for by explicit measures. This suggests that specifically math–anxiety associations may be relevant in math anxiety and math behavior. Therefore, the aims of the current study were to investigate, first, whether implicit measures of math–anxiety associations were related to explicit measures of math anxiety; second, whether math–anxiety associations predicted unique variance in math behavior as well as state math anxiety; and third, whether anxiety associations specifically predicted behavior for the same domain only. Because math anxiety peaks during adolescence, the current study was performed with adolescents.

The current study

In the current study, adolescents' anxiety associations and explicitly self-reported anxiety for three domains—math anxiety, foreign language (English) anxiety, and trait anxiety—were assessed and related to math behavior as well as state math anxiety. Associations were assessed using three versions of the Single-Target Implicit Association Test (ST-IAT; Wigboldus, Holland, & van Knippenberg, 2004; see also Karpinski & Steinman, 2006), one for each domain. The ST-IAT has properties similar to the IAT but assesses the associations between only one target category and the evaluative attributes. This allows for a direct and independent comparison of anxiety associations between different targets (Karpinski & Steinman, 2006; Wigboldus et al., 2004).

First, it was predicted that, in general, adolescents would show a stronger association between math and anxiety (a negative evaluation; Nosek et al., 2002a, 2002b) than between math and calmness. Second, it was predicted that math–anxiety associations would be positively correlated with explicit math anxiety (Greenwald et al., 2009; Hofmann, Gawronski, Gschwendner, Le, & Schmitt, 2005). Third, it was expected that math–anxiety associations would be related to and uniquely predict math behavior as well as state math anxiety when accounting for explicit math anxiety (Egloff & Schmukle, 2002; Nosek et al., 2002b). Math behavior was broken down into math grade, drop in math performance, and chosen difficulty level of math problems (an indication of avoidance behavior). More specifically, it was expected that stronger math–anxiety associations would be related to and uniquely predict lower math grades, higher drops in performance, lower chosen difficulty levels, and higher state math anxiety above and beyond explicit math anxiety. Lastly, it was expected that ST-IAT measures of anxiety associations for one domain (e.g., math) would be specifically related to both explicit anxiety and behavior for that domain. Relations between implicit and explicit as well as behavior measures in different domains were expected to be nonsignificant (Gschwendner et al., 2008).

Method

Participants

A total of 189 third-year (Grade 9; 13–16 years of age) secondary school students in The Netherlands participated in the study. Participants were recruited through one regular secondary school. Passive informed consent from parents was obtained, where parents received an information letter and were given the opportunity to exempt their children from participating. Participants received no reward for their participation. This study was approved by the ethical review board of the Faculty of Social and Behavioral Sciences, University of Amsterdam. Data from 7 participants were excluded from analyses after data preparation (see "Data preparation" section in Results).

The final sample consisted of 182 participants (84 boys and 98 girls; M_{age} = 14.7 years, SD = 0.50). For 72.0% of the participants both parents were born in The Netherlands, for 14.8% one parent was born in The Netherlands, and for 11.5% neither parent was born in The Netherlands (1.6% unknown). All educational levels were represented (lower: 36.8%; middle: 27.5%; higher: 35.7%). A total of 24 participants (13.2%) attended bilingual education; that is, they followed part of the school subjects in a foreign language (English). In addition, 22 participants (12.1%) self-reported as being diagnosed with dyslexia. No significant gender differences were found with regard to distribution of educational level, $\chi^2(2) = 1.08$, $p = .582$, $V = .08$.

Materials

Single-target implicit association test

The ST-IAT (Wigboldus et al., 2004; see also Karpinski & Steinman, 2006) was used as the implicit measure of anxiety associations. There were three separate ST-IATs, one for each of the three domains: math anxiety ST-IAT, English anxiety ST-IAT, and trait anxiety ST-IAT. Each ST-IAT assessed the relative strength of associations between a target category and the evaluative attributes. The target category differed for the three ST-IATs (i.e., math, foreign language, and trait/self, respectively), whereas the evaluative attributes were the same for all domains (i.e., anxious vs. calm). Each ST-IAT consisted of three blocks: a practice block and two combination blocks. Participants were instructed to classify word stimuli as fast and accurately as possible, and their reaction times were recorded. See Fig. 1 for a schematic overview of example trials in each block of the math anxiety ST-IAT.

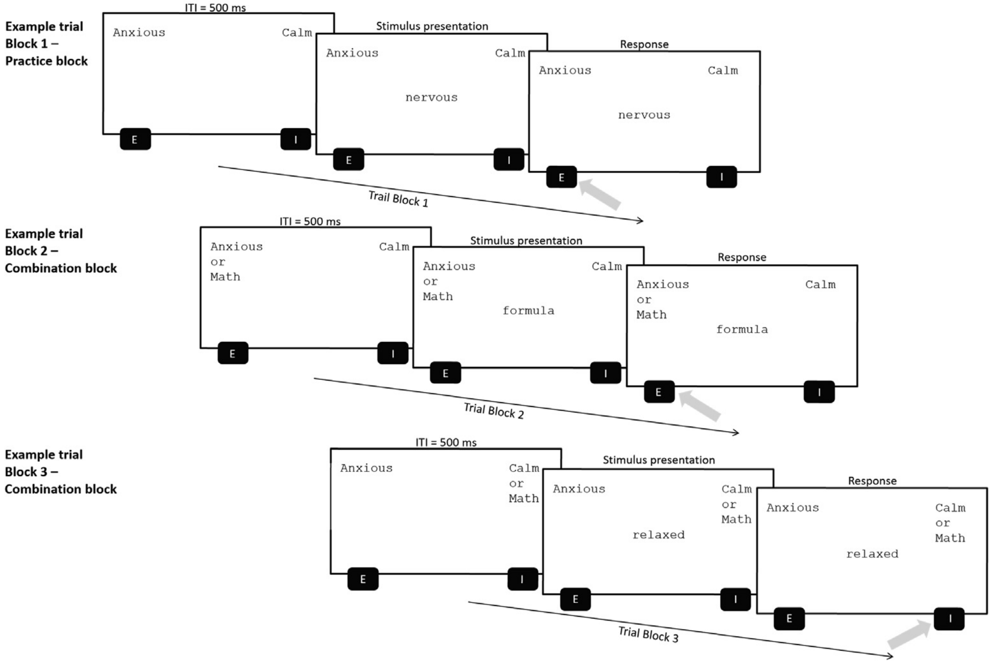

Fig. 1. Schematic overview of example trials of the three blocks in the math anxiety Single-Target Implicit Association Test (ST-IAT). E and I represent the E and I keys on the keyboard, respectively. Gray arrows represent correct responses. Stimuli and labels were presented until a correct response was given. Incorrect responses were followed by a red cross in the center lower half of the screen until the correct response was given. In this example, "Anxious" is presented on the left side of the screen and "Calm" is presented on the right side of the screen. However, the location of these evaluative attributes was randomized between participants. ITI, inter-trial interval.

