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What's metacognition got to do with the relationship between test anxiety and mathematics achievement?

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Abstract
Research examining the joint relationships between test anxiety, metacognition, and mathematics achievement revealing the mediational role of metacognition in the relationship between test anxiety and mathematics achievement is sparse. A mediation study was designed to redress this imbalance. The Children's Test Anxiety Scale (CTAS), Junior Metacognitive Awareness Inventory (Jr. MAI), and Mathematics Achievement Test (MAT) were distributed to 943 (442 males and 501 females) Grade 7 *(n* = 477*)* and Grade 8 *(n* = 466*)* students aged between 11–12 (M_{age} = 11.5, *SD* = .88) and 11–13 (M_{age} = 12, *SD* = .91) years, respectively. In this study, multiple mediation models were tested to explore the role of metacognition as a mediator of the effect of test anxiety on mathematics achievement. Results indicate that although both test anxiety and metacognition were significantly related to mathematics achievement, metacognition was not a statistically significant mediator in the relationship between test anxiety and mathematics achievement. Specifically, the knowledge of cognition component of metacognition was the only significant mediator, mediating the relationship between off-task behaviors and mathematics achievement. Findings support the beneficial role of metacognition with the rewarding side of a key implication that without developing *metacognitive knowledge*, efforts at alleviating test anxiety to maximize achievement in mathematics may well be fruitless. Educational and practical implications are discussed.

Keywords Test anxiety · Metacognition · Mathematics achievement · Middle school · Mediation

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Introduction

Mathematics is typically conceived of as being a core discipline in curricula at all levels of education (Wittmann, 1995). For this reason, mathematics achievement is crucial to student placement and selection for admission to schools and/or universities in most countries' educational systems around the world (Nasser & Birenbaum, 2005). This information is also highly relevant because testing is a common educational practice in contemporary society, which is widely used for decision-making about an individual's standing (e.g., achievement level) across primary, secondary, and higher education (Zeidner, 1998).

Test anxiety is a key affective variable that can impede both achievement in general (Cassady & Johnson, 2002; Fonteyne et al., 2017; Hancock, 2001) and mathematics achievement, in particular (Higbee & Thomas, 1999; Ma, 1999). It is defined as a subjective emotional state that includes responses (e.g., cognitive, physiological, and behavioral) to possible concerns about poor performance (i.e., fear of failure, experienced before or during evaluative situations (Bodas et al., 2008; Sparfeldt et al., 2013). Although early test anxiety researchers (Mandler & Sarason, 1952; Sarason et al., 1960) perceived test anxiety as being unidimensional, subsequent researchers (Liebert & Morris, 1967) advanced the theory that test anxiety was comprised of distinct cognitive and affective-physiological components, referred as *worry* (i.e., negative thoughts/self-cognitions concerning test performance) and *emotionality* (i.e., perceptions/autonomic reactions that occur during test taking), respectively. Their formulations of two components of test anxiety have been operationalized by Wren and Benson (2004) in the development of the CTAS conceptualizing cognitive component as similar to but more encompassing than the worry component of adult test anxiety (i.e., *thoughts*), representing affective-physiological component as a single component (i.e., *autonomic reactions*), and proposing behavioral (i.e., *off-task behaviors*) components. The *thoughts* cognitive component includes worrisome cognitions that occur during test-taking (e.g., self-critical thoughts, test-related concerns, and test-irrelevant thoughts). It centers on concerns such as comparing self-performance to peers, feeling unprepared for evaluative situations, and causing sorrow for parents. The *autonomic reactions* physiological component displays physiological arousal and somatic signs of anxiety to test-related stress. It embodies manifestations such as perspiring stomach problems, increased galvanic skin response, and dizziness. The *off-task behaviors* behavioral component involves nervous habits and inattentive/distracted behaviors. It focuses on attentional aspects such as auto-manipulation (e.g., playing with hair), object manipulation (e.g., biting pencils), and inattentive behaviors (e.g., looking around the classroom). Using such a domain-general approach (Vogelaar et al., 2017) in which test anxiety was viewed to be a situation-specific trait (Putwain et al., 2021) allows researchers to capture a broader perspective of test anxiety experienced in schools (Fréchette-Simard et al., 2022), which is manifest during various formal evaluative/testing situations in all subject areas (e.g., mathematics, science, literature). Researchers using a domain-general approach to test anxiety have reported that 40% of school-aged children suffer from test anxiety at a moderate level (Plante et al., 2022), while the proportion of elementary and secondary school students who experienced high levels of test anxiety may range from as little as 10% to as much as 30% (Segool et al., 2013). Given these widely varying distributions of test anxiety in typical classrooms, the domain-general approach appears to be particularly relevant for examining the relations between test anxiety and other indicators that are both specific (e.g., mathematics achievement) and unspecific (e.g., metacognition) to a domain, which is the case in the current study.

Research studies focusing on the relationship between test anxiety and performance have established that the two constructs are negatively correlated (Ng & Lee, 2015), that is high levels of anxiety are associated with lower levels of performance (Spada et al., 2006). Since schools put excessive pressure on students to be high achievers in mathematics, the demanding nature of this qualification prompts teachers and researchers to identify the factors, which primarily affect mathematics achievement negatively and seek ways to reduce the influence of those factors in students. Affective variables like test anxiety (Hembree, 1988) seem to be one of the primary predictors of mathematics achievement (Ma, 1999). However, also cognitive variables—in particular metacognition—play an essential role in mathematics achievement, as they shape students' recognition of their own cognitive abilities and control of their own cognitive processes in educational settings (Lucangeli & Cornoldi, 1997; Schoenfeld, 1987). Metacognition is causally referred to as one's awareness and regulation of own cognitive processes (Flavell, 1979). It is consisted of two components namely knowledge of cognition and regulation of cognition (Brown, 1987). Although research on metacognition has made it quite clear that highly metacognitive students perform better than their less metacognitive counterparts on most performance assessments including mathematics tests (Hacker et al., 1998), the role of test anxiety in activating metacognitive knowledge and regulatory processes is much less clear (Everson et al., 1994). In particular, it has been documented that the effect of affective factors such as test anxiety on performance is also related to metacognition (Zeidner, 1998). However, the bulk of studies predominantly investigated the influence of each factor in isolation and mainly in relation to general performance that places little demand on specifically mathematics achievement.

