

ARTICLE

Executive functions, math anxiety and math performance in middle school students

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Abstract

Previous studies mainly investigated working memory (WM) and math anxiety (MA) leaving almost unexplored other aspects of executive functions (EFs) in middle school period. Filling the gap in the literature, the aims of this study were: (1) to better examine the relationship between MA and math performance, (2) to better examine the relationship between EFs and math performance and (3) to investigate the interplay between EFs and MA on math performances. This study confirmed a significant and negative relationship between MA and math performance, indicates a significant and positive relationship between visuospatial WM and math performance, shifting and math performance and highlight a scarcely investigated indirect influence of MA through the measure of shifting on math performance. Our findings shed further light on the mediating role of EFs between MA and math performance and underline some future perspectives.

KEYWORDS

executive functions, math anxiety, math performance, middle school students

[Correction added on 13 May 2022, after first online publication: CRUI-CARE funding statement has been added.]

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BACKGROUND

Given the relevance of math skills at both individual and social levels, knowing which factors are crucial to mathematical acquisition and possibly understanding how they interact, is a salient topic for our society. The literature indicated that domain-general precursors like intelligence (Giofrè et al., 2014), executive functions (EFs) (Passolunghi & Siegel, 2001, 2004) and emotional factors (Ashcraft & Kirk, 2001) modulate math achievement. For decades, cognitive factors were studied separately from emotional factors. In the last 20 years, researchers have tried to propose a convergent model of the complex interplay between cognitive and emotional factors behind math acquisition (Ashcraft & Kirk, 2001; Ramirez et al., 2013). These studies have mainly investigated working memory (WM) and maths anxiety (MA), but leaving almost unexplored other aspects of EFs such as inhibition and shifting.

Furthermore, studies extensively assessed primary school children (Mammarella et al., 2015), secondary school students (Passolunghi et al., 2016) or adults (Ashcraft & Kirk, 2001), while middle school students are understudied (but see Trezise & Reeve, 2014, for exceptions). Studies showed a decline in motivation and performance for many students as they move from primary to the middle school environment (Midgley et al., 1989), and the literature showed that the academic developmental needs of middle school students are different from those of elementary and high school students (Eccles et al., 1993). The middle school period is a period of changes when teachers have higher expectations and a grading system with more pressure on performance, the period when students need to invest more time in studying (Midgley et al., 1995). Various changes bring difficulties for students, and unsurprisingly students in this period showed less motivation (Lepper et al., 2005), a decline in grades (Blackwell et al., 2007) and an increase in negative attitudes towards school (Anderman & Midgley, 1998).

To fill this gap, the aims of our study are (1) to better examine the relationship between MA and math performance, (2) to better examine the relationship between EFs and math performance and (3) to investigate the interplay between EFs (VWM, VSWM, inhibition and shifting) and MA on math performance in the middle school students.

Executive functions and mathematics achievement

Diamond (2013) described EFs as: 'skills essential for mental and physical health; success in school and life; and cognitive, social, and psychological development'. Diamond (2013) agreed that three components of EFs exist: WM and inhibitory control distinguishing them from cognitive flexibility (the third), which 'builds on the other two and comes in much later in development'.

The study demonstrated the importance of EFs to the development of mathematical skills and showed that children with poor EFs could experience difficulties in various areas of mathematics (Viterbori et al., 2017). Further evidence demonstrates relations among EF skills and achievement through late childhood and early adolescence (e.g. St Clair-Thompson & Gathercole, 2006). Usai et al. (2018) longitudinally investigated EF profiles in 5-year-old children and their later math achievement. They showed that children with weak WM-shifting profiles (performed equally with typical EF profile groups in arithmetic and math problems tasks in Grade 1) showed difficulties as a group of children with a general deficit in EFs in Grade 3. Viterbori et al. (2015) longitudinally analysed whether EF measured during preschool predicts math achievement in primary school. The results showed that the WM-flexibility component measured in the preschool period predicts math achievement in Grade 3. WM-flexibility predicted math scores at Grade 1 and Grade 3. The WM-flexibility component in Grade 3 predicted problem-solving and arithmetical facts. The study of Orbach et al. (2020) showed the negative influence of state-MA on math performance through core EFs (inhibition, cognitive flexibility, WM capacity, a global measure of core EFs) in the sample of fourth- and fifth-grade students.

Considering the impact of different EF components on math achievement, WM extensively studied mathematical achievement and abilities, revealing its involvement in performing arithmetical operations, especially in the mental calculation (Passolunghi & Siegel, 2001, 2004). Various studies found that

Statement of contribution

What is already known on this subject

1. Previous studies have mainly investigated working memory and math anxiety, but leaving almost unexplored other aspects of executive functions.
2. Negative influence of math anxiety on math performance in young children and adults.

