ПСИХОЛОГИЯ И ПСИХИАТРИЯ
PSYCHOLOGY AND PSYCHIATRY

PSYCHOMETRIC PROPERTIES OF THE ABBREVIATED MATH ANXIETY SCALE ON A SAMPLE OF RUSSIAN HIGH SCHOOL STUDENTS

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ABSTRACT

Background. *Math anxiety is a state of fear and anxiety that an individual experiences when interacting with mathematical problems. Currently, there is a lack of questionnaires to measure mathematical anxiety for Russian-speaking schoolchildren.*
The aim. *The study analyzed the factor structure and psychometric properties of the Abbreviated Math Anxiety Scale (AMAS).*
Materials and methods. *The study involved 1,198 schoolchildren in grades 10–11. The psychometric properties of the AMAS were analyzed.*
Results. *AMAS demonstrated bifactor structure: subscales of Learning Math Anxiety (LMA) and Math Evaluation Anxiety (MEA) and general scale of Math Anxiety. The bifactor model demonstrated the best fit indices. Analysis confirmed reliable internal consistency (Cronbach's alphas for LMA = 0.82, MEA = 0.75, total AMAS = 0.95). External validity of AMAS has been confirmed. LMA showed lower scores than MEA. The distribution of scores on the general AMAS scale was shifted to low values. Girls showed higher scores on all scales of the questionnaire. The analysis also confirmed measurement invariance for both boys and girls.*
Conclusion. *Based on the analysis, we can conclude that the AMAS is a valid tool for assessing mathematical anxiety in high school students.*

Key words: *math anxiety, Abbreviated Math Anxiety Scale, factor validity, psychometric properties, high schoolers*

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ПСИХОМЕТРИЧЕСКИЕ СВОЙСТВА СОКРАЩЁННОЙ ШКАЛЫ МАТЕМАТИЧЕСКОЙ ТРЕВОЖНОСТИ НА ВЫБОРКЕ РОССИЙСКИХ СТАРШЕКЛАССНИКОВ

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РЕЗЮМЕ

Обоснование. *Математическая тревожность – это состояние страха и тревоги, которое испытывает индивид, когда взаимодействует с математическими задачами. В настоящее время имеется недостаток опросников для измерения математической тревожности у русскоговорящих школьников.*

Цель исследования. *В исследовании анализировались факторная структура и психометрические свойства Сокращённой шкалы математической тревожности (СШМТ).*

Методы. *В исследовании приняли участие 1198 школьников 10–11-х классов. Производился анализ психометрических свойств по СШМТ.*

Результаты. *Анализ СШМТ выявил бифакторную структуру опросника с субшкалами тревожности изучения математики (ТИМ) и тревожности математической оценки (ТМО) и общей шкалой математической тревожности. Бифакторная модель продемонстрировала лучшие индексы соответствия. Анализ подтвердил надёжные оценки внутренней согласованности (альфа Кронбаха для субшкалы ТИМ = 0,82, для субшкалы ТМО = 0,75, для общей СШМТ = 0,95). Была подтверждена внешняя валидность СШМТ. ТИМ обнаружила меньшие оценки по сравнению с ТМО. Распределение оценок общей шкалы СШМТ было смещено к низким значениям. Девочки продемонстрировали более высокие показатели по всем шкалам опросника. Анализ также подтвердил инвариантность измерения как для мальчиков, так и для девочек.*

Заключение. *На основе проведённого анализа можно сделать вывод, что СШМТ является валидным инструментом для оценки математической тревожности у старшеклассников.*

***Ключевые слова**:* *математическая тревожность, Сокращённая шкала математической тревожности, факторная валидность, психометрические свойства, старшеклассники*

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INTRODUCTION

Mathematical anxiety (MA) is a state of fear and worry that a person experiences when solving problems related to mathematics. Possible definitions are provided by Lazarus, Hembree, Ashcraft and Faust, and other authors [1].