Previous research on test anxiety, metacognition, and mathematics achievement

Metacognition and its components are closely associated with test anxiety and mathematics achievement. First, the associations between metacognition and mathematics achievement are found to be significant (Mevarech & Amrany, 2008). Possessing high levels of metacognition may facilitate the engagement in mathematical activities (e.g., problem-solving) (Jacobse & Harskamp, 2012), deepen the acquisition of declarative, conditional, and procedural knowledge (Aydın & Ubuz, 2010a), and improve the performance on mathematics-related tasks (Desoete & De Craene, 2019).

Furthermore, components of metacognition—*knowledge of cognition* and *regulation of cognition*—are also closely associated with test anxiety. Specifically, researchers (Miesner & Maki, 2007; Silaj et al., 2021; Stöber & Esser, 2001; Tobias & Everson, 1997) support the hypotheses that high test-anxious students will exhibit lower metacognitive knowledge (e.g., report low confidence in their ability to solve a problem) and display lower metacognitive regulation (e.g., give low confidence judgements for self while performing the solution steps). Likewise, students with low mathematics achievement are more likely to experience test anxiety (Devine et al., 2012) and have poorer metacognitive awareness including knowledge of cognition and regulation of cognition (Pennequin et al., 2010). Given the strength of these diminutions across these constructs, one avenue to explain declines in test anxiety and mathematics achievement relates to the fact that metacognition may be a mediator between test anxiety and performance (Veenman et al., 2000) and between test anxiety and study strategies (Spada et al., 2006).

Thoughts, *off-task behaviors*, and *autonomic reactions* are three components of test anxiety, which correspond to mathematics achievement (Kazelskis et al., 2000). To be more specific, worrisome thoughts concerning failure, off-task behaviors concerning nervous habits and distracting behaviors, and autonomic reactions concerning the individuals' general/specific somatic indications of anxiety suggest that students with high test anxiety often show a lower level of mathematics achievement compared to students with low test anxiety. Mathematics achievement can be enhanced if a student has more awareness and consciousness that anxiety and worrying are controllable (Spada et al., 2006). Rightfully, Veenman et al. (2000) claimed that thoughts, off-task behaviors, and autonomic reactions are triggered by a student's poor metacognition, which in turn distracts the students from adequate cognitive performance in mathematics. In this sense, metacognition is beneficial because it provides students with the ability to assess (e.g., knowledge of cognition) and control (e.g., regulation of cognition) their cognitive processes and may thus play a key role in determining whether negative thoughts (e.g., thoughts), perceptions of physiological states (e.g., autonomic reactions), and poor study/test-taking skills (e.g., off-task behaviors) during the tests escalate to such an extent that valuable performance capacity and cognitive functioning necessary for adequate mastery in mathematics are depleted.

Although from a theoretical perspective, students' appraisal, control, interpretation, and modification of their own thinking should mediate the relationship between test anxiety and mathematics achievement, empirical work supporting this hypothesis is scarce. In a similar fashion, prior studies failed to examine the mediational links between components of test anxiety and metacognition in mathematics from a joint perspective. Furthermore, a great deal of research exists on the role of self-efficacy and/or self-regulation in mediating the relationship between test anxiety and cognitive performance (see Nie et al., 2011) or the role of test anxiety in mediating the relation between self-efficacy and self-regulation and cognitive performance (Schnell et al., 2015); however, there is a notable lack of empirical evidence for the role of metacognition in mediating the relationship between test anxiety and mathematics achievement.

Up to our knowledge, there is only one study in Turkish context that highlighted the impact of test anxiety on academic performance indicated by grade point average in general, thereby neglecting mathematics achievement in particular (Ergene, 2011). Majority of the national studies have investigated the causes and correlates of math anxiety (e.g., Oksal et al., 2013; Tok, 2013; Yenilmez & Özbey, 2006). It is important to acknowledge that, unlike test anxiety, math anxiety occurs during examination context, as well as in other non-academic contexts in one's daily life (Ashcraft, 2002). Indeed, since the pioneering work of Richardson and Suinn (1972), math anxiety has been commonly defined as a specific feeling of pressure, worry, or fear/tension that directly interferes with mathematics performance (Ashcraft & Kirk, 2001), which is generated by manipulating the numerical stimuli in academic situations and daily life (Passolunghi et al., 2020). These thought-provoking results open a window onto the fact that math anxiety is another form of test anxiety (Kazelskis et al., 2000) and that test anxiety might be hidden under math anxiety (Stöber & Pekrun, 2004). These views were supported by the findings of several studies indicating that there are substantial correlations (i.e., moderate and positive) between math anxiety and test anxiety (Carey et al., 2017; Devine et al., 2012). Whether speaking of test anxiety in general or math anxiety in particular, the results of these studies are intriguing for providing evidence that an increased test/math anxiety led to a decrease in students' performance while taking examinations.

On the whole, despite a lack of empirical studies to establish the joint interrelationships among test anxiety, metacognition, and mathematics achievement, the reviewed literature suggests that high test anxiety could act as a trigger to low metacognitive skillfulness, which in turn could be detrimental to mathematics achievement. In addition, since metacognition could be critical for coping with test anxiety (Silaj et al., 2021), it is reasonable to hypothesize that metacognition could mediate the subsequent relationships between test anxiety and mathematics achievement. In exploring this hypothesis empirically, the present study will fill an important gap in our understanding of the underlying processes explaining declines in mathematics achievement. Determining the role of metacognition would be of theoretical value in establishing the factors that hinder performance and further have educational implications by suggesting the aspects of metacognition, which should be taken into account while developing test anxiety interventions.

