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What Explains Maths Fluency in Children? Maths Anxiety, Strategies and Cognitive Factors

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Abstract

Math fluency and the use of advanced cognitive strategies are thought to be influenced by affective and cognitive factors from primary school onward. This study aims to examine the relationship between the components of maths anxiety, use of advanced cognitive strategies and basic maths tasks. Additionally, it investigates the role of general cognitive factors, including verbal working memory and nonverbal reasoning in the choice of solving strategies and maths fluency. One hundred and thirty-nine female third-grade students took a set of tests for maths fluency, solving strategies in maths, and cognitive abilities: nonverbal reasoning and updating verbal working memory and ranked themselves on a scale for maths anxiety. Ten students were excluded for reasons including not completing the tests or misunderstanding the instructions. The results show that although maths anxiety predicts maths fluency, the components of maths anxiety have different predictability levels. Additionally, maths evaluation anxiety predicts maths fluency while learning maths anxiety does not predict maths fluency. Although, maths evaluation anxiety is not related to decrease in use of advanced cognitive strategies, it is negatively correlated with maths fluency. Nonverbal reasoning and updating of verbal working memory are directly and indirectly related to maths fluency, with the use of advanced cognitive strategies as a mediator. These findings indicate that affective and cognitive factors have different impacts on the use of solving strategies in maths. Researchers and educators should focus in teaching children advanced cognitive strategies to improve maths fluency. Moreover, training general cognitive abilities should be taken in account in any trials for developing students' maths abilities. Furthermore, understanding the factors which are related to the increase of maths evaluation anxiety requires further research.

Keywords: advanced cognitive strategies, cognitive abilities, maths anxiety, maths fluency, primary school students.

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ما الذي يفسّر الطلاقة الرياضية لدى الأطفال؟ قلق الرياضيات، والاستراتيجيات، والعوامل المعرفية

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الملخص

يعتقد أن الطلاقة الرياضية واستخدام استراتيجيات معرفية متقدمة تتأثر بعوامل وجدانية ومعرفية ابتداءً من مرحلة المدرسة الابتدائية ثم ما يليها. وتهدف هذه الدراسة إلى اختبار العلاقة بين مكونات قلق الرياضيات، واستخدام استراتيجيات معرفية متقدمة، ومهام رياضية أساسية. إضافة إلى ذلك فهي تتقصى عوامل معرفية عامة، تشمل: الذاكرة العاملة اللفظية، والاستدلال غير اللفظي في اختيار استراتيجيات الحل والطلاقة الرياضية. وقد أدّت 139 طالبة في الصف الثالث مجموعة من الاختبارات في الطلاقة الرياضية، واستراتيجيات الحل في الرياضيات، والقدرات المعرفية: تحديث الذاكرة العاملة اللفظية، والاستدلال غير اللفظي، وقيموا ذواتهم على مقياس تقدير ذاتي لقلق الرياضيات. وقد استُبعدت عشرة من الطالبات لأسباب تشمل عدم إكمال الاختبارات، أو الفهم الخاطئ للتعليمات. وتشير النتائج إلى أنه على الرغم من أن قلق الرياضيات يتنبأ بالطلاقة الرياضية إلا أن مكونات قلق الرياضيات لها مستويات مختلفة من القدرة على التنبؤ، فقلق تقييم الرياضيات يتنبأ بالطلاقة الرياضية بينما قلق تعلم الرياضيات لا يتنبأ بالطلاقة الرياضية. ولا يتصل قلق تقييم الرياضيات بنقص استخدام الاستراتيجيات المعرفية المتقدمة على الرغم من أن الأول يتصل سلبًا بالطلاقة الرياضية. ويرتبط الاستدلال غير اللفظي وتحديث الذاكرة العاملة اللفظية بشكل مباشر وغير مباشر بالطلاقة الرياضية؛ بوجود استخدام الاستراتيجيات المعرفية المتقدمة كمتغير وسيط. وهذه النتائج تبيِّن أن العوامل الوجدانية والمعرفية لها تأثيرات مختلفة على استخدام استراتيجيات الحل في الرياضيات. ويجب على الباحثين والمربين أن يركزوا على تعليم الأطفال استراتيجيات معرفية متقدمة لتحسين الطلاقة الرياضية. إضافة إلى ذلك فينبغي أخذ تدريب القدرات المعرفية العامة في الحسبان في أي محاولة لتطوير قدرات الطلبة الرياضية. علاوة على ذلك، فإن فهم العوامل التي تتصل بزيادة قلق تقييم الرياضيات يتطلب بحوثًا مستقبلية.

الكلمات المفتاحية: الاستراتيجيات المعرفية المتقدمة، القدرات المعرفية، قلق الرياضيات، الطلاقة الرياضية، تلاميذ المرحلة الابتدائية.

