The relation between cognitive and emotional factors and arithmetic problem-solving

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Abstract
Literature that investigates the factors underlying arithmetic problem-solving achievement extensively evaluates the cognitive components, such as working memory (WM) and processing speed, at the basis of this acquisition. Recently, studies have shown that also the emotional factors, such as math anxiety (MA), could play a crucial role in the resolution of arithmetic problem-solving even during the first years of formal education. In this study, we tested 145 fourth-grade students to evaluate the possible combined effect of cognitive (i.e., WM, processing speed) and emotional (i.e., math anxiety) factors in untimed arithmetical problem-solving achievement. Regression analysis showed that MA contributed significantly to explain arithmetic problem-solving achievement even after having accounted for the cognitive abilities (WM and processing speed). In addition, the comparison between high-MA and low-MA children showed that the former had decreased performance in arithmetical problem-solving and WM tasks. On the whole, data seemed to corroborate the findings concerning the crucial role of math anxiety on math achievement even in untimed math tasks. Findings are discussed in terms of math educational context, and they underline the need to take into consideration also the emotional factors—apart from the cognitive skills—when developing interventions on math achievement.

Keywords Math anxiety · Working memory · Arithmetical problem solving · Processing speed · Mathematics acquisition

The fundamentals of mathematics are among the most important abilities that a person needs to master not only for school achievement but also for the management of everyday life activities and for economic success (e.g., Dougherty, 2003; Reyna & Brainerd, 2007; Reyna, Nelson, Han, & Dieckmann, 2009). This article will focus in particular on arithmetic problem-solving, one of the salient domains of mathematics. Problem-solving tasks represent an important part

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of the math curriculum program already at the primary school level and a crucial ability through which arithmetical notions are applied to the real-world context.

Research has widely investigated the cognitive abilities acting as precursors of math learning: Some authors indicated that this kind of achievement lays on domain-specific abilities involving number processing (Geary, Hamson, & Hoard, 2000; Geary, Hoard, Byrd-Craven, & De Soto, 2004), whereas other researchers supported the fundamental role of domain-general (i.e., not math-specific) cognitive abilities (Karagiannakis, Baccaglini-Frank, & Papadatos, 2014). On the other hand, the influence of emotional aspects is generally neglected when studying the process of arithmetic problem-solving (Hoffmann, 2010). In general, the role of these aspects—such as anxiety—is not yet well understood not only in respect to problem-solving but also in relation to overall math proficiency when dealing with young, primary-school students. For instance, some scholars, but some teachers as well, underestimate the impact of math anxiety (MA), which is the anxiety subtype specifically associated with mathematics (Cargnelutti, Tomasetto, & Passolunghi, 2017b; Hembree, 1990; Ramirez, Gunderson, Levine, & Beilock, 2013; Wu, Barth, Amin, Malcame, & Menon, 2012; Wu, Willcutt, Escovar, & Menon, 2014).

Therefore, the main aim of this work was to evaluate the links between MA, cognitive abilities and arithmetic problem-solving proficiency, and to explore the effect of MA on problem solving. In particular, concerning these abilities, we assessed working memory (WM) and processing speed, abilities that have both been demonstrated to be involved in math learning (De Smedt et al., 2009; Fuchs et al., 2006; Passolunghi, Lanfranchi, Altoè, & Sollazzo, 2015). In fact, whereas the relation between WM and anxiety in the determination of math proficiency is well established, little is known about the relation between processing speed and anxiety. This type of research is relevant in the educational context, especially in light of the long-term effects and well-established detrimental consequences of anxiety on mathematical achievement (Ashcraft, 2002; Dowker, Sarkar, & Looi, 2016). Therefore, among all the factors that were observed to intervene in the process of math achievement, we opted to focus on the mentioned cognitive (i.e., working memory and processing speed) and emotional (i.e., math anxiety) aspects, although conscious of the relevant role that many other factors can have.

1 Arithmetical problem-solving and cognitive processes

Comprehending and solving a math problem require different processes: A good linguistic comprehension, understanding of the situation, detecting the relevant information while neglecting that which is irrelevant, the understanding of the right formal procedure to be applied, the related arithmetical operations to be carried out to reach the solution, and, finally, the computational ability (Mayer, Larkin, & Kadane, 1984).

As highlighted by Verschaffel and colleagues (Verschaffel & De Corte, 1997; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009), several aspects contribute to the development of problem-solving achievement. Among them are the characteristics of the task itself (e.g., amount of unnecessary information in the text, verbal complexity of the problem, familiarity with the described situation), the specific abilities of the student (especially in relation to cognitive abilities), and context characteristics (educational method, socio-economical context). These aspects could influence students' ability to make flexible representational choices (defined, by Verschaffel et al., 2009, as the more or less conscious selection and use of the most appropriate solution strategy for a particular problem in a given socio-cultural context). This approach to the theme of math problem solving allows attention to be drawn not only to the way the tasks are solved but also to the students' and context characteristics (Acevedo Nistal, Van Dooren, Clarebout, Elen, & Verschaffel, 2009). Acknowledging this ecological and broad approach to the theme, we investigated specifically some aspects of the students' personal characteristics such as the emotional (e.g., math anxiety) and cognitive aspects (e.g., working memory, processing speed) related to the attitude to the discipline.