The current study

The goal of this study was to evaluate the mediating role of metacognition in the expected decreases in test anxiety and increases in mathematics achievement. Specifically, the current study was guided by the following hypotheses. First, we sought to examine the associations among test anxiety, metacognition, and mathematics achievement. We hypothesized that overall test anxiety would be negatively associated with metacognition which in turn would be positively associated with mathematics achievement (Hypothesis 1). Second, we proposed that components of metacognition would each uniquely mediate the relations between components of test anxiety and mathematics achievement. It was thus expected that thoughts would predict knowledge of cognition and regulation of cognition, which in turn would predict mathematics achievement (Hypothesis 2); off-task behaviors would predict knowledge of cognition and regulation of cognition, which in turn would predict mathematics achievement (Hypothesis 3); and autonomic reactions would predict knowledge of cognition and regulation of cognition, which in turn would predict mathematics achievement (Hypothesis 4).

Method

Participants

The sample consisted of 943 (442 males and 501 females) students in their last 2 years of elementary education referred to as Grade 7 *(n* = 477*)* and Grade 8 *(n* = 466*)* in Turkey, aged between 11–12 (M_{age} = 11.5, *SD* = .88) and 11–13 (M_{age} = 12, *SD* = .91) years, respectively. Grades 7 and 8 were selected for two key reasons: (1) The assessment tools designed to gauge test anxiety among Turkish students covered both middle and high school levels (e.g., Totan, 2018) and (2) those specifically tailored for middle school students (e.g., Şan & Akdağ, 2017) recognized the domain-specific nature of test anxiety, particularly focusing on "mathematics examination anxiety" with a distinct conceptualization.

Measurements

Children's Test Anxiety Scale (CTAS)

The CTAS, which was originally developed by Wren and Benson (2004) to measure test anxiety in children in grades 3 through 6 (equivalent to ages 8–12), was used to assess students' test anxiety. The instrument was adapted to Turkish by Aydın and Bulgan (2017). Students responded to each statement of the CTAS on a 4-point scale: (1) *almost never*, (2) *some of the time*, (3) *most of the time*, and (4) *almost always*. The adapted 30-item scale comprised three subscales—*Thoughts:* "While I am taking tests, I worry about doing something wrong," 13 items; *Off-Task Behaviors:* "While I am taking tests I tap my feet," 8 items; and *Autonomic Reactions:* "While I am taking tests I feel warm," 9 items. The possible scores on the CTAS ranged from 30 (low test anxiety) to 120 (high test anxiety). The Cronbach's alpha reliability coefficients for thoughts, off-task behaviors, autonomic reactions, and the total scale were .82, .72, .75, and .88, respectively. The adequate reliability and validity have been demonstrated elsewhere (see in detail Aydın & Bulgan, 2017) and the CTAS is appropriate for use with Turkish children aged 8–12. It is noteworthy that there are subsequent studies using the CTAS (e.g., Fergus et al., 2020; Owens et al., 2012; Putwain & Daniels, 2010) among higher grade levels (e.g., Grade 7 and Grade 8) in older ages (e.g., 11 to 12-years old and 12 to 13-years old) in different contexts (e.g., UK). Furthermore, the CTAS can be used to screen the prevalence of test anxiety among large or targeted groups of students with relative ease and minimal intrusiveness (von der Embse et al., 2013, p. 69).

Junior Metacognitive Awareness Inventory (Jr. MAI)

The Jr. MAI, which was originally developed by Sperling et al. (2002) to measure metacognitive awareness in children in grades 3 through 9, was used to assess students' metacognition. The instrument was adapted to Turkish by Aydın and Ubuz (2010b). Students responded to each statement of the Jr. MAI on a 5-point scale: (1) *never*, (2) *seldom*, (3) *sometimes*, (4) *often*, and (5) *always*. The adapted 17-item inventory comprised two subdimensions—*Knowledge of Cognition:* "I know when I understand something," 8 items, and *Regulation of Cognition:* "I think of several ways to solve a problem and then choose the best one," 9 items. The Cronbach's alpha reliability coefficients for knowledge of cognition, regulation of cognition, and the total scale were .75, .79, and .85, respectively. The possible scores on the Jr. MAI ranged from 17 (low metacognitive awareness) to 85 (high metacognitive awareness). The reliability and validity of the inventory have been demonstrated elsewhere (see in detail Aydın & Ubuz, 2010b).

Mathematics Achievement Test (MAT)

The MAT, which was constructed by the researchers, was used to assess students' mathematics achievement. The test was composed of 18 multiple-choice items originally released by the Trends in International Mathematics and Science Study (TIMSS) from those used in TIMSS 2007, 2011, and 2015. The items were released by the Ministry of National Education [MoNE] (2018) and were adapted into Turkish (available from http://timss.meb.gov.tr/www/aciklanan-sorular/icerik/1). The construction process of the MAT involved two steps: Step 1, question pool generation, and Step 2, refinement of the test. An initial question pool, including 57 items out of the released 315 items for Grade 4 (n = 143) and Grade 8 (n = 172), was generated in the light of learning objectives on middle school mathematics (MoNE, 2018). To refine the items, expert evaluations were conducted. The 57 items were submitted to two middle school mathematics teachers, who had significant teaching experience over 20 years, in order to review them for their congruity with both grade levels (Grades 7 and 8). Based on their feedback, 26 items were eliminated and thus the test for the next stage contained 31 items. These items were reviewed by the researchers in terms of their content domains—Number, Algebra, Geometry, and Data and Chance and cognitive domains—Knowing, Applying, and Reasoning. In line with the percentages targeted in TIMSS assessment frameworks devoted to content domains, Number, Algebra, Geometry, and Data and Chance, 30%, 30%, 20%, and 20%, respectively, and cognitive domains, Knowing, Applying, and Reasoning, 35%, 40%, and 25%, respectively, 13 items were deleted leading the test for the final stage with 18 items.

