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Characterizing Mathematics Anxiety and Its Relation to Performance in Routine and Adaptive Tasks

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Abstract

Mathematics anxiety hinders students' mathematical achievement already in primary school, but research on its effects beyond whole number knowledge is limited. The main aim of the current study is to examine how state and trait mathematics anxiety relate to performance across five tasks that are relevant for the development of mathematics in primary school, including a measure of adaptive expertise with school mathematics. These include mathematical tasks with non-symbolic quantities, whole numbers, and rational numbers. The participants were 406 primary school students attending the 5th grade (N = 188) and 6th grade (N = 218). Our results showed that state anxiety varies across task type. Furthermore, students' self-evaluated state and trait mathematics anxiety had varying negative relations with performance depending on the task type. In particular, we found that mathematics anxiety may limit students' adaptive expertise with rational numbers, even after controlling for other relevant mathematical skills. Overall, our results indicate that existing accounts on the role mathematics anxiety plays in school mathematics should expand to consider differences across task type and measures of anxiety.

Keywords

mathematics anxiety, spontaneous mathematical focusing tendencies, rational number, adaptive expertise, primary school

Mathematics anxiety is a potential barrier to students' mathematical achievement (Barroso et al., 2021; Namkung et al., 2019). Research in primary school students has traditionally focused on mathematics anxiety in relation to whole number knowledge. Even though rational number knowledge is a crucial feature of mathematical development that many students struggle with (Siegler & Pyke, 2013), little is known about the role of mathematics anxiety in rational number knowledge. This gap in research is problematic as the relations between mathematics anxiety and performance may not be the same across tasks. For instance, mathematics anxiety differs in response to task characteristics such as mathematics difficulty (Trezise & Reeve, 2018). In addition, mathematics anxiety could affect the ability to flexibly apply well-connected procedural and conceptual knowledge in solving novel tasks, referred to as adaptive expertise (Baroody, 2003; Verschaffel et al., 2009). Thus, the present study aims to examine the relation between mathematics anxiety and performance on a wide variety of mathematical tasks beyond whole number knowledge, such as adaptive expertise with rational numbers. This will provide a first glimpse into how mathematics anxiety may be related to adaptive expertise in primary school mathematics.

Mathematics Anxiety

Mathematics anxiety refers to negative feelings about mathematics-related situations and tasks (Ashcraft & Moore, 2009; Foley et al., 2017). It negatively correlates with students' mathematical performance already in primary school (Ramirez et al., 2016; Sorvo et al., 2017; Vukovic et al., 2013). Some studies have found that higher mathematics anxiety leads to lower mathematical performance and vice versa, with recent reviews suggesting a bidirectional mathematics anxiety-performance relation (Carey et al., 2016; Foley et al., 2017). One way mathematics anxiety may impair mathematics performance is by depleting cognitive resources, such as working memory (Ashcraft & Kirk, 2001; Ramirez et al., 2013; Vukovic et al., 2013). For instance, the need for higher cognitive resources in complex tasks combined with the reduced cognitive resources from mathematics anxiety may over-burden students' cognitive functioning. This may explain why negative effects of mathematics anxiety are greater for more complex and advanced mathematical skills than foundational skills (Caviola et al., 2022; Namkung et al., 2019; Trezise & Reeve, 2018). In this regard, mathematics anxiety is expected to be related to performance more negatively on tasks requiring complex mathematics skills.

Research examining mathematics anxiety has differentiated between trait and state mathematics anxiety. Trait mathematics anxiety is a tendency to feel anxious about mathematics while state anxiety is the anxiety experienced in a given mathematics-related situation (Conlon et al., 2021). Typically, self-reported questionnaires are used to assess trait mathematics anxiety. Individuals with higher trait mathematics anxiety have more inaccurate and slower mathematics performance than less anxious individuals (Ashcraft & Kirk, 2001; Chan & Tang, 2020). In contrast, state mathematics anxiety is typically assessed while completing a mathematics task. Studies examining state mathematics anxiety have shown students' state anxiety can vary in response to mathematics problem difficulty and time pressure (Trezise & Reeve, 2018). Thus, it is possible that the mathematics anxiety-performance relation varies in response to other differences in tasks.

There has been little examination of these more nuanced effects of mathematics anxiety across task types, especially in primary school. The mathematical content of the task is one feature that may affect students' state anxiety responses. For example, rational numbers are recognized as one of the most challenging topics to learn in primary school (Lortie-Forgues et al., 2015). Compared to whole numbers, primary school students have less positive attitudes towards fractions (Sidney et al., 2021) and problem solving with rational numbers is cognitively more demanding (Begolli et al., 2018). Additionally, studies into the mathematics anxiety-performance relation are generally done in explicitly mathematical contexts, such as arithmetic or algebraic problem solving (e.g., Sorvo et al., 2017; Trezise & Reeve, 2014; Vukovic et al., 2013). Thus, little is known about how mathematics anxiety manifests in contexts where the mathematical features of the task are less explicit. Finally, Verschaffel et al. (2009) suggested that affective factors, such as mathematics anxiety, might affect adaptive expertise with mathematics. Given that mathematics anxiety changes over the course of learning (Vollman et al., 2022), state mathematics anxiety may vary between routine tasks and tasks that require applying knowledge in novel ways. Thus, in the present study, we examine students' mathematics anxiety responses in a range of mathematical tasks relevant for the development of mathematical skills in primary school.

Mathematics Anxiety and Task Performance

Meta-analyses have shown that mathematics anxiety is negatively associated with students' performance across different types of mathematical knowledge (Caviola et al., 2022; Namkung et al., 2019). However, research in primary school has mainly focused on whole number arithmetic knowledge. Thus, the current study expands examinations of the role of mathematics anxiety in primary school to focus on five tasks covering a range of arithmetic mathematical knowledge, including non-symbolic quantities, whole numbers, and rational numbers. These tasks include two novel measures, spontaneous focusing on quantitative relations (SFOR) and adaptive rational number knowledge. Their relation with mathematics anxiety has not been examined previously.