From a cognitive point of view, given the complexity of problem-solving procedures, a variety of diverse cognitive abilities, such as WM and processing speed, are required to perform successfully. WM is a cognitive ability particularly involved in problem-solving (Bull & Sherif, 2001; Fürst & Hitch, 2000; Hitch & McAuley, 1991; Logie, Gilhooly, & Wynn, 1994; Passolunghi & Cornoldi, 2000; Passolunghi & Siegel, 2001, 2004; Swanson, 1994). The memory model first proposed by Baddeley and Hitch (1974; see also Baddeley, 1986, 1996) attributed a fundamental role to the central executive—meaning the attentional system—in the resolution of the task. The execution of a math problem, in fact, not only is based on the retention of either verbal or visuo-spatial information (by the phonological loop and the visuo-spatial sketchpad, respectively), but also requires a representation of the problem situation and the integration of the to-be-processed information (by central executive component, Cornoldi, Drusi, Tencati, Giofrè, & Mirandola, 2012; Passolunghi, Cornoldi, & De Liberto, 1999; Re, Lovero, Cornoldi, & Passolunghi, 2016).

Another critical aspect related to arithmetical problem-solving is processing speed, a fundamental time-related cognitive function connected with WM. Research showing the relation between these two cognitive abilities highlighted that the quicker information processing is, the more information WM can process in a time unit (Salthouse, 1996; Salthouse & Meinz, 1995). Each cognitive process needs time to complete the activity, and during this time, the information deteriorates, losing quality and accuracy. If processing speed is optimally operating, WM could manage an elevated amount of information with increased accuracy. On the other hand, if processing speed is slow, the amount of retained information decreases and impoverishes (Salthouse, 1994).

Processing speed has actually been found to be the best predictor of arithmetical competence in 7-year-old students (Bull & Johnston, 1997), in particular for tasks involving additions and subtractions (Fuchs et al., 2006; Swanson & Kim, 2007). When measured in kindergarten, processing speed was observed to predict the score achieved in a test assessing overall math competence (i.e., logics, arithmetic, and geometry) at the end of the first grade (Passolunghi & Lanfranchi, 2012). In addition, processing speed was observed to be poor in children with arithmetical disabilities in fourth grade (D'Amico & Passolunghi, 2009).

2 Arithmetical problem-solving and math anxiety: A developmental perspective

The process of problem-solving could be influenced not only by the cognitive factors but also by emotional and motivational aspects. For instance, math performance has been shown to be negatively influenced by a specific form of anxiety, known as math anxiety (MA). This condition is defined as a feeling of tension or fear that interferes specifically with the execution of tasks involving numbers, not only in the academic context, but also in a vast variety of everyday life situations (Richardson & Suinn, 1972). This emotional factor was therefore shown to negatively affect mathematical performance to a substantial extent (e.g., Dowker et al., 2016). The effect of MA on performance translates into difficulties in maintaining concentration and perseverance in the school activities related to mathematics. This interior state could prevent recalling already memorized data, therefore compromising the outcome of a test or exam. From an emotional–motivational point of view, if negative emotions prevail, people tend to enjoy mathematics less or even avoid it, to have a lower perception of their own math skills, and to not see the value of this discipline in everyday life (Hembree, 1990; Meece, Wigfield, & Eccls, 1990).

The effects of MA on math achievement have been widely documented (e.g., Faust, Ashcraft, & Fleck, 1996; Ma & Xu, 2004), but the majority of the studies monitored students from middle school onward (e.g., Faust et al., 1996). Only recently, research has begun to evaluate the effect of anxiety in young schoolchildren. However, these studies reported contradicting findings: Some studies showed a negative impact of MA on math performance even in the first grades of primary school (Dossey, Mullis, Lindquist, & Chambers, 1988; Newstead, 1998: Ramirez et al., 2013; Vukovic, Kieffer, Bailey, & Harari, 2013; Wu et al., 2012, 2014), whereas others did not show this type of association (Cain-Caston, 1993; Dowker, Bennett, & Smith, 2012; Haase et al., 2012; Krinzinger, Kaufmann, & Willmes, 2009).

These differences could be due to the test used for the assessment of MA. Indeed, the way MA is evaluated seems to be crucial, given that different questionnaires appeared to address slightly different aspects related to anxiety. In particular, the Mathematics Anxiety Rating Scale (MARS, Richardson & Suinn, 1972) addresses numerical and test anxiety by using a 5-point scale from "not-at-all anxious" to "very anxious," with higher scores indicating greater anxiety. The items of the MARS test focus on the affective dimension of negative reactions to numbers (Vukovic et al., 2013; Wu et al., 2012, 2014). When this test (or its subsequent adaptations) was used, a relation between anxiety and math performance was traced even in very young children.

On the other hand, the Math Anxiety Questionnaire (MAQ), developed by Thomas and Dowker (2000), seems to investigate more tightly the worrisome thoughts arisen by this condition. However, this questionnaire does not address the more 'direct' emotional (e.g., avoidance behaviour) and physiological reactions (e.g., increased agitation and related heart beat frequency) associated with anxiety. Actually, when this test was used, it did not reveal a link between these aspects of math anxiety and math performance in young students (Dowker et al., 2012; Haase et al. 2012, 2012; Wood et al., 2012).