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What Explains Maths Fluency in Children? Maths Anxiety, Strategies and Cognitive Factors

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Introduction

Processing speed and the use of optimal solving strategies in mathematics from primary school onward has a clear impact on students' academic wellbeing (Rodriguez et al., 2020) and future academic achievement (Duncan et al., 2007; Geary et al., 2013). Thus, it is important to highlight the cognitive and affective factors related to the ability to adopt advanced cognitive strategies from an early stage of education as the effects of cognition and emotion combine and interact in affecting such ability (Trezise & Reeve, 2014a).

Over the past decade, studies have consistently provided evidence of the negative relation between maths anxiety and mathematical performance in primary school (Allen & Tourangeau, 2016; Cargnelutti et al., 2017; Devine et al., 2018; Gunderson et al., 2018; Harari et al., 2013; Justicia-Galiano et al., 2017; Ma & Xu, 2004; Passolunghi et al., 2019; Ramirez et al., 2013; Ramirez et al., 2016; Sorvo et al., 2017; Vukovic et al., 2013; Wu et al., 2014, 2017); for a review, see Dowker and colleagues (2016). Despite such evidence, however, some studies have failed to detect significant correlations (Krinzinger et al., 2009; Rodic et al., 2018; Tsui & Mazzocco, 2006). This flags up the fact that issues remain unresolved regarding this relation. For instance, it remains unclear whether the relation between maths anxiety and performance is direct or mediated by other variables. The current study focuses on a particular mediatory role for advanced cognitive strategies between maths anxiety and maths fluency. Additionally, the current research aims to determine whether advanced cognitive solving strategies mediate the relation between general cognitive abilities and maths fluency. The focus on maths fluency blossomed from the fact that it is foundational to all other mathematical abilities as speed in processing maths problems is not only a key element in accuracy, but also motivates students to complete other maths tasks (Dowker, 2005) and supports the accomplishment of complex maths problems (Nunes et al., 2012; Powell et al., 2016; Wang et al., 2016).

Overview of the literature

Maths Anxiety & Mathematical Abilities

Studies show that maths anxiety appears as early as primary school (Pappas et al., 2019), and that it is negatively correlated with mathematical abilities (Cargnelutti et al., 2017; Harari et al., 2013; Ramirez et al., 2016; Vukovic et al., 2013). In contrast, other studies which have examined the correlation between maths anxiety and mathematical abilities showed null findings (Krinzinger et al., 2009; Rodic et al., 2018; Tsui & Mazzocco, 2006).

It has been proposed that mathematical abilities are related to maths anxiety as a state but not as a trait (Orbach et al., 2019). This might be one view of the relation between maths anxiety and mathematical abilities. Another view might be derived from separating the components of maths anxiety (e.g., learning maths anxiety & maths evaluation anxiety) (Carey et al., 2017; Hopko et al., 2013). It might be that different components of maths anxiety are related to different mathematical abilities.

Maths anxiety is, in essence, defined as feelings of fear of tasks that involve mathematics and of being evaluated in mathematics performance (Ma & Xu, 2004). Maths anxiety has been assessed as a trait by several measures and in several dimensions, departing from the Mathematics Anxiety Rating Scale developed by Richardson and Suinn in 1972. The adapted measures were abbreviated but found to be still reliable, and include the Math Anxiety Rating Scale (Suinn et al., 1988), the Revised Mathematics Anxiety Rating Scale (RMARS), (Alexander & Martray, 1989), Scale of Early Math Anxiety (SEMA) (Wu et al., 2012), and Abbreviated Math Anxiety Scale (AMAS) (Carey et al., 2017; Hopko et al., 2003); for a review, see Eden and colleagues (2013). The AMAS, in particular, is a commonly used measure. It has only nine items and consists of two subscales: anxiety from learning maths and anxiety from maths evaluation (Carey et al., 2017; Hopko et al., 2013). The multidimensionality of the scales and the essential trait flags up the differences between the subscales in their relation to mathematical abilities.

On the other side, specific math domains are different in their relations to maths anxiety. For instance, when maths anxiety was studied among primary school children engaged in both basic arithmetic and geometry, it was revealed to have a negative relationship only with basic arithmetic (Vukovic et al., 2013). Nevertheless, basic arithmetic has a smaller negative correlation than maths reasoning with maths anxiety (Wu et al., 2012).

Task settings are a further factor determining the relation between maths anxiety and a specific mathematical ability. In this realm, it was found that maths anxiety correlates only with time-limited tasks (Ashcraft & Moore, 2009). These findings together pinpoint the specificity of the correlation between maths anxiety and particular mathematical abilities within particular settings.

Working Memory, Mathematical Performance, & Maths Anxiety

Mathematical performance and all components of working memory are positively and strongly related (Ertl et al., 2019; DeStefano & LeFevre, 2004; Korpippaa et al., 2017; Peng et al., 2016; Trezise & Reeve, 2014b; Wu et al., 2017). For instance, it was found that tasks related to the central executive component of working memory are related to mathematical performance in primary school (De Smedt et al., 2009). Tasks that involve both the phonological loop and central executive components, such as digit updating, are also related to mathematical performance (Friso-ban Dan Bos et al., 2013; Justicia-Galiano et al., 2017). Additionally, difficulty in learning maths was found to be related to low visuospatial working memory (Soltanlou et al., 2019). However, it seems that not all working memory components are equally related to mathematical performance. The relation between tasks related to the phonological loop and mathematical performance becomes stronger after the first grade in school whereas the relation between tasks related to visuospatial working memory and mathematical performance gradually weakens (De Smedt et al., 2009).