What the present study adds

1. Better examination of relation between math anxiety and math performance in middle school students.
2. Better examination of relation between executive functions and math performance in middle school students.
3. The interplay between executive functions (working memory, inhibition and shifting) and math anxiety on math performances.

children who performed poorly in WM tasks did not reach the expected levels of math performance (Gathercole & Pickering, 2000; Geary et al., 2004; Passolunghi & Mammarella, 2010, 2012). The study of Trezise and Reeve (2014) with 14-year-old girls showed an association between high worry, low WM and poor algebra results, also between low worry, high WM and high results on algebra tasks but without the impact of high worry with moderate WM. The previous literature showed the influence of verbal WM (VWM) and visuospatial WM (VSWM) on math performance in different ages. According to some researchers, VWM has a more significant role in math achievement than VSWM (Friso-Van den Bos et al., 2013). On the other hand, a comprehensive study with a large sample of typical 9-year-olds with extensive battery measures showed the predictive role of VSWM, but not VWM on mathematical achievement (Szűcs et al., 2013). The study by Giofrè et al. (2018) on middle school students (in sixth to eighth grades) confirmed that VSWM predicts math performance and VWM predicts reading abilities. The different role of WM components on math achievement is explained not only by the different tasks used to measure math abilities (De Smedt et al., 2009), but also with the differences in the age of the participants (Cragg et al., 2017). Given the crucial role of WM in the learning process, it is essential to investigate the architecture of this function in more detail, especially as regards the complex interplay with other EFs.

While WM is extensively studied, other EF components such as inhibition and shifting have been much less investigated or indicate contradictory results (Blair & Razza, 2007; Yeniad et al., 2013). The relationship between inhibition and mathematical performance in preschool and school children has emerged in various studies (Usai et al., 2018). Bull and Scerif (2001) reported that the main difficulty for primary school children lies in inhibiting a strategy already learned and switching to a new one. St Clair-Thompson and Gathercole (2006) partially confirmed the existence of several differences between EFs finding an important role of WM in English and math and the important role of inhibition in English, math and science. Their study did not show results related to the shifting process in middle school students. On the other hand, Cragg et al. (2017) investigated the role of EFs in factual knowledge, procedural skills, conceptual understanding and overall math achievement in a sample with the age range between 8 and 25 years. They found a significant relationship between VWM, VSWM and overall math achievement, but did not find a significant relationship between inhibition, shifting and overall math achievement. The explanation for their results found in the evidence that inhibition and shifting account for less variance in math performance (Friso-van den Bos et al., 2013), but suggested that inhibition and shifting can contribute a unique variance to math achievement when they are studied independently from measures of WM (Lee & Bull, 2016).

As a third aspect in the Diamond model, the shifting component seems to be relevant in math performance. Cragg and Nation (2009) conducted two experiments with children in different age groups and showed that younger children (5–8 years old) had greater difficulty inhibiting unrelated information than older children (9–11 years old). A meta-analysis conducted by Yeniad et al. (2013) highlighted the predictive role of shifting in performance in mathematics and reading across developmental ages. They showed an association between shifting and math performance and found that children with a greater capacity for shifting achieved better results in mathematics. They also provided a precise structure for classifying shifting tasks by the level of complexity. The previously mentioned meta-analysis also showed the variety of tasks used to measure shifting and the different scoring methods involved (reaction time, accuracy, efficiency or combined scores). The shifting role was implicit in some studies and explicit in others.

Previous studies showed contradictory results, a paucity of studies on middle school students and needs for more developmentally sensitive measures, especially for shifting. Heterogeneity in the shifting tasks causes heterogeneity in the results obtained in previous studies because different shifting tasks used different dependent variables (Yeniad et al., 2013). On the other hand, the predictability of WM measures across development makes these measures more stable compared with the measures for shifting (Ahmed et al., 2019). However, to the best of our knowledge, no studies have yet examined the mediating role of different EFs (VWM, VSWM, inhibition and shifting) in a sample of middle school students, leaving the influence of EFs on math achievement in this developmental period almost unexplored.