3 Working memory and math anxiety

Different studies tried to clarify the reciprocal effect between WM and MA. Some authors proposed MA to decrease the level of math performance by reducing the WM resources usually devoted to the task execution (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Eysenck & Calvo, 1992; Miller & Bichsel, 2004; Young, Wu, & Menon, 2012). Ashcraft and Faust (1994) observed that a high level of MA did not affect the performance of easy mathematical tasks such as one-digit additions (e.g., $2 + 3$) but could negatively impact the execution of more complex and less automatic tasks, such as those with operations requiring carrying steps (e.g., $46 + 25$). To explain this experimental evidence, Ashcraft (Ashcraft, 2002; Ashcraft & Kirk, 2001) underlined the central role of the Central Executive: If this component of WM does not work properly, for instance because of anxiety, an adequate elaboration of the information relevant to the task and the concurrent inhibition of irrelevant information do not take place (Ashcraft, Kirk, & Hopko, 1998). A study conducted by Ashcraft and Kirk (2001) on adults showed that the higher the WM was, the better the individuals could manage both math performance and anxiety-driven thoughts. In this line, Miller and Bichsel (2004) showed that the adults with MA having high spatial WM showed the best performance in calculation and problem-solving.

4 The present study

Given the scarcity of the literature on the subject, particularly referring to primary-school students, we deemed it crucial to shed light on the importance of both cognitive and emotional factors on children's performance in a specific math competence, naming in arithmetical problem-solving. In doing this, we aimed to extend the results from previous studies in several ways. First, we explored the different contributions provided by cognitive and emotional factors in explaining the variance in arithmetical problem-solving. We focused in particular on the role of MA, in order to explore if it could retain a significant relation in problem-solving performance after having accounted for the cognitive abilities shown to prompt math attainment. We explored this relation in children attending fourth grade, in order to check if the role of MA already in primary school is significant and if it can possibly become relevant around that age, as hypothesized in the previous studies that had not observed a relevant role of MA in a younger sample (e.g., Cargnelutti et al., 2017b; Thomas & Dowker, 2000).

Secondly, we wanted to inspect the relation between MA and both problem-solving and the cognitive abilities at the basis of it and in particular the role of WM. We judged this analysis fundamental to provide potential important hints in the educational perspective. To do so, we classified the students according to their MA levels, in order to evaluate if children with high versus low MA could significantly differ in their performance in problem-solving and cognitive abilities. Concerning the latter, we opted to investigate WM, which has been already assessed in relation to MA in previous studies (Cargnelutti, Tomasetto, & Passolunghi, 2017a; Passolunghi, Caviola, De Agostini, Perin, & Mammarella, 2016; Ramirez et al., 2013; Vukovic et al., 2013). In particular, we assessed the WM abilities associated with the central executive subsystem, which were those observed to be both mainly involved in math learning and also greatly affected by anxiety.

Nevertheless, it is necessary to highlight that there is still a lack of consensus on the interconnection between WM and anxiety in children (Dowker et al., 2016). Some studies, in parallel with findings on adults (Beilock, 2008), observed a specific detrimental effect of MA already in young students and especially in those with high levels of WM (Ramirez et al., 2013); on the other hand, a low performance both in math and in WM tasks was highlighted in children with high MA in middle-school children (Passolunghi et al., 2016) and in atypical samples (Mammarella, Hill, Devine, Caviola, & Szűcs, 2015).

Beside WM, we opted to assess also processing speed. This skill has been shown to be implicated in math learning, but its relation to MA is far from being explored. We therefore aimed to fill this gap in the literature by investigating the relation between anxiety and diverse cognitive abilities.

Furthermore, in this study, we also attempted to overcome assessment biases regarding MA by using a reliable test: Given the importance of the way children are tested (Dowker et al., 2016), here we used the MARS-R (adapted in Italian by Saccani & Cornoldi, 2005), which assesses the level of anxiety experienced by children when faced with various settings and experiences involving math. This tool has a very good reliability (alpha for the math-related subscales >0.80) and therefore had the potential to overcome problems related to MA assessment encountered in previous studies (e.g., Ramirez et al., 2013, in which the effect of MA on arithmetical problem-solving was demonstrated, but MA was assessed with a marginal-reliability scale, reported alpha = .55). Another advantage of the questionnaire we used is that it allowed us to separately assess anxiety related to math and anxiety related to other school subjects. In addition, with respect to the former, two different subscales allowed us to distinguish between MA associated with *learning* the discipline and MA associated to the fact of *being tested* in it. In this way, the questionnaire allowed us to make inferences about the math-related settings that could induce greater levels of anxiety in students.

Our hypotheses were that both cognitive abilities and MA could significantly explain arithmetical problem-solving performance. In detail, we expected arithmetical problem solving to inversely correlate with MA, explaining a specific quote of variance even beyond the effect of cognitive abilities. Concerning the differences between children with different levels of anxiety, we expected those with high anxiety to display significantly lower performance on both the problem-solving and cognitive ability assessments.

5 Method

5.1 Participants

Participants were students attending the fourth year of primary school in two different primary schools located in the northeast part of Italy. The socio-economic status of the sample was primarily middle class, established on the basis of school records. Parental consent was obtained for each child participating in the study. A total of 152 signed parental consent forms were returned; seven children were excluded from the analysis (four children had diagnosis of learning disabilities and three of general intellectual disabilities). The remaining sample included 145 students (71 F, 74 M) with a mean age of 10 years and 4 months at the time of the assessment. In Italy, the fourth-grade math program includes number knowledge (e.g., how to write digits up to nine, number comparison, rounding numbers, associative and commutative properties of numbers), to be able to use fractions and decimals, geometry (shapes, segments, rays, lines, angles, polygons, and circles, calculation of perimeter, and area), systems of measurement (length, weight, capacity), and arithmetic word problem solving (e.g., to solve a problem using the basic arithmetic operations and using diagrams and charts). To acquire arithmetic problem solving abilities, the students follow a standard program where the search for the correct arithmetic operation is made by a selective reading of the text, identifying the relevant data, then by selecting the correct arithmetic operations, and finally by executing the proper computations.