In Block 1 (practice block), participants learned the response keys related to the evaluative attributes. The left and right response keys were the E and I keys, respectively. The labels of the evaluative attributes (anxious and calm) were presented on the top left and top right of the screen (see Example trial Block 1 in Fig. 1). After an inter-trial interval (ITI) of 500 ms, a word stimulus was presented in the center of the screen (see Stimulus presentation in Fig. 1). The word stimulus represented one of the evaluative attributes (e.g., "nervous" for anxious, "relaxed" for calmness), and participants needed to classify the word by pressing the response key that corresponded to the location of the label. In the example in Fig. 1, the word stimulus "nervous" required pressing the left response key (i.e., E as indicated by the gray arrow) because the anxious attribute was presented on the left side. For each evaluative attribute, five word stimuli were used, and each was presented once in Block 1 (10 trials in total).

In the combination blocks, the target category was combined with one of the evaluative attributes to assess the association between target and evaluative attributes. In Block 2 (combination block: anxious + target), the label of the target category (math, English, or I) was presented on the same side of the screen as the anxious attribute (see Example trial Block 2 in Fig. 1). In this block, word stimuli representing the target category (e.g., "formula" for math) and anxious attribute required the same response (i.e., pressing the E key in Fig. 1). Word stimuli representing the calm attribute required the other response (i.e., pressing the I key in Fig. 1). In Block 3 (combination block: calm + target), the label of the target category was presented on the same side of the screen as the calm attribute (see Example trial Block 3 in Fig. 1). Word stimuli representing the target category or calm attribute required the same response (i.e., pressing the I key in Fig. 1). Word stimuli representing the anxious attribute required the other response (i.e., pressing the E key in Fig. 1). Each combination block consisted of 60 trials. Each of five target stimuli was presented five times, all stimuli of the evaluative attribute sharing the response with the target were presented two times, and all stimuli of the other evaluative attribute were presented five times. This resulted in the assignment of 7:5 (or 5:7) responses to the left key versus the right key. The word stimuli were based on previous studies (Glashouwer et al., 2012; Nosek et al., 2002b) and matched on mean number of syllables per concept (see Appendix A).

Stronger associations between the target and the anxiety attribute (vs. the target and calmness attribute) are indicated by faster responses in Block 2 (anxious + target) than in Block 3 (calm + target). For each ST-IAT, built-in error penalty D scores were calculated following the algorithm of Greenwald, Nosek, and Banaji (2003). Corrected mean reaction times of Block 2 were subtracted from corrected mean reaction times of Block 3. Higher D scores represented faster responses to Block 2 than to Block 3 and, thus, indicated stronger target–anxiety associations relative to target–calmness associations.

Stimuli were presented in black against a white background. Instructions were presented before each ST-IAT and each block. Stimuli remained on the screen until a response was given. When an error was made, a red cross was presented in the center of the lower half of the screen until the participant pressed the correct response. Feedback in order to raise participants' pace (i.e., "Too slow! Try to respond faster!") was presented for 500 ms on correct but slow responses (>3000 ms). Assignment of attributes to response keys (i.e., anxious assigned to left or right) was random across participants but remained constant across ST-IATs within participants. Stimuli of the practice blocks were presented in random order. For all combination blocks, the order of stimuli presentation was fixed to prevent multiple successive responses to one concept or on the same response key.

Abbreviated math anxiety scale

The Dutch version of the Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003) was used to measure explicit math anxiety. Participants needed to rate how anxious they would feel in a given math situation (9 items) on a 5-point Likert scale ranging from 1 (*almost not anxious*) to 5 (*very anxious*). Participants entered the number representing their score (1–5). Higher mean scores indicated higher math anxiety. The Dutch version of the AMAS was obtained using back-and-forward translation and showed good internal consistency in the current sample ($\alpha = .84$, $n = 154$).

Foreign language classroom anxiety scale

An adapted and translated (Dutch) version of the Foreign Language Classroom Anxiety Scale (FLCAS; Horwitz, Horwitz, & Cope, 1986) was used to measure explicit anxiety for learning English, a foreign language. The original FLCAS, a widely used scale for assessing general foreign language anxiety, was translated into Dutch using back-and-forward translation and was adapted to focus on English specifically. That is, foreign language was replaced by English (see Pichette, 2009). Participants needed to rate how much, in general, they agreed with a statement (33 items; e.g., "In English class, I can get so nervous I forget things I know") on a 5-point Likert scale ranging from 1 (*strongly agree*) to 5 (*strongly disagree*). Participants entered the number representing their score (1–5). After recoding scores on several items, higher mean scores indicated higher anxiety for learning English. Internal consistency in the current sample was good ($\alpha = .93$, $n = 89$).

State–trait anxiety inventory for children

The trait scale of the Dutch version of the State–Trait Anxiety Inventory for Children (STAI-C; Spielberger, Edwards, Lushene, Montuori, & Platzek, 1973; Dutch translation Zelf-Beoordelings-Vragenlijst voor Kinderen [ZBV-K]; Bakker, van Wieringen, van der Ploeg, & Spielberger, 1989) was used to measure explicit trait anxiety. Participants needed to indicate how often each of the 20 statements applied to them on a 3-point Likert scale ranging from 1 (*almost never*) to 3 (*often*). Participants entered the number representing their score (1–3). Higher scores indicated higher trait anxiety. Internal consistency in the current sample was good ($\alpha = .88$, $n = 135$).

Grades in math and English

As indicators of math performance and English performance, participants were asked to report the math and English grades of their school report at the end of the previous school year. Grades of the

Dutch educational system range from 1.0 to 10.0, with higher grades representing better performance and 5.5 being considered the minimum to pass.