Mathematics anxiety and math performance

Cognitive aspects shape math performance, but an emotional component could also have a specific role in math performance (Mammarella et al., 2019). Ashcraft (2002) defined MA as ‘a feeling of tension, apprehension, or fear that interferes with math performance’ and showed that individuals with more severe MA avoid situations in which they need to perform mathematical tasks. Such avoidant behaviour can give rise to less competence, exposure and practice, leaving students more anxious and mathematically less well prepared. Studies have shown a negative correlation between math achievement and MA (Ashcraft, 2002) and a lower quality of math learning in individuals experiencing MA (Dowker et al., 2016). Feeling anxious about math-related situations is a pretty stable phenomenon already in second grade by the end of secondary school. Ma and Xu (2004) examined the development of anxiety about math-related situations from seventh to twelfth grades. They found that MA remained relatively stable from Grade 8 onwards (1-year stability coefficients were slightly below 0.60).

Six meta-analyses have examined the relationship between MA and maths performance (Barroso et al., 2020; Caviola et al., 2021; Hembree, 1990; Ma, 1999; Namkung et al., 2019; Zhang et al., 2019) and confirmed a negative influence of MA on math performance. The fundamental aspect that came to light was that cognitive and emotional problems underlying math difficulties could be mainly considered dissociable (Devine et al., 2018).

Anxiety and executive functions

Connections between EFs and anxiety have been examined, particularly through the relationship between WM and anxiety (Beilock & Carr, 2005; Eysenck & Calvo, 1992; Mammarella et al., 2015; Passolunghi et al., 2020; Pellizzoni et al., 2019, 2020). Stressful situations and negative feelings (such as anxiety) can interfere with success in mathematical performance (Caviola et al., 2017). Attentional control theory (ACT), developed by Eysenck et al. (2007), describes anxiety as a disrupter of our ability to control our attention, which means that we are more readily distracted while

performing a task. ACT thus suggests that anxiety reduces our cognitive capacity and impairs our efficiency, regardless of whether the stimuli prompt are internal (worrying thoughts) or external (tasks). According to this theory, anxiety influences WM and interferes with effective performance, particularly in complex tasks. Studies on adults assessing the joint influence of WM and MA on math performance generated contrasting results, and the literature offers different approaches. Ashcraft and Kirk (2001) suggested that individuals with a greater WM capacity have more cognitive resources and can simultaneously manage anxiety-related thoughts and solve math tasks. Beilock and Carr (2005) took another view, claiming that individuals with a greater WM capacity are more susceptible to performance deficits as a result of WM disruptions (what they called a ‘choking under pressure’ effect).

Most studies investigated only the relationship between MA and WM, without considering the role of other EF constructs. The studies were also conducted on primary school children (Ramirez et al., 2013; Vukovic et al., 2013) or adults (Beilock & Carr, 2005), leaving the years of early adolescence almost unexplored. Based on the ACT proposed by Eysenck and Calvo (1992), which postulates that anxiety decreases attentional control and increases attention to threat-related stimuli, Hopko et al. (1998) indicated that math-anxious individuals show a deficient in the inhibition mechanism through which WM resources are consumed by task-irrelevant distracters. These data were more recently confirmed by different studies that underline how math anxiety (MA) impairs the inhibition control system with specific effects on math abilities (Mammarella et al., 2017; Van den Bussche et al., 2020). This study could be the first attempt to assess the influence of different EFs and emotional aspect (MA) on math performance and to observe how they will connect in the middle school period.

The present study

In the present study, we examined the role of EFs (VWM, VSWM, inhibition and shifting) and MA on math performance in middle school students, and we tried to reach the following aims: (1) to better examine the relationship between MA and math performance; (2) to further examine the relationship between EFs and math performance, often left unexplored during the middle school period and (3) to investigate, for the first time, the interplay between EFs (VWM, VSWM, inhibition and shifting) and MA on math performance.

To achieve our aims, we hypothesized that:

1. MA would have a significant and negative relationship with math performance, referring specifically to middle school students (Barroso et al., 2020),
2. Different EF components would correlate positively with math performance in middle school students (e.g. WM, inhibition and shifting; Giofrè et al., 2018; Trezise & Reeve, 2014; Usai et al., 2018). With respect to WM, some studies have shown the relative contributions of memory components to general mathematics learning in secondary school students (Giofrè et al., 2018). In line with this research, we hypothesized a specific correlation with VSWM, but not with VWM during this school period.
3. The relation between MA and math performance will mediate through cognitive factors (VSWM, inhibition and shifting) in middle school students (Cragg et al., 2017; Giofrè et al., 2018; Justicia-Galiano et al., 2017).

Figure 1 shows the theoretical model based on the variables included in our study.

To reach these aims, students were assessed in two phases: during the first phase at the beginning of the school year, cognitive (VWM, VSWM, inhibition and shifting) and emotional factors (MA) were tested. Then, 7 months later, their maths abilities were tested in the second phase.