5.2 Procedure

Children were tested in two sessions. In the first session, administered in a collective way, MA and processing speed were evaluated. The second session included an individual assessment of WM and a collective assessment of math problem-solving.

Tasks
Cognitive abilities

5.3 Working memory

Three different tasks were administered to test WM skills.

Digit Span Backward Task is one of the tasks of the Wechsler Intelligence Scale for Children (WISC-IV, Wechsler, 2003). The task was proposed in the backward modality to test WM. In this task, children were required to repeat an increasing number of digit spans (two to eight digits per span) in the inverted order with respect to that presented by the experimenter. The correct recall of each span was scored 1 point.

The Word Span Backward Task (see Passolunghi et al., 1999) used an increasing number of two-syllable familiar words (two to eight words per span) to be recalled in the opposite order to that of presentation. All items were nouns with high imagery values and high word frequency values.

Listening Span Task (Italian adaptation of Daneman & Carpenter, 1980; see also Passolunghi et al., 1999) included four levels, each containing two series of an increasing number of sentences (two to five). These sentences could be either true or false. An example of a true sentence was “A and B are the first two letters of the alphabet” and an example of a false sentence was “The hen is a mammal that lives in the sea.” Children were asked to indicate, as quickly as possible, if the answer was true or false. At the end of each set of sentences, children were instructed to recall the final word of each sentence in order of presentation and avoid saying non-final words. For example, if children had processed the sentences noted above, the correct response had to be “alphabet, sea” Three scores were obtained from the recall task: First, the span level reached by the participant (i.e., Listening span-Series); second, the raw number of words recalled correctly (i.e., Listening span-Correct); and third, the number of non-target words erroneously recalled (i.e., Listening span-Intrusions). The latter is considered a measure of cognitive inhibition (De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Passolunghi & Siegel, 2001, 2004).

5.4 Processing speed

In the Woodcock-Johnson III visual matching task (Woodcock, McGrew, & Mather, 2001), hereafter indicated as the Woodcock-Johnson, we asked the children to locate and circle two identical symbols that appeared in a row of six symbols; the children had 3 min to complete 60 rows and earned a credit by correctly circling the matching symbols in each row. The total score was the number of correct answers given in the allocated time.

Speed pattern comparison (a modified version of Salthouse, 1993), hereafter named as Salthouse, required participants to examine complex visual patterns in order to decide as quickly as possible whether or not the two patterns in each pair were identical. A total of 60 pairs of patterns were presented in a time limit of 1 min. The total score was the number of correct answers given in the allocated time.

5.5 Anxiety

To test MA, we administered the MARS-R (Mathematics Anxiety Rating Scale- Revised, Italian version adapted by Saccani & Cornoldi, 2005), a 24-item version of one of the most widely used measures of MA (Hopko, 2003). The reliability of the questionnaire is high (please see Table 1 for the reliability values of this and the other administered tests). The MARS-R assesses an individual's level of apprehension and anxiety about math on a one to four Likert scale (from 1 = "no fear" to 4 = "very much fear") by asking participants how anxious they feel in various settings and experiences involving math (e.g., "Talking about the math section of a standardized test."). In particular, questions assess both anxiety related to the aspect of learning the discipline (e.g., to start a math lesson, to buy a math book, to use tables at the end of the text book) and anxiety related to the testing condition (e.g., to participate in math Olympic games, to be asked a geometry question during an oral test, to get the lowest mark of all the students in a test). Scores could therefore be associated with two different subscales, which we named Anxiety-Learning (eight items) and Anxiety-Testing (eight items). This questionnaire also includes a third subscale, which we called Anxiety-Control and which comprises eight items investigating the participants' anxiety level related to other school subjects (e.g., have a geography oral exam, to read sheet music, to ask a teacher for an explanation). The inclusion of this third variable could indicate if anxiety is specific to math or generalized also to other disciplines.

5.6 Mathematics

5.6.1 Arithmetical problem-solving

Eight different standard arithmetic word problems were administered to the children, without any time limits. These tasks are presented as a short text that includes information and data necessary to solve the problem. A question is proposed to children at the end of the tasks. To solve these types of problems, it is necessary to apply a series of arithmetical calculations (see Mayer, 1992).

This test aimed to assess the students' ability to correctly set up the problem for solution and therefore to indicate which were the operations to be performed for solving it. Hence, if the children identified the correct operation necessary to solve the problem, they scored 1 point for each. An example of an arithmetic word problem is: Two friends go to a "pizzeria." Each of them eats a pizza which costs 9.5 Euro and orders a drink which costs 2.3 Euro. What does the bill come to? If one of them pays with a bill of 50,000 Euro, how much change will he receive?

