



# The interplay of math anxiety and math competence for later performance

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## Abstract

Math anxiety's negative effects on performance are well-documented. The interplay of math anxiety and mathematical competence regarding later performance is under-explored. We investigated whether math anxiety's detrimental effects on learning depend on previous mathematical competence. Hypothesizing a moderation effect, we expected that trait math anxiety should affect pupils of higher competence to a greater extent than pupils with lesser competence. Based on 8th graders in secondary school, we found the expected interaction of math anxiety and math competence (represented by previous math grade) predicting performance three months later. The interaction of math anxiety and math competence on later performance remained despite controlling for math self-concept and gender (and previous topic-specific performance). The moderation showed differential slopes for the effects of math competence on later performance depending on trait math anxiety: At lower competence levels, math anxiety played a lesser role than for higher competence levels. Later performance was lowest for more competent pupils with higher math anxiety relative to their peers with similar competence levels but lower math anxiety. Although the data imply directionality, our design cannot imply causality. Nevertheless, one interpretation of the results is in line with the notion of greater performance losses over time for more competent pupils with higher levels of math anxiety: the learning progress may be aggravated for those, who have the prerequisite in ability to advance their performance. The optimal development of math capabilities may be compromised by math anxiety; good math abilities and low math anxiety may both be prerequisites for long-term learning success.

**Keywords** Math anxiety · Learning · Math abilities · Math grade · Test performance

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## 1 Introduction

### 1.1 The math anxiety—math performance link

Graded performance tests are an integral part of teaching and learning in schools and this is not different for the mathematical education. Graded tests can be anxiety evoking (Khanna, 2015) and mathematics in itself is an anxiety-evoking subject for many learners (Chinn, 2009; Dowker et al., 2016). Math-anxiety as trait encompasses the apprehension and fear of math (Ashcraft & Kirk, 2001), encompassing negative emotions (e.g. nervousness), cognitions (e.g. worry), and physiological reactions (e.g. cardiovascular; for overviews see Dowker et al., 2016; Suarez-Pellicioni et al., 2016). Math anxiety is prevalent among pupils. According to the OECD report of 2013 based on PISA results of 2012, about one third indicated to feel nervous and helpless when solving math problems (OECD, 2013).

It is well-documented that the results of performance tests in math can not only be influenced by competence and skill, but also by math anxiety (Hembree, 1990; Ma, 1999; Zhang et al., 2019). The negative association of math anxiety and performance has been repeatedly demonstrated in multiple meta-analysis over the last two decades (e.g.,  $r = -.27$ , Ma, 1999;  $r = .34$ , Namkung et al., 2019;  $r = .30$ , Zhang et al., 2019). Moreover, across OECD countries, 14% of the criterion variability in performance is accounted for by math anxiety (OECD, 2013). This negative relationship is stable even when controlling for test anxiety, trait anxiety, gender, or socioeconomic status (Lukowski et al., 2016; OECD, 2013; Wu et al., 2012).

### 1.2 Theoretical accounts of the math anxiety—math performance link

Throughout the years, multiple theoretical accounts of the negative (math) anxiety—(math) performance link have been advanced and refined (for an overview see Carey et al., 2016; Chang & Beilock, 2016). Based on interference explanations (e.g., Ashcraft & Krause, 2007; Pizzie & Kraemer, 2017; Sarason, 1972; Tobias, 1986; Wine, 1980), task-irrelevant thoughts and attentional misallocation compromise performance by reducing cognitive capacity and working-memory functions in the acquisition and retrieval phase during learning and during test-taking. Based on deficit explanations (e.g., Beilock & Willingham, 2014; Kirkland & Hollandsworth, 1980; Maloney et al., 2011; Tobias, 1990), inadequate preparation by avoidance of math-related content, and low domain-specific abilities, such as numerical (processing) competence, evoke anxiety and low performance. Consequently, math anxiety is merely a manifestation of one's awareness of low math abilities.

In essence, cognitive interference explanations identify math anxiety induced processing problems as the cause for performance decrements, while deficit explanations pinpoint math ability deficits as the cause for math anxiety and performance losses. There is evidence for both accounts, but the evidence does not clearly favor one above the other. Carey and colleagues (2016) reason instead that deficit mechanisms unfold long-term, while interference mechanisms act more immediate on

performance by taxing working memory. From an integrative perspective of interference and deficit accounts, time is therefore an important factor to consider in the math anxiety—performance link. Indeed, various findings suggest mutually inclusive and reciprocal relationships (cf. Carey et al., 2016; Foley et al., 2017): detrimental bidirectional links of (math) anxiety on poor math skills, and of poor math performance on math anxiety may form a negative feedback loop (Ashcraft et al., 2007; Field et al., 2019; Jansen et al., 2013; Pekrun, 2006). In this perspective, math anxiety and academic skills are not pitted against each other. Instead, the contribution of (math) anxiety and math abilities on immediate and later performance are examined.

### 1.3 Evidence for the math anxiety—math performance link over time

In a longitudinal, nation-wide youth study in the USA, Ma and Xu (2004) explored the reciprocal effects of math abilities on next year's math anxiety and math abilities across six grade levels. Overall math abilities (basic skills, algebra, geometry, and quantitative literacy) across the years showed negative correlations of  $r = -.20$  to  $r = -.11$  with trait math anxiety. In contrast, trait math anxiety's correlation to math ability fell in the range of  $r = -.01$  to  $r = -.05$ , albeit significant. Thus long-term, prior underachievement in math manifested in deficient math abilities, which may have led to future trait math anxiety (for recent evidence, see Field et al., 2019). Such findings are in line with deficit accounts.

More immediate, the effects of math anxiety on performance are more differentiated: For example, Ashcraft et al. (1998) reported that highly math anxious students did not have a priori global ability deficits, but as the math problems became more complex, so increased the link of trait math anxiety on subsequent performance (see also Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007). Thus, short-term math anxiety did not uniformly and directly translate to performance but was the result of an interaction with other variables. Such findings are in line with interference accounts. Given the relevance of such (short-term) moderation effects to the present study, we consider these interactions in the following.

#### 1.3.1 Short-term performance: interaction effects of trait math anxiety

The pivotal point of math-anxiety's short-term effects is centered around cognitive aspects. In this respect, a critical moderator for the math anxiety performance link is working memory (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; but for a discussion see Suárez-Pellicioni et al., 2016): When taxed by a dual task of holding irrelevant letters in mind, students with high trait math anxiety performed substantially worse than peers low in trait math anxiety; even though their performance was only somewhat worse when not taxed by a dual-task and hence when they had more available working memory resources. As such, differential effects of math anxiety are to be expected if the task at hand varies in complexity and therefore cognitive demands on working memory. Likewise, differential effects of math anxiety are expected depending on individual differences in working memory capacity. These results are based on an

interference explanation: Trait math anxiety itself acts like a dual-task, preoccupying working memory in addition to the actual task.