The nature of math anxiety and math anxiety theories

Sources of MA can be found in attitudes, upbringing, and school traumas. Twin studies show that environmental factors explain up to 70 % of math anxiety [2, 3], among them such as: parents' fear of mathematics, low expectations from the child, bad school experience, gender stereotypes and other related reasons [4–12].

The theory of mechanisms of insufficient inhibition [8] describes the MA feedback loop: first, the MA is triggered by a mathematical problem; then, when an individual begins to experience anxiety, it limits their working memory and impairs their ability to solve mathematical problems, which in turn leads to incorrect solving of a mathematical problem. In other words, MA primarily affects working memory, and people who exhibit high levels of MA devote some of their working memory capacity to rumination about their anxiety. EEG source localization using specialized approaches (in particular, sLORETA) shows that brain regions such as the insula and amygdala are activated in people with MA. The insula is involved in reactions to pain, and the amygdala is associated with emotional experiences (fear, stress, anxiety). These data support the theory that explains MA by the anticipation of pain [9]. The attentional control theory of anxiety posits that anxiety reduces the effective functioning of attention and increases attention to threat-related stimuli [10]. Thus, individuals with high MA demonstrate reactive (post factum) control, whereas individuals with low anxiety demonstrate proactive (anticipatory) control.

Math anxiety and test anxiety

Since mathematics is an academic subject that is taught in most schools and universities, when studying it, schoolchildren and students inevitably face the situation of assessing their knowledge in this course. Assessment of mathematical knowledge is associated with so-called test anxiety – stress associated with passing a test, often leading to a decrease in performance (as defined by the American Psychological Association Dictionary). The concept of test anxiety began to develop in the middle of the 20th century [11]. Test anxiety has a negative impact on academic achievement and test scores. However, in the Russian context there is no instrument for measuring the level of test anxiety of students, and the terms "test anxiety" and "exam stress" are used as synonyms. When measuring MA, it is important to have a tool that can differentiate it itself from evaluation-related test anxiety. This is especially true for scales that are developed for older groups of students, since they often find themselves in knowledge assessment situations and demonstrate test anxiety.

Sex differences and gender stereotypes in the development of math anxiety

Studies show increased MA levels in girls [12]. This may be due to the influence of gender stereotypes: girls are often told that they are less mathematically inclined than boys. This influences girls' attitudes towards mathematical activities. On the other hand, some studies also report that instead of math anxiety, girls may be affected by test anxiety [13]. Thus, girls may experience more stress in a math test situation. Some studies report that in adolescence, girls begin to rate their mathematical abilities lower than boys, which can be explained by the increasing influence of gender stereotypes with age [14].

The Abbreviated Math Anxiety Scale

The Abbreviated Math Anxiety Scale (AMAS) was developed by D.R. Hopko and colleagues [15]. The scale is designed to measure MA. Each task describes a situation associated either with the process of learning mathematics or with the process of testing mathematical knowledge. Participants are required to report the level of their anxiety in the described situation on a five-point scale. Answers range from "low" to "high" anxiety. Filling out the form takes no more than 5 minutes. This scale was originally developed for undergraduate students. It consists of 9 items and includes two subscales: LMA (learning math anxiety) and MEA (math evaluation anxiety). The ability to measure both components of MA (in the situation of learning mathematics and assessing mathematical knowledge) is a noticeable advantage of this technique. At the same time, the two-factor structure is not the only one possible based on the results of analysis in different countries. Some authors report a two-factor configuration, others report a different structure, particularly with one question belonging to two scales [16–19]. The test has high internal consistency ($\alpha = 0.90$) and reliability (two-week period, $r = 0.85$) [15]. Convergent validity of the AMAS was demonstrated using the MARS-R (the Mathematics Anxiety Rating Scale) and reached $r = 0.85$. In Russia, the AMAS has not previously been tested among high school students. Validation of the AMAS will allow the use of a questionnaire that separates MA itself and anxiety associated with assessing mathematical knowledge, which is important for high school students who are constantly faced with exams and tests in mathematics. This will allow to evaluate the differences between the two components of MA in boys and girls. Thus, the purpose of this study is to confirm and evaluate such psychometric properties of the AMAS as factorial validity, internal consistency, external validity, and measurement invariance between genders in a sample of high school students in grades 10–11. Research on MA in general and its diagnostics in particular is an important step in the prevention of anxiety disorders characterized by significant and uncontrollable experiences of anxiety and fear, such that a person's social, professional and personal functions are disrupted. Our study contributes to public health by validation of MA scale aimed at early detection of MA. This investigation will help specialists to prevent the negative consequences of MA on the mental health and well-being of adolescents.