SFOR tendency is defined as the tendency of spontaneous (i.e., unguided) focusing of attention on and using quantitative relations in situations that are not explicitly mathematical (McMullen et al., 2014), such as everyday-like contexts. SFOR tendency may support self-initiated practice with applying quantitative relations in situations in and out of the mathematics classroom (McMullen et al., 2019). For example, noticing there are twice as many oranges as apples in a bowl or stating that 1/3 of the fruit are apples. SFOR tendency with multiplicative relations uniquely predicts the development of rational number knowledge (McMullen, Hannula-Sormunen, et al., 2016; Van Hoof et al., 2016), including adaptive expertise with rational numbers (e.g., McMullen et al., 2022). Importantly, SFOR tendency is not entirely explained by individual differences in students' ability to recognize and describe multiplicative relations when explicitly guided to do so (McMullen et al., 2014; McMullen, Hannula-Sormunen, et al., 2016). Thus, we also include a parallel, explicitly mathematical version of the SFOR task, in which students' are explicitly asked to describe mathematical aspects of an everyday-like situation, hereafter referred to as *guided multiplicative relations.* Including these two parallel tasks allows for the characterization of mathematics anxiety in recognizing and applying mathematical knowledge in everyday-like contexts. Furthermore, we can examine whether there is an effect of mathematical explicitness on mathematics anxiety.

Adaptive expertise in mathematics has been traditionally examined using behavioral manifestations of procedural flexibility (e.g., Torbeyns et al., 2006). We include a measure of adaptive expertise with rational number arithmetic known as adaptive rational number knowledge. More recently, adaptive number knowledge has been identified as another behavioral manifestation of adaptive expertise with arithmetic (Bakker et al., 2022; Hickendorff (2022, this issue); McMullen, Brezovszky, et al., 2016; McMullen et al., 2020). Adaptive number knowledge has been examined in relation to both whole number and rational number arithmetic, and found to require well-connected knowledge of numerical characteristics and arithmetic relations (e.g., McMullen, Brezovszky, et al., 2016; McMullen et al., 2020). Adaptive *rational* number knowledge has been argued to require the integration of multiple concepts and procedures (McMullen et al., 2020), such as understanding the relations between fraction magnitudes (e.g., 1/4 is less than 1/2), representations (e.g., 1/4 = 0.25), operations (e.g., multiplying by 1/2 leads to a smaller outcome), and arithmetic procedures (e.g., to multiply fractions you multiply the numerators together and the denominators together). Not all students who had high levels of routine procedural and conceptual rational number knowledge could apply this knowledge in the novel arithmetic sentence production task (McMullen et al., 2020). Given the complexity in integrating the rational number knowledge and the cognitive resources required, mathematics anxiety may be hindering some students from making the complex connections required for adaptive rational number knowledge.

Dispositional factors, such as mathematics attitudes, have been theorized as important sources of individual differences in adaptive expertise with school mathematics (Verschaffel et al., 2009). Trait mathematics anxiety may not be as relevant in distinguishing between adaptive expertise and high levels of routine knowledge, as high competence in mathematics is shown to predict lower trait mathematics anxiety (Gunderson et al., 2018). Accordingly, students who have the skills and knowledge required for adaptive rational number knowledge should generally have low trait anxiety. However, it is one thing to perform well-rehearsed tasks and another to apply one's knowledge in a novel task. Even students with high mathematical competence and low trait anxiety could still experience state anxiety during an adaptive mathematical task. Yet, there is little empirical evidence of the role of dispositional factors play in adaptive expertise in school mathematics. Thus, we examine whether state mathematics anxiety is related to task performance in adaptive rational number knowledge, after accounting for relevant mathematical skills and knowledge, including SFOR tendency (McMullen et al., 2022), guided multiplicative relations (McMullen et al., 2022), routine whole number arithmetic knowledge (Bakker et al., 2022), and routine fraction knowledge (McMullen et al., 2020).

The Present Study

The main aim of the current study was to expand the research of mathematics anxiety to cover a wide range of measures relevant for the development of mathematical knowledge in primary school. These tasks measure SFOR, guided multiplicative relations, whole number arithmetic knowledge, fraction arithmetic knowledge, and adaptive rational number knowledge We aim to contribute to the literature by examining how state anxiety manifests across the various tasks, including the relation between state and trait mathematics anxiety and performance, especially concerning performance on the measure of adaptive rational number knowledge.

We ask three questions:

1. What are the differences in state mathematics anxiety responses across tasks?

Studies have shown that state anxiety responses are affected by task characteristics such as difficulty and mathematics content (Caviola et al., 2022; Namkung et al., 2019; Trezise & Reeve, 2018). However, most studies on mathematics anxiety amongst primary school students examine whole number knowledge or mathematics composite scores (e.g., Orbach et al., 2020; Sorvo et al., 2017), and little is known about differences in state anxiety responses across mathematical tasks. Thus, we examined state anxiety responses between 5th and 6th grade students across five tasks relevant for primary school mathematical knowledge. We expected state anxiety responses to vary across these tasks, as differences in task characteristics affect state anxiety responses in older students (Trezise & Reeve, 2018).

2. What is the relation between (state and trait) mathematics anxiety and task performance across the tasks?

Mathematics anxiety, primarily measured as trait anxiety, is negatively associated with students' performance in different types of mathematical knowledge (Barroso et al., 2021; Namkung et al., 2019). However, there has been little research on the strength of the relations for trait and state anxiety on performance across tasks measuring various mathematical knowledge, especially in primary school. We expect a negative relation between state mathematics anxiety and performance on all the tasks. Furthermore, we examine whether state mathematics anxiety explains variance in task performance beyond trait mathematics anxiety.

3. Is state anxiety related to adaptive rational number knowledge after controlling for mathematical skills relevant for the task?

Even students with adequate routine knowledge may become anxious during a novel task and do not perform according to the level that could be expected based on their related mathematical skills. The mathematical skills relevant for adaptive rational number knowledge included in the present study are SFOR tendency, guided multiplicative relations, whole number arithmetic knowledge, fraction arithmetic knowledge, and fraction magnitude knowledge. Fraction magnitude knowledge is part of the routine conceptual knowledge required for adaptive rational number knowledge and is therefore included in this part of the analysis (McMullen et al., 2020). However, state anxiety was not measured for fraction magnitude knowledge, so it could not be included in the mathematics anxiety analyses.