Math anxiety problem solving task

The Math Anxiety Problem Solving Task (MAPST) is a computer task developed to measure math behavior (drop in math performance and chosen difficulty level) and state anxiety during math performance (state math anxiety). Participants needed to solve algebraic equations in low-anxiety and high-anxiety conditions. In the low-anxiety condition, no external pressure was provided and participants were free to choose 4 of 12 equations presented per screen. The equations were presented by level of difficulty in three separate columns. In the high-anxiety condition, participants were presented with 4 equations per screen. Anxiety was induced by introducing time pressure and social pressure. Participants were instructed to solve the equations as quickly as possible, and a running digital clock was shown on the screen. Furthermore, at the start of this condition, a general instruction stated that participants' performance would be compared with that of their classmates. The social comparison was not, however, performed in reality, which was only revealed in the debriefing. No feedback was provided. In addition, control of participants was reduced given that they needed to solve all 4 equations presented on the screen and no choice was allowed. To ensure comparability of difficulty of equations between conditions within participants, equations presented in the high-anxiety condition were one-on-one matched to equations chosen in the low-anxiety condition. In both conditions, six screens were presented, totaling 24 equations per condition. Equations were presented in multiple-choice format, and participants needed to figure out the value of x. Example equations are $x + 4 = 8$ (Level 1), $x - 21 = 67$ (Level 2), and $3x + 18 = 36$ (Level 3).

The MAPST provided three outcome measures. First, the *performance drop* score was calculated by subtracting the proportion correct in the high-anxiety condition from the proportion correct in the low-anxiety condition. Higher scores indicated a stronger drop in performance in the high-anxiety condition in comparison with the low-anxiety condition. Note that difficulty level is comparable between conditions within individuals but varies between individuals. Second, the *chosen difficulty level* score was calculated by adding the difficulty level for the chosen equations in the low-anxiety condition. Each equation of Level 1 counted as 1, of Level 2 counted as 2, and of Level 3 counted as 3. Higher scores indicated choosing more difficult items. Third, state math anxiety was measured using the Faces Anxiety Scale (FAS; adapted from McKinley, Coote, & Stein-Parbury, 2003; see also Trezise & Reeve, 2014a, 2014b), which consisted of a row of five faces with increasing expressions of anxiety. Participants needed to slide the bar toward the face that most represented their current anxiety level. The FAS was presented at the start (baseline) and three times within each condition. *State math anxiety* scores per condition, ranging from 1 to 5, were average scores of these three occasions, excluding the baseline assessment. Higher scores indicated higher state math anxiety.

Procedure

The assessment took place in computer rooms at school. After a classical instruction, participants completed the assessment individually on a computer, starting with questions on demographics and school grades. Next, the three questionnaires were alternated with three ST-IATs (i.e., three times a questionnaire was followed by an ST-IAT). The order of the three questionnaires and the order of the three ST-IATs were random and independent of each other. Previous research suggested that the order of implicit and explicit measures does not have a strong influence on implicit or explicit effect magnitudes, implicit–explicit correlations, or internal consistencies (Nosek et al., 2005). Demographics questions, ST-IATs, and questionnaires were programmed and administered using E-Prime 2.0. Participants were instructed to inform the test leader after finishing the last ST-IAT, and the test leader then started the MAPST using online software (Qualtrics). The conditions of the MAPST were presented in a fixed order, starting with the low-anxiety condition. An example equation of Level 1 was explained first. The assessment lasted approximately 45 min. Participants were debriefed and thanked for their participation.

Results

Data preparation

Following Greenwald et al. (2003), ST-IAT data were deleted for participants with $\geq$10% fast responses (<300 ms), that is, 6.4%, 3.7%, and 6.9% of participants for math anxiety, English anxiety, and trait anxiety ST-IATs, respectively. In addition, incomplete task data for the math anxiety ST-IAT ($n = 1$) were deleted. For the questionnaires, incorrect responses with double numbers were corrected (e.g., 11 into 1), and others (e.g., 23, 511) were handled as missing. Data of participants with >10% missing responses were deleted (AMAS: 17.5%; FLCAS: 5.9%; STAI-C: 2.1%). During the MAPST, a programming error allowed participants to respond on more than 4 equations per screen, which happened mostly on the first screen. Data of the first screen in both conditions were excluded from analyses for all participants. In addition, MAPST data for participants with >4 responses on a later screen (1.6%) were deleted. After data cleaning on the separate tasks, data from 7 participants were excluded from analyses because of missing data on three or more of the tasks. The final sample consisted of 182 participants.

Next, ST-IAT effects were calculated with the built-in error penalty D-scoring algorithm, excluding fast (<300 ms) and slow (>10,000 ms) responses (Greenwald et al., 2003). Higher D scores corresponded to faster responses when the target was paired with anxiety than when it was paired with calmness and, thus, indicated stronger target–anxiety associations. The overall error percentages were 9.3%, 9.8%, and 9.8% for math, English, and trait anxiety ST-IATs, respectively, which are relatively low in comparison with other studies using the ST-IAT in adolescents (11.7%: de Hullu, de Jong, Sportel, & Nauta, 2011; 17.7% Thush & Wiers, 2007). Reliabilities, as indexed by the average Spearman–Brown corrected intercorrelations between split-half D scores for 10 random sets of trials (de Hullu et al., 2011; Karpinski & Steinman, 2006), indicated acceptable internal consistency ($\alpha = .70$, $\alpha = .73$, and $\alpha = .72$ for math, English, and trait anxiety ST-IATs, respectively), in line with previous studies ($\alpha = .76$: de Hullu et al., 2011; αs = .43–.52: Thush & Wiers, 2007).

Preliminary analyses

Randomization checks revealed no significant effects of key response assignment on ST-IAT scores (all $ps \geq .503$). A significant effect of ST-IAT administration order was found for the math anxiety ST-IAT, $F(5, 166) = 2.657$, $p = .024$, $\eta^2 = .07$; however, post hoc comparisons with Bonferroni correction showed no significant differences (all $ps \geq .052$). No significant administration order effects were found for other ST-IATs (all $ps \geq .103$) or for the questionnaires (all $ps \geq .172$).