At the final stage, the 18 items were submitted to a staff member in a private university, with expertise over 20 years in conducting research on cross-cultural comparisons in international assessments. Based on the suggestions indicating that (1) TIMSS assesses students' problem-solving skills in a wide range with about two-thirds of the items that reflect applying and reasoning skills and (2) TIMSS theoretical framework puts less emphasis on the knowing domain and greater emphasis on the reasoning domain (Mullis et al., 2003), the final version of the MAT was reviewed in its entirety and no further changes were made. A single booklet was created including the 18 items (Knowing, 4 items; Applying, 8 items; and Reasoning, 6 items). Each item was scored either 0 (incorrect) or 1 (correct). Possible scores on the test ranged from 0 to 18. The Cronbach's alpha coefficient was .82, indicating adequate reliability (i.e., acceptable internal consistency) for the total score. Specimen items of the MAT are presented in Fig. 1.

Procedure

The data were collected during the spring semester in 2018/2019 academic year. Prior to the administration process, the "Ethical Approval Statement" was obtained from the University Ethics Commission as well as the Governorship of Mersin, Turkey, and National Education Directorate. Student participation from five public middle schools (Grades 5–8) was voluntary, and each participant provided a parental consent before taking part in the study. Students who gave consent to participate in the study completed the CTAS, the Jr. MAI, and the MAT in two consecutive mathematics classes during regular class time (each 40 min). The second researcher administered the instruments to participants with assistance of mathematics teachers at each school. Along with each instrument students' self-reports on their school, classroom, grade, and gender were also collected.

Data analysis

Analyses for the study included descriptive statistics, Pearson's correlation coefficients, intraclass correlation coefficients, and mediation analyses. Prior to preceding the mediation analysis, a preliminary analysis of assumption testing was conducted to check for normality, linearity, homoscedasticity, multicollinearity, and independence of errors. Along with Baron and Kenny (1986), no violations were noted. Descriptive analyses were performed to compute the means and standard deviations of the study variables by grade level and gender. The intraclass correlation coefficients of all the study variables were computed to control the design effect in the sample (i.e., nested data) (Raudenbush & Bryk, 2002). Analyses were conducted using SPSS (v. 21.0).

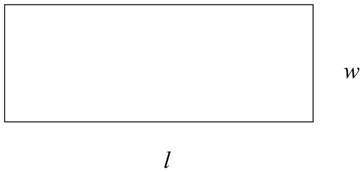
To examine the hypothesized mediation models, the PROCESS macro, a component of the statistical software that analyses observed variable mediation (i.e., whether a variable is a potential mediator), was used (Hayes, 2017). For the overall test anxiety, metacognition, and mathematics achievement, we initially tested Hypothesis 1 (H1) to examine whether metacognition mediated the effect of test anxiety on mathematics achievement, using Model 1 shown in Fig. 2. The following estimates were calculated as follows: (a) standardized path from test

Item 1 Content Domain: Number - Cognitive Domain: Knowing

Which number is closest in size $\frac{3}{4}$?

A. 0.34
B. 0.43
C. 0.74
D. 0.79

Item 8 Content Domain: Algebra - Cognitive Domain: Applying



The shape above is a rectangle, with length *l*, and width *w*. If the length is doubled and the width stays the same, which formula gives the area (*A*) of the new rectangle?

A. $A= 2l + 2w$
B. $A= 2l + 4w$
C. $A= 2lw$
D. $A= 4lw$

Item 18 Content Domain: Data and Chance - Cognitive Domain: Reasoning

A car salesman placed this advertisement in the newspaper: "Old and new cars for sale, different prices, average price 5,000 zeds." Form the advertisement, which of the following must be true?

A. Most of the cars would cost between 4,000 zeds and 6,000 zeds.
B. Half of the cars would cost than 5,000 zeds, and half would cost more than 5,000 zeds.
C. At least one of the cars would cost 5,000 zeds.
D. Some of the cars would cost less than 5,000 zeds.

Fig. 1 Specimen items of the MAT

anxiety to mathematics achievement (before and after controlling for metacognition), (b) standardized path from test anxiety to metacognition, (c) standardized path from metacognition to mathematics achievement, (d) total indirect effect (the combined effect of the pathway from test anxiety to mathematics achievement through metacognition), and (e) the separate indirect effect of test anxiety on mathematics achievement through metacognition.

For each of the three components of test anxiety, we then tested Hypotheses 2 (H2), 3 (H3), and 4 (H4) to explore whether components of metacognition (*knowledge of cognition* and *regulation of cognition*) mediated the effect of components of test anxiety (*thoughts*, *off-task behaviors*, and *autonomic reactions*) on mathematics achievement, using Models 2, 3, and 4 shown in Fig. 2. More specifically, we performed three sets of mediation analyses with thoughts, off-task behaviors, and autonomic reactions as predictors; knowledge of cognition and regulation of cognition as two mediators; and mathematics achievement as a single outcome variable.

It is advantageous to use the bootstrapping approach (i.e., 5000 bootstrap samples) for mediation analysis because it accounts for the non-normality of the sampling distribution for indirect effects and provides robust standard errors (SE) and bias-corrected 95% accelerated confidence intervals (CIs) for the mediation effects (Preacher & Hayes, 2008). If bootstrapped CIs crossed zero, the significance of the indirect effect was ruled out. Figure 2 presents the