### 1.3.2 Short-term performance: interaction effects of state (math) anxiety

Detrimental effects of math anxiety do not need to be based on dispositional math anxiety, but also have been observed with situationally induced math-anxiety or test-anxiety (Tempel & Neumann, 2014). Any anxiety-inducing situation has similar detrimental effects on available working memory resources, which, depending on a person's general working memory capacity, can have differential effects on subsequent math performance. Beilock and Carr (2005) surprisingly showed that students with high working memory capacity suffered the highest performance drops for complex math problems under pressure (state anxiety). This is counterintuitive as one might have assumed that higher working memory buffers against the anxiety-induced performance declines. Case in point, first and second graders with higher working memory demonstrated the strongest negative relationship between math anxiety and math achievement, corroborating the previous findings in adults (Ramirez et al., 2013).

### 1.3.3 Long-term performance: interaction effects of trait math anxiety

Such an interaction effect of math anxiety and working memory was also shown in a longitudinal study: Young math-anxious learners with higher working memory progressed less over the year relative to their high working-memory, low math anxiety peers (Vukovic et al., 2013). Surprisingly, the interaction of trait math anxiety and working-memory was not replicated cross-sectional (short-term). Vukovic and colleagues (2013) reasoned that any effects need to be considered not only for performance, but also learning, stating: "Over time, however, the anxiety that some children with higher working memory experience when confronting mathematical applications may become a barrier to learning, whereas children with lower levels of working memory alongside high levels of mathematics anxiety remain able to benefit from instruction (or at least their anxiety does not block their learning). As a result, children with higher levels of both working memory and mathematics anxiety may learn less mathematical applications over time." (page 8).

This statement can be seen to interactively consider interference explanations taking effect on immediate performance and deficit explanations unfolding over time on long-term learning; and identifying students at risk. In this respect, Foley and colleagues (2017) reported that the anxiety—performance link for those at the top of PISA's math performance distribution seems more pronounced than for those at the bottom. They conclude that "students with higher potential to succeed in math are at greater risk of not reaching their full potential if they are math anxious" (page 54).

## 2 The present research and hypotheses

The present research concerns the intertwined nature of math competence and trait math anxiety regarding its effects on later learning success. Longitudinal research focused on the intercorrelations and relative contributions of trait math anxiety and math abilities for later achievement levels in math (e.g., Ma & Xu, 2004). The central idea behind these studies concerns the causal direction of which concept influences which, to which degree, and the importance of both concepts for achievement. Studies on immediate test performance centered on the interplay of (trait and state) math anxiety at varying levels of working memory. Therein the central idea concerns the qualification of the effects of what are, and how they are moderated, which can address the “cost” of math anxiety for immediate performance depending on individual differences in cognitive architecture (e.g., Ashcraft & Krause, 2007).

The novelty of the present study consists of applying the logic of research on immediate performance effects (moderation) to the design of longitudinal studies on later performance effects: We consider a potential interaction effect of individual differences in previous math competence being tied to the level of trait math anxiety and posit that their interplay can unfold over time. Such an approach is barely utilized and to the best of our knowledge has not focused specifically on the interaction of previous math competence and math anxiety (for a longitudinal exception, yet concerning the interaction of working memory and math anxiety, see Vukovic et al., 2013).

The study by Vukovic et al. (2013) concerns working memory as individual difference variable in working memory. The focus of the present study is on math competence as broader individual difference variable (which is more closely related to deficit accounts and longitudinal studies). If a moderation of working-memory and trait math anxiety was detectable for learning, the interaction should also be detectable for a broader competence variable and trait math anxiety for later performance.

It is to be tested, whether an interaction effect of math anxiety and math competence can also be demonstrated for later performance, and not merely for immediate or short-term performance; and whether the pattern of the interaction resembles previous findings on short-term outcomes, such that learners with more advantageous prerequisites in ability or cognitive architecture show similar performance declines long-term as demonstrated short-term (e. g., Ashcraft and Krause, 2007; Beilock & Carr, 2005).

We therefore investigated the negative effects of math anxiety on long-term learning dependent on pupils' prior math competence level. We did not only assess the correlation of math anxiety, math competence and future mathematical performance (as usually done in longitudinal designs) but targeted the interaction effect of math anxiety and math competence (similar to paradigms of experimental designs focusing on short-term performance)—yet not for immediate but for later performance. Based on the rational above, it is conceivable that the negative relationship of math anxiety and long-term learning is more pronounced for learners with higher previous

Prior in-class session 1: before new curricular content on linear functions <b>(relevant to the present paper)</b>	In-class session 1	Interim time	Three months later in-class session 2	
	<u>(not relevant to the present paper)</u>		Part 1 <u>(not relevant to the present paper)</u>	Part 2 <b>(relevant to the present paper)</b>
At home, questionnaire including measurement of <b>math anxiety</b> ( <i>main variable</i> ) and <b>math self-concept</b> ( <i>control variable</i> ) and <b>gender</b> ( <i>control variable</i> ); the teacher reported the previous <b>math grade</b> in the last school certificate ( <i>main variable</i> )	Learning phase on linear functions over the duration of a double lesson concluding with Test A labeled as initial topic-specific test performance (exploratory control variable in Appendix B)	Normal math lessons conducted by math teachers without researcher's interference	Retest of Test A (exact same test; not used in the present paper; see note below)	New test problems on linear functions labeled <b>later performance</b> ( <i>main dependent variable</i> )

**Fig. 1** Timeline and Schematic Design Denoting Relevant Procedures and Variables. Note. All variables central to the present analyses are bold and in italics. The variables stem from the first and last part of the study design. The present paper does not concern the performance differences across time in performance for Test A because this difference is the focus of another study (Reinhard et al., 2019). For the purpose of the present research question, we designed in-class session 2 to include new test problems as dependent variable and we had embedded the measurement of math anxiety and math competence in the initial questionnaire prior in-class session 1. Therefore, all main variables in this paper have not been considered elsewhere and are unlikely to be affected by the in-class session 1 three months earlier

competence levels. In other words, those who are principally able to perform and learn well are the ones who may be hindered the most by math anxiety.

We expected to observe a moderation effect of math anxiety on later performance depending on previous math competence such that higher levels of trait math anxiety and higher competence levels interact and relate to lower performance in a test three months later. We used pupils' math grade in their last school certificate as a proxy for their overall math competence (similar to Musch & Bröder, 1999).<sup>1</sup> We asked pupils to self-report their trait math anxiety at the beginning of an instructional unit on linear functions in the 8th grade of secondary school. After three months had passed—the topic of linear function was completed, and the math courses had progressed to different topics—we requested pupils to solve curricular problems on linear functions.