Descriptive statistics on all measures for the total sample, and for girls and boys separately, are reported in Table 1. Manipulation checks for the MAPST revealed that, as intended, state math anxiety was significantly higher in the high-anxiety condition in comparison with the low-anxiety condition, $t(176) = -2.81$, $p = .005$, $d = 0.21$ (see Table 1). Unexpectedly, accuracy did not differ significantly between the two conditions (low: $M = .93$, $SD = .10$; high: $M = .92$, $SD = .13$), $t(176) = 1.02$, $p = .307$, $d = 0.08$, indicating that there was no significant performance drop between conditions. Examination of gender differences (Table 1) revealed a significant gender difference for the math anxiety ST-IAT, indicating that girls showed a stronger math–anxiety association than boys. In addition, on all explicit anxiety measures, girls reported significantly higher anxiety than boys. All further analyses were performed for the total sample as well as by gender or gender was taken into account; gender effects were reported only if they deviated from the overall pattern.

Math–anxiety associations and the relation with explicit math anxiety

To test the first hypothesis that, in general, adolescents would show a stronger association between math and anxiety than between math and calmness, a one-sample t test was performed. As expected, the D score deviated significantly from zero, indicating that overall participants showed a relatively stronger math–anxiety association than math–calmness association, $t(174) = 4.23$, $p < .001$, $d = 0.32$.

Table 1
Ranges, *N*s, means (and standard deviations), and gender differences on implicit and explicit anxiety measures, grades, and MAPST outcomes for total sample and by gender.

	Range	*N*	Total sample *M* (*SD*)	Boys *M* (*SD*)	Girls *M* (*SD*)	Gender difference *p*	Gender difference Cohen's *d*
Math anxiety ST-IAT	−0.7 to 0.8	175	0.10 (0.30)***	0.04 (0.31)	0.14 (0.29)***	.031	0.33
English anxiety ST-IAT	−0.7 to 1.0	180	0.12 (0.31)***	0.12 (0.30)***	0.13 (0.33)***	.900	0.02
Trait anxiety ST-IAT	−1.0 to 0.5	175	−0.33 (0.30)***	−0.32 (0.32)***	−0.34 (0.29)***	.633	0.07
Explicit math anxiety	1.0 to 3.7	154	1.69 (0.61)	1.57 (0.54)	1.79 (0.66)	.027	0.36
Explicit English anxiety	1.3 to 4.5	175	2.35 (0.58)	2.19 (0.48)	2.49 (0.62)	.001	0.53
Explicit trait anxiety	1.0 to 3.0	180	1.51 (0.34)	1.39 (0.25)	1.61 (0.38)	<.001	0.68
Math grade	3.0 to 9.0	179	6.59 (1.07)	6.54 (1.06)	6.63 (1.08)	.564	0.09
English grade	4.0 to 9.0	178	6.94 (0.98)	6.89 (0.96)	6.98 (0.99)	.534	0.09
Performance drop	−0.2 to 0.6	177	0.01 (0.10)	0.01 (0.10)	0.01 (0.09)	.707	0.06
Chosen difficulty level	20.0 to 60.0	177	38.77 (14.82)	39.28 (15.21)	38.36 (14.57)	.682	0.06
State math anxiety–low	1.0 to 4.0	177	1.22 (0.53)	1.16 (0.42)	1.28 (0.60)	.114	0.24
State math anxiety–high	1.0 to 4.3	177	1.33 (0.65)	1.26 (0.60)	1.38 (0.68)	.223	0.18

Note. MAPST, Math Anxiety Problem Solving Task; ST-IAT, Single-Target Implicit Association Test; state math anxiety–low/high, state math anxiety in low/high-anxiety condition of MAPST. The *p* values and Cohen's *d* for gender differences were based on independent *t* tests.
*** Significantly different from zero ($p < .001$).

This result was found for girls, $t(95) = 4.78$, $p < .001$, $d = 0.49$; however, boys did not show a stronger math–anxiety association than math–calmness association, $t(78) = 1.22$, $p = .226$, $d = 0.14$.

The Pearson correlation between math anxiety ST-IAT and explicit math anxiety (AMAS) revealed that, in contrast to our second expectation, math–anxiety associations were not significantly related to self-reported math anxiety (see Table 2).

Math–anxiety associations in relation to math behavior and state math anxiety

Pearson correlations among math anxiety ST-IAT, explicit math anxiety, and math behavior as well as state math anxiety were calculated (see Table 2). Results revealed that math–anxiety associations were not significantly related to any measure. Note that explicit math anxiety did show significant correlations with math behavior except for performance drop.

To evaluate whether math–anxiety associations uniquely predicted math behavior and state math anxiety when accounting for explicitly, self-reported math anxiety (AMAS), we performed two separate hierarchical regression analyses with math grade and state math anxiety in the high-anxiety condition as dependent variables. Chosen difficulty level and performance drop were not considered because of the weak or nonsignificant correlations with the anxiety measures. *Explicit math anxiety* (Step 1) and math–anxiety associations (*math anxiety ST-IAT*) (Step 2) were entered as predictors (Model 1). Results revealed that only explicit math anxiety significantly predicted math grade and state math anxiety (8% and 18% explained variance, respectively) (see Table 3). Note that the results were similar when gender was included in the model and gender was not a significant predictor in any analysis (all *p*s > .272).

In addition, Bayesian analyses were performed to examine the probability of a null effect for math–anxiety associations predicting math grade and state math anxiety. Two separate Bayesian linear regression analyses were performed using JASP 0.9.2.0 (JASP Team, 2018; van Doorn et al., 2019), predicting math grade and state math anxiety by explicit math anxiety and math anxiety ST-IAT. The reported Bayes factor (BF_{01}) compared the best model including explicit math anxiety only (H_0) with the alternative model including both explicit math anxiety and math anxiety ST-IAT (H_1) as predictors. For math grade, the Bayes factor ($BF_{01} = 2.20$) indicated weak evidence in favor of the H_0 model including only explicit math anxiety. For state math anxiety, the Bayes factor ($BF_{01} = 4.46$) indicated moderate evidence in favor of the H_0 model including only explicit math anxiety. The posterior probabilities for inclusion of math anxiety ST-IAT in the model, P(incl|data), were .47 and .31 for the model

Table 2
Pearson correlations among implicit and explicit anxiety measures, grades, and MAPST outcomes for the total sample.