MATERIALS AND METHODS

Sample

Initially, 2,409 participants completed the questionnaire. The following were removed from the sample:

- those who specified their age as lower than 12 y. o.;
- those who didn't identify their sex;
- those who took less than 100 ms to complete the test;
- those who took more than 1,500 ms to complete the test;
- those with Mahalanobis distance *p*-value less than 0.001.

Exclusion of those who reported their age below 12 is because of the implausibility of such age for high school students. Exclusion of who did not specify their gender is due to the impossibility of including them in the analysis of gender differences. The exclusion of those who completed the test in less than 100 ms or more than 1,500 ms, as well as those with Mahalanobis distance p-value less than 0.001, is due to a high probability of poor questionnaire completion and, consequently, unreliable data [20, 21].

Thus, the final sample consisted of 1,198 schoolchildren. Age ranged from 15 to 18 years (mean = 16.52; median = 17.0; standard deviation = 0.63). Among respondents 502 (42 %) were male, 696 (58 %) were female. The study included grades 10 and 11. There were 583 children in grade 10 and 615 were in grade 11.

Procedure

The study was conducted online. Informed consent was obtained from the parents of all participants. The study was approved by the Ethics Committee of the Psychological Institute of the Russian Academy of Education (protocol No. 2020/4-1 of April 2, 2020).

Scales

The Abbreviated Math Anxiety Scale (AMAS) consists of 9 items. The AMAS was adapted from the work of D.R. Hopko et al. [15]. This version has been translated into Russian by professional translators (Table 1). Translation, reverse translation and adaptation of the test were performed by the Cognitive and Interdisciplinary Research Laboratory (Sirius). The questionnaire consists of 9 items: 5 items for the Learning Math Anxiety scale and 4 items for the Math Evaluation Anxiety scale. Respondents were asked to rate each statement in terms of how anxious they felt in each of the situations described. Responses were given on a Likert scale from 1 (low anxiety) to 5 (high anxiety).

State-Trait Anxiety Inventory STAI-T (Scale of Personal Anxiety trait) [22]. This scale is one of the scales of State-Trait Anxiety Inventory (STAI-Scale) of Reactive and Personal Anxiety by Spilberger. The STAI-T assesses relatively stable aspects of anxiety proneness, including general states of calm, confidence, and security. Participants need

TABLE 1

ABBREVIATED MATH ANXIETY SCALE IN ENGLISH AND RUSSIAN

Item No.	English	Russian
1	Having to use the tables in the back of a math book.	Используя таблицы в конце учебника по математике.
2	Thinking about an upcoming math test 1 day before.	Думая накануне о предстоящем тесте по математике.
3	Watching a teacher work an algebraic equation on the blackboard.	Наблюдая, как преподаватель объясняет алгебраическое уравнение на доске.
4	Taking an examination in a math course.	Выполняя экзамен по математике.
5	Being given a homework assignment of many difficult problems that is due the next class meeting.	Получая домашнюю работу с большим количеством трудных задач, которую нужно решить к следующему занятию.
6	Listening to a lecture in math class.	Слушая лекцию на занятии по математике.
7	Listening to another student explain a math formula.	Слушая, как другой студент объясняет математическую формулу.
8	Being given a "pop" quiz in math class.	Выполняя внеплановую контрольную на занятии по математике.
9	Starting a new chapter in a math book.	Начиная новую главу по математике.