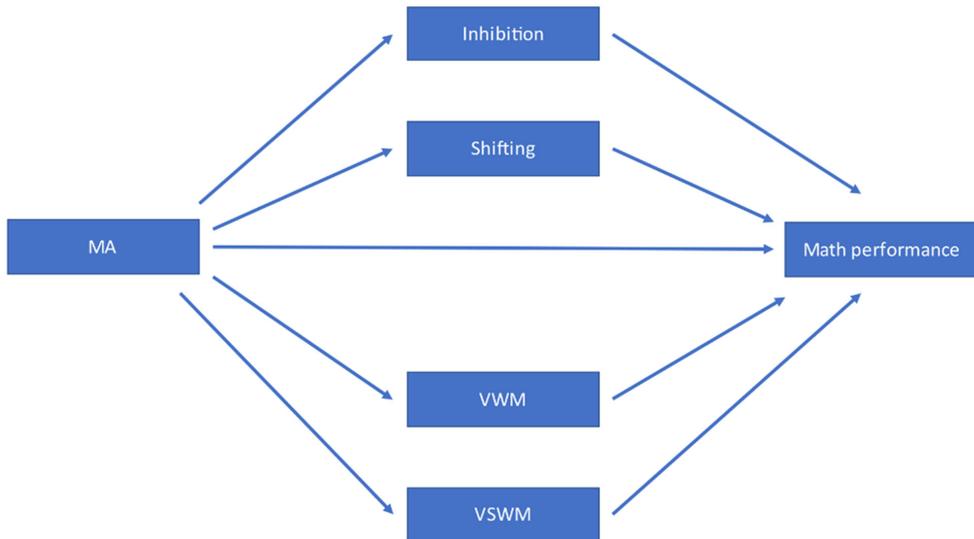


FIGURE 1 Theoretical model

METHOD

Participants

The research was carried out at four different middle schools in northeastern Italy. The study enrolled 105 middle school students (48 males and 57 females; $M_{\text{age}} = 12.62$, $SD = 0.67$, age range from 11 to 14 years old), two of whom did not participate in the final assessment. None of the students were diagnosed with learning disabilities (the information that we got from the teachers). The final sample thus included 103 participants, all Caucasian. The sample's SES was primarily middle class, judging from the school records. The student's parents and the school's principals signed a written informed consent form following the Declaration of Helsinki. This study was conducted following the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists. Emotional factor (15 min) and math abilities (45 min) were assessed in a collective way; cognitive factors were assessed individually in the quiet room at school, each student for this assessment needed around 30 min.

Measures

Cognitive factors

Verbal working memory. The *Letters and Numbers Sequencing* subtest of the WISC-IV test battery (Wechsler Intelligence Scale for Children, 2003) measures verbal WM, an individual's ability to retain and manipulate verbal information in their memory. After the examiner read a string of letters or numbers in random order, participants need to repeat them in alphabetical or numerical order. There were three pairs of strings (of letters and numbers) of increasing length, from two letters and two numbers to four letters and four numbers. The total raw score for the test is obtained by awarding 1 point for each correct answer and 0 for each wrong answer. The sum of the raw scores was converted into a scaled score using a specific conversion table.

Visuospatial working memory. A computerized version of the *Dot Matrix* subtest (adapted from Miyake et al., 2001) was used. This task measures the ability to simultaneously process visuospatial information

and to maintain information in the visuospatial store. The task required the participant to verify a matrix equation while simultaneously remembering the location of the X in a 5×5 matrix. Each trial contains a set of matrix equations followed by a 5×5 matrix containing one X. Participants had 4500 ms to verify the sum of two segments correctly or not described by a third presented pattern. Immediately after matrix addition, a 5×5 matrix with an X in a cell was displayed for 1500 ms on the screen. After, participant had to recall the appearance of X in the 5×5 matrix by clicking in the empty 5×5 matrix. The result presents the proportion of correct answers of participant.

Inhibition

The NEPSY-II Inhibition test (Korkman et al., 2007) comprises two different trials (shapes and arrows) and three conditions: Naming, Inhibition and Switching. With the condition Inhibition, participants were presented with a series of black and white shapes (circles and squares) or black and white arrows pointing in a given direction and had to say the opposite shape or direction as quickly as they can. Response time, number of errors, number of self-corrections, the sum of errors and the number of self-corrections recorded for each condition. The final score presents the sum of response time and sum of errors converted into a scaled score using a specific conversion table.

Shifting

The NEPSY-II Inhibition test (Korkman et al., 2007; Switching condition). Participants are asked to