Table 1 Descriptive statistics of all variables

	M (*SD*)	Min	Max	Reliability
Problem-solving	6.15 (1.99)	0.00	8.00	.77
MARS-Learning	12.28 (3.25)	8.00	25.00	.89
MARS-Testing	17.24 (4.92)	8.00	29.00	.89
MARS-Control	11.97 (3.55)	8.00	22.00	.76
Listening span-Series	2.02 (0.95)	0.00	5.00	.84
Listening span-Correct	12.99 (3.02)	8.00	20.00	.82
Listening span-Intrusions	3.19 (1.98)	0.00	5.00	.84
Backward word span	3.78 (0.55)	3.00	5.00	.87
Backward digit span	3.94 (0.91)	2.00	7.00	.78
Woodcock-Johnson	45.95 (10.33)	9.00	60.00	.91
Salthouse	42.22 (8.89)	21.00	6.00	.72

6 Results

Statistical analyses were performed by PAW Statistic (version 21) software. Table 1 reports descriptive statistics and reliability indices of all measures. Zero-order correlations are reported in Table 2. From the inspection of the correlation results, it is possible to notice that problem-solving was significantly and negatively correlated with the two MARS-R subscales assessing MA (MARS-Learning: $r = -.32$, $p < .001$; MARS-Testing: $r = -.25$, $p = .002$), but not to the one assessing anxiety related to the other school disciplines (MARS-Control: $r = -.13$, $p = .122$). Concerning the relation between the two MA subscales and the WM tasks, a significant negative correlation emerged only with the Listening Span-Series measure (MARS-Learning: $r = -.25$, $p = .002$; MARS-Testing: $r = -.17$, $p = .047$). MA was not correlated with any other memory test score (Digit and Word span backwards). Concerning the relation between problem-solving and the cognitive abilities, a significant correlation was observed with all the WM measures (Listening Span-Series: $r = .26$, $p = .002$; Listening Span-Correct: $r = .17$, $p = .044$; Listening Span-Intrusions: $r = -.24$, $p = .005$; Backward word span: $r = .18$, $p = .027$; Backward digit span: $r = .23$, $p = .006$). The processing speed measures were not significantly correlated with any measures of either problem-solving or MARS-R.

6.1 Hierarchical regressions

The first analysis we conducted aimed to show the relation between problem-solving performance and both cognitive skills and MA. In particular, we wanted to investigate whether MA could contribute significantly even after having accounted for the role of the cognitive variables. We therefore ran a series of hierarchical regressions. In an initial attempt, we inserted processing speed first, followed by WM, and MARS finally. We then wanted also to explore whether the interaction between all the assessed constructs could be relevant. We therefore ran diverse stepwise regressions in which the following interactions were inspected: working memory × processing speed, working memory × math anxiety, and processing speed × math anxiety. Of all the explored interactions, the only one that was found to be significant was that between the WM measure of Listening span-Series and the MA subscale of MARS-Learning. Hence, we also inserted it in a separate model block and drew different models by changing the order of this variable: between the processing speed and WM blocks, between WM and MARS blocks and, lastly, between processing speed and MARS. The interaction was found to be significant in the first two models, but not when inserted after all the other variables. We hence retained these two as the most relevant models, which we detailed below.

Importantly, regarding the WM variables, the three Listening span measures we used appeared highly correlated to each other and actually manifested a problem of multicollinearity in the analyses that were performed. For this reason, we opted to insert the variable that was found to be the most relevant and that corresponded to Listening span-Series (as emerged from the inspection of the overall correlations with the variables we assessed and from the subsequent computation of the partial correlations through which we partialled out the effects of related variables).

On the whole, all the variables inserted into the models accounted for 21% of problem-solving variance (see Table 3 It is interesting to observe the absence of a significant contribution of processing speed ($\Delta R^2 = 0.02$, $p = .180$). In model 1, Listening span-Series × MARS-Learning was entered in the second block and significantly contributed to problem-solving variance ($\Delta R^2 = 0.04$, $p = .031$; $\beta = 0.18$, $p = .03$). Also, WM significantly contributed to

Table 2 Zero-order correlations between all measures

		1	2	3	4	5	6	7	8	9	10	11
1	Problem-solving	–										
2	MARS-Learning	− .32***	–									
3	MARS-Testing	− .25**	.62***	–								
4	MARS-Control	− .13	.62***	.45**	–							
5	Listening span-Series	.26**	− .25**	− .17*	− .15	–						
6	Listening span-Correct	.17*	− .16	− .14	− .15	.75***	–					
7	Listening span-Intrusions	− .24**	.12	.11	.07	− .62***	− .47***	–				
8	Backward word	.18*	− .12	− .10	− .13	.25**	.11	− .19*	–			
9	Backward digit	. 23**	− .08	− .05	− .09	.27***	.16	− .26**	.32***	–		
10	Woodcock-Johnson	.14	− .03	− .03	− .05	.17*	.21*	− .06	.10	.07	–	
11	Salthouse	.03	.04	− .07	.10	.10	.04	− .06	.13	.03	.54***	–

$^{*}p \leq .05$; $^{**}p \leq .01$; $^{***}p \leq .001$

problem-solving performance ($\Delta R^2 = 0.08$, $p = .006$), in particular through Listening span-Series ($\beta = 0.18$, $p = .04$). Interestingly, an additional significant quote of variance was explained by the MARS ($\Delta R^2 = 0.07$, $p = .007$), in particular, due to the significant contribution of MARS-Learning ($\beta = -0.26$, $p = .03$). However, after having entered the MARS variables, both the interaction and the contribution of Listening span-Series lost significance.