Note. Instruction for participants: please rate each statement in terms of how much anxiety you feel in each of the situations described. Response scale: 1 – low anxiety; 2 – slight anxiety; 3 – moderate anxiety; 4 – major anxiety; 5 – high anxiety.

to rate how they usually feel. Ratings range from "almost never" to "almost always".

Perceived Difficulty of Math (scale of Questionnaire "Gender stereotypes and incremental beliefs about STEM") [23]. The scale is aimed at identifying difficulties associated with learning mathematics, according to self-reports of schoolchildren. This scale includes 4 items ("I usually do well in math (reverse coded)", "Math is harder for me than for many of my classmates", "Studying math gives me anxiety", "Math is harder for me than other subjects"). Participants rated all items on the same 4-point Likert scale (with 2 negative and 2 positive ratings). Cronbach's alpha (0.8) for the scale demonstrates good internal consistency.

Data analysis

The first stage of analysis included the calculation of descriptive statistics. Confirmatory factor analysis (CFA) was then conducted using the WLSMV estimator. The following fit indices were used to evaluate the model: Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Tucker – Lewis Index (TLI), and Standardized Root Mean Square Measure (SRMR). The next step in the analysis was to assess internal consistency using Cronbach's alpha. External validity was measured using Spearman correlations of the AMAS scales and other questionnaires. Differences between sexes were then assessed by comparing means. In addition, measurement invariance across genders was analyzed using structural equation modeling (SEM), a procedure that selected the "automatic" estimator in SEM offered in JASP. Measurement invariance was assessed using two measures: configural and metric invariance. Configurational invariance was assessed by the CFI and RMSEA indices. Metric invariance was assessed using ΔCFI and ΔRMSEA. All statistical measurements were performed in R version 4.2.1 and JASP.

RESULTS

Descriptive statistics

At the first stage of the analysis descriptive statistics were calculated. The results are presented in Table 2. As can be seen, LMA is less pronounced than MEA.

TABLE 2

DESCRIPTIVE STATISTICS FOR LMA, MEA AND AMAS_TOTAL

Scales	Number of items	Mean	Std	Median	Max
LMA	5	2.0	3.3	0.0	20
MEA	4	6.8	4.0	7.0	16
AMAS_total	9	8.8	6.3	8.0	36

Distribution graphs of the AMAS total scale and two subscales are presented in Figure 1. In general, the distribution of the AMAS is shifted towards low values. The obtained result is one of the typical variants of the distribution of MA scores: it has been shown that low MA scores are most common in the population [24]. Pearson's correlation between LMA and MEA is 0.51.