Furthermore, working memory is a moderator for the relation between mathematical performance and maths anxiety. Nevertheless, its moderating role is somewhat controversial. One cluster of findings suggests that high working memory is related to a negative relation between maths anxiety and mathematical performance (Ramirez et al., 2013; Vukovic et al., 2013). Fourth-grade students with a high verbal working memory show a larger negative correlation between maths anxiety and mathematical performance than students with a low working memory (Passolunghi et al., 2019). These findings in regard to an increased negative relation between mathematical performance and maths anxiety in high working memory are consistent with those of other studies (Passolunghi et al., 2014; Vukovic et al., 2013).

The choking-under-pressure effect explains why a high working memory moderates the relation between feeling pressure (maths anxiety) and low mathematical abilities (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Ramirez et al., 2016). High working memory allows participants to use an optimal solving strategy when no pressure is induced. Nevertheless, when they feel that they are under pressure during math tasks, their working memory resources are consumed by inhibiting anxiety and they switch to less optimal strategies that do not depend heavily on a central executive working memory component. Hence, their performance in maths drops (Beilock & Carr, 2005; Beilock & DeCaro, 2007). This assumption is supported by findings from the study by Orbach and colleagues (2020), which show that maths anxiety as a state shows the strongest negative correlation with mathematical performance in children with high executive functions.

Other studies suggest that low working memory is related to the negative relation between mathematical performance and maths anxiety. For instance, maths anxiety negatively correlates with algebra in low-working-memory secondary school students (Trezise & Reeve, 2014b). This was also confirmed by a study of sixth- to eighth-grade Italian schoolchildren, in which children with maths anxiety, as opposed to normal children and children with dyscalculia, were assessed by means of a backward verbal memory recall and found to be impaired in verbal working memory (Mammarella et al., 2015).

Eysenck and Calvo's (1992) processing efficiency theory suggests that maths anxiety consumes the sources of working memory which are required for attention when performing a task (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Owens et al., 2008; Trezise & Reeve, 2014b). Whether maths anxiety dampens the use of suitable strategies or limits the resources of working memory, in both cases its disruptive effect on mathematical performance is thought to flow from the central executive component in working memory (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Suarez-Pellicioni et al., 2016).

Working Memory & Solving Strategies in Math

Several studies have investigated the solving strategies adopted by students to solve arithmetic problems (Carr & Alexeev, 2011; Geary et al., 2004; Ramirez et al., 2016). Strategies include concrete rudimentary strategies, such as counting on fingers, drawing lines, or using calculus. Advanced cognitive strategies include decomposition of the problems into easier, smaller problems and retrieval of already known answers (Carr & Alexeev, 2011).

First- and second-grade students with a high working memory show larger use of advanced strategies in arithmetic tasks than students with a low working memory, who use rudimentary strategies (Ramirez et al., 2016). These advanced strategies are positively correlated with accuracy and fluency in mathematical performance in primary school (Carr & Alexeev, 2011; Geary et al., 2012).

The relation between high working memory and advanced cognitive strategies is also seen in regard to maths anxiety. Returning to the choking-under-pressure effect theory, the level of maths anxiety only correlates with children's use of advanced cognitive solving strategies when their working memory is high. Thus, it was concluded that students with high working memory cannot use optimal solving strategies when their maths anxiety is high (Ramirez et al., 2016).

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In contrast, fixation on counting strategies is related to both a deficit in working memory and larger error rates (Geary et al., 2004). Nevertheless, it was found that concrete strategies have a positive impact in reducing maths anxiety. Allowing participants to, for instance, move tokens while counting the answer is likely to reduce maths anxiety. It was found that when fifth- and sixth-grade students are asked to count by interacting or not with tokens, mathematical performance improves with interaction as compared to without interaction among those who have a high level of maths anxiety (Allen & Vallee-Tourangeau, 2016). Together, these findings indicate the complexity of the relation between solving strategies and working memory in the presence of maths anxiety.

Research Questions and Hypotheses

The current study aims to answer three research questions: (a) Do learning maths anxiety and maths evaluation anxiety predict maths fluency in primary school students? (b) Do general cognitive abilities, namely nonverbal reasoning and verbal working memory, moderate the relation between maths anxiety and maths fluency? (c) Does the use of advanced cognitive solving strategies mediate the relation between general cognitive abilities and maths anxiety and maths fluency?

It is expected that a negative correlation will be found between maths anxiety and maths fluency, since the former is performed under time pressure (Tsui & Mazzocco, 2006). Additionally, it is expected that a positive correlation will be found between maths anxiety and general anxiety and that only maths anxiety negatively correlates with maths fluency (Cargnelutti et al., 2017).