For a more stringent test of our hypothesis, we measured pupil's math self-concept (self-appraisal of one's math abilities; cf. Ahmed et al., 2012) as central control variable in the initial questionnaire (see Fig. 1): math anxiety and math self-concept are negatively related ( $r = -.71$ , Hembree, 1990), and higher math self-concepts predict greater test performance and academic achievement (Guay et al., 2003; Martin & Debus, 1998). Given that many findings on differences in math anxiety and math performance relate to gender (Devine et al., 2012; Hembree, 1990), we also

<sup>1</sup> Math grade is not specific to a particular topic (e.g. fractions, geometry, roots, etc.) but reflects the previous performance across topics more generally. Math grade was of interest for us as competence indicator because grades are acknowledged and frequently used as predictors (e.g., even university admissions are often based on grades rather than subject-specific skill assessments).

included gender as control variable. The present research was embedded within a larger study; therefore, we also had the possibility to (exploratory) analyze data on initial topic-specific performance at the beginning of the instructional unit as a control variable (see ''Appendix B'').

To summarize: We predict an interaction between trait math anxiety (assessed at the beginning of a new learning unit) and previous competence (based on previous math grade). Later performance should be a function of trait math anxiety and individual differences in previous math competence: Later performance scores of pupils with higher math competence should be lower for higher math anxiety levels relative to pupils with lower levels of math anxiety. Said differently, trait math anxiety should affect students of higher math competence to a greater extent than students with lesser competence with respect to their long-term learning (represented by their performance in a test on linear functions after three months). This interaction effect should remain despite controlling for math self-concept and gender.

### 3 Method

#### 3.1 Participants and procedure

The present data stem from an experimental study conducted within the framework of a large-scale project "desirable difficulties: intrinsic cognitive motivation and performance expectancies as moderators of the effectiveness of the generation effect", funded by the federal state of Hessen, Germany. Ethical approval was granted by the Hessian Ministry of Education and Cultural Affairs. All procedures carried out were also in line with the Declaration of Helsinki (for example, participation was entirely voluntarily and could be revoked any time without negative consequences). Participants were children in the 8th grade of the secondary school track recruited from three schools located in two medium sized towns in Germany. Consent was obtained from the principals, teachers, parents, and children, which resulted in an initial sample of  $N=111$  (age:  $M=13.74$ ,  $SD=0.57$ ). At the first in-class session, 103 (53 females) pupils participated. The central dependent variable of later test performance emanates from the second in-class session three months later, which 102 (49 females) pupils attended. Importantly, the central dependent variable (later performance) and the central independent variables (math anxiety and math grade) have not been used previously, although they come from the same sample used in another study (Reinhard et al., 2019). The participation was anonymized by utilizing pseudonymized codes. The pupils received sweets and a small gift (puzzles) at the end of the study.

At home (prior to the first in-class session), the pupils were requested to fill out a short questionnaire (paper-pencil), which the teacher had handed them previously. The questionnaire assessed multiple personality characteristics (for details see Reinhard et al., 2019), of which math anxiety and math self-concept are relevant for the present paper. Pupils' math grade was reported by their teachers. Prior to the first in-class session, the teachers had introduced the topic of linear functions. This means the study began at a time when all pupils started to learn the new curricular content

about linear functions. However, the teachers were instructed to omit any exercises that would be related to computing slopes and functions in their introductory teachings, which were the focus of the in-class session (for details see Reinhard et al., 2019). In short, we captured pupils' previous knowledge on the subject, then randomly assigned pupils to learn with worked-examples or problem solving and right thereafter tested their immediate performance (there were no overall group differences and thus we used it as an exploratory control variable to represent topic-specific test performance in [Appendix B](#)).

Most importantly, though, we returned after 3 months. In the meantime, all teachers had finished the topic of linear functions and had progressed to different curricular content. The in-class session after 3 months was split into two parts. In the first half (and not relevant for the present paper), we retested the students on the material they had learned in the first in-class session with the same test they already had received three months earlier.<sup>2</sup> The second part entailed a new test designed for the present purpose: a selection of typical problems in a curricular math test on linear functions comparable to a test a teacher would give to students. The problems were chosen in co-operation with math didactics (see [Appendix A](#)) and the pupils had 20 min to solve them. The second part concluded with a very brief questionnaire with probe questions (e.g. how difficult these test problems were; none of which were used any further).

## 3.2 Measures

### 3.2.1 Math anxiety

Assessed on 5-point scales (1 = strongly agree to 5 = strongly disagree), we used 5-items to capture math anxiety (Ferla et al., 2009). This scale was included in PISA 2012. A sample item reads: "I get very nervous, when I have to solve mathematical problems". Cronbach's  $\alpha = 0.87$ .

### 3.2.2 Math self-concept

We included the German 5-item version of math self-concept (Ferla et al., 2009) used in PISA 2012. Measured on 5-point scales (1 = strongly agree to 5 = strongly disagree). A sample item is: "I am just not good at Mathematics", measured on 5-point scales (1 = strongly agree to 5 = strongly disagree); Cronbach's  $\alpha = 0.89$ .

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<sup>2</sup> Note the difference across time in initial test performance in Test A and later test performance in Test A three months later is the explicit focus of another study (see Reinhard et al., 2019) and therefore this performance difference or the later test performance in Test A after three months is *not* reused as dependent variable.



**Table 1** Bivariate correlations, means, and standard deviations of criterion, predictor and control variables

Variable	1	2	3	4	5	<i>M</i>	<i>SD</i>
Math anxiety	–					2.08	0.99
Math grade	.52*** <sup>b</sup>	–				3.23	1.03
Math self-concept	-.74*** <sup>b</sup>	-.69*** <sup>b</sup>	–			2.91	1.08
Gender	.28*** <sup>b</sup>	.03 <sup>a</sup>	-.32*** <sup>b</sup>	–			
Later test performance (after three months)	-.40***	-.28*** <sup>c</sup>	-.41*** <sup>d</sup>	-.26* <sup>c</sup>	–	3.57	2.17

Bivariate correlation coefficients were based on Spearman's Rho. \* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$  (two-tailed). Math grade was left in its original form: higher numbers mean worse grades. Gender (0 = male; 1 = female) <sup>a</sup>  $n = 110$ , <sup>b</sup>  $n = 107$ , <sup>c</sup>  $n = 97$ , <sup>d</sup>  $n = 95$

### 3.2.3 Math-competence

We used pupils' math grade in their last school certificate as a proxy for math competence as reported by the teacher (similar to Musch & Bröder, 1999), ranging from 1 = very good (A) to 6 = fail (F).