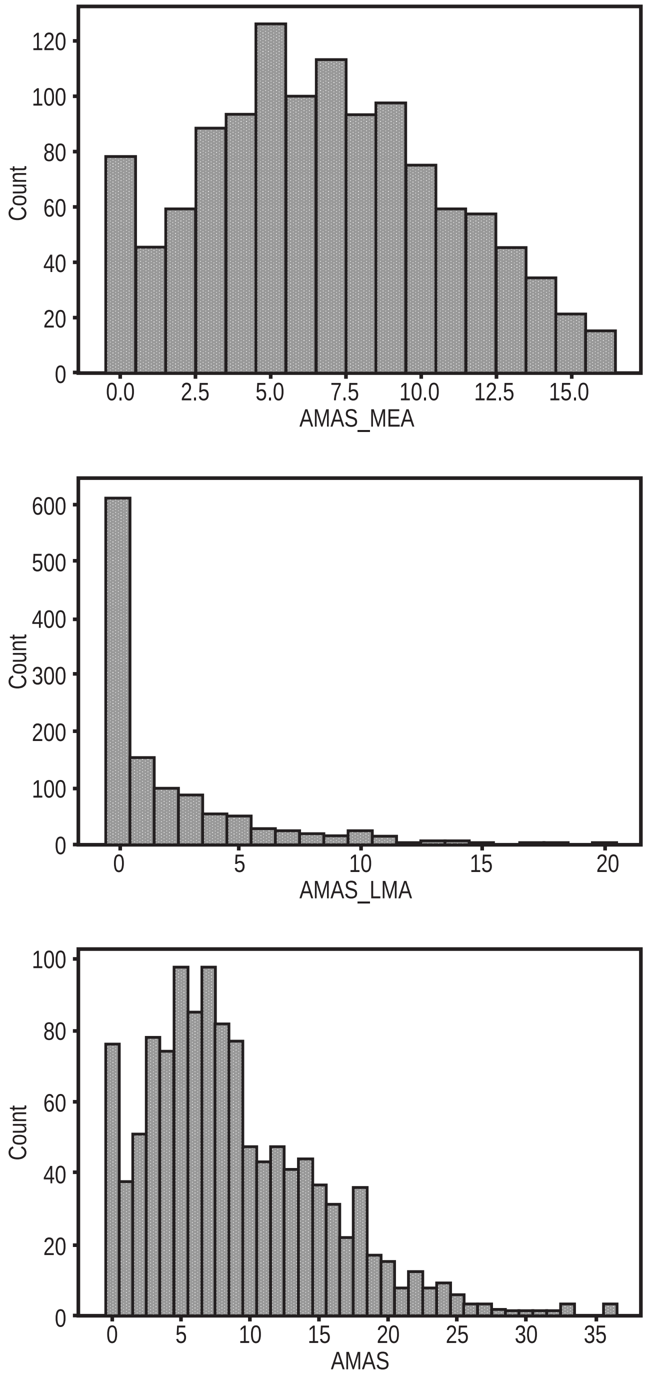

FIG. 1.
Frequency histograms for LMA, MEA and total AMAS scales

Confirmatory factor analysis (CFA)

The CFA tested three models: one-factor, two-factor, and bifactor. The following indicators were used as standards in evaluating model fit indices: Standardized Root Mean Square (SRMR) < 0.08, Tucker – Lewis index (TLI) scores approaching 1, Comparative Fit Index (CFI) > 0.95, and Root Mean Square Error of Approximation (RMSEA) < 0.08. The bifactor model demonstrated good statistics and had better fit indices than the others: RMSEA = 0.018, CFI = 1.000, TLI = 0.999, SRMR = 0.023 (Table 3).

TABLE 3

MODEL FIT INDICATORS (CONFIRMATORY FACTOR ANALYSIS, CFA)

Models	CFI	TLI	RMSEA	SRMR
1-factor	0.972	0.962	0.143	0.115
2-factor	0.995	0.993	0.062	0.053
Bifactor	1.000	0.999	0.018	0.023

Standardized CFA loadings for the bifactor model are presented in Table 4.

Factor configuration of our data appropriates two factors of Learning Math Anxiety and Math Evaluation Anxiety with general (common) Math Anxiety Factor. LMA includes 5 items (1, 3, 6, 7, 9) MEA – 4 items (2, 4, 8, 5). The factor model is presented on Figure 2.

TABLE 4

STANDARDIZED CFA LOADINGS FOR THE BIFACTOR MODEL

Item	Estimate		
	Learning Math Anxiety	Math Evaluation Anxiety	General Math Anxiety
1	0.279	–	0.647
3	0.306	–	0.825
6	0.469	–	0.777
7	0.500	–	0.704
9	0.290	–	0.791
2	–	0.518	0.704
4	–	0.675	0.519
8	–	0.584	0.685
9	–	0.246	0.592

Internal consistency

To assess internal consistency, Cronbach's Alpha was analyzed and demonstrated the following: 0.82 for LMA, 0.75 for MEA, 0.92 for the total MA scale. The obtained alpha values above 0.7 showed good internal consistency and confirmed the internal consistency of the data.