Method

Participants

The participants were 406 primary school students attending the 5th grade (N = 188, 51% female) and 6th grade (N = 218, 50% female) from 27 Finnish-language classrooms (5th grade N = 12) within 10 schools. In both grades, 31% of the students had completed the ongoing academic year's fraction learning before testing. The mean (*SD*) age of the 5th grade students was 11.42 (0.3) years and of the 6th grade students was 12.39 (0.4) years. The schools were from two similar-sized urban municipalities in Southern Finland.

We received permission for conducting the study from the municipalities, principals, and classroom teachers. Written consent was obtained from the guardians of the students. Before conducting the testing, each student was informed that taking part in the study was voluntary and students were allowed to stop taking part in the study at any point. The ethical guidelines of the Finnish national board on research integrity (TENK) were followed.

Procedures

The testing was conducted on a digital platform and guided by participants' classroom teacher due to the COVID-19 situation. Students completed the test individually on their computer. Before each task, students received instructions for completing the task including how much time they had to complete the task. The duration of each task was limited to ensure that each participant spent the same amount of time per task, with a total duration of 34 minutes for the whole test. The measures were presented in the following order: SFOR tendency, trait mathematics anxiety, guided multiplicative relations, adaptive rational number knowledge, fraction magnitude knowledge, whole number arithmetic knowledge, and fraction arithmetic knowledge. After each task, except fraction magnitude knowledge, students were asked to rate the level of anxiety they experienced during the task, as a measure of state anxiety.

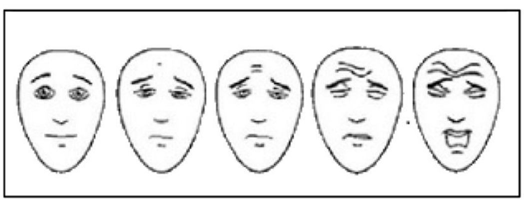
For measuring SFOR tendency, extra precautions were taken to ensure that the students were not aware of the mathematical nature of the test. The teachers were told not to mention mathematics prior to the first measurement point and the parental consent forms did not mention mathematics. Instead, the study was referred to as measuring thinking skills and study motivation.

Measures

Trait mathematics anxiety was examined with a questionnaire including nine statements of anxiety within mathematics (e.g., I feel anxious about mathematics; I get anxious when I have to complete mathematics homework; I get anxious when I have to do mental arithmetic). These specific statements were chosen to avoid statements involving similar characteristics with social or test anxiety. The scale was continuous from one to five (i.e., not at all to very much) with faces that changed from less anxious to more anxious (see Figure 1). The faces scale was adapted from Trezise and Reeve (2014). The average score for the nine items was used as the measure for trait anxiety. Cronbach's alpha for the measure was 0.94.

Figure 1

The Faces Scale for Trait and State Mathematics Anxiety



Note. Adapted from Trezise and Reeve (2014).

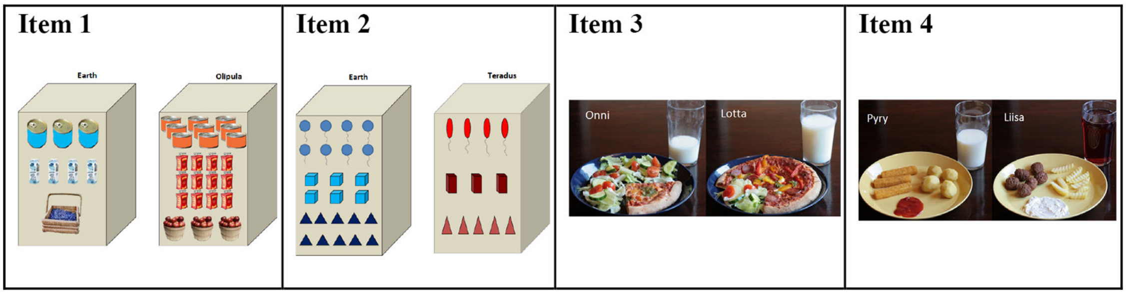
State mathematics anxiety was assessed after each task with a prompt to evaluate how much anxiety a student had experienced during the task, "How anxious were you while doing the previous task?" Students responded using the same continuous faces scale as in trait mathematics anxiety.

SFOR tendency was measured using two items from the teleportation task and two items from the plate task (McMullen, Hannula-Sormunen, et al., 2016). Each item includes two sets of objects that need to be compared (Figure 2). In the teleportation task, the objects all transform in shape, color, and quantity in a uniform way. In the plate task, the two meals differ in food items and quantities in a uniform way. The students were asked to describe the pictures in writing, e.g. "Describe how the objects have changed. Describe in as many ways as you can think of." The task measures a student's ability to notice multiplicative relations, including fractions, without being guided to do so. The students had two minutes to complete each item. One point was given for each description of a multiplicative relation whether or not it was mathematically accurate (e.g. writing four times as many cans instead of three times, or 1/3 of the pizza instead of 1/4). Cronbach's alpha for the task was 0.60.

Guided multiplicative relations was measured with four items adapted from the SFOR tendency measures. The items were one teleportation task item and one plate task item from the SFOR tendency task and two novel items with photos of everyday situations (Figure 3). Students were asked to compare objects in the pictures and the mathematical nature of the task was made explicit, for example "Compare mathematically how the objects have changed. Compare them in as many ways as you can think of." This measures a student's ability to recognize and describe multiplicative relations in an everyday context when guided towards mathematical features. The students had 1.5 minutes to complete each item. One point is given for each description of a multiplicative relation or fraction (e.g., "one third (or 1/3 or one out of three) of the cars is black," "there are twice as many black cars as white cars", "the pastry is being cut in half"). There was no maximum limit but the highest achieved score on an item was 6 points. Cronbach's alpha for the task was 0.53.