### 3.2.4 Later test performance (after three months)

The Appendix A depicts the four new test problems, which required formulating, calculating, and plotting linear functions. Created for the purpose of this study, the problems were chosen in co-operation with math didactics. Two independent rater coded pupils' answers (see the Appendix A for the correct solution and coding scheme. Note, in case the correct solution was derived based on an alternative approach as the depicted one, we still awarded the respective points). At a maximum, 14 points could be achieved, if all answers were correct. The minimum score was 0. The agreement between both raters was very high with an intra-class correlation coefficient of  $r = .99$ ; any remaining discrepancies between both raters were resolved. The pupils had rated the test to be difficult ( $M = 2.29$ ,  $SD = 0.98$ ) on a scale from 1 (= very difficult) to 5 (= very easy) and had been confronted with linear functions in the math curriculum for the very first time; thus, the average performance was low ( $M = 3.56$ ,  $SD = 2.16$ ).

## 4 Results

Prior testing the proposed interaction effect, we looked at the bivariate correlations of math anxiety, math competence and later mathematical performance (Table 1). Math anxiety moderately and negatively related to later test performance ( $r = -.40$ ); and explained 16% of the criterion variance. The math competence indicator (math grade) also moderately and negatively correlated with later test performance ( $r = -.28$ ), explaining 8% variance. The partial correlation of math anxiety and

later test performance, when the effect of math grade is removed, was  $r = -.24$ ,  $p = .02$ , two-tailed,  $n = 92$ . Vice versa, math competence and later performance had an association of  $r = -.26$ ,  $p = .01$ , two-tailed,  $n = 92$ , when math anxiety is partialled out. This suggests that both have an independent effect on later performance, although math anxiety and math grade were sizably interrelated ( $r = 0.51$ ) and shared 26% variance. However, we are interested in the combined effect and posit that their interplay holds predictive power beyond their individual contributions.

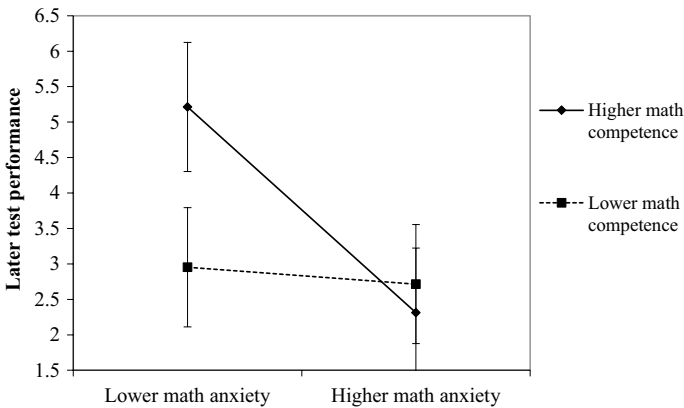
Therefore, we conducted hierarchical regression analyses with later test performance (after three months) on linear functions as criterion variable. As predictor variables, Model 1 included pupils' math anxiety score and pupils' math grade in the previous school certificate as an indicator of their math competence. Both predictor variables were centered to allow for meaningful interpretations of the main effects. Model 2 entailed both predictors and additionally the interaction effect (centered). Model 3 included two control variables: the centered math self-concept score and gender. An overview of the results of the models of the hierarchical regression is depicted in Table 2.

These control variables were chosen for theoretical and empirical reasons. Math anxiety and math self-concept are closely related, and both have been shown to predict learning outcomes (Ahmed et al., 2012). The interplay of gender, math anxiety, and test performance is documented and thus of relevance (Devine et al., 2012; Hembree, 1990). The pattern of intercorrelations in Table 1 shows that the inclusion of all variables for control purposes is warranted.

Model 1 explained 21% variance in later test performance  $F(2, 85) = 11.35$ ,  $R^2 = 0.21$ . Given that math anxiety alone explained 16%, this amounts to about 5% more variance accounted for when math competence is considered, too. Both, math anxiety,  $B = -0.48$ ,  $SE = 0.24$ ,  $t(85) = 2.00$ ,  $p = .049$ , 95% CI  $[-0.95, -0.002]$ ,  $sr^2 = .04$ , and math competence,  $B = -0.62$ ,  $SE = 0.23$ ,  $t(85) = 2.66$ ,  $p < .01$ , 95% CI  $[-1.08, -0.16]$ ,  $sr^2 = .07$  predicted later test performance. Although math anxiety's  $p$ -value is 0.05, it must be noted that this is two-tailed with an  $n$  of 87; together with the partial correlations based on  $n = 92$  described above, math anxiety and math competence seem to be independent predictors. Moreover, multi-collinearity is unlikely to be a problem as the variance inflation factor (VIF) was 1.37 with a tolerance of 0.73.

Given centering, the effect of math anxiety is to be interpreted for the average math grade, which was 3 and means satisfactory (C): As math anxiety increased by one unit at the level of the average math grade, later test performance was lower by about half a point. Vice versa, at the average level of test anxiety, a worse math grade predicted about a 2/3-point lower test performance score. However, central to this research is the interplay of math anxiety and math competence.

Therefore, Model 2 contained both predictors and the interaction term: We found a significant main effect of math anxiety,  $B = -0.75$ ,  $SE = 0.24$ ,  $t(84) = 3.16$ ,  $p = 0.02$ , 95% CI  $[-1.22, -0.28]$ ,  $sr^2 = .08$ , and math grade,  $B = -0.49$ ,  $SE = 0.22$ ,  $t(84) = 2.18$ ,  $p < .05$ , 95% CI  $[-0.93, -.04]$ ,  $sr^2 = 0.04$ , as well as the expected interaction effect,  $B = 0.75$ ,  $SE = 0.21$ ,  $t(84) = 3.53$ ,  $p < .001$ , 95% CI  $[0.33, 1.18]$ ,  $sr^2 = .10$ , indicating that the effect of math anxiety was moderated (see Fig. 2). Model 2



**Fig. 2** Later Test Performance (after 3 Months) by Two-Way Interaction of Math Anxiety and Math Competence. Note. Error bars represent the 95% CI

**Table 2** Hierarchical regression explaining later test performance (after 3 Months)

Variable	Model 1	Model 2	Model 3
Math anxiety	-.48†	-.75**	-.49
Math competence	-.62**	-.49*	-.43
Math anxiety* <i>math competence</i>		.75***	.69**
Math self-concept (C)			.21
Gender (C)			-.55
<i>R</i> <sup>2</sup>	.21	.31	.33
Adjusted <i>R</i> <sup>2</sup>	.19	.29	.29
$\Delta F$	11.35**	12.49***	1.23
$\Delta R^2$	.21	.10	.02

*n* = 87, regression coefficients show the unstandardized and centered beta coefficients, †*p* = .05, \**p* < .05; \*\**p* < .01; \*\*\**p* < .001, two-tailed. C = control variable. Math competence is based on math grade, higher numbers mean worse grades. Gender (0 = male; 1 = female)

explained 31% variance in later test performance,  $F(3, 84) = 12.76, R^2 = .31$ . Multicollinearity was of no concern in this model, as the VIF ranged between 1.12 and 1.41 with respective tolerances of 0.89 and 0.71. The change in explained variance between Model 1 and Model 2 by about 10% was significant  $\Delta F(1, 84) = 12.49, p < .001$ .