	1	2	3	4	5	6
1. Math anxiety ST-IAT						
2. English anxiety ST-IAT	.12					
3. Trait anxiety ST-IAT	.04	.26**				
4. Explicit math anxiety	.15	−.16*	.03			
5. Explicit English anxiety	−.03	.11	.05	.09		
6. Explicit trait anxiety	.10	.00	−.02	.34***	.44***	
7. Math grade	−.11	.10	.02	−.28**	.29***	.10
8. English grade	.08	−.14	−.02	.30***	−.40***	.08
9. Performance drop	.06	.03	.10	.04	.10	−.10
10. Chosen difficulty level	−.07	−.00	.01	−.17*	−.02	.09
11. State math anxiety–low	.07	.05	.03	.44***	.17*	.40***
12. State math anxiety–high	.06	.07	.06	.42***	.17*	.42***

Note. MAPST, Math Anxiety Problem Solving Task; ST-IAT, Single-Target Implicit Association Test; state math anxiety–low/high, state math anxiety in low/high-anxiety condition of MAPST. *N* differs per correlation (range = 148–178).
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 3
Hierarchical regression analyses predicting math grade and state math anxiety in the high-anxiety condition of MAPST by implicit and explicit math anxiety measures.

	Math grade				State math anxiety–high[a]			
	B	*SE* (B)	*B*	*p*	B (95% BCa CI)	*SE* (B)	*B*	*p*
Model 1 Step 1[b]								
Explicit math anxiety	−0.49	0.14	−.28	.001	0.46 (0.25 to 0.69)	0.11	.42	.001
Model 1 Step 2[b]								
Explicit math anxiety	−0.46	0.14	−.26	.001	0.46 (0.26 to 0.72)	0.11	.43	.001
Math anxiety ST-IAT	−0.37	0.29	−.10	.210	−0.12 (−0.36 to 0.12)	0.13	−.05	.390

Note. MAPST, Math Anxiety Problem Solving Task; ST-IAT, Single-Target Implicit Association Test; state math anxiety–high, state math anxiety in the high-anxiety condition of MAPST. Math grade Model 1: $R^2 = .076$ in Step 1 ($p = .001$); $\Delta R^2 = .010$ in Step 2 ($p = .210$); $N = 149$; State math anxiety–high Model 1: $R^2 = .177$ in Step 1 ($p < .001$); $\Delta R^2 = .003$ in Step 2 ($p = .491$); $N = 146$.
[a] Standard errors (and *p* values) are based on 1000 bootstrap samples. 95% BCa CI, 95% bias-corrected and accelerated bootstrap confidence interval.
[b] Model 1: *Explicit math anxiety* (Step 1) and *math anxiety ST-IAT* (Step 2) were entered.

predicting math grade and state math anxiety, respectively. These posterior probabilities decreased from the prior probability of .50. In sum, the evidence against including math anxiety ST-IAT into the models was interpreted as weak for math grade and weak to moderate for state math anxiety (van Doorn et al., 2019; Wagenmakers, 2007).

Domain specificity of anxiety associations and explicit anxiety measures

One-sample *t* tests revealed that English anxiety ST-IAT and trait anxiety ST-IAT D scores differed significantly from zero. Results indicated that, in general, participants associated English relatively stronger with anxiety than with calmness, $t(179) = 5.31$, $p < .001$, $d = 0.40$, whereas participants associated themselves relatively stronger with calm than with anxious, $t(174) = -14.33$, $p < .001$, $d = 1.08$.

To examine domain specificity of anxiety associations, Pearson correlations between the ST-IAT and explicit measures for the three domains as well as math behavior, state math anxiety, and English grades were calculated (see Table 2). In contrast to our hypothesis, no significant correlations between anxiety associations and explicit anxiety measures within the same domain were found. Unexpectedly, results revealed that English–anxiety associations were negatively, but weakly, correlated to explicit math anxiety, but this was found only for girls (girls: $r = -.31$, $p = .005$; boys: $r = .06$, $p = .628$). Also unexpectedly, no significant correlations were found for anxiety associations and behavior within the same domain. Further analyses for explicit anxiety measures revealed indications of domain specificity given that only explicit math anxiety related significantly, although weakly, to chosen difficulty level. Higher math anxiety was associated with chosen lower difficulty level, however this was found only for girls (girls: $r = -.23$, $p = .035$; boys: $r = -.07$, $p = .589$). In addition, analyses revealed that explicit anxiety measures were significantly correlated with behavior within the same domain—however, unexpectedly, also across different domains. That is, explicit math anxiety was significantly associated with lower math grade and higher English grade, whereas this pattern was reversed for English anxiety. Note that only girls showed a significant correlation between explicit math anxiety and English grade (girls: $r = .36$, $p = .001$; boys: $r = .22$, $p = .069$). All explicit anxiety measures were significantly, positively correlated with state math anxiety in both conditions of the MAPST; however, explicit math anxiety and trait anxiety were correlated moderately and English anxiety was correlated only weakly. In addition, significant correlations between ST-IATs of different domains and between explicit measures of different domains were found. Note that only boys did show significant correlations between explicit math anxiety and trait anxiety (boys: $r = .51$, $p < .001$; girls: $r = .21$, $p = .059$) and between explicit math anxiety and English anxiety (boys: $r = .25$, $p = .040$; girls: $r = -.07$, $p = .519$).

To evaluate whether only math–anxiety associations and explicit math anxiety specifically predicted math behavior and state math anxiety, we performed two separate hierarchical regression analyses for math grade and state math anxiety in the high-anxiety condition. Explicit anxiety variables (*explicit math anxiety, explicit English anxiety,* and *explicit trait anxiety*) (Step 1) and anxiety association variables (*math anxiety ST-IAT, English anxiety ST-IAT,* and *trait anxiety ST-IAT*) (Step 2) were entered as predictors (Model 2). Results revealed that the model including explicit anxiety measures significantly predicted math grade (Step 1: $R^2 = .223$, $p < .001$) and state math anxiety (Step 1: $R^2 = .285$, $p < .001$) (see Table 4). However, including anxiety association variables in the model did not significantly improve the model for math grade (Step 2: $\Delta R^2 = .016$, $p = .427$) and only marginally significantly improved it for state math anxiety (Step 2: $\Delta R^2 = .042$, $p = .050$). Results of Step 1 indicated that lower explicit math anxiety and higher explicit English anxiety were significantly and independently related to higher math grade (13% and 6% unique explained variance, respectively). Higher explicit math anxiety and higher explicit trait anxiety were significantly and independently related to higher state math anxiety (10% and 7%, respectively). In addition, and unexpectedly, results of Step 2 indicated that stronger English–anxiety associations were related to higher state math anxiety (3%). Note that when gender was included in the model, it was not a significant predictor in any analysis (all $ps > .231$) and results remained the same, although entering anxiety association variables in the model was no longer significant for state math anxiety ($\Delta R^2 = .038$, $p = .066$). See Online Supplementary Material S1 for additional Bayesian analyses.