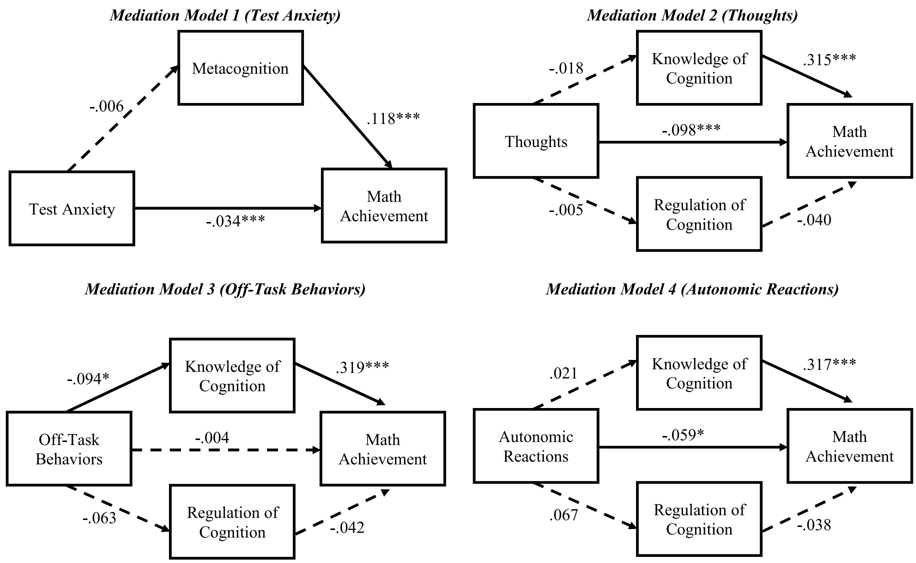


Fig. 2 Multiple mediation models testing whether metacognition mediates the relationship between test anxiety and mathematics achievement. Note: Path models were run separately for each component of test anxiety. All path coefficients are standardized. The non-significant paths were denoted by dotted lines. $*p < .05$, $***p < .001$

path coefficients and Table 4 presents the indirect effects along with bias-corrected confidence intervals. Results are described in the following section for each of the three components of test anxiety.

Results

Descriptive statistics

Table 1 presents the means and standard deviations of the scores on the test anxiety, metacognition, and mathematics achievement across grade level and gender.

Table 2 provides means, standard deviations, and reliabilities for each of the study variables as well as the correlations between each variable and their relationship to the outcome variable, mathematics achievement.

In accordance with our first hypothesis, test anxiety showed a significant negative correlation with mathematics achievement. However, our expectation that it would show a significant negative correlation with metacognition was not met. As hypothesized, metacognition was significantly and positively related to mathematics achievement. Thoughts and autonomic reactions components of test anxiety were not significantly related to knowledge of cognition and regulation of cognition components of metacognition. Only the off-task behaviors showed a significant negative correlation with knowledge of cognition but was not significantly related to regulation cognition. Thoughts and autonomic reactions showed a significant negative relationship

Table 1 Descriptive statistics across grade and gender

	Grade				Gender			
	Grade 7 ($n = 477$)		Grade 8 ($n = 466$)		Female ($n = 501$)		Male ($n = 442$)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Mathematics achievement	9.88	4.14	10.42	4.33	10.37	4.15	9.89	4.33
Test anxiety	63.16	15.59	64.50	14.34	64.68	15.48	62.85	14.38
Metacognition	63.54	11.26	62.74	11.09	64.17	10.91	61.98	11.38

Table 2 Descriptive statistics, reliability, and correlations among all study variables ($N = 943$)

Variable	Descriptive statistics			Correlations					
	Mean	*SD*	*α*	1		2		3	
1. Test anxiety	63.82	14.99	.90	-		−.008		−.123**	
2. Metacognition	63.14	11.18	.84			-		.311**	
3. Math achievement	10.15	4.24	.82					-	
	Mean	*SD*	*α*	1	2	3	4	5	6
1. Thoughts	29.72	6.97	.83	-					
2. Off-task behaviors	14.62	4.28	.80	.48**	-				
3. Autonomic reactions	17.09	5.71	.83	.65**	.52**	-			
4. Knowledge of cognition	31.22	5.59	.88	−.02	−.07*	.02	-		
5. Regulation of cognition	25.55	5.89	.85	.00	−.03	.05	.60**	-	
6. Math achievement	10.15	4.24	.82	−.16**	−.02	−.07*	.37**	.18**	-

*$p < .05$, **$p < .01$

with mathematics achievement, strongest for thoughts than the autonomic reactions. Off-task behaviors was not significantly related to mathematics achievement. All two components of metacognition were significantly correlated with mathematics achievement. In fact, knowledge of cognition showed the strongest relationship with mathematics achievement. The relationship between components of the two constructs—test anxiety and metacognition—and mathematics achievement was strongest for knowledge of cognition and smallest for autonomic reactions.

Intraclass correlation coefficients

The intraclass correlation coefficients (ICCs) of the study variables attached to grade and gender are presented in Table 3. These low ICC values (i.e., close to zero) with non-significant *p* values suggested that multilevel analysis incorporating grade level and gender is not needed (Luke, 2019).

Mediation analysis

Metacognition as a mediator of the relationship between test anxiety and mathematics achievement

In Model 1, with metacognition as the mediator and mathematics achievement as the outcome (see Fig. 2), we observed (a) a negative and statistically significant coefficient for the path from test anxiety to mathematics achievement (β= −.034, *SE* = .009, *p* < .001, bootstrapped 95% CI = −.048 to −.017) and (b) a positive and statistically significant coefficient for the path from metacognition to mathematics achievement (β = .118, *SE* = .012, *p* < .001, bootstrapped 95% CI = .101 to .140). The direct effect of test anxiety on metacognition was not statistically significant (β = −.006, *SE* = .024, *p* > .001, bootstrapped 95% CI = −.046 to .039). Although the indirect effect of test anxiety on mathematics achievement was not statistically significant (indirect effect = −.000, *SE* = .003, *p* > .001, bootstrapped 95% CI = −.007 to .006), the total effect (i.e., direct and indirect effect) of test anxiety on mathematics achievement was negative and statistically significant (total effect = −.035, *SE* = .009, *p* < .001, bootstrapped 95% CI = −.046 to −.018). In sum, the impact of test anxiety on mathematics achievement is independent of metacognition.