To test the nature of this interaction, we decomposed the interaction by simple slope analyses by means of regression. Recap, we hypothesized that later test performance after three months should be affected more negatively for more capable pupils with math anxiety than for less capable students with math anxiety: The relationship between prior competence and later performance should be moderated by math anxiety such that the competence—performance link is attenuated for highly math anxious persons. We found that for lower levels of math anxiety, math competence

was a significant predictor,  $B = -1.11$ ,  $SE = 0.27$ ,  $t(91) = 4.13$ ,  $p < .001$ , 95% CI [-1.64, -0.58],  $sr^2 = .13$ . As math competence decreased ( $-1SD \approx$  grade 4  $\approx$  C-/D+), so did later performance; and accordingly, increased competence ( $+1SD \approx$  grade 2  $\approx$  B) translated to higher performance later on provided low levels of math anxiety. In contrast, for higher levels of math anxiety competence was no longer a significant predictor of later performance,  $B = 0.19$ ,  $SE = 0.32$ ,  $t(91) = 0.58$ ,  $p = .56$ , 95% CI [-0.45, 0.82],  $sr^2 = .00$ . Irrespective of the math competence level, those higher in math anxiety scored equally low. We interpret this to indicate that the later performance of students with higher competence levels was dampened by higher levels of math anxiety (This interpretation is contemplated in the discussion section).

To bolster these results, we included two important control variables in Model 3: the centered math self-concept score and gender (0 = male; 1 = female).<sup>3</sup> Model 3 explained 33% variance in later test performance  $F(5, 82) = 8.19$ ,  $R^2 = .33$ , which was about 2% more than Model 2,  $\Delta F(2, 82) = 1.23$ ,  $p = .30$  and therefore did not add predictive power. Of the control variables, neither math self-concept,  $B = 0.21$ ,  $SE = 0.36$ ,  $t(82) = 0.58$ ,  $p = .56$ , 95% CI [-0.50, 0.92],  $sr^2 = 0.00$ , nor gender (female compared to male),  $B = -0.55$ ,  $SE = 0.43$ ,  $t(82) = 1.27$ ,  $p = .21$ , 95% CI [-1.40, 0.31],  $sr^2 = 0.01$ , were significant. The interaction, however, remained significant,  $B = 0.69$ ,  $SE = 0.22$ ,  $t(82) = 3.15$ ,  $p = .002$ , 95% CI [0.26, 1.13],  $sr^2 = .08$ . Multicollinearity indices varied between 1.19 (VIF) for the interaction and 4.39 (VIF) for math self-concept.

## 5 Discussion

### 5.1 Overall summary of rational and results

The present paper focused on the interplay of pupils' math competence (as math grade in their previous school certificate) and math anxiety prior learning new math content on linear functions with respect to their test performance on linear functions three months later. We explored whether (trait) math anxiety's negative effects on learning and later performance interacted with pupils' mathematical competence. We expected that the relationship between prior competence and later performance should be moderated by trait math anxiety. The later test scores of more competent students with higher levels of math anxiety should be lower than the test scores of more competent students with lower levels of math anxiety.

Indeed, we found a moderation effect of math competence on performance three months later depending on pupils' level of trait math anxiety. For lower levels of math anxiety, prior math competence was a significant predictor, while for higher levels of math anxiety, prior math competence was not a significant predictor. The interaction effect remained despite controlling for math self-concept and gender (as well as, in an exploratory manner, for previous topic-specific performance). The

<sup>3</sup> Entering math self-concept and gender each in separate models did not change the interaction effect neither did any other order, combination, or in-/exclusion of the control variables: the interaction effect of math anxiety and math grade remained always  $p < .01$ .

predicted moderation showed differential slopes for effects of math competence on performance depending on math anxiety: At lower competence levels, math anxiety's effects played a lesser role than for higher competence levels. Later performance was lower for more competent pupils with higher math anxiety relative to their peers with similar competence levels but lower math anxiety.

We investigated our proposition based on 8th graders in secondary school with curricular content on linear functions as an integral part of a larger study on long-term learning (see also Reinhard et al., 2019). On the one hand, previous experimental studies being concerned with the interaction of math anxiety and cognitive aspects, often lacked the long-term perspective (e.g., Ashcraft & Kirk, 2001; Ramirez et al., 2013; exception e.g., Vukovi et al., 2013). These studies were concluded within a few sessions or a single day. On the other hand, important longitudinal studies often focus on the association and causal ordering of (trait) math anxiety and math competence rather than their interaction effects (e.g. Cargnelutti et al., 2017; Ma, & Xu, 2004; exception Krinzinger et al., 2009).

Thus, the embedding as part of a larger study helped to realize the goal of investigating the interaction effects on performance later on. The time component allowed directionality (although not causality): Pupils' math grade in their previous school certificate covered a period of six months prior to our assessment of trait math anxiety; Pupils' math anxiety was measured prior to learning about linear functions; and pupils' later performance was measured three months after the assessment of trait math anxiety. The embedding came with the additional advantage of having a topic-specific performance variable from the beginning of the learning phase three months earlier (stemming from the first in-class session): This allowed a further exploratory test of the proposed interaction effect (see [Appendix B](#)).

To summarize, we captured pupils' trait math anxiety, math self-concept, and math competence prior to learning about linear functions, and tested them on a problem set on linear functions three months later. Consequently, we obtained the predicted interaction effect; a finding, which we could hedge against the alternative variables of math self-concept and gender (as well as—explorative—previous topic-specific performance).