With regards to the moderating effect of general cognitive abilities, it is expected that verbal working memory will be found to have a moderating effect, with increase in working memory related to a larger negative correlation between maths anxiety and mathematical performance (Beilock & Carr, 2005; Beilock & DeCaro, 2007).

Furthermore, it has previously been found that working memory capacity and fluid intelligence are indicators of high cognitive abilities (Conway et al., 2003); hence, a positive correlation is expected between nonverbal reasoning and maths fluency and accuracy.

Finally, in relation to the mediating role of advanced cognitive strategies, it is expected, based on the study by Carr and Alexeev (2011), that a significant positive correlation will be found between frequency of use of advanced cognitive strategies and both fluency and accuracy in arithmetic. Additionally, it is expected that a positive correlation will be found between working memory and frequency of use of advanced cognitive strategies, based on the findings of previous studies (Gerry, 2011; Ramirez et al., 2016). In contrast, a negative correlation is expected between maths anxiety and frequency of use of advanced cognitive strategies. This is because maths anxiety is thought to disrupt performance in complex arithmetic tasks and strategies that load on the central executive (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007).

Interactions are predicted between nonverbal reasoning, working memory, and maths anxiety as predictors for mathematical performance via the mediation of advanced cognitive strategies. This prediction is based on the findings of Ramirez and colleagues (2016), that solving strategies mediate the relation between maths anxiety and maths achievement only in the presence of high working memory.

The current study will focus on girls as several studies have found significant differences between boys and girls in mathematical performance and the adoption of certain types of solving strategies. Different use of strategies by the sexes is evident from primary school onward: girls prefer concrete strategies and boys prefer advanced cognitive strategies (Carr & Alexeev, 2011). Moreover, boys and girls who have high mathematical abilities differ in their level of mathematical performance in timed tasks (Tsui & Mazzocco, 2006). Additionally, although some studies show a similar level of maths anxiety in boys and girls (Harari et al., 2013; Rodic et al., 2018), others show that girls differ from boys in regard to maths anxiety as a trait (Bieg et al., 2015; Devine et al., 2018; Goetz et al., 2013), being more likely to develop both maths anxiety and dyscalculia (Devine et al., 2018). For all these reasons, the current study focuses on girls.

Method

Participants

The study recruited 139 girls in third grade from three public schools in Riyadh. Seven students were excluded because they were above the age of 10. Another three students failed to attend one of the sessions of the study and were excluded. Consequently, the final number of participants was 129 children, ranging between the ages of eight and ten (M = 8.92, and SD = 0.49). Of these 129, two children misunderstood the instructions of one measure, one a digit updating task, and one a visuospatial working memory task. These two were only excluded from the analysis of the respective measures. Students were from low- (82.39%) and medium-income (18.6%) families. Consent letters containing information about the study and the confidentiality of student information were sent to parents. All parents signed the consent forms and returned them to the school with their children at the time of the study.

Instruments

Arithmetic Fluency. The design of this task was derived and adapted from the design of the Woodcock Johnson arithmetic fluency test, which was used by several studies (e.g., Casey et al., 2017) and has three parts. Each part consisted of 60 simple arithmetic problems printed in two rows on a single sheet. The first part consisted of addition problems; the second part consisted of subtraction problems; and the third part was a mixture of addition, subtraction, and multiplication problems. Addition and subtraction problems included either two single-digit integers or one single- and one double-digit integer, with the restriction that neither any integer nor sum-up total for the addition problems could exceed 20. For multiplication, all problems included two single-digit integers. Children were given two minutes to solve each part and scored 1 for each correct answer. The test has excellent reliability: tested by Kuder-Richardson, it revealed $\alpha = 0.959$ for the whole test, and $\alpha = 0.935$, 0.926, and 0.765, for the three parts of the test in their respective order.

Solving Strategies Measure. This measure was taken from Casey and colleagues (2017), with amendments to the method of administration and strategy reporting. There were 10 addition and 10 subtraction problems, of which 30% were simple (two single-digit integers) and 70% were mixed (one-digit and two-digit integers). The integers were all less than 20, and integers with (0 or 1) in the units were excluded. Neat problems with two same integers were not included. The answers to the addition problems ranged between 9 and 24, and the answers for subtraction problems ranged between 3 and 15.

In order to make the task appropriate for group administration to third-grade students, it was presented on a sheet of A4 paper. Each arithmetic problem was written horizontally, in a single row, in the right-hand column. The addition problems were presented first, followed by the subtraction problems. Four squares appeared next to each problem, representing a solving strategy: counting with fingers, counting using paper and pencil, analyzing the answer in the student's mind, and recall without analysis. Each strategy was presented to the students with a short phrase and a symbol (e.g., an image of a hand for the counting-on-fingers strategy). The child had to tick the solving strategy used to solve each arithmetic problem.