Thoughts For Model 2, where the mediators were the two components of metacognition (knowledge of cognition and regulation of cognition) and mathematics achievement was the outcome (see Fig. 2), the direct effect of thoughts on mathematics achievement was negative and statistically significant (β = −.098, *SE* = .018, *p* < .001, bootstrapped 95% CI = −.137 to −.062). However, the coefficients for (a) the path from thoughts to knowledge of cognition (β = −.018, *SE* = .026, *p* > .001, bootstrapped 95% CI = −.075 to .026) and (b) the path from thoughts to regulation of cognition (β = −.005, *SE* = .031, *p* > .001, bootstrapped 95% CI = −.066 to .064) were negative and statistically non-significant. Although the direct effect of knowledge of cognition on mathematics achievement was positive and statistically significant (β = .315, *SE* = .029, *p* < .001, bootstrapped 95% CI = .268 to .380), the direct effect of regulation of cognition on mathematics achievement was not statistically significant (β = −.04, *SE* = .025, *p* > .001, bootstrapped 95% CI = −.086 to .008). Thoughts did not contribute significantly to mathematics achievement either indirectly via knowledge of cognition (indirect effect = −.005, *SE* = .008, *p* > .001, bootstrapped 95% CI = −.002 to .011) or via regulation

Table 3 Intraclass correlation coefficients (ICCs) by grade and gender

	Grade		Gender	
	ICC	*p**	ICC	*p**
Mathematics achievement	.006	.325	.004	.294
Test anxiety	.001	.093	.005	.119
Thoughts	.002	.063	.002	.218
Off-task behaviors	.002	.960	.000	.148
Autonomic reactions	.001	.073	.009	.252
Metacognition	.000	.412	.016	.431
Knowledge of cognition	.001	.167	.009	.273
Regulation of cognition	.001	.213	.016	.761

*All *p* values greater than .05

of cognition (indirect effect = .000, *SE* = .002, $p > .001$, bootstrapped 95% CI = −.003 to .004). Nevertheless, the total effect of thoughts on mathematics achievement remained negative and statistically significant (total effect = −.103, *SE* = .02, $p < .001$, bootstrapped 95% CI = −.003 to .004). In conclusion, the impact of thoughts on mathematics achievement is not mediated by knowledge of cognition and regulation of cognition.

Off-task behaviors Moving on to Model 3, where the mediators were the two components of metacognition (knowledge of cognition and regulation of cognition) and mathematics achievement was the outcome (see Fig. 2), the direct effect of off-task behaviors on knowledge of cognition was negative and statistically significant ($\beta = -.094$, *SE* = .042, $p < .05$, bootstrapped 95% CI = −.181 to −.007). However, the direct effects of off-task behaviors on regulation of cognition and mathematics achievement were negative and statistically non-significant ($\beta = -.063$, *SE* = .050, $p > .001$, bootstrapped 95% CI = −.175 to .074 and $\beta = -.004$, *SE* = .030, $p > .001$, bootstrapped 95% CI = −.068 to .055, respectively). Similar to Model 2 of thoughts, in Model 3 of off-task behaviors, the direct effect of knowledge of cognition on mathematics achievement was positive and statistically significant ($\beta = .319$, *SE* = .030, $p < .001$, bootstrapped 95% CI = .271 to .387), whereas the direct effect of regulation of cognition on mathematics achievement was not statistically significant ($\beta = -.042$, *SE* = .025, $p > .001$, bootstrapped 95% CI = −.079 to .023). Although off-task behaviors had a significant indirect contribution to mathematics achievement via knowledge of cognition (indirect effect = −.030, *SE* = .014, $p < .001$, bootstrapped 95% CI = −.06 to −.003), the indirect effect of off-task behaviors on mathematics achievement through regulation of cognition was not significant (indirect effect = −.002, *SE* = .003, $p > .001$, bootstrapped 95% CI = −.002 to .010). The total effect of off-task behaviors on mathematics achievement was also not statistically significant (total effect = −.024, *SE* = .03, $p > .001$, bootstrapped 95% CI = −.070 to .064). Thus, results indicated that only knowledge of cognition significantly mediates the effect of off-task behaviors on mathematics achievement.

Autonomic reactions Finally, in Model 4, where the mediators were the two components of metacognition (knowledge of cognition and regulation of cognition) and mathematics achievement was the outcome (see Fig. 2), the direct effect of autonomic reactions on mathematics achievement was negative and statistically significant ($\beta = -.059$, *SE* = .024, $p < .05$, bootstrapped 95% CI = −.103 to −.014). However, the direct effects of autonomic reactions on knowledge of cognition and regulation of cognition were not statistically significant ($\beta = .021$, *SE* = .032, $p > .001$, bootstrapped 95% CI = −.045 to .086 and $\beta = .067$, *SE* = .037, $p > .001$, bootstrapped 95% CI = −.015 to .168, respectively). Similar to Models 2 and 3, in Model 4, the direct effect of knowledge of cognition on mathematics achievement was positive and statistically significant ($\beta = .317$, *SE* = .029, $p < .001$, bootstrapped 95% CI = .270 to .387), whereas the direct effect of regulation of cognition on mathematics achievement was not statistically significant ($\beta = -.038$, *SE* = .025, $p > .001$, bootstrapped 95% CI = −.078 to .024). Autonomic reactions did not make a significant indirect contribution to mathematics achievement either via knowledge of cognition (indirect effect = .006, *SE* = .01, $p > .001$, bootstrapped 95% CI = −.013 to .027) or via regulation of cognition (indirect effect = −.00, *SE* = .002, $p > .001$, bootstrapped 95% CI = −.008 to .001). Nevertheless, the total effect of autonomic reactions on mathematics achievement remained negative and statistically significant (total effect = −.059, *SE* = .024, $p < .001$, bootstrapped 95% CI = −.015 to .032). In sum, the effect of autonomic reactions on mathematics achievement was not mediated by knowledge of cognition and regulation of cognition (Table 4).