External validity

One of the possible ways to test the external (construct) validity of the AMAS may be to use school anxie-

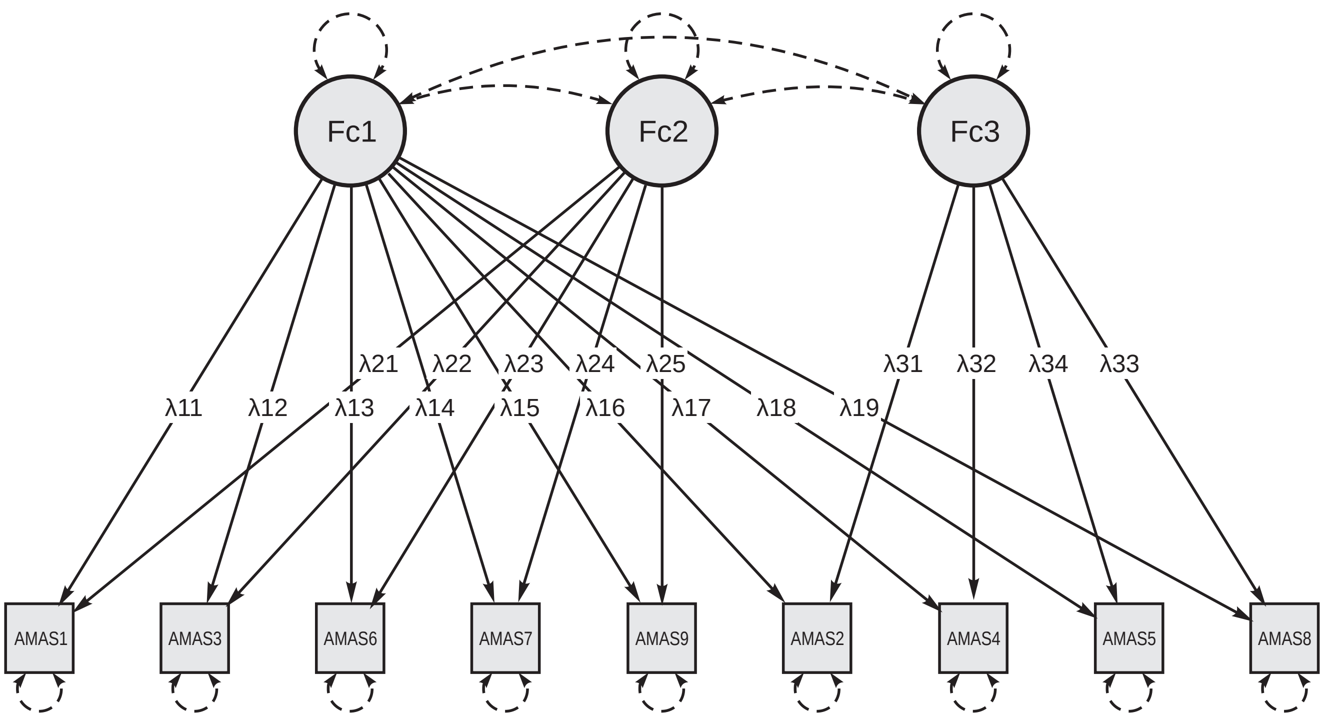

FIG 2.
Model plot for factor structure of AMAS

ty scales. The most common tool for assessing school anxiety in Russia is the Phillips School Anxiety Scale. However, it was adapted either in the form of a teacher's report, which does not allow the results to be directly correlated with the AMAS, which uses self-report, or for younger participants (grades 3–8) – our adaptation of the AMAS was carried out on schoolchildren in grades 10–11 [25–27]. The scope of this scale includes the manifestation of anxiety in educational activities, social stress at school, social behavior, which is not directly related to MA. This scale is quite difficult for screening because it consists of 8 subscales, including 58 questions. It is criticized in the literature [28]. These limitations do not allow the use of school anxiety scales to assess the external validity of the AMAS.