## 5.2 Limitations

Prior to delineating the implications of our findings, the following paragraphs will discuss some details and caveats of the present research. One aspect that needs to be addressed concerns the use of pupils' math grade in their last school certificate as proxy for their math competence (cf. Musch & Bröder, 1999). It could be argued that math grades samples more generally the mastery of the learned content regarding a broad range of math topics over a longer period of time. Math grades may be less prone to short-term performance fluctuations in a single test. However, math grades are the results of cumulated tests, and testing per se may lower the math grades of certain students, which are those who have mastery but are blocked by the testing situation (Faust et al., 1996; Naveh-Benjamin et al., 1987). If so, the math grade underestimates their actual competence level. Nevertheless, the problem of

confounding the assessment of math abilities by testing is inherent and hard to separate. Thus, the dependent variable (resulting from a test) would be biased, too.

One may, however, argue that the testing bias is stronger in math grades—as teachers' math tests have real world consequences, while this is not the case for our test. Such a constellation would make (theoretically) the interaction effect harder to obtain. Since we found an interaction nonetheless, this may speak in favor of our findings. Though, future research may assess pupils' math skills based on common aptitude tests and administer it in a less-threatening manner or control for test anxiety. It is necessary to replicate our results based on a larger sample, across different grades and school forms with other math competence indices. It also could be interesting to re-analyze existing data sets in order to further scrutinize the interaction effect and to obtain a better quantification of the short- and long-term “costs of math anxiety” for performance and learning.

Moreover, the testing bias may be more of a concern for short-term studies. The long-term approach is the strength of this design. It allows tapping into the effects of math anxiety, which exert its influences on the learning process over time, when no testing takes place, for example how students (motivationally) engage in math classes and deal with difficulties in solving math problems (Skaalvik, 2018), how often they complete homework or how intensively they prepare for math tests. Consequently, our findings represent meaningful relationships of trait math anxiety and learning beyond the limitation of the testing situation as confound.

Such an argument also correspond to findings that the effects of math anxiety on performance outcomes remained irrespective of test anxiety considerations (Devine et al., 2012). For example, math anxiety goes along with neurological and behavioral avoidance reactions to math content: Highly math anxious individuals strive for less exposure to math content and less time spent therewith (Ashcraft, 2002; Ashcraft & Faust, 1994; Ashcraft & Krause, 2007; Lyons & Beilock, 2012; Meece et al., 1990). These avoidance mechanisms may be at play for math anxious students, whose performance may not be affected by tests. Avoidance mechanisms may be more important in the long run and compliment short-term mechanism, such as working memory impairments, which may impede the most qualified individuals to succeed (Beilock & Carr, 2005).

Avoidance mechanism as potential mediator for the unfavorable relation of math competence, math anxiety, and later performance are also of interest due to their association with prior math grades, math anxiety, and self-protective coping mechanisms (Skaalvik, 2018): While math grades were not directly associated with problem-focused coping (an advantageous strategy to handle difficulties in solving math problems) or self-protective coping (a less functional strategy), math grades were indirectly linked via performance avoidance and math anxiety to self-protective coping. Performance avoidance correlated (moderately) positively with self-protective coping and with (trait) math anxiety. Such findings open up the possibility that higher math anxiety, by links to avoidance motivation and disadvantaged coping strategies, may depress learning (long-term) despite sufficient math competence.

Another aspect regarding math grade, which needs attention, concerns a potential misunderstanding of the results. We refer to those of “higher competence” and those of “lesser” competence. This phrasing is intentional and should emphasize the

relational character of the statements. It is not to be (mis-)understood in absolute terms, we explicitly do not make statements about the most competent pupils. In our sample and analyses, we refer to those of lesser competence as pupils one standard deviation below the mean (with a math grade of  $4 \approx C-/D+$ ) and of higher competence as pupils one standard deviation above the mean (with a math grade of  $2 \approx B$ ). Therefore, it would be incorrect to generalize our results to the lowest or highest performing students in math. Our pattern of results is, however, similar to a sub-group analysis of the PISA-data for pupils with a test performance in the 10th percentile relative to the 90th percentile (OECD, 2013): “On average across OECD countries, the performance difference that is associated with a change of one unit in the index of mathematics anxiety is 37 points among the highest-achieving students but only 28 points among the lowest-achieving students (p. 103)”. For the German-speaking countries, this difference is less dramatic, and rather subtle (a few points), but significant. Overall, among the highest-achieving pupils, those with less math anxiety demonstrated a greater performance advantage. For the lowest-achieving students, math anxiety had a smaller performance disadvantage. In PISA, a 34-score difference in points has been described as representing the equivalent of almost one school year, so on average, 10 points may be interpreted as being four months behind.

Despite the PISA results matching our findings, there is an important difference when thinking about the data. PISA shows an association, while our design can establish a directional link (but not causality): Pupils math grade in their last school certificate reflected the previous six months of math lessons prior to our measurement of trait math anxiety (after which three months passed before assessing the later test performance). Caution when comparing is also necessary with respect to procedural differences. For example, teachers tend to repeat contents and prepare their pupils prior to the PISA examination, which was not the case for our performance test. Our performance test can be interpreted as what is learned and forgotten about linear functions, without further preparation and when the class curriculum continued as usual. Note that our later performance test on linear functions was weeks after the teacher’s section test on linear functions when they already had started new content. In this respect, it is less surprising that the overall performance level was low and rather at the bottom. The pupils reported the test to be difficult and it was the first time for the pupils to learn about linear functions in the school curriculum.

The gist of our findings is that trait math anxiety’s effect on learning differs depending on pupils’ prior competencies (as indicated by math grade). We (cautiously) interpret the observed interaction effect to mean that the later performance of students with higher competence levels was dampened by higher levels of math anxiety. Only more competent students lower in math anxiety showed the highest long-term performance scores. Higher levels of math anxiety may be “costly” especially for students, who, according to their competence level, should perform better than their less competent counterparts, but underachieve due to their math anxiety. This concurs with the idea that those who can gain more also can lose more. As such, those pupils with elevated math anxiety, who should be able to advance their math competences, showed the greatest performance “losses” later on (relative to

their low-anxiety counterparts). Said differently, the findings suggest that competent but math anxious students, may progress less than would be expected. Note, albeit this is a plausible interpretation, the implied causality in this interpretation cannot be derived from the research design or the data (only the directionality).

The interpretation of our findings is debatable. The observed interaction effect, due to its multiplicative computation, would also allow an interpretation that the lack of math anxiety provides a performance boost to more competent students. Although possible, we think that this is unlikely to be the case. By means of practical reasoning, eliminating math anxiety in the term math anxiety\**math competence* leaves competence. One cannot perform beyond one's competence levels. In other words, when eliminating a negative factor, one cannot perform better than one's own competence. Moreover, our interpretation of the interaction effect is theory-driven, and accounts of math anxiety do not suggest math anxiety to have boosting effects but suppressor effects. Therefore, we conclude that the pupils, who should be able to advance their skills, may be negatively affected the most by math anxiety. Optimal performance seems to be tied to low math anxiety and good math abilities. The pupils who underachieve and miss to unfold their full potential may be the more promising ones.