It was decided that the children would be asked to indicate their solving strategies by choosing one strategy from alternatives, instead of verbally describing what they did, as in the original study by Casey and colleagues (2017). This was because the strategies included here were based on distinct methods related to concrete objects or actions. The counting on fingers and using paper and pencil were the alternatives for the counting strategy (both counting all and counting on) in Casey's task. Analyzing the problem in the mind and recall without analysis were the alternatives for decomposition and retrieval, respectively.

To administer the test, the researcher first explained the four strategies for solving arithmetic problems, with a solid example for each strategy. For instance, the researcher explained the strategy of analyzing the problem in the mind by saying, "You might solve '20 – 12' by saying that 12 is 10 plus 2. So, I will subtract the 10 from 20 and this will give me 10, and then will remove 2, and the answer is 8." After that, the researcher handed the task paper to the children, covered over by a blank sheet. The child was then asked to move the blank sheet down step by step to view each problem. The researcher read each problem aloud and asked the children to write down the answer and tick the strategy they used.

Arithmetic accuracy was calculated for each of the addition and subtraction problems by giving 1 or 0 for correct and incorrect answers, respectively. For the solving strategies, the frequency of use of each strategy was calculated separately for addition and subtraction. The Kuder-Richardson-20 formula was used to calculate the reliability of the addition and subtraction accuracy scores for the current study and revealed adequate reliability: $\alpha = 0.706$ for addition, and $\alpha = 0.677$ for subtraction.

Maths Anxiety. This scale was a nine-item scale adapted from the AMAS for children (Carey et al., 2017; Caviola et al., 2017). It presented students with situations related to maths, for example “Watching the teacher break down a complex problem on the blackboard”, after which they were asked to rate how much they feel anxious on a five-point scale, where “5” indicated the highest level of anxiety. The scale was translated into Arabic and then backward into English, with each step performed by two translators who are fluent in both languages. The researcher then produced the provisional version based on the consistencies in the translated versions, and presented it to six judges, namely three university psychology professors and three teachers. The judges suggested shortening the sentences, using verbs instead of nouns, simplifying words, and clarifying the rating scale. Based on the judges’ comments, the final version of the scale was produced, with the same five-point rating scale used by Carey and colleagues (2017). Icons with smiley, neutral, or sad faces reminded the children of the meaning of each number in the scale.

Internal consistency showed significant correlations between all items and the total score, ranging between 0.303 and 0.772. Cronbach’s alpha shows adequate reliability ($\alpha = 0.774$). When considering each of the scale dimensions separately, learning maths anxiety scale showed low reliability, ($\alpha = 0.519$), whereas maths evaluation anxiety showed adequate reliability ($\alpha = 0.713$). The results of confirmatory factor analysis (CFA), ran by Lavaan package in R studio (Rosseel, 2012), using the maximum likelihood estimation method (Kline, 2016), showed adequate fit indices

(Kenny, 2020), x2 (26) = 32.091, p = 0.190, CFI = 0.974, TLI = 0.964, RMSEA = 0.043, with 90% confidence interval boundaries (0.00 - 0.086). The estimates of items loading on learning maths anxiety factor ranged between (0.304 – 1.968), and the range for loading of items on the maths evaluation anxiety factor was (1 – 2.086).

General Anxiety Scale. This scale was a subscale of the Arabic version of Spence anxiety scale for children (Alsherbini & Alsayed, 2013). It assessed general anxiety with six items, rated with a four-point scale. The reliability of the scale in the current sample was re-examined via Cronbach's alpha, and it showed good reliability, ($\alpha = 0.699$).

Digit Updating Task. This task measured functions related to updating verbal information in the working memory (Kessler & Oberauer, 2014). The paradigm of the current task was taken from the study by Sidney and colleagues (2019), and was shifted from a computer-based to a paper-based task. In this task, students listened to 12 sequences of letters, varying in length between seven and 12 letters. Then, they had to write on the answer sheet the three last letters at the end of each sequence. Students were given four practice sequences at the beginning, followed by the 12 test sequences. The researcher first explained the task on the board, and then started by reading aloud the sequences at a rate of one digit per second. Feedback was given to students only on the first two practice sequences. The task was scored by giving one mark for each correct digit recalled in its position. This test showed a good level of reliability, $\alpha = 0.769$.

Raven's Progressive Matrices. This non-verbal reasoning paper-based test, validated on an Arabic sample by Ali (2013), consisted of 36 items. Each item was presented on a single page of the test booklet in the form of a matrix; the child had to choose among different images to identify the missing part of this shape. The test was administered in the classroom, where the researcher showed the children an example on the board, after which they were given 15 minutes to solve all 36 items. This study used the raw score of the test, which is the total number of correct responses.