Discussion

This study investigated the role of adolescents' implicitly measured associations between math and anxiety in relation to explicitly measured math anxiety. It was investigated whether these associations predicted math behavior as well as state math anxiety independent of explicit math anxiety. In addition, the domain specificity of anxiety associations for predicting behavior was investigated. Therefore, anxiety associations (using the ST-IAT) and self-reported anxiety were assessed for three domains: math anxiety, foreign language (English) anxiety, and trait anxiety. As expected, results revealed that, in general, adolescents showed relatively stronger math–anxiety associations in comparison with math–calmness associations. In addition, we found that overall adolescents showed stronger self–calmness associations (relative to self–anxiety associations) and stronger English–anxiety associations (relative to English–calmness associations). These findings are in line with previous research showing that math is generally more strongly associated with negative evaluations and self is more strongly associated with calmness and positive evaluations (de Jong, 2002; Gamer et al., 2008; Nosek et al., 2002a, 2002b). In addition, in line with previous research, girls reported stronger negative associations with math (e.g., math + anxiety) than boys (Nosek et al., 2002b; see also Kessels et al., 2006), girls

Table 4
Hierarchical regression analyses predicting math grade and state math anxiety in the high-anxiety condition of MAPST by implicit and explicit math, English, and trait anxiety measures.

	Math grade				State math anxiety–high[a]			
	B	*SE* (B)	*β*	*p*	B (95% BCa CI)	*SE* (B)	*β*	*p*
Model 2 Step 1[b]								
Explicit math anxiety	−0.68	0.15	−.38	<.001	0.39 (0.19 to 0.61)	0.11	.35	.002
Explicit English anxiety	0.52	0.16	.29	.001	−0.06 (−0.24 to 0.12)	0.09	−.05	.523
Explicit trait anxiety	0.40	0.28	.13	.156	0.61 (0.20 to 0.99)	0.20	.32	.008
Model 2 Step 2[b]								
Explicit math anxiety	−0.69	0.15	−.39	<.001	0.44 (0.22 to 0.67)	0.11	.39	.002
Explicit English anxiety	0.51	0.16	.28	.002	−0.12 (−0.32 to 0.07)	0.10	−.11	.191
Explicit trait anxiety	0.45	0.28	.15	.117	0.65 (0.25 to 1.02)	0.20	.34	.004
Math anxiety ST-IAT	−0.31	0.29	−.08	.293	−0.21 (−0.47 to 0.05)	0.14	−.09	.144
English anxiety ST-IAT	−0.25	0.29	−.07	.402	0.41 (0.04 to 0.79)	0.18	.19	.031
Trait anxiety ST-IAT	0.31	0.28	.09	.275	0.11 (−0.18 to 0.41)	0.16	.05	.481

Note. MAPST, Math Anxiety Problem Solving Task; ST-IAT, Single-Target Implicit Association Test; state math anxiety–high, state math anxiety in the high-anxiety condition of MAPST. Math grade Model 2: R^2 = .223 in Step 1 ($p < .001$); ΔR^2 = .016 in Step 2 (p = .427); N = 139; state math anxiety in high-anxiety condition (state math anxiety–high) Model 2: R^2 = .285 in Step 1 ($p < .001$); ΔR^2 = .042 in Step 2 (p = .050); N = 137.

[a] Standard errors (and *p* values) are based on 1000 bootstrap samples. 95% BCa CI, 95% bias-corrected and accelerated bootstrap confidence interval.

[b] Model 2: *Explicit math anxiety, explicit English anxiety,* and *explicit trait anxiety* (Step 1) and *math anxiety ST-IAT, English anxiety ST-IAT,* and *trait anxiety ST-IAT* (Step 2) were entered.

reported higher anxiety on all explicit anxiety measures (Devine, Fawcett, Szücs, & Dowker, 2012; Frenzel, Pekrun, & Goetz, 2007; McLean, Asnaani, Litz, & Hofmann, 2011), and no gender differences were found for state math anxiety (Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013). Evidence of the gender difference on implicitly measured associations matches commonly replicated gender differences on explicit measures and suggests that girls might actually be more anxious than boys and do not just report on it in a more extreme way.

The innovative aspects of this pioneering study are the implicit assessment of math–anxiety associations using an ST-IAT and that these associations were related to an explicit self-report questionnaire of math anxiety as well as math behavior. Theoretical models conceptualize associative processing in anxiety as distinct from rule-based processing and propose that both processes jointly influence behavior (Ouimet et al., 2009). Based on this, it was expected that math–anxiety associations would relate to and explain unique variance in math behavior and state math anxiety. In contrast to our hypotheses, math–anxiety associations were not related to explicit math anxiety. Furthermore, math–anxiety associations did not relate to or uniquely predict math behavior and state math anxiety.

It should be noted that although relations between the ST-IAT and explicit anxiety and between the ST-IAT and grades were not significant, they were in the expected direction. But Bayesian analyses indicated weak to moderate evidence against math–anxiety associations as a predictor of math grade and state math anxiety. Regarding the relation between the IAT and explicit measures as well as predictive validity of the IAT, previous findings have also been mixed. Meta-analyses have reported overall mean effect sizes between the IAT and explicit measures of .21 (±95% confidence interval = .04 and ranging from .09 to .54 for separate domains; Greenwald et al., 2009) and .24 (with 90% credibility interval between .01 and .47; Hofmann et al., 2005). For IAT measures predicting behavior, a meta-analysis reported an average effect size of r = .27 (range = .17–.48; Greenwald et al., 2009). However, there is variation across domains and types of anxiety (e.g., Roefs et al., 2011). Weak or no correlations between the IAT and explicit measures have found to be more likely when a topic is more sensitive to motivational processes (de Jong, 2002; Gawronski, Hofmann, & Wilbur, 2006) and when, like in the current study, questionnaires are used (Hofmann et al., 2005). More important, because associative and rule-based processes might operate independently, the relation between implicit and explicit measures could be absent and still both measures could predict behavior independently (Egloff & Schmukle, 2002; Greenwald et al., 2009; Nosek et al., 2002b). However, our findings did not support this.