In model 2 (see Table 3 where the interaction was entered in the third block, both its contribution and that of WM in explaining problem solving variance remained significant:

Table 3 Model 1 and model 2 of hierarchical regression for problem-solving

Independent variables (blocks)		R^2	ΔR^2	p	β	p	Partial r	Semi-partial r
Model 1								
1.	Woodcock-Johnson	0.02	0.02	.180	0.18	.07	.15	.15
	Salthouse				− 0.07	.49	− .06	− .06
2.	Woodcock-Johnson	0.06	0.04	.031	0.18	.08	.15	.15
	Salthouse				− 0.07	.48	− .06	− .06
	Listening-Series × MARS Learn				0.18	.03	.18	.18
3.	Woodcock-Johnson	0.14	0.08	.006	0.13	.17	.18	.11
	Salthouse				− 0.08	.42	− .07	− .06
	Listening-Series × MARS Learn				0.16	.04	.17	.16
	Listening-Series				0.18	.04	.18	.17
	Backward word				0.08	.34	.08	.08
	Backward digit				0.14	.11	.14	.13
4.	Woodcock-Johnson	0.21	0.07	.007	0.14	.12	.13	.12
	Salthouse				− 0.09	.35	− .08	− .07
	Listening-Series × MARS Learn				0.12	.13	.13	.12
	Listening-Series				0.12	.17	.12	.11
	Backward word				0.07	.37	.08	.07
	Backward digit				0.15	.08	.15	.13
	MARS-Learning				− 0.26	.03	− .19	− .17
	MARS-Testing				− 0.12	.23	− .10	− .09
	MARS-Control				0.14	.17	.12	.11
Model 2								
1.	Woodcock-Johnson	0.02	0.02	.180	0.18	.07	.15	.15
	Salthouse				− 0.07	.49	− .06	− .06
2.	Woodcock-Johnson	0.11	0.09	.004	0.13	.16	.12	.11
	Salthouse				− 0.08	.43	− .07	− .06
	Listening-Series				0.18	.04	.18	.17
	Backward word				0.09	.30	.09	.08
	Backward digit				0.14	.10	.14	.13
3.	Woodcock-Johnson	0.14	0.03	.004	0.13	.17	.12	.11
	Salthouse				− 0.08	.42	− .07	− .06
	Listening span-Series				0.18	.04	.18	.17
	Backward word				0.08	.34	.08	.08
	Backward digit				0.14	.11	.14	.13
	Listening-Series × MARS Learn				0.16	.04	.17	.16
4.	Woodcock-Johnson	0.21	0.07	.007	0.14	.12	.13	.12
	Salthouse				− 0.09	.35	− .08	− .07
	Listening-Series				0.12	.17	.12	.11
	Backward word				0.07	.37	.08	.07
	Backward digit				0.15	.08	.15	.13
	Listening-Series × MARS Learn				0.12	.13	.13	.12
	MARS-Learning				− 0.26	.03	− .19	− .17
	MARS-Testing				− 0.12	.23	− .10	− .09
	MARS-Control				0.14	.17	.12	.11

WM ($\Delta R^2 = 0.09$, $p = .004$, through Listening span-Series: $\beta = 0.18$, $p = .04$) and Listening span-Series × MARS-Learning ($\Delta R^2 = 0.03$, $p = .044$; $\beta = 0.16$, $p = .04$).

6.2 Between-group comparison

The following aim of this study was to investigate the relation of different MA levels on proficiency in both problem-solving and cognitive math abilities. Therefore, we took the standardized scores of the MARS-Learning and MARS-Testing scales and we averaged them in order to have the index of MA (therefore excluding MARS-Control). Next, we defined the criterion of 1 *SD* below and above the mean value to identify respectively the two groups of low-MA ($n = 23$) and high-MA ($n = 27$). We then carried out a *t* test to inspect the differences between these two groups. Results are reported in Table 4. The analysis showed significant group differences (with lower values for all in the high-MA group) in problem-solving ($\Delta M = 2.37$, $t(49) = 4.34$, $p < .001$, Cohen's $d = 1.23$) and, concerning the cognitive abilities, in Listening Span-Series ($\Delta M = 0.85$, $t(49) = 3.40$, $p = .001$, Cohen's $d = 0.96$). The difference in Backward Word span was relevant, but it did not reach statistical significance ($\Delta M = 0.25$, $t(49) = 1.75$, $p = .08$, Cohen's $d = 0.48$).

7 Discussion

Literature in the field of math acquisition shows that both cognitive and emotional factors have an impact on math performance, also in children attending the first years of primary school (Cargnelutti et al., 2017a; Ramirez et al., 2013; Vukovic et al., 2013). However, the majority of the studies have investigated the effects of MA on general math ability, whereas only recently, the research has focused on specific abilities of math performance, such as calculation or problem-solving (Passolunghi et al., 2016; Ramirez et al., 2013). The main aim of this study was to explore the contribution of both cognitive and emotional factors in arithmetical problem-solving performance specifically. We focused in particular on the role of MA, given that its effects across the primary school grades are not yet clear (e.g., Cargnelutti et al., 2017b; Thomas & Dowker, 2000). We also wanted to explore whether these emotional factors could be related to the cognitive factors supporting math learning and performance.

Regarding the first point, the data suggests that, overall, both cognitive and emotional factors were significantly related to arithmetical problem-solving performance. Notably, MA explained arithmetical problem-solving performance to a relevant extent; its role, in fact,

Table 4 Statistics of problem-solving and cognitive abilities for the two anxiety groups

	Low-MA	High-MA			95%CI		
Variable	*M* (*SD*)	*M* (SD)	*t*(49)	*p*	Cohen's *d*	*LL*	*UL*
Problem-solving	6.78 (1.44)	4.41 (2.38)	4.34	< .001	1.23	1.23	3.52
Listening span	2.52 (0.95)	1.67 (0.83)	3.40	.001	0.95	0.35	1.36
Backward word	3.91 (0.51)	3.67 (0.48)	1.75	.087	2.47	− 0.04	0.53
Backward digit	4.04 (1.02)	3.74 (0.86)	1.14	.126	1.61	− 0.23	0.84
Woodcock-Johnson	44.39 (11.56)	44.59 (9.78)	− 0.07	.95	− 0.09	− 6.27	5.87
Salthouse	42.56 (9.38)	42.77 (7.76)	0.10	.93	0.13	− 6.37	5.20