Procedures

The tasks were performed in the classrooms in two separate sessions on two days within the same week. Each session lasted 70-90 minutes. As the average number of students in each class was 27, the researcher was present in all sessions, accompanied by a qualified research assistant in addition to an administrator. For the general anxiety scale, maths anxiety scale, maths accuracy and solving strategy, and digit updating task, the researcher explained the instructions and then performed the task by reading each item out loud so the students could write down their responses. For the timed tests: the maths fluency and Ravin's matrices tests, the students were given the instructions and then a sign was made to start the task and continue until the stopwatch alarm sounded. Students were given a break of around 10 minutes after each task. The order of the tasks was randomized within and across sessions, with the restrictions that the maths anxiety scale was performed first in whichever session it was administered, but was not performed on the same day as either the maths fluency or maths accuracy tasks. This was done to avoid any mutual sensitivity effects between maths tests and the maths anxiety scale.

Results

For descriptive statistics, Table 1 shows the means and standard deviations for each variable. A series of Pearson correlations were performed as a preliminary check of the data, and their results are presented in Table 2. Considering the general cognitive abilities, updating verbal working memory and nonverbal reasoning correlated with maths evaluation anxiety and frequency of use of advanced cognitive strategies.

Table (1)
Means and standerd deviations of the study variables.

	M	SD
General anxiety (GA)	11.775	3.915
Learning maths anxiety (LMA)	8.759	2.737
Maths evaluation anxiety (MEA)	8.852	3.471
Maths fluency (MF)	45.426	15.629

Table (1)

	M	SD
Maths accuracy (MAcc)	17.899	2.869
Percentage of use of advanced cognitive strategies (ACS)	32.480	27.628
Updating verbal working memory (UVWM)	23.664	7.526
Nonverbal reasoning (NR)	20.674	6.394

Table (2)
A matrix of correlations between the study variables.

	GA	LMA	MEA	MF	ACS	UVWM	NR
GA							
LMA	0.18*						
MEA	0.397***	0.657***					
MF	-0.191*	-0.122	-0.268**				
ACS	-0.088	-0.081	-0.151*	0.319***			
UVWM	-0.105	-0.097	-0.175*	0.389***	.303***		
NR	-0.164	-0.016	-0.181*	0.362***	0.358***	0.179*	

* means p < 0,05; ** means p < 0,01; *** means p < 0,001

In order to answer the first question of the study, a linear regression was performed with the total scores of maths anxiety as a predictor and maths fluency as an outcome. Maths anxiety predicted maths fluency, r = 0.223, r 2 = 0.050, F (128) = 6.661, p = 0.011. Additionally, multiple regression was performed to examine the predictability of maths fluency by maths anxiety components: learning maths anxiety (LMA) and maths evaluation anxiety (MEA). In all regression models, levels of significance were corrected for multiple testing. Table 3 shows the values for each predictor and model. For maths fluency, maths evaluation anxiety was a significant predictor but learning maths anxiety was not. As shown by the beta value, each unit increase for maths evaluation anxiety predicts a third unit decrease in maths fluency. Therefore, the remaining analysis focused only on maths evaluation anxiety and excluded learning maths anxiety.

This table shows the values of multiple regression models when maths learning anxiety (LMA) and maths evaluation anxiety (MEA) are used as predictors for maths fluency.

Table (3)
Multiple regression models to predict maths fluency.

Outcome	Predictors	r^2	F	P	ß	t	P
Maths fluency	LMA	0.077	5.5257	0.006	0.096	0.843	0.401
	MEA				-0.331	2.914	0.004
	MEA				0.089	0.758	0.450

In relation to the second question of the study, which focuses on the moderating effect of general cognitive abilities between maths evaluation anxiety and maths fluency, the method of moderation package in R (), with the bootstrapping method by Preacher and Hayes (2004), was used. The model did not show significant fit, $F (123) = 11.01$, $p = 0.155$. Furthermore, nonverbal reasoning and working memory showed a marginally significant effect in predicting maths evaluation anxiety, $F (124) = 2.619$, $p = 0.053$, whereas nonverbal reasoning and updating verbal working memory significantly predicted maths fluency: 0.733, $p = 0.006$.

Finally, to answer the third question of the study, the mediatory role of cognitive strategies between nonverbal reasoning, updating working memory and maths evaluation anxiety as predictors and maths fluency as an outcome was conducted. The frequency of use of cognitive strategies was calculated by first coding the counting-on-fingers and paper-pencil choices as rudimentary strategies, and the calculation-in-my-head and remember-the-answer as advanced cognitive strategies. Only strategies with correct answers ($M = 17.875$, $SD = 2.869$) were included. Then, the frequency of use of advanced cognitive strategies was used as an outcome for three different linear regressions. (See Table 4 for the values and levels of significance for each model.) Hence, advanced cognitive models were predicted by both nonverbal reasoning and updating verbal working memory and were not predicted by maths evaluation anxiety, these being the two different mediation analyses applied.

This table shows the values of linear regression models when each of maths evaluation anxiety (MEA), nonverbal reasoning (NR) and verbal updating working memory (UVWM) are used as predictors for frequency of use of advanced cognitive strategies.