Figure 2

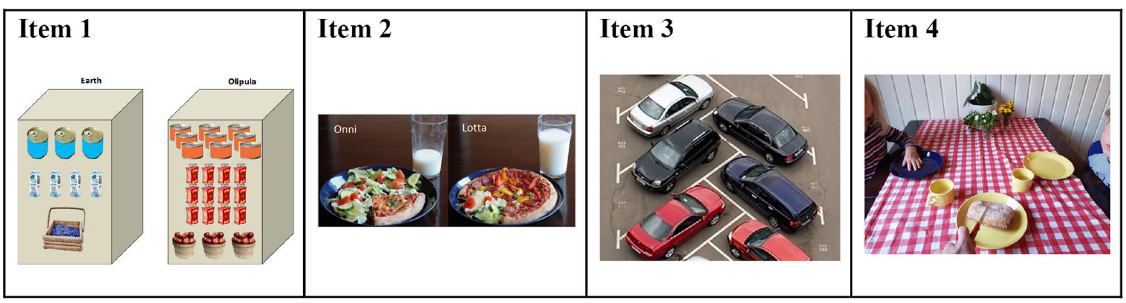
SFOR Tendency



Note. Items 1 and 2 are from the teleportation task with the teleported material on the right, and Items 3 and 4 are from the plate task.

Figure 3

Guided Multiplicative Relations



Note. Item 1 is the teleportation task with the teleported material on the right, Item 2 is the plate task with two meals to compare, and Items 3 and 4 are novel items with photos of everyday situations.

Whole number arithmetic knowledge was assessed with a fill-in-the-blank task that is considered a routine whole number arithmetic task for Finnish students of this age. In the task, the students had to fill in the missing number that would make both sides of the equation to be of equal value. There were six item: 1) 12 + __ = 11 + 15; 2) 6 × __ = 2 × 15; 3) 2 × 16 = __ × 8; 4) 54 - 48 = 18 ÷ __; 5) __ ÷ 7 = 6 ÷ 3; 6) 50 ÷ 2 = 27 - __). The students had 2.5 minutes to complete the task. One point was given for each correct answer with a maximum of six points. Cronbach's alpha for the task was 0.86.

Fraction arithmetic knowledge was assessed with eight items of fraction addition and subtraction problems: 1) 1/3 + 1/3; 2) 1/4 + 1/2; 3) 3/8 + 1/4; 4) 2/5 + 1/2; 5) 3/7 + 1/3; 6) 3/4 - 1/4; 7) 4/6 - 1/2; 8) 4/5 - 1/4). The students had 2.5 minutes to complete the task. One point was given for each correct answer with a maximum of eight points. Cronbach's alpha for the task was 0.84.

Fraction magnitude knowledge was assessed using an ordering task, in which students order three fractions from smallest value to largest. There were five items: 1) 2/3, 2/7, 2/5; 2) 3/4, 2/8, 8/16; 3) 1/4, 3/4, 1/2; 4) 2/7, 5/9, 1/2; 5) 5/8, 1/3, 3/4. The students had two minutes to complete the task. One point was given for each correct ordering with a maximum of five points. Cronbach's alpha for the task was 0.87. No state anxiety question was asked after the fraction magnitude knowledge task.

Adaptive rational number knowledge was assessed with a rational number version of the arithmetic sentence production task adapted from McMullen, Brezovszky, et al. (2016). Participants had two minutes to form as many valid arithmetic sentences as they can, using a set of five given numbers, to produce a target number. Participants could use each number and operation repeatedly. First participants completed a practice task (one minute) with whole numbers 1, 2, 3, and 4, and a target number six. Then they completed two test items. Each test item includes two pairs of equivalent fractions and decimals (e.g., 1/2 and 0.5, 1/4 and 0.25), a single whole number (e.g., 4), and a target number (e.g., 1). One point is given for each correct arithmetic sentence. There was no maximum limit but the highest number correct was 11 for the first item and 10 for the second item. The sum score for the two items was used. Cronbach's alpha for the two items was 0.80.

Data Analysis

Data was analyzed using IBM SPSS Statistics 27. Independent samples *t*-tests were conducted to examine differences between grades (5^{th} and 6^{th} grade) on all the dependent variables. Furthermore, Pearson correlations were conducted to examine the relation between state and trait mathematics anxiety and performance. In order to correct for multiple comparisons, the Bonferroni corrected α-value was set at $p < .0033$ (i.e., 0.05/15). To examine differences in state mathematics anxiety, a two-way repeated measures ANOVA was conducted including state anxiety as the dependent variable, task as a within-subject factor and grade as a between-subject factor. Further analysis was conducted with pairwise comparisons. In addition, separate hierarchical regression analyses were conducted to examine whether state mathematics anxiety explains unique variance in the performance of each task. The dependent variable was performance on the task and independent variables were entered in two steps: 1) background variables (i.e., gender and grade) and trait mathematics anxiety, and 2) state mathematics anxiety for the task.

To explore whether differences in mathematical knowledge explain the relation between state anxiety and performance on the adaptive rational number task, a hierarchical regression analysis was conducted. The dependent variable was performance on the adaptive rational number knowledge task. The independent variables were background factors (i.e., gender and grade), performance on all other mathematical tasks (i.e., SFOR, guided multiplicative relations, whole number arithmetic knowledge, fraction arithmetic knowledge, and fraction magnitude knowledge), trait mathematics anxiety, and state mathematics anxiety for the adaptive rational number task.

Results

Table 1 reports on the descriptive statistics and the between grades comparisons for state mathematics anxiety and mathematics performance.