### 5.3 Implications

From a broader perspective, the present research contributes to the question: How does math anxiety negatively influence math achievements in the long run? One interpretation of our findings may suggest that it gets in the way of developing one's math skills by reducing the learning progress. The potential "costs of math anxiety" over time are unfortunate when considering a potential feedback loop (which is debated, Carey et al., 2016): Math anxiety may not only be influenced by previous math competence, but math anxiety and math competence might interact and lower one's future math competence, which in turn may heightens one's math anxiety (cf. Ma & Xu, 2004). Such a vicious cycle may carry into adulthood and contribute why many STEM-subjects are avoided (Beilock, & Maloney, 2015), even by individuals, who would have had the potential. The earlier the cycle starts, the less reversible its effects may become. It may lead to more serious emotional, motivational, effort and ability related obstacles. However, reciprocal effects are debated, and the interplay of math anxiety and math competence is not well understood. Much more longitudinal and developmental studies are needed.

In this respect, it is unclear at which time point math anxiety's influence on performance emerges, whether math anxiety is a consequence or cause of lower math abilities, or when mutual influences evolve over time. Research in elementary school between 1st and 3rd grade yields inconsistent findings. Some (longitudinal) studies do not find an early math anxiety—performance link (Dowker et al., 2012; Krinzinger et al., 2009), while some (cross-sectional) do (Wu et al., 2012, 2014), and yet others found a qualification of this link being only tied to pupils with higher working



memory capacity (Ramirez et al., 2016; Vukovic et al., 2013). In later grades, the relationship is present (Devine et al., 2012; Ma, 1999).

These discrepancies regarding the onset, the direction, and the reciprocal development have implications for when a potential interaction effect of math competence and math anxiety might be observable. At the early stages, the interaction might not exist. Math anxiety's effects are not yet stable. Thomas and Dowker (2000) suggest an increase of math anxiety over time, with math anxiety apparently peaking around the 8th/9th grade (Ma & Xu, 2004; Wigfield & Meece, 1988). In these grades, a reciprocal relationship between math anxiety and math achievement can be found (Ma & Xu, 2004). As such, 7th to 9th grade seems to be a critical period of time in which to look for potential interactions. At this time, math anxiety may contribute to the perpetuation of previous ability and performance deficits, as well as to an underachievement and reduced progress of principally capable pupils.

Although it is generally desirable to recognize and reduce trait math anxiety and math competence deficits (for an overview of treatments see Dowker et al., 2016; Furner & Berman, 2003; Hembree, 1990; Maloney & Beilock, 2012), it may therefore be necessary to do so early on with respect to more promising students. Developing their mathematical resilience and regulation and coping skills may be beneficial (e.g., Ader & Erktin, 2010; de la Fuente et al., 2015; Lee and Johnston-Wilder, 2017; Putwain et al., 2013). Mild to moderate improvements may put trait math anxious students in a position to take advantage of their anxiety (Wang et al., 2015). In the long run, they might benefit the most from interventions.

For successful long-term development of math abilities, it may not be sufficient to reduce trait math anxiety. Situation-induced math-anxiety by stereotype threat reduced (short-term) math performance of students with low trait test anxiety to levels of students with high habitual test anxiety (Tempel & Neumann, 2014): The lowest performance was the result of anxiety, irrespective of whether the performance suppression was due to temporarily induced state-anxiety or permanent trait anxiety. This has implications for trainings. The reduction in one source of anxiety (state or trait) may not translate to immediate or long-term performance gains, because otherwise the effects of the other source of anxiety could take effect; and both could have unique negative consequences, either in terms of immediate cognitive interference impairments or later long-term deficits due to, for example, avoidance motivations (e.g., Ashcraft & Krause, 2007; Skaalvik, 2018).

## 6 Conclusion

Given similar competence prerequisites, trait math anxiety appears to negatively relate to learning and performance over time. One interpretation is that trait math anxiety may deprive students of developing their math abilities to their full potential, especially for those, for which mastery is not beyond their abilities, but beyond their fear. The interplay of trait math anxiety and math abilities seems to go beyond a mere reciprocal relationship being quantitatively similar across different levels of math competence. Instead, long-term effects on later performance appear to be qualified in a way similar to a moderation effect of math anxiety and working-memory

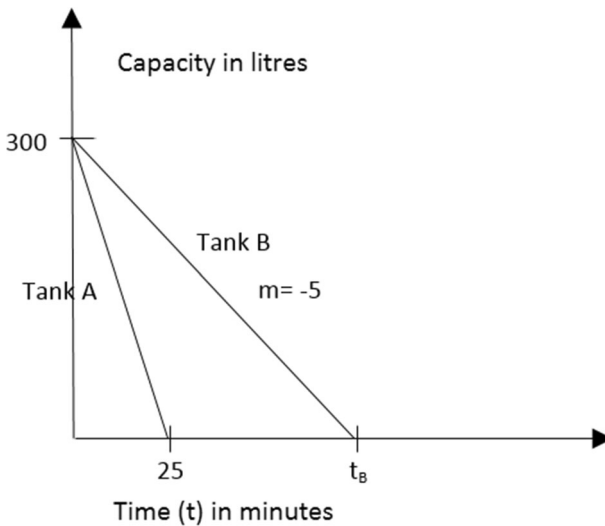
on short-term performance. Future studies may further scrutinize this interaction effect and reanalyze existing data sets examining the differential “costs of math anxiety” for pupils at varying levels of math competence.

## Appendix A

Mathematical problems of the performance test after 3 months

1. The diagram shows the pumping process of two tanks A and B.
  - a. Which tank is emptied with the stronger pump?

Answer: Tank A (1 point).