Discussion

Test anxiety has increasingly attracted the attention of education policymakers, educational psychologists, and researchers as well as teachers and school administrators around the world. We proposed and tested an integrated model of the pathways through which test anxiety influences mathematics achievement, mediated by metacognition, which provide some fine-grained knowledge of the role of metacognition in coping with test anxiety, and thus prompting mathematics achievement. The results of mediation analysis revealed three key findings as follows.

First, although test anxiety and metacognition were directly related to mathematics achievement, they were not significantly related to one another. The non-significant relationship between test anxiety and metacognition was puzzling in view of reports that high test anxiety in students was one of the major reasons for students showing low metacognitive skillfulness. One reason for failing to find significant associations may rest with problems inherent in self-report measures in general and self-reports of test anxiety and metacognition in particular. It is easily possible for students to deny responses indicative of test anxiety and to present themselves as not caring about how well they might function on tests in terms of cognitive, affective, and behavioral aspects of test anxiety. Likewise, students may minimize

Table 4 Results of mediation models for the effect of test anxiety and its components on mathematics achievement through metacognition and its components

Mediation models	Paths	*Std. Est.*	*SE*	Bootstrapping (95% CI, bias-corrected)	
				Lower limit	Upper limit
1. Test anxiety	TA→MATHACH	−.034***	.009	−.048	−.017
	TA→META	−.006	.024	−.046	.039
	META→MATHACH	.118***	.012	.101	.140
2. Thoughts	THGT→MATHACH	−.098***	.018	−.137	−.062
	THGT→KNOCOG	−.018	.026	−.075	.026
	THGT→REGCOG	−.005	.031	−.066	.064
	KNOCOG→MATHACH	.315***	.029	.268	.380
	REGCOG→MATHACH	−.040	.025	−.086	.008
3. Off-task behaviors	OFFTB→MATHACH	.004	.030	−.068	.055
	OFFTB→KNOCOG	−.094*	.042	−.181	−.007
	OFFTB→REGCOG	−.063	.050	−.175	.074
	KNOCOG→MATHACH	.319***	.030	.271	.387
	REGCOG→MATHACH	−.042	.025	−.079	.023
4. Autonomic reactions	AUTOR→MATHACH	−.059*	.024	−.103	−.014
	AUTOR→KNOCOG	.021	.032	−.045	.086
	AUTOR→REGCOG	.067	.037	−.015	.168
	KNOCOG→MATHACH	.317***	.029	.270	.387
	REGCOG→MATHACH	−.038	.025	−.078	.024

Note: *Std. Est.* standardized parameter estimates, *SE* standardized errors, *TA* test anxiety, *META* metacognition, *MATHACH* mathematics achievement, *KNOCOG* knowledge of cognition, *REGCOG* regulation of cognition, *THGT* thoughts, *OFFTB* off-task behaviors, *AUTOR* autonomic reactions; *$p < .05$, ***$p < .001$s responses indicative of metacognition and reflect themselves as not caring how aware they are of their own knowledge and regulatory processes. However, the MAT makes it difficult for students to present and/or reflect themselves in a more favorable light or intended way since achievement is determined by test performance rather than self-report. These differences may account for the significant associations in mathematics achievement and their absence on the association between test anxiety and mathematics achievement. In a related vein, another plausible interpretation involves the nature of the study constructs themselves. Test anxiety and metacognition are multifaceted and intricate constructs, encompassing cognitive, affective, and behavioral dimensions. Our operationalization of these constructs might not have captured their full complexity, potentially influencing the observed relationships. Further refinement of measurement tools or the consideration of additional dimensions for test anxiety (e.g., emotionality and worry) and metacognition (e.g., metacognitive awareness and metacognitive beliefs) in future research may provide more clarity on this matter. Indeed, integrating additional subdimensions might prove useful in understanding our findings that the relation of metacognition to mathematics achievement was stronger than that of test anxiety. The results are consistent with many previous researches (e.g., Devine et al., 2012; Ma, 1999; Silaj et al., 2021) indicating that high-test anxious students would be more likely to have less sufficient mathematical skills than low-test anxious students whereas on the contrary, high-metacognitive students tend to be more competent in solving mathematical tasks compared to their low-metacognitive counterparts.

Second, we intended to further address whether the association between components of test anxiety and mathematics achievement is mediated by components of metacognition. On the whole, results partially support this hypothesis in showing that only the relationship between off-task behaviors and mathematics achievement was mediated only by knowledge of cognition. Although this aligns with theoretical frameworks suggesting that metacognitive processes may serve as a cognitive pathway through which emotional factors, such as test anxiety, manifest in academic performance outcomes, none of the cognitive, behavioral, and affective-physiological components of test anxiety was mediated by regulation of cognition in their relation to mathematics achievement. The non-mediation of other components of test anxiety, such as cognitive and affective-physiological aspects, by regulation of cognition introduces an intriguing dimension to the discussion. This suggests that the relationship between these specific components of test anxiety and mathematics achievement may operate through pathways other than metacognition. Future research might delve into these alternative pathways, providing a more comprehensive understanding of the multifaceted nature of the interplay between psychological factors and academic outcomes. These findings were in contrast with previous research documenting those aspects of metacognition such as metacognitive beliefs and metacognitive skillfulness, which reflect components of metacognition in the present study, appear to play a crucial role in investigating whether test anxiety leads to a lower performance or not (e.g., Spada et al., 2006; Spada & Moneta, 2014; Veenman et al., 2000). However, such findings extend prior work on the topic in increasing our understanding of the challenges related to test anxiety, metacognition, and mathematics achievement combination, while highlighting the susceptibility of knowledge of cognition component of metacognition to off-task component of test anxiety, especially that with behavioral not those with cognitive (i.e., thoughts) and affective-physiological (e.g., autonomic reactions).