In our study, the external validity of the AMAS general scale was assessed by Spearman correlations with the STAI-T and Perceived Difficulty of Math. The STAI-T technique is highly reliable and is used in a variety of practices. It has proven itself well in previous studies assessing the external validity of the MA technique, in particular, in the recent study by M.I. Núñez-Peña and G. Guilera on the validation of the brief MA scale in a Spanish-speaking sample [29]. The STAI-T is also used to differentiate between different forms of anxiety. For example, in a study by L. Buratta et al. [30], the use of the STAI was able to differentiate the role of MA from other forms of anxiety and found that levels of trait anxiety and situational anxiety did not correlate with or negatively affect math performance. The use of the "Perceived Difficulty of Math" scale from the "Gender stereotypes and incremental beliefs about STEM" questionnaire allows, firstly, to additionally monitor the occurrence of a negative emotional state associated with mathematics (the item "Studying math gives me anxiety"), similar to the MA questionnaire SIMA, which consists of one question and has high correlations with the AMAS [31]. Secondly, the use of the scale provides to assess the student's self-esteem of abilities specifically in mathematics, and not within the framework of the entire educational process.

As a result, significant correlations between the AMAS and the used scales were found (Table 5).

TABLE 5

CORRELATIONS BETWEEN AMAS TOTAL SCALE, STAI-T AND PERCEIVED DIFFICULTY OF MATH

Indices	AMAS Total
STAI-T	0.38*
Perceived Difficulty of Math	0.35*

Note. * – $p < 0.001$.

Gender differences and measurement invariance across genders

The next step in our analysis was to assess sex differences. The results are presented in Table 6. Overall, girls showed higher MA, which is consistent with previous studies. However, for LMA differences are insignificant.

Measurement invariance across genders was also investigated in this study (Table 7). Two models were tested: model 1 corresponds to configural invariance, model 2 characterizes metric invariance. The following indices were selected as demonstrating good model 1 fit: the CFI of > 0.95, and RMSEA < 0.08. CFI = 1.000 and RMSEA = 0.000 obtained for model 1 are within acceptable values, which demonstrates that the data is invariant in terms of configural invariance. Metric invariance (model 2) demonstrated ΔCFI = 0.000 and ΔRMSEA = 0.000, $p = 0.497$. As reported, ΔCFI < 0.010 and ΔRMSEA < 0.015 demonstrates metric invariance [32].

TABLE 6

GENDER DIFFERENCES AND DESCRIPTIVE STATISTICS FOR LMA, MEA AND AMAS_TOTAL

Scales	Male		Female		Mean difference	*p*-value
	M	Sd	M	Sd		
LMA	1.8	3.2	2.2	3.4	0.5	0.02
MEA	5.6	3.8	7.6	3.9	2.0	< 0.001
AMAS_total	7.4	6.0	9.9	6.4	2.5	< 0.001

TABLE 7

FIT INDICES FOR MEASUREMENT INVARIANCE ACROSS GENDERS

Models	CFI	RMSEA	Baseline test			Difference test				
			χ^2	Df	P	ΔCFI	ΔRMSEA	$\Delta\chi^2$	Δdf	*p*
Model 1	1.000	0.000	31.749	36	0.671	–	–	–	–	–
Model 2	1.000	0.000	46.284	51	0.661	0.000	0.000	14.373	15	0.497

DISCUSSION

This study had several objectives, including: assessing the factorial validity of the AMAS questionnaire, assessing the internal consistency of the methodology, assessing the external validity of the scale, and analyzing sex differences and measurement invariance. All stated goals were achieved and the results are discussed in more detail below.