Table 1

Descriptive Statistics for State Mathematics Anxiety and Performance With Independent Samples t-Test

Variable	Whole sample (n = 406), M (SD), Min to Max	5th grade (n = 188), M (SD)	6th grade (n = 218), M (SD)	Mean difference [95% CI]	t(404)	p	d
State anxiety							
SFOR tendency	1.85 (0.98), 1 to 5	1.84 (0.97)	1.86 (0.99)	-0.61 [-1.16, -0.07]	-0.20	0.84	0.02
Guided multiplicative relations	2.00 (1.14), 1 to 5	2.05 (1.17)	1.96 (1.12)	0.10 [-0.13, 0.32]	0.84	0.40	0.08
Whole number arithmetic	2.02 (1.27), 1 to 5	2.12 (1.27)	1.93 (1.26)	0.18 [-0.07, 0.43]	1.41	0.16	0.14
Fraction arithmetic	2.15 (1.29), 1 to 5	2.18 (1.29)	2.12 (1.28)	0.06 [-0.20, 0.31]	0.43	0.67	0.04
Adaptive rational number knowledge	2.17 (1.27), 1 to 5	2.22 (1.25)	2.13 (1.30)	0.10 [-0.15, 0.35]	0.76	0.45	0.08
Performance							
SFOR tendency	1.70 (2.79), 0 to 12	1.37 (2.54)	1.99 (2.98)	-0.61 [-1.15, -0.08]	-2.24	0.03	0.22
Guided multiplicative relations	4.58 (3.32), 0 to 13	3.79 (3.04)	5.33 (3.41)	-1.55 [-2.18, -0.92]	-4.83	< 0.001	0.48
Whole number arithmetic	4.02 (2.10), 0 to 6	3.69 (2.13)	4.31 (2.03)	-0.63 [-1.03, -0.22]	-3.03	0.003	0.30
Fraction magnitude	2.31 (1.99), 0 to 5	1.76 (1.87)	2.80 (1.98)	-1.04 [-1.42, -0.67]	-5.41	< 0.001	0.54
Fraction arithmetic	2.28 (2.21), 0 to 8	1.73 (1.72)	2.76 (2.47)	-1.03 [-1.44, -0.62]	-4.94	< 0.001	0.48
Adaptive rational number knowledge	5.35 (4.45), 0 to 18	3.93 (3.83)	6.58 (4.58)	-2.65 [-3.47, -1.83]	-6.35	< 0.001	0.62

Note. Comparisons between the 5th and 6th grade students.

According to the independent samples *t*-tests shown in Table 1, there were no significant grade differences in the state mathematics anxiety experienced during any of the tasks (see Figure A.1 in the Appendix for box plots). There was a significant difference in performance with 6th graders performing better than 5th graders on all measures (see Figure A.2 in the Appendix for violin plots), with effect sizes varying from small to medium. For trait mathematics anxiety, the mean (*SD*) for 5th graders was 1.42 (0.56) and for 6th graders was 1.60 (0.80).

The correlations in Table 2 show that trait mathematics anxiety has a significant positive correlation with state anxiety for each task with moderate effect sizes. There are low negative correlations between trait mathematics anxiety and performance on measures of whole number arithmetic, fraction arithmetic, and adaptive rational number knowledge. State anxiety responses negatively correlated with performance on measures of whole number arithmetic knowledge and adaptive rational number knowledge with moderate effect sizes. Neither trait nor state mathematics anxiety correlated with SFOR tendency or guided multiplicative relations.

Table 2

Pearson Correlations (N = 406) for Trait Mathematics Anxiety, and State Anxiety and Performance for Each Task

Variable	1	2	3	4	5	6	7	8	9	10
1. Trait anxiety	–									
2. SA SFOR	**.35*****	–								
3. SA Guide	**.53*****	.54***	–							
4. SA Whole number	**.51*****	.33***	.50***	–						
5. SA Fraction	**.44*****	.35***	.49***	.65***	–					
6. SA ARNK	**.57*****	.47***	.64***	.66***	.54***	–				
7. SFOR	**-.03**	**.01**	.06	-.06	.03	-.08	–			
8. Guided	**-.08**	-.02	**-.10**[a]	-.17***	-.05	-.14**	.47***	–		
9. Whole number	**-.20*****	-.04	-.03	**-.43*****	-.01	-.23***	.24***	.36***	–	
10. Fraction	**-.17*****	-.04	-.02	-.14**	**-.06**	-.12*	.07	.26***	.37***	–
11. ARNK	**-.16****	-.03	-.06	-.26***	-.04	**-.27*****	.25***	.33***	.50***	.41***

Note. The Correlations of Interest to Research Question 2 are in Bold. SA = state anxiety; Guided = guided multiplicative relations; Whole number = whole number arithmetic knowledge; Fraction = fraction arithmetic knowledge; ARNK = adaptive rational number knowledge.

[a]Not statistically significant after Bonferroni correction.

$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

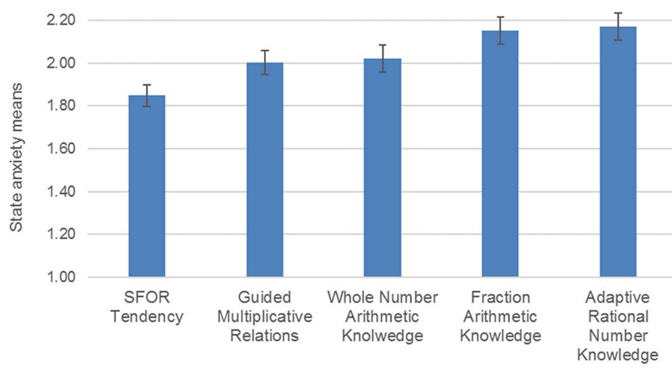
Differences in State Anxiety Across Tasks

To examine whether task type affected the state mathematics anxiety levels and whether these differed between the grades, we conducted a two-way repeated-measures ANOVA. The results showed a violation of the sphericity assumption $\chi^2(9) = 103.16$, $p < .001$, leading to the reporting of Huyn-Feldt corrected results ($\varepsilon = 0.89$). As depicted in Figure 4, the results showed a within-subjects main effect of task type on state anxiety levels, $F(3.57, 1441.21) = 10.19$, $p < .001$, $\eta_p^2 = .09$, but no interaction between grade and task or a between-subjects main effect of grade. Thus, we conducted Bonferroni corrected pairwise comparisons.

Students had higher state anxiety responses on the task measuring adaptive rational number knowledge than whole number arithmetic knowledge ($p < .05$), guided multiplicative relations ($p = .01$), and SFOR tendency ($p < .001$), but not higher than the fraction arithmetic task. State anxiety levels did not significantly differ between the tasks measuring guided multiplicative relations, whole number arithmetic knowledge, and fraction arithmetic knowledge. Students had lower state anxiety responses in the task measuring SFOR tendency than fraction arithmetic knowledge ($p < .001$) and guided multiplicative relations ($p = .02$), but not less than whole number knowledge ($p = .06$). Since only 38% of the students described multiplicative relations in the SFOR task (i.e., at least one SFOR response), we further analyzed the state anxiety responses amongst these students. The results show that even these students had significantly lower state anxiety on the SFOR task compared to all other tasks ($p < .01$ for each pairwise comparison) except whole number arithmetic. This confirms the results that students' state anxiety responses were lower on the SFOR task in general.