Third, our study showed that links between thoughts, autonomic reactions, and mathematics achievement were not mediated by either knowledge of cognition or regulation of cognition; these two components did have a negative direct effect on mathematics achievement. Existing research suggests that test anxiety in students is likely to undermine their engagement in mathematics cognitively and affectively (Tempel & Neumann, 2014). Our findings further support the existence, among a diverse sample of Grade 7 and Grade 8 students, of a joint phenomenon wherein students' difficulties in mathematics are linked with the two components of test anxiety. These results are among the first to suggest that students' knowledge about their own learning (i.e., paying attention to important information), rather than regulation of that learning (i.e., using active learning strategies for a specific task), is particularly relevant to off-task behaviors (i.e., trying to finish the test fast). One plausible explanation relates to students with immature metacognitive knowledge are likely not able to reflect on the influence of their test anxiety (Wang et al., 2021), thereby escalating behavioral symptoms of test anxiety and fueling a cycle of (i) auto manipulation (playing with clothes/hair), (ii) object manipulation (playing with pencils/paper), and (iii) inattentive or distracted behaviors (looking around room/others) (Everson et al., 1994). In this respect, the mediation Model 3 is especially informative, given that inattentive or distractive behaviors during test-taking may be associated with poor metacognitive knowledge and that students attending to task-irrelevant stimuli may not be aware—at least in a cognitive sense—of their own strengths and weaknesses and therefore have lower mathematics achievement levels. However, it does not posit necessarily to the suggestion that off-task behaviors and the associated mathematics achievement are functionally related to self-regulatory processes. In other words, accurate planning, monitoring, and evaluation of one's mathematical task performance may not result in increases in worry cognitions (*thoughts*), auto- and object-manipulation behaviors (*off-task behaviors*), and emotional somatic responses (*autonomic reactions*). Further research is required to pursue that intriguing finding related to off-task behaviors and knowledge of cognition linkage.

The components explaining the relationship between integrative test anxiety, metacognition, and mathematics achievement certainly merit future research. Following Tobias and Everson (1997), metacognitive theory may be relevant to understanding the link between test anxiety and the adoption of a performance approach to studying mathematics. To date, however, this assumption has not been empirically tested by gathering knowledge and regulatory components of metacognition together with the cognitive, affective-physiological, and behavioral components of test anxiety. In this regard, our findings and their educational implications for intervention are worthy of discussion.

Limitations and future research

The results of this study must be considered with regard to two design limitations: using (1) cross-sectional and (2) self-report data sources for test anxiety and metacognition. When asked to report test anxiety and metacognition (e.g., Craig et al., 2020), it is not uncommon for individuals to respond in biased ways that do not accurately reflect their true experiences and/or behaviors (e.g., perceived test anxiety and perceived metacognition). Since this creates a risk for the validity that the participants might provide what they perceive as the desired answer, it is important to consider response bias when using self-report instruments. However, despite these limitations, we believe that both instruments may already be useful for eliciting levels of test anxiety and metacognition and in providing a further step towards the development of a general overview and conceptualization of test anxiety and metacognition. It is, therefore, recommended that future studies include teacher observations or ratings (e.g., Sperling et al., 2002) and open-ended questions (e.g., Paulhus & Vazire, 2007) to reduce self-reporting bias. Additionally, inferences regarding directions of effect cannot be made due to the cross-sectional design of the study.

Finally, the possibility of reverse causality holds our assumption that metacognition mediates the relationship between test anxiety and mathematics achievement. It is also plausible that test anxiety may mediate the relationship between metacognition and task performance (e.g., Spada et al., 2006; Spada & Moneta, 2014). The results would be more convincing if future studies test additional models, which employ test anxiety and its components as mediators.

Educational and practical implications

Bearing in mind the prominence of mathematics achievement for the community especially for students, parents, and teachers, and that testing is an integral part of schooling, how testing can be utilized to help students learn mathematics is an important discussion for educators, school psychologists, and educational psychologists. The current study, although preliminary, confirmed some previous findings, determined new predictive associations, and presented comprehensive mediation models of test anxiety, metacognition, and mathematics achievement bringing the multidimensionality of test anxiety and metacognition on the scene. So, it could lay the basis for future metacognition-based intervention programs to cope students' test anxiety and mathematics achievement. Educators and school psychologists are aimed at helping students cope with test anxiety, especially while taking mathematics exams. As they are uniquely suited to provide direct and indirect such services, both educators and school psychologists are expected to inspire students to recognize the importance of awareness of their knowledge in studying and learning mathematics. Educators can use the results to inform targeted interventions for students experiencing test anxiety. Focusing on enhancing metacognitive skills, such as knowledge of cognition, may prove effective in mitigating the negative effects of test anxiety on mathematics achievement. Interventions could include strategies to improve students' awareness of their learning processes and the development of effective cognitive regulation strategies. Moreover, the study suggests the need for a critical examination of assessment practices. Traditional self-report measures may have limitations in capturing the nuanced relationship between test anxiety and metacognition. Educators may consider incorporating alternative assessment methods, such as teacher observations or ratings, to complement self-report data and provide a more comprehensive understanding of students' experiences.

In sum, the present study represents probably the first attempt to examine knowledge and regulation components of metacognition as mediators of the effects of thoughts, off-task behaviors, and autonomic reactions components of test anxiety on mathematics achievement. Thus, the study's findings add to the large body of evidence on the important role of metacognition in reducing test anxiety and fostering mathematics achievement. The findings go beyond those of previous studies by emphasizing that a sense of nervous habits in one's test anxious behaviors is vital for developing an awareness of knowledge and thus improving mathematics achievement. Overall, the study highlights the benefits of multidimensionality of test anxiety and metacognition and suggests that the advantages may span various domains, including mathematics achievement.

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Declarations

Conflict of interest The authors declare no competing interests.

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Utkun Aydin

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Mathematical thinking. Metacognition. Test anxiety. Educational assessment. University-school partnerships

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Meriç Özgeldi

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