CI confidence interval, *LL* lower limit, *UL* upper limit appeared to be even greater than that of any other single cognitive variable (see beta values). This important finding was in agreement with those observed in previous studies involving primary school students (Cargnelutti et al., 2017a; Ramirez et al., 2013; Vukovic et al., 2013; Wu et al., 2012, 2014). With regard to problem-solving ability, Ramirez et al. (2013) already underlined a significant effect of MA, but this was found only in a subgroup of students (see afterwards) and by means of a not highly reliable tool to test anxiety. In this study, we overcame assessment biases thanks to the use of a more reliable tool (MARS-R). Importantly, we highlighted the significant relation between MA and problem-solving tasks not entailing a time limit, thus discounting the hypothesis that MA could exert a negative role only to the extent it increases pressure during timed math tasks (e.g., Faust et al., 1996).

Another important finding that needs to be discussed regards the relation with the different MARS-R subscales that we used in this study. As expected, anxiety related to other disciplines (i.e., Anxiety-Control) was not related to arithmetical problem-solving achievement; this reinforces results on the specificity of MA, which can be dissociated from the other forms of anxiety observed in the academic environment (e.g., Cargnelutti et al., 2017b; Hembree, 1990; Passolunghi et al., 2016; Wu et al., 2012). In relation to MA, the crucial subscale was represented by MARS-Learning. This finding seems to suggest that, at least in relation to the problem-solving ability, the most salient anxiety component was that related to the discipline learning. It is then possible to speculate that anxiety associated with the testing condition might arise and therefore become relevant to performance, only in a subsequent step, meaning after a recurrent (negative) experience in math. In a future study, it would be interesting to monitor these subtypes of MA in a longitudinal perspective in order to inspect whether and how the trend might develop over time.

Findings on the role of MA are actually contradictory, particularly for those studies concerning younger children (i.e., those attending the first grades of primary school). In fact, while some studies did find a significant impact of MA on math performance from this stage (e.g., Ramirez et al., 2013; Vukovic et al., 2013; Wu et al., 2012, 2014), others did not and speculate that MA starts to have a relevant role only in higher grades (e.g., Thomas & Dowker, 2000). Future studies should therefore address more specifically the different components of MA, in order to inspect whether divergent findings can be attributed to the fact of having not differentiated between them. Based on the current findings, we may indeed speculate the learning component to arise and have effects from a very early age, far before the impact of later-occurring negative testing experiences. This assessment should be further carried out by taking into account other math domains, in order to see if these results might depend on the math skill that is assessed.

Concerning the role of the cognitive abilities, WM has been confirmed as a factor with a relevant relation to arithmetical problem-solving competence, thus supporting previous evidence both in typically and atypically developing children (Passolunghi & Mammarella, 2010; Passolunghi et al., 2016). Among the WM measures, the main contribution was provided by the measure of Listening span. This appears reasonable given that this task, which is a dual task, entailed a high level of information manipulation comparable to that required when solving arithmetic problems, as confirmed by other studies in the field (Cornoldi & Giofrè, 2014). Interestingly, our findings also agree with those of Fuchs et al. (2010), who observed that there was, in a younger sample, a significant correlation between this WM task and problem-solving performance.

Another finding that needs to be discussed concerns the significant impact of the interaction between WM and MA, more specifically between Listening span and MARS-Learning. This result highlights how even in young students a relation between these two constructs is already established and exerts a relevant role. A general interaction between WM and MA was also outlined in Ramirez et al. (2013), but they observed an impact only in a subgroup of students, meaning in those with high WM, who resulted to be those with a decreased performance due to high MA. Conversely, our findings suggest that the interaction between these two variables (beside their unique contribution) could be observed overall. Being its relation positive, we may speculate that children having both high WM and low MA are those performing at the top in problem solving. This speculation leads us to suggest that other not-assessed variables may intervene in the process, and it prompts a future deep investigation of the interplay between these two constructs.

The last variable to be discussed is processing speed, which our data, differently from previous studies with younger participants (Passolunghi et al., 2015), seems to suggest that processing speed does not significantly contribute to arithmetical problem-solving competence. We may explain these data in relation to the characteristics of the processing speed tasks we used, which required a rapid comparison of visuo-spatial information. Moreover, it is also possible that processing speed has a relevant role in tasks such as number comparison, one-to-one correspondence, and counting, used to assess early numeracy abilities in younger children, whereas untimed arithmetical problem-solving rely less on this cognitive function.

The regression analysis reported in the "Results" section showed that the variables taken into consideration explained only a moderate quote of problem-solving variance (which was at 21%). This result is possibly due to the fact that we only assessed general cognitive abilities (i.e., WM and processing speed), meaning abilities that are involved in a variety of cognitive processes that are not specific to mathematics. Our assessment did not include other relevant general abilities with a known involvement in math achievement, such as intelligence (Cargnelutti et al., 2017b; Giofrè, Borella, & Mammarella, 2017) or visuo-spatial WM (Bizzaro, Giofrè, Girelli, & Cornoldi, 2018; Passolunghi & Mammarella, 2010; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2013). In particular, intelligence has been consistently associated with mathematic achievement, and it seems to mediate the relation between achievement and WM (Giofrè et al., 2017). It is noteworthy, anyway, that intelligence tends to be greatly related to WM compared to other general factors such as processing speed (Demetriou et al., 2014; Swanson, 2011).