Figure 4

Means for State Anxiety on Each Task With Error Bars



Note. ± one standard error.

Mathematics Anxiety and Task Performance

To look more closely at the relation between state and trait mathematics anxiety and performance for each task, we conducted separate hierarchical regression analyses, which are shown in Table 3. First, we looked at trait mathematics anxiety, after controlling for background variables. Then, we examined whether state anxiety explains unique variance in performance. As expected, trait mathematics anxiety negatively correlated with performance on all tasks, except SFOR tendency. State anxiety explained a significant amount of unique variance, above and beyond trait anxiety, only in whole number arithmetic knowledge and adaptive rational number knowledge. As to background variables, higher grade level was associated with higher performance for all tasks, while female gender was associated with lower performance only on the adaptive rational number task. All in all, one must note that the total variance explained by the variables was quite low for every task.

Table 3

Hierarchical Regression Analysis Examining Unique Variance Explained by State Anxiety in Performance for Each Task

	SFOR tendency		Guided multiplicative relations		Whole number arithmetic		Fraction arithmetic		Adaptive rational number	
Model	***b***	**Δ*R*²**	***b***	**Δ*R*²**	***b***	**Δ*R*²**	***b***	**Δ*R*²**	***b***	**Δ*R*²**
Step 1		.01		.07***		.07***		.10***		.20***
Grade	.12*		.25***		.18***		.26***		.32***	
Female	-.01		-.01		-.02		-.04		-.27***	
Trait anxiety	-.04		-.11*		-.22***		-.20***		-.15***	
Step 2		.00		.00		.12***		.00		.03***
Grade	.12*		.24***		.12**		.26***		.29***	
Female	.01		.00		-.01		-.04		-.26***	
Trait anxiety	-.05		-.09		-.01		-.22***		-.03	
State anxiety	.02		-.04		-.41***		.05		-.20***	
Total *R*²		.01		.07		.20		.10		.22

*p < .05. **p < .01. ***p < .001.

Mathematics Anxiety and Adaptive Rational Number Knowledge

We conducted a hierarchical regression analysis, shown in Table 4, to examine whether state and trait mathematics anxiety related to performance on the adaptive rational number knowledge task, after accounting for mathematical skills relevant for the task. Based on the above results, gender and grade are related to performance, so we also controlled for them. Predictor variable analysis revealed no issues of multicollinearity (VIF > 1.40). The regression results indicated that whole number arithmetic knowledge, fraction arithmetic knowledge, and fraction magnitude knowledge are significantly associated with adaptive rational number knowledge. Furthermore, higher grade level and male gender were positively correlated with adaptive rational number knowledge. In addition, state anxiety was significantly related to adaptive rational number knowledge, with lower anxiety being related to higher performance, even after controlling for all other relevant independent variables. Trait mathematics anxiety, however, did not explain unique variance in adaptive rational number knowledge, even when state anxiety was not included in the model.

Table 4

Hierarchical Regression Analysis Examining Factors Related to Adaptive Rational Number Knowledge

	Adaptive rational number knowledge	
Predictor variable	**Model 1 *b***	**Model 2 *b***
Grade	.13***	.12**
Female	-.21***	-.21***
SFOR tendency	.08	.08
Guided multiplicative relations	.04	.04
Whole number arithmetic	.25***	.24***
Fraction arithmetic	.15***	.16***
Fraction magnitude	.32***	.31***
Trait anxiety	-.02	.05
State anxiety	–	-.11**
Total R^2	.50	.51

Note. Including performance on the other mathematical tasks.
**p* < .05. ***p* < .01. ****p* < .001.

Discussion

The present study confirms that mathematics anxiety responses and their relations with performance differ across a wide range of mathematical tasks in primary school students. This result highlights the nuanced relations between trait and state anxiety that should be considered when examining the role of mathematics anxiety in mathematical development. For instance, some mathematical tasks are more likely than others to elicit anxiety, and differences within tasks appear to influence the relations state and trait mathematics anxiety have with performance. In particular, state, but not trait, mathematics anxiety negatively correlated with performance on a measure of adaptive rational number knowledge, even after controlling for other relevant mathematical skills. These findings reveal for the first time that dispositional factors, in addition to high routine knowledge, may contribute to the development of adaptive expertise. In total, our results indicate that mathematics anxiety may affect performance already in primary school, especially with particular task types.

Our results underline the importance of examining mathematics anxiety in response to a variety of different mathematical tasks. We provide the first evidence of how mathematics anxiety manifests in tasks not explicitly mathematical, such as the SFOR task. Unsurprisingly, students had higher state anxiety responses for the explicitly mathematical tasks than the SFOR task. As is typical to SFOR tasks (e.g., McMullen et al., 2014), many students did not necessarily pay attention to the mathematical aspects of the task; instead, they described other details than multiplicative relations from the pictures. However, even the students who provided SFOR responses had lower state anxiety for the SFOR task than the tasks with an explicitly mathematical context. Intriguingly, state anxiety responses did not differ between mathematically explicit non-symbolic, whole number, and fraction arithmetic tasks, despite the fraction task being more difficult than the whole number task. This is not in line with previous findings or less positive attitudes towards fractions than whole numbers in this age group (Sidney et al., 2021), or with previous evidence that task difficulty should increase anxiety responses (Trezise & Reeve, 2018). However, state anxiety was higher on the adaptive rational number knowledge task than the whole number arithmetic task. In sum, while the SFOR task may elicit less anxiety overall, individual variability may be more relevant in mathematically explicit tasks.