Table (4)
Linear regression models to predict frequency of use of advanced cognitive strategies

Predictors	r^2	F	P	ß	t	P
MEA	0.023	2.930	0.089	-0.151	1.712	0.089
NR	0.131	19.073	0.001	0.363	4.367	0.001
UVWM	0.092	12.700	0.001	0.303	3.564	0.001

Therefore, the mediation analysis was performed twice: once with nonverbal reasoning as a predictor and again with updating verbal working memory as a predictor. The mediator was advanced cognitive strategies and the outcome was maths fluency. For the former model, both nonverbal reasoning and advanced cognitive strategies predicted maths fluency, $t = 3.180$, $p = 0.002$, $t = 2.508$, $p = 0.013$, respectively, $F(125) = 12.77$, $p < 0.001$. The indirect effect was = 0.196, $p = 0.008$, and the direct effect was = 0.685, $p < 0.001$.

Similar findings were found for updating verbal working memory. Maths fluency was predicted by both updating verbal working memory and advanced cognitive strategies, $t = 3.825$, $p < .001$, and $t = 2.649$, $p = 0.009$, respectively, $F(125) = 15.29$, $p < 0.001$. The indirect causal mediation effect of updating verbal working memory on maths fluency was significant, at 0.140, $p = 0.01$, as was the direct effect, at 0.680, $p < 0.001$.

Discussion

This study aims to examine cognitive factors that influence the well-known negative relation between maths anxiety and mathematical performance among female third-grade students. First, it aims to break down maths anxiety into separate components, mainly the maths anxiety related to learning maths situations and that related to maths evaluation. Additionally, it focuses on maths fluency as one of the basic mathematical abilities in primary school children. Maths evaluation anxiety predicted maths fluency while maths learning anxiety did not act as a significant predictor. When examining the role of nonverbal reasoning and updating verbal working memory in maths fluency via the mediation of maths evaluation anxiety, it was shown that maths fluency was directly predicted by nonverbal reasoning and updating verbal working memory; however, the indirect path via maths evaluation anxiety was not significant. Finally, in relation to the use of advanced cognitive solving strategies, the results found no evidence suggesting a relation between maths evaluation anxiety and the use of advanced cognitive strategies. Rather, it showed that advanced cognitive strategies have a mediating role between maths fluency and both nonverbal reasoning and updating verbal working memory. Figure 1 depicts a diagram of the relations between the study variables. This indicates that an increase in either nonverbal reasoning abilities or verbal working memory efficiency partially led to the increased use of advanced cognitive strategies, which led to improvements in maths fluency. Explanations and implications are further discussed below.

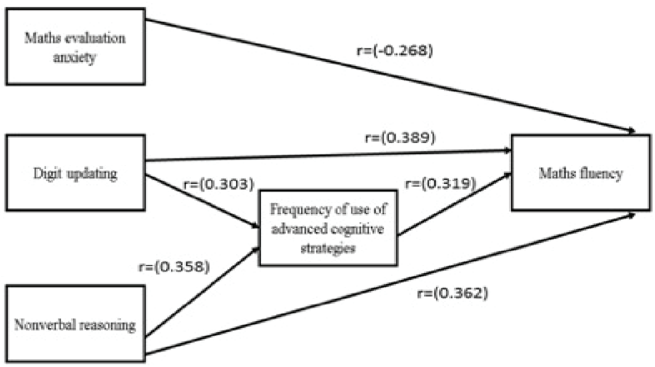

Figure (1)

Shows the Relations and Correlation Values Between the Study Variables

Maths Anxiety Components and Maths Fluency

The findings of the current study are consistent with the findings of Cargnelutti and colleagues (2017), Harari and colleagues (2013, Ramirez and colleagues (2016), and Vukovic and colleagues (2013), whereby a negative correlation between maths anxiety and mathematical performance was revealed among third-grade students. Additionally, they emphasize the differences between the various components of maths anxiety components, and, similarly, those of mathematical abilities. Indeed, it has been found that maths anxiety correlates with timed maths tests; hence the relationship between the timed maths fluency test and maths evaluation anxiety (Ashcraft & Moore, 2009). Additionally, it has been suggested that maths anxiety is specifically related to self-assessment in maths (Haase et al., 2012). Hence, the findings of differences between the components of maths anxiety in terms of their relation to mathematical performance helps explain why studies on children have found a range of different relations between maths anxiety and mathematical performance.

The above adds to the recent explanation given by Orbach and colleagues (2020) for the absence of correlation between maths anxiety as a trait and mathematical performance: that the contradictory findings are related to different measures. Maths anxiety measured as a trait, which is defined as the fear of failure in maths, was not found to be correlated with mathematical performance in primary school children, despite its correlation with mathematical performance in secondary school. In contrast, maths anxiety as a state was negatively correlated with mathematical performance in primary school children. The current study indicates that the maths evaluation anxiety trait, when independently considered, is also negatively correlated with mathematical performance in primary school children.