The current findings add to previous mixed results on the relevance of implicitly measured processes in relation to math anxiety. For example, some studies have found preliminary evidence for affective priming effects in children with developmental dyscalculia (Rubinsten & Tannock, 2010) and attentional bias in math-anxious individuals (Rubinsten, Eidlin, Wohl, & Akibli, 2015; Suárez-Pellicioni, Núñez-Peña, & Colomé, 2015; see also Hopko, McNeil, Gleason, & Rabalais, 2002). However, others were not able to replicate such affective priming effects (Kucian et al., 2018). In addition, other findings have suggested that math anxiety might negatively predict performance only in interaction with other factors such as working memory capacity and cortisol responses (Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011; Pletzer, Wood, Moeller, Nuerk, & Kerschbaum, 2010). These results might question the additive value of implicit measures in math anxiety, and it could be that a theoretical model with a clear distinction between two information processing systems (i.e., dual-process model) does not accurately describe math anxiety (see e.g., Hommel & Wiers, 2017, for an alternative model to dual-routes models; see also Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013). However, this conclusion might be too premature given the line of evidence for threat-associative processing in schema-based information processing in other domains of anxiety (Ouimet et al., 2009; see also Beck & Clark, 1997; Mathews & MacLeod, 2005). In addition, although math anxiety concerns learned anxiety without direct evolutionary benefits, it does share cognitive, affective, and behavioral components as well as general anxiety vulnerability with other domains of anxiety (see Dowker, Sarkar, & Looi, 2016; Hopko, McNeil, Zvolensky, & Eifert, 2001). Moreover, positive results have also been found, and several other explanations for the current lack of findings are also possible.

First, it is uncertain whether the IAT is sensitive to capture underlying associations between concepts and threat (see Mathews & MacLeod, 2005; see also de Houwer, 2006; de Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009). The math anxiety ST-IAT did not significantly correlate to any measure, suggesting that the current ST-IAT might not adequately capture the associations involved in math anxiety and math behavior. One possibility is that the use of a single-target version of the IAT (ST-IAT), which intentionally precludes a relative comparison of math with another subject, has affected the strength of the associations being measured. For academic subjects, using a contrasting category may be of practical importance because academic choices rarely occur without alternatives (Cvencek et al., 2011; Nosek et al., 2002b). On the other hand, the ST-IAT has been successfully applied to a broader range of topics (e.g., Bongers, Jansen, Houben, & Roefs, 2013; de Hullu et al., 2011; Houben & Wiers, 2008; Karpinski & Steinman, 2006; Thush & Wiers, 2007). Furthermore, reliabilities of the current ST-IATs were adequate and comparable to previous studies with adolescents, as were the error percentages (de Hullu et al., 2011; Thush & Wiers, 2007). A possibility is that the current attribute (anxiety) is not optimal. Theoretically, anxiety results from the activation of a threat concept that is associated with the concept of the encountered stimulus (e.g., math; Ouimet et al., 2009). It is possible that math is not so strongly associated with anxiety as with the expectancy of failure, which is considered threatening and causes anxiety (Pekrun, 2006). Accordingly, it might be more likely that an association between math and failure (as alternative threat concept) is underlying math anxiety. Future studies could adapt the evaluative attributes of the current ST-IAT into failure versus success (instead of anxiety vs. calmness) to investigate whether math–failure associations might relate to explicit math anxiety and predict math behavior.

Another possibility is that associations might not predict the type of behavior used in the current study. Whereas previous literature suggested that implicit anxiety measures specifically predicted spontaneous or nonverbal behaviors (Egloff & Schmukle, 2002; Gschwendner et al., 2008; Nosek et al., 2002b), our measures might have assessed behavior that is more strongly influenced by rule-based processing as well as other factors. Chosen difficulty level, which was intended to be an indicator of spontaneous math behavior, may instead represent a deliberate, rule-based process, integrating one's self-efficacy and the difficulty of the represented problems. A weak correlation between chosen difficulty level and explicit math anxiety supports this idea. Future studies could focus on assessing more spontaneous math behavior. Self-reported math grade was also used as a behavior outcome, and it is likely that many factors have had an impact on it (e.g., motivation, learning strategies). However, it is a relevant outcome measure, also for future studies, given that this reflects daily life achievement. Regarding performance, previous research suggested that implicit measures predicted change scores and relative scores (i.e., a difference between math and verbal scores; Egloff & Schmukle, 2002; Nosek et al., 2002b). The lack of findings on our performance drop measure, however, might be due to limitations of the MAPST. A performance drop typically occurs when anxiety is moderate to high (Ashcraft & Moore, 2009), but low state math anxiety in the high-anxiety condition (1.3 on a scale of 1–5) and high accuracy in both conditions (>90%) suggested that the anxiety manipulation was not effective. Therefore, adaptations of the MAPST are needed to induce higher anxiety levels, for example, by using stronger anxiety manipulations, more difficult equations, and randomization of condition order to prevent practice and familiarization effects. Furthermore, in line with previous research (Egloff & Schmukle, 2002), only explicit anxiety predicted self-rated state math anxiety, potentially suggesting that self-report state anxiety assessments capture more rule-based, explicit processing. It is possible that implicit measures are more relevant in predicting experimenter-rated changes in state anxiety or physiological changes (Egloff & Schmukle, 2002). However, more variation in state math anxiety is necessary to investigate this further. In sum, the current findings suggest that further research is needed to disentangle to what extent math behavior is influenced by implicitly measured anxiety associations and to investigate which types of behaviors or indicators are specifically predicted by these associations. Therefore, future studies should focus on ways to improve the measurement of task performance and spontaneous or nonverbal behaviors in math anxiety.

The current study investigated anxiety in an unselected sample of secondary school students. Overall, anxiety ratings were relatively low, and it is possible that the number of individuals with strong math–threat associations was low in the current sample. This could also have resulted in a lack of relations between associations and other variables. Therefore, future studies should focus on individuals high in math anxiety.