We expected mathematics anxiety to be related to performance on all mathematical tasks. While this was the case in most of the mathematical tasks, our results provide the first evidence that there is no relation between SFOR tendency and mathematics anxiety. Furthermore, the relation between mathematics anxiety responses and performance on the guided multiplicative relations task was very low. Performance on tasks including non-symbolic quantities may be less correlated with mathematics anxiety, because they are less tied to formal mathematics instruction at this age (Starling-Alves et al., 2022). Nevertheless, these findings suggest that mathematics anxiety may not substantially hinder students' tendency to recognize mathematical relations and apply their mathematical knowledge in everyday-like situations.

Studies with primary school students have also shown that state anxiety is more related to performance than trait mathematics anxiety (Orbach et al., 2020; Punaro & Reeve, 2012; Sorvo et al., 2017). Our results support this with whole number arithmetic knowledge and adaptive rational number knowledge, but not with fraction arithmetic knowledge. One possibility is that the students who used incorrect whole number strategies (e.g. 1/3 + 1/3 = 2/6), which accounted for 37% of all the answers across items in the fraction arithmetic task, did not realize that these strategies were incorrect. This reflects the well-established whole number bias in this age group (Braithwaite et al., 2019; Van Hoof et al., 2015). Consequently, these students may have had low performance and low state anxiety, and this may be why the fraction task did not result in significantly higher state anxiety on the group level than the whole number task. Additionally, it appears that state anxiety-performance correlations are stronger in tasks where students are more familiar with the correct strategies or answers. Thus, state anxiety responses measured after a task may reflect an individual's concurrent task appraisal, such as perceived difficulty (Punaro & Reeve, 2012; Trezise & Reeve, 2018), in addition to trait mathematics anxiety. Examining both trait and state anxiety contributes to a more nuanced picture of how task differences may affect the relations between mathematics anxiety and performance.

Mathematics Anxiety and Performance Within Adaptive Rational Number Knowledge

We provide the first evidence of how mathematics anxiety manifests in a task related to adaptive expertise in school mathematics, adaptive rational number knowledge. In line with previous research, our results show that differences in levels of routine knowledge are not sufficient for describing individual differences in behavioural manifestations of adaptive expertise, such as adaptive rational number knowledge (McMullen et al., 2020). We found that mathematics anxiety, especially state anxiety, might play a distinct role in limiting some students' abilities to apply their knowledge in novel, complex contexts. This confirms that affective factors play a role in adaptive expertise as previously suggested (Verschaffel et al., 2009). Trait anxiety, however, did not uniquely contribute to explaining performance on the adaptive rational number knowledge task, after controlling for mathematical knowledge. Students' responses to the trait anxiety questionnaire are generally based on their typical mathematical experiences, which are less likely to include tasks requiring adaptive expertise. Hence, state anxiety appears useful for capturing anxiety in individuals without high trait mathematics anxiety, especially in novel tasks.

In comparison to a routine fraction arithmetic task, the need to integrate multiple concepts and procedures in solving the adaptive rational number knowledge task did not inherently increase mathematics anxiety across all students. Yet, state anxiety could be a reflection of some students' inability to apply their rational number knowledge in a novel context due to poorly integrated conceptual and procedural knowledge of fractions and decimals (McMullen et al., 2020). Then again, students' experiences of state anxiety may negatively affect their use of different strategies, especially ones requiring working memory resources (Caviola et al., 2017; Ramirez et al., 2016). Further research is needed on the relations between different strategies and state anxiety, such as use of cross-notational knowledge. While the direction of the relation cannot be determined, exposure to mathematical stimuli in multiple contexts could be a key to lowering students' anxiety in novel tasks. As well-integrated knowledge should be a sought-after outcome of education, more research is needed on the role of anxiety and other motivational factors in the development of adaptive expertise with school mathematics.

While not our primary focus in the present study, we found effects of grade and gender on the relations between mathematics anxiety and task performance. While 6^{th} graders had higher performance, the improved performance did not directly translate to reduced state or trait mathematics anxiety. As to gender, higher state anxiety and female gender were negatively related to performance on the adaptive rational number task, even after controlling for the other measured mathematical skills. Research on gender and mathematics anxiety has typically found higher mathematics anxiety in females, but many still report no gender differences (Caviola et al., 2022; Geary et al., 2019). Thus, gender in relation to mathematics anxiety and performance within adaptive mathematical tasks warrants further investigation.

Limitations and Future Research

The present study has limitations that should be considered when drawing conclusions from it. First, while we include a wide variety of tasks, a more systematic approach would be needed to examine the impact of specific task features on mathematical anxiety and its relation to performance. For instance, further examination with a wide range of fraction and whole numbers tasks would be needed to ascertain the role that fraction content plays in state anxiety responses. Second, a wider range of tasks measuring SFOR would be valuable to examine more nuanced relations between attention to the mathematical nature of tasks, mathematics anxiety and SFOR tendency. Unlike in previous studies measuring SFOR tendency (e.g., McMullen, Hannula-Sormunen, et al., 2016), the measure used in the current study was limited to only written responses, and did not include action-based tasks. This may account for the low number of SFOR responses and the low reliability of the measure. In addition, task order should be randomized in future studies as it may have influenced anxiety responses, if students based their responses in comparison to the previous task(s).

As the study is mainly based on correlational data, we cannot determine whether anxiety towards different types of mathematical tasks affects the learning of mathematical knowledge or vice versa. Furthermore, it cannot determine whether state or trait anxiety is a better predictor of later performance or anxiety. Longitudinal research on the development of performance and the trait-state anxiety relations would be valuable, as it might shed light on the reciprocal relations between anxiety and performance (Foley et al., 2017). In addition, the relations between state anxiety and performance could change as students become more acquainted with tasks, such as fraction knowledge. The fraction arithmetic task appeared too difficult for most students, and this may have limited its relation to state mathematics anxiety. Furthermore, examining the relation between mathematics anxiety and performance on tasks that are confounded by a whole number bias may be valuable for future research.