Actually, being beyond our purposes, we did not assess the math-specific cognitive abilities such as numeracy, counting, or previous mathematics competence. In fact, in the studies where these abilities were tested, they were observed to determine an increased quote of explained variance of the assessed math skill (e.g., Cargnelutti et al., 2017a; Fuchs et al., 2010; Passolunghi et al., 2015; Passolunghi, Vercelloni, & Schadee, 2007). In addition, other factors such as self-efficacy would have certainly increased the quote of problem solving explained variance. Nevertheless, it has to be underlined that WM and MA were alone sufficient to explain a quote of variance in problem-solving performance that, despite not being huge, was however not negligible.

7.1 Comparison between high-MA and low-MA children

Interesting findings regarding the relation between WM and MA emerged from the between-group comparison we carried out between children with high versus low MA. Our data showed a strong inverse relation between MA and both arithmetical problem-solving and WM. Specifically, high-MA children were not only more impaired in problem-solving, but also in WM (and not in processing speed). Notably, also in this case, the relevant WM measure appeared to be the Listening Span task.

In the research literature, different accounts have tried to clarify the reciprocal effect of WM and MA. Some authors proposed that MA decreases the level of math performance by negatively impacting the WM resources recruited for task execution (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Eysenck & Calvo, 1992; Miller & Bichsel, 2004; Young et al., 2012). Ashcraft and Kirk (2001), in a study on adults, showed that the higher the WM is, the better an individual could manage both math performance and anxiety-driven thoughts (see also Miller & Bichsel, 2004). Our results on fourth-grade children extended the findings of a recent study proposed by Passolunghi et al. (2016), who observed that highly anxious secondary-school students showed both a low level ability in several tasks of math performance and also lower scores on WM tasks.

However, the interplay between WM and MA in the definition of math performance has been explored in other studies and also by taking a different perspective. Actually, as already illustrated, Ramirez et al. (2013) found that first- and second-grade students with high levels of WM (indicated by high scores on a digit span task) were more affected by anxiety than students with low WM when they were asked to solve arithmetic word problems. This was interpreted to occur because individuals with high WM strongly rely on this cognitive ability when performing math and become incapable of successfully using it when affected by high MA. These results are not directly comparable to ours, owing to the fact that these authors differentiated children by the level of WM and we instead looked at the level of MA. Furthermore, we also used different tasks and questionnaires to assess the two variables. Nevertheless, our findings seem to diverge from those of Ramirez et al. (2013) in that they suggest a negative impact of MA on WM as well. However, more research has to be carried out to account for the developmental effects. In fact, in the cited study, the sample was represented by very young children (first and second graders), and it is possible to speculate that the relation between MA and math performance could be observed only in those with high WM because only these children were already aware of their emotional condition.

7.2 Limitations and practical relevance of the study

Our study has some limitations. First, we did not take into consideration the level of the child's general anxiety, which was observed to be strongly related to general math performance, at least in younger students (Cargnelutti et al., 2017b; Passolunghi et al., 2016). Similarly, we evaluated only verbal but not visuo-spatial WM. Recent findings instead indicate that visuo-spatial WM plays a crucial role in general mathematics achievement (Mammarella, Caviola, Giofré, & Szűcs, 2017; Szűcs et al., 2013).

Concerning the assessment of problem solving, we purposefully did not administer time-related tasks, which could represent an important source of anxiety, in the reciprocal effect between MA and WM (Beilock & Carr, 2005; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011). Future research could evaluate the effect of math anxiety on timed versus untimed arithmetical problem-solving ability. Furthermore, it would also be interesting, in future studies, to investigate whether the execution of timed math tasks is related to processing speed ability.

Besides these specific comments regarding the variables we assessed, it is fundamental to underline that educational literature has highlighted that several other aspects contribute to problem solving achievement (e.g., task characteristics, students' cognitive and emotional characteristics, and educational and socio-economical characteristics) and could influence students' ability to make flexible representational choices (Verschaffel & De Corte, 1997). In this study, we focused on the investigation of some salient emotional and cognitive aspects related to the individual attitudes/abilities connected with the discipline. In doing this specific selection of variables, we acknowledge that it would be necessary to evaluate anxiety as well as WM and processing speed with a more broad perspective (e.g., evaluating more specific aspects related to the type of arithmetical problem solving proposed as well as teaching methodology and cultural context). For this reason, we believe that further research on this topic is needed to provide a more comprehensive view on the multiple factors that are involved in arithmetical problem solving.

However, the present findings have interesting clinical and educational implications. Typically, poor performance on arithmetical problem-solving is attributed impairments in cognitive abilities, whereas our study provided evidence for the relevant role of anxiety. In the case of high MA, these findings therefore support the development of training procedures focused on MA and for instance devoted to the suppression of negative thoughts and in fostering a positive attitude towards this discipline. This could result in some gains in math performance in different math-related settings. In particular, trying to shed light on the age at which MA begins to negatively correlate with math attainment will also be useful to prompt very early interventions and thus prevent the full manifestation of its negative effects.

In conclusion, this can be considered as one of the first attempts to shed light on the possible relation between MA and arithmetical problem-solving. Our findings highlighted the fact that difficulties in mathematics could be strongly related not only to a weak cognitive functioning but also to negative emotional aspects, which need to be considered as crucial in the educational system.

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