- b. Calculate how many litres per minute are being pumped from tank A.

$$m = \frac{300 - 0}{25 - 0} = 12 \text{ (1 point)}$$

- c. How many minutes does it take to empty tank B? Calculate  $t_B$ .

$$\begin{aligned} y &= -5x + 300 \\ 0 &= -5x + 300 \\ -300 &= -5x \\ x &= 60 \text{ (1 point)} \end{aligned}$$

2. A baker has fixed monthly costs of 495,00 €. In addition, he expects material costs of 0,50 € per loaf of bread. He sells each loaf of bread for 1,60 €.
- a. Set up a functional equation for the fixed costs; and set up a functional equation for the price per loaf of bread.

$$y = 0.5x + 495 \text{ (1 point)}$$

$$y = 1.60x \text{ (1 point)}$$

- b. How many loaves of bread does he need to sell to break even?

$$0.50x + 495 = 1.60x$$

$$0.50x + 495 = 1.60x \quad | - 0.50x$$

$$495 = 1.10x$$

$$450 = x \text{ (1 point)}$$

3. Offers to develop photos:



Calculate which provider is cheaper depending upon the number of photos. Formulate a short answer to the question: “Up to which number of photos is which provider cheaper and when does it change, and the other provider is cheaper?” (take notes of all intermediate calculations).

$$y = 0.12x + 2.95$$

$$y = 0.17x$$

$$0.12x + 2.95 = 0.17x \quad | -12$$

$$2.95 = 0.005x \quad | :0.05$$

$$59 = x$$

$$(1 \text{ point})$$

Answer: Until 58 photos provider B is cheaper, they are even at 59 photos, and from 60 photos on provider A is cheaper.

$$(1 \text{ point})$$

4. There are three laid pipes supposed to be drawn into the sketch of a wall. The first pipe runs according to the equation  $y = 2,5x$ . The second pipe runs with a slope of  $m = 2$  beginning at the point of origin. The third pipe runs perpendicular to

the second pipe and intersects it at point P (1; 2). Tip: If two straight lines are perpendicular to each other, the formula  $m_1 \cdot m_2 = -1$  applies for the slope.

- a. Draw all three pipes into the coordinate system. (1 point for each of the three correct lines).



- b. Determine the equation for the line of pipes 2 and 3.

Pipe 2:  $y = 2x$  (1 point).

Pipe 3:  $y = -0.5x + 2.5$  (1 point).

- c. A craftsman wants to drill into points A (4.5; 3) and B ( $\frac{30}{20}$ ; 3) Can he do that without hitting a pipe?

Point B is hit: No (1 point).

## Appendix B

### Exploratory analysis: initial topic-specific test performance

Our measure of later performance after three months is specific to a particular topic (linear functions). The embedding within a larger study allowed the possibility to exploratorily include an initial measure of topic-specific performance at the beginning of the learning phase three months earlier as control variable. The pattern of

**Table 3** Bivariate correlations, means, and standard deviations of predictor, criterion, and control variables with initial topic-specific test performance

Variable	Initial topic-specific test performance
Math anxiety	-.38*** <sup>b</sup>
Math grade	-.45*** <sup>a</sup>
Math self-concept	.48*** <sup>b</sup>
Gender	-.11 <sup>a</sup>
Later test performance (after 3 months)	-.47*** <sup>c</sup>

Initial topic-specific test performance:  $M=19.07$ ,  $SD=7.90$ . Bivariate correlation coefficients were based on Spearman's Rho. \*\*\* $p < .001$  (two-tailed). Math grade was left in its original form: higher numbers mean worse grades. Gender (0 = male; 1 = female)<sup>a</sup>  $n = 102$ , <sup>b</sup>  $n = 99$ , <sup>c</sup>  $n = 90$

**Table 4** Hierarchical regression explaining later test performance (after 3 Months)

Variable	Model 4
Math anxiety	-.46
Math competence	-.25
Math anxiety* <i>math competence</i>	.61**
Math self-concept (C)	.07
Gender (C)	.47
Initial topic-specific test performance (C)	.08**
$R^2$	.39
Adjusted $R^2$	.35
$\Delta F$	8.06**
$\Delta R^2$	.06

For Model 1, Model 2, and Model 3, see Table 2 of the main text,  $n = 87$ , regression coefficients show the unstandardized and centered beta coefficients, \*\* $p < .01$ ; two-tailed. C=control variable. Math competence is based on math grade, higher numbers mean worse grades. Gender (0 = male; 1 = female)

intercorrelations below in Table 3 shows that the inclusion for control purposes is sensible.

Table 4 depicts Model 4, which includes (centered) math anxiety, (centered) math performance, and its interaction effect, as well as both previous control variables (centered math self-concept and gender); it is extended by the centered topic-specific initial test performance three months earlier. Model 4 explains 39%,  $F(6, 81) = 8.75$ , which is 6% more as Model 3,  $\Delta F(1,81) = 8.06$ ,  $p < .01$ . But most importantly, even when controlling for an earlier test performance on a related content,  $B = 0.08$ ,  $SE = 0.03$ ,  $t(81) = 2.84$ ,  $p < .01$ , 95% CI [0.02, 0.14],  $sr^2 = .06$ , the interaction of math anxiety and math competence was robust,  $B = 0.61$ ,  $SE = 0.21$ ,  $t(81) = 2.88$ ,  $p = 0.005$ , 95% CI [0.19, 1.03],  $sr^2 = .06$ . Multicollinearity indices varied between 1.21 (VIF) for the interaction and 4.48 (VIF) for math self-concept.

## Further exploratory analyses

Note the difference across time in initial test performance in Test A (see Fig. 1) and later test performance in Test A three months later (see Fig. 1) is the focus of another paper (see Reinhard et al., 2019) and therefore this performance difference or the later test performance in Test A after three months is *not* of interest as dependent variable for the paper's research question. Even when conducting the analyzes described in the results section of the main text with later test performance in Test A as dependent variable (which we did not plan on doing), we find the interaction effect: Model 2,  $B = 2.98$ ,  $SE = .80$ ,  $t(84) = 3.71$ ,  $p < .001$ , 95% CI [1.38, 4.57]. The interaction remained significant when entering the control variables, Model 3,  $B = 2.86$ ,  $SE = .82$ ,  $t(82) = 3.22$ ,  $p = .002$ , 95% CI [1.01, 4.28], Model 4,  $B = 2.04$ ,  $SE = .66$ ,  $t(81) = 3.08$ ,  $p = .003$ , 95% CI [0.72, 3.35]. Likewise, if we conduct further exploratory analyses and compute a rANOVA with the Test A performance across time, condition, math anxiety and math competence and its interaction as well as all other interaction terms, we still find the 2-way interaction effect of math anxiety and math competence,  $F(1,84) = 8.88$ ,  $p = .004$ ,  $\eta^2 = 0.10$ . Importantly, we found a three-way interaction of math anxiety, math competence and time,  $F(1,84) = 5.82$ ,  $p = .018$ ,  $\eta^2 = .07$ : Math anxiety and math competence did not interact to predict initial topic-specific test performance,  $F(1,84) = 1.64$ ,  $B = 1.30$ ,  $SE = .79$ ,  $p = .104$ , 95% CI [-.27, 2.88],  $\eta^2 = .03$ , but interacted to predict later topic-specific test performance after three months,  $F(1,84) = 3.71$ ,  $B = 2.98$ ,  $SE = .80$ ,  $p < .001$ , 95% CI [1.38, 4.57],  $\eta^2 = .14$ , underscoring an interpretation in line with the moderation effect unfolding over longer time periods.

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