Conclusion

The present study provides valuable insight into the nature of mathematics anxiety in relation to mathematical development in primary school, including the development of adaptive expertise. Students' mathematics anxiety and performance relations differ depending on the type of mathematical knowledge and the type of anxiety measured. Thus, researchers and educators should account for nuanced interactions in how trait and state mathematics anxiety relate to students' performance on various mathematical tasks and how these relations may develop over time. Increased consideration for these issues in research and educational settings is a first step to addressing the problem, as mathematics anxiety can negatively affect students' mathematical achievement and future career choices. In particular, the potentially limiting role of mathematics anxiety on students' adaptive rational number knowledge may be relevant for future research on developing adaptive expertise in school mathematics. Overall, these results confirm the value of examining not only trait anxiety, but also state anxiety in multiple contexts for understanding the role of mathematics anxiety as a barrier to success in the classroom.

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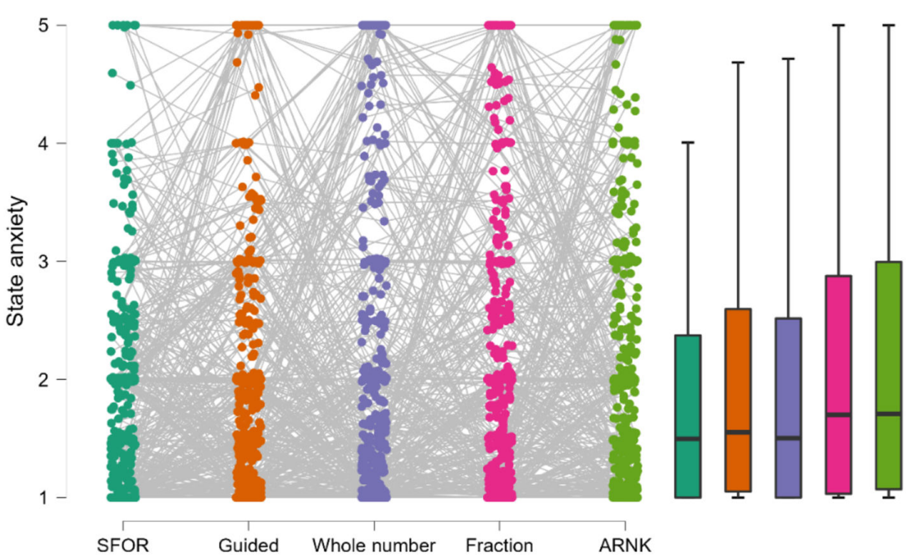
Appendix A: Plots for State Anxiety and Performance

Figure A.1

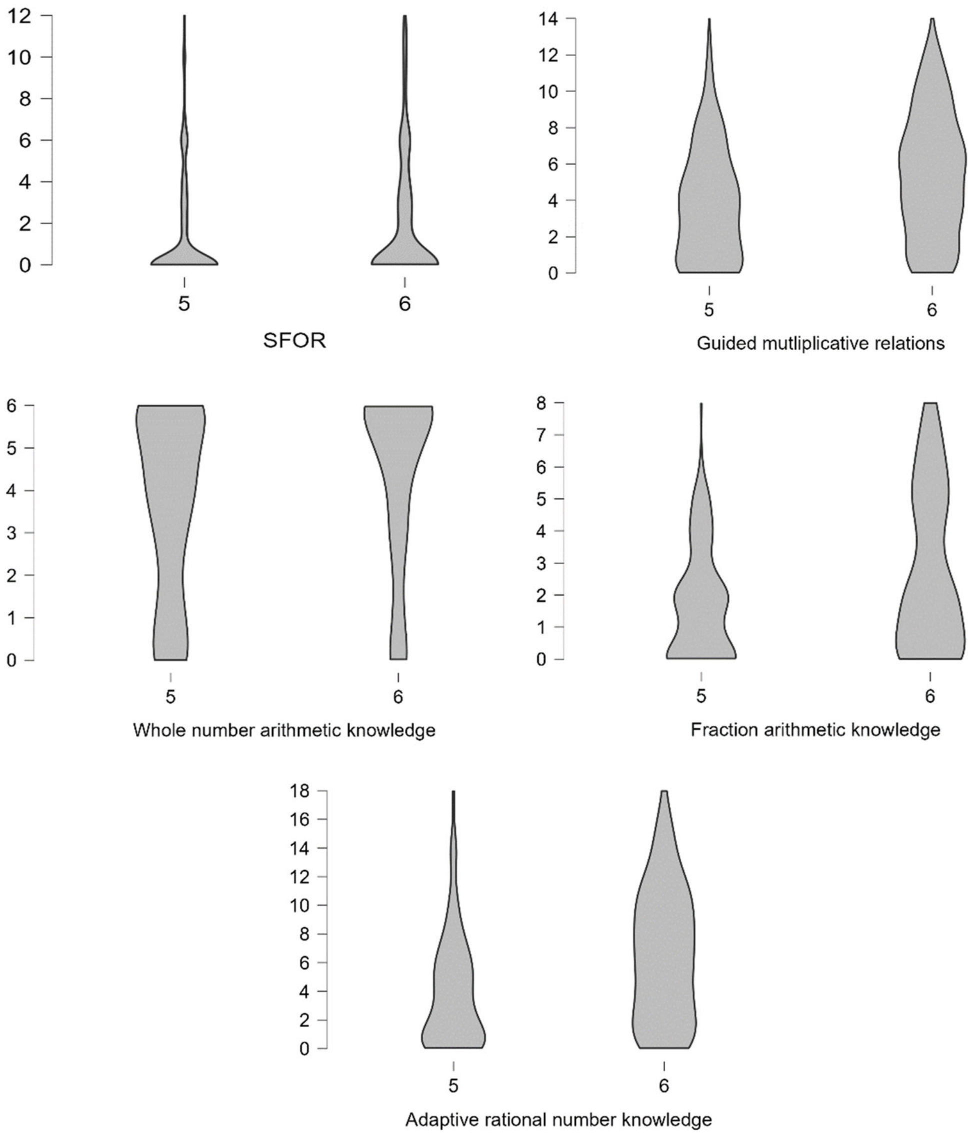
Distribution of the State Anxiety Responses for Each Mathematics Task



Note. Guided = guided multiplicative relations; Whole number = whole number arithmetic knowledge; Fraction = fraction arithmetic knowledge; ARNK = adaptive rational number knowledge.

Figure A.2

Violin Plots of Performance on the Mathematics Tasks Across the Grades



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