First, analysis of factor validity was carried out. A confirmatory factor analysis procedure was used to assess the factorial validity of AMAS. Three models were evaluated: one-factor, two-factor and bifactor (with a general MA factor and two subscales). The analysis showed that the bifactor model provided a better fit to the data. The obtained result is consistent with the conclusions of other studies demonstrating the best fit of this model [16, 33]. Thus, our version of the questionnaire consists of two subscales: LMA (5 items) and MEA (4 items). The distribution of questions on scales was the same as in previous studies [15]. This analysis allows us to measure math anxiety using AMAS both in a learning situation and in a situation of knowledge assessment.

Second, internal consistency was evaluated. In our study, high scores were obtained on the Cronbach's alpha for general math anxiety, as well as on the LMA and MEA subscales. This indicates a high internal consistency of the questionnaire. The results obtained are consistent with original version [15].

Third, external validity was estimated. A study of Cipora and colleagues has shown that mathematics anxiety correlates with general anxiety [17]; therefore, the Spielberger State – Trait Anxiety Inventory STAI-T was chosen to assess external validity. This study has shown low but significant correlations between AMAS and STAI-T [17], a similar result was observed in our study. We also used the Perceived Difficulty of Math questionnaire (scale of Questionnaire "Gender stereotypes and incremental beliefs about STEM") for the first time to test external validity. The results showed low but significant correlations. This may indicate that perceived difficulty of math and math anxiety are related constructs: math-anxious individuals perceive math as a complicated subject to tackle and become anxious when dealing with it. This can also work in reverse: anxiety prevents concentrating on math problem, so it is perceived by the student as difficult. Possible mechanism may be related to overload of working memory, which is consistent with the Deficient Inhibition Mechanism theory [8].

Finally, sex differences and measurement invariance across sexes were evaluated. The assessment of sex differences in AMAS in our study was provided separately on the LMA and MEA subscales and the total scale of math anxiety. This seems to be justified, since, on the one hand, studies describe an increase in math anxiety scores in girls, on the other hand, some report an increase in math anxiety only in the assessment situation. Therefore, it is important to separate these constructs in the analysis. Our results are consistent with previous studies [8]. An increase in general math anxiety, MEA, which characterizes specific anxiety in the assessment of math knowledge, and LMA, math anxiety in a learning situation were shown. Thus, older adolescent girls experience greater anxiety when studying and assessing their knowledge, which may be the result of the influence of gender stereotypes. Most likely, this increase in anxiety is due to the girls of this age being more exposed to gender stereotypes over their lifetime. The performed analysis of measurement invariance demonstrated configural invariance, which suggests the unity of the math anxiety construct measured by AMAS in both sexes. Also, our data demonstrated the similarity of factor loadings in boys and girls, as evidenced by metric invariance.

The strengths and weaknesses of the present study should be noted. One obvious advantage of this study is the sufficient sample size, which ensured the reliability of the statistical analysis and the conclusions drawn from it. Another advantage is that for the first time in the Russian-speaking sample, the invariance of the measurement by sex was assessed. As for limitations of this study, there is a lack of analysis of test-retest reliability, which should be carried out in future studies.

CONCLUSIONS

AMAS demonstrated acceptable psychometric properties and factorial validity, which makes it a sufficiently effective tool to assess mathematics anxiety in high school students. The unique advantage of the scale lies in the possibility of distinguishing between the measurement of test anxiety in the situation of evaluating mathematical concepts, and mathematics anxiety in the situation of everyday learning. This scale can be useful in pedagogy. It can be used by practicing psychologists, for example, at school, to detect and prevent cases of mathematics anxiety in a timely manner, which can reduce the distress that occurs in the classroom. In general, this can make education more effective, as it assesses individual differences in anxiety and takes them into account when organizing the educational environment.

Conflict of interests
The authors of this article declare no conflict of interest.

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