Domain specificity of math–anxiety association

Lastly, we expected that anxiety associations would be specifically related to measures for the same domain. Results revealed that implicit measures were not specifically related to explicit anxiety within the same domain or to grade or other outcomes. Surprisingly, English–anxiety associations correlated negatively with explicit math anxiety. This was true only for girls, possibly affected by more extreme scores in math anxiety. Note that although the correlation between math–anxiety associations and explicit math anxiety was not significant, it was positive and almost similar in magnitude. Although, as discussed above, overall our results suggest that ST-IAT measures need improvement, these results may point to the relevance of associations for anxiety as well as domain specificity of associations for school subjects.

Results of explicit anxiety measures did show indications of domain specificity. State math anxiety was uniquely predicted by explicit math anxiety and trait anxiety but not English anxiety. In addition, chosen difficulty level was correlated only to math anxiety. Furthermore, in line with previous research, math anxiety was related to trait anxiety as well as state anxiety but could be differentiated because only math anxiety predicted math grade (Caviola, Primi, Chiesi, & Mammarella, 2017; Hembree, 1990; Hopko et al., 2003; Wang et al., 2014; see also Carey, Devine, Hill, & Szücs, 2017).

For domain specificity of explicit math and English anxiety and grades, the pattern of results was more mixed. Previous studies have, however, also reported inconsistent findings. Some studies have reported weak or negligible relations between anxiety for math and English as well as for relations between anxiety and achievement across the two domains (Goetz, Cronjaeger, Frenzel, Lüdtke, & Hall, 2010; Goetz et al., 2006, 2007; Hill et al., 2016). However, other studies showed strong cross-domain relations between anxiety in math and anxiety in English (Green, Martin, & Marsh, 2007), and worse math and reading performance for academic, but not general, anxious individuals (Carey et al., 2017). In the current study, it was found that both explicit math anxiety and English anxiety uniquely predicted math grade and related to English grade, but the pattern was reverse. Furthermore, math anxiety and English anxiety were not correlated to each other (except for boys). These findings suggest that math anxiety and English anxiety can be differentiated from each other, supporting previous findings of domain-specific anxiety in academics (Goetz et al., 2006, 2007, 2010). However, in contrast to some previous literature, cross-domain relations between anxiety and grades were found. It is unlikely that these cross-domain relations can be explained by a general anxiety factor, as previously suggested (Hill et al., 2016), because trait anxiety was accounted for in the current study.

However, different anxiety profiles (Carey et al., 2017) might be possible, which may be the focus of future studies. In addition, other explanations are possible.

First, self-reported grades were used, which might not accurately represent the actual achievement, and the validity has been questioned. On the other hand, self-reported grades have been used frequently in secondary school students' samples, and strong correlations (>.80) between self-reported grades and actual grades have supported validity of these reports (Chatard, Guimond, & Selimbegovic, 2007; Goetz et al., 2006; Kuncel, Credé, & Thomas, 2005; Steffens & Jelenec, 2011). Even when self-reported grades might correspond to the actual grades, using grades as a measure of achievement might be a limitation. As stated, grades might be influenced by many other factors besides achievement per se such as motivation, learning strategies, classroom environment, and class performance. Standardized tests might be less affected by these factors. Therefore, including standardized tests of achievement in future studies might facilitate a less biased clarification of the relationships between anxiety and achievement.

Second, the cross-domain relations might resemble the influence of a third factor that is influencing both anxiety and grade. According to the internal/external frame of reference model (Marsh, 1986; Marsh & Craven, 2006; Möller, Pohlmann, Köller, & Marsh, 2009), students evaluate their achievement in a given subject with that of other students (external frame of reference) as well as with their own achievement in other subjects (internal frame of reference). As a result of an internal comparison, students think of themselves as either a math person or a language person. It might be possible that someone who is good in either math or language, but not the other, might not report anxiety for this subject but does so for the other subject. In addition, it could be that other psychological factors such as competence beliefs, values, and stereotypes affect both the experience and self-report of anxiety and achievement. These factors can also have differential effects for boys and girls, possibly explaining inconsistent findings for gender (Frenzel et al., 2007; Galdi, Cadinu, & Tomasetto, 2014; Pekrun, 2006).

Conclusion

This pioneering study investigated adolescents' implicitly measured associations between math and anxiety in relation to self-reported math anxiety and math behavior. We demonstrated that math was more strongly associated with anxiety in comparison with calmness and that this association was stronger for girls than for boys, suggesting potential relevance of math–anxiety associations. However, math–anxiety associations were not related to explicit math anxiety, and only explicit math anxiety predicted math behavior. Furthermore, we demonstrated that explicit math anxiety could be differentiated from explicit anxiety for learning a foreign language. The current lack of relations between math–anxiety associations and explicit math anxiety and math behavior adds to previous inconsistent findings on implicit measures of math anxiety. Given that research on math–anxiety associations is still in its infancy, and given the current limitations that warrant alternative explanations, it is worthwhile to develop tasks that capture the most relevant math–threat associations and to investigate which math behavior might be most strongly influenced by these associations. The lessons learned from the current thorough study invite such research, which is necessary before drawing a final conclusion on the relevance of implicit measures above explicit measures of math anxiety.

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Appendix A

The word stimuli for the target categories and evaluative attributes that were used in the three Single-Target Implicit Association Tests (ST-IATs) are shown here. The target categories for the ST-IATs differed and were math, English, and I for the math anxiety ST-IAT, English anxiety ST-IAT, and trait anxiety ST-IAT, respectively. The evaluative attributes in the three ST-IATs were always anxious and calm.

Stimuli per target category

Math: formula ("formule"); rectangle ("rechthoek"); equation ("vergelijking"); number ("getal"); math ("wiskunde").

English: textbook ("textbook"); grammar ("grammar"); reading ("reading"); listening ("listening"); English ("Engels").

I: self ("zelf"); myself ("mezelf"); mine ("mijn"); own ("eigen"); I ("ik").

Stimuli for the evaluative attributes

Anxious: anxious ("bang"); insecure ("onzeker"); nervous ("nerveus"); worried ("ongerust"); afraid ("angstig").

Calm: stable ("stabiel"); restful ("rustig"); relaxed ("ontspannen"); secure ("zeker"); calm ("kalm").

Note. Stimuli were matched on mean number of syllables per concept (anxiety: 2.2; calm: 2.0; math: 2.8; English: 2.2; I: 1.4).

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2019.05.013.

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