The explanation for the differences between maths evaluation anxiety and learning maths anxiety might be that the former is related to specific situations where students receive feedback on their maths skills and, hence, poor performance feeds and increases levels of maths evaluation anxiety. This idea is supported by longitudinal studies which showed that low mathematical abilities lead to an increase in maths anxiety (Vukovic et al., 2013). In contrast, learning maths anxiety is related to situations where students might think that they have the ability to learn and their low performance does not necessarily lead to an increase in learning maths anxiety. This idea is supported by the notion that primary school students are not able to accurately judge their learning proficiency (Fisher, 1988).

Although the current study was performed on girls whose first language is Arabic and were in a particular grade level, the results are not simply different in variant essences because of these boundaries. Maths anxiety, assessed by RMARS on children aged between six and nine, was not found to vary across eastern and western cultures, including China, Russia, and the United Kingdom (Rodic et al., 2018). This highlights the importance of emphasizing the topic of maths anxiety correlated with mathematical performance; as the findings show, it is related to maths evaluation.

Cognitive Abilities, Maths Anxiety and Maths Fluency

The current findings showed the significant effects of both nonverbal reasoning and updating verbal working memory in predicting maths fluency. These findings are consistent with previous findings (e.g., Friso-ban Dan Bos et al., 2013; Justicia-Galiano et al., 2017). Digit stimuli in the digit updating task might be a source of the relation between verbal working memory and maths fluency. Alternatively, this might be attributed to the idea that dependence on verbal working memory components to solve arithmetic problems varies across grades. Previous studies revealed that the phonological loop is more related to mathematical performance than the visuospatial working memory in primary school children after first grade (De Smedt et al., 2009).

The current findings did not show mediation via maths anxiety between general cognitive abilities and maths fluency. Hence, the above denoted differences in maths anxiety components can neither be attributed to these factors nor reserved from their effects. Perhaps designing a similar study with situational factors, including maths anxiety as a state and working memory tasks concurrent with the mathematical abilities tests, would help in understanding the sources of the differences between maths evaluation and learning maths anxiety in their relations to maths fluency.

For example, this design might reveal whether maths evaluation anxiety as a trait compared to anxiety as a state is a more accurate indication of maths fluency.

Advanced Cognitive Strategies and Maths Fluency

The current study revealed a significant positive correlation between advanced cognitive strategies and maths fluency. This finding is consistent with Carr and Alexeev (2011), who argued that fluency and accuracy predict use of cognitive strategies, combining decomposition and retrieval. The current study showed evidence of a positive correlation between frequency of use of advanced cognitive strategies and maths fluency.

The findings indicated that nonverbal reasoning and updating verbal working memory were significant predictors of maths fluency, and also predicted maths fluency via increasing the use of advanced cognitive strategies. In fact, it was previously shown that verbal working memory is more useful for retrieval strategies (Delazer et al., 2005). Additionally, the updating task taps on both phonological loop and the central executive (Sidney et al., 2018), which indicates that updating is critical for advanced cognitive strategies. As mentioned in the introduction, this can be explained in terms of developmental changes, whereby students come to rely on verbal working memory components to solve arithmetic problems (De Smedt et al., 2009).

Limitations

There are methodological restrictions, as suggested by Carey and colleagues (2016), regarding studies of the relation between maths anxiety and mathematical performance. Longitudinal studies are required to uncover the reciprocal relation between the two as restricted designs cannot identify which variable develops first. Additionally, it should be noted that the students considered in the present study were of a low to medium socioeconomic status, and that low status has been shown to have a negative impact on maths achievement and number competence (Jordan et al., 2009). This might be a factor that confounds some of the study findings.

Furthermore, the current study focused on girls. Nevertheless, differences in mathematical performance and maths anxiety between young boys and girls might be related to future differences in choosing fields of study. Indeed, it has been widely observed that few females specialize in the maths, engineering, and technology fields (Ertl et al., 2019). Thus, a focus on girls would help to bridge the gap and increase of number of females specializing in maths-related subjects.

Conclusion and Recommendations

The current findings highlight the different roles of the components of maths anxiety, which, in turn, might explain the differences among previous findings. In addition to the explanation by Orbach and colleagues (2020), that maths anxiety as a state predicts mathematical performance in primary school children but maths anxiety as a trait does not, differences can be also attributed to different choices in regard to which components of maths anxiety as a trait are considered. Asking why maths evaluation anxiety is more inherently related to mathematical performance in primary school children opens up a further line of research. Furthermore, general cognitive abilities can be independent of maths anxiety in their effects on maths fluency. Flexibility in using solving strategies that rely on working memory components not consumed by maths anxiety might be key to attenuating the negative impact on maths anxiety on mathematical performance. This idea is recent and requires further verification.

Identifying factors that increase maths anxiety can attenuate its negative impact on mathematical performance. These factors might include methods used to teach mathematics and methods of maths evaluation in schools. Teaching methods which focus on encouraging students to be flexible in adopting the most suitable strategies from an early age are suggested, and can be verified via further studies. Teaching students a wide range of solving strategies and how to switch between them is theoretically feasible since it was found that students are able to shift their strategies according to task demands from an early age (Luwel & Verschaffel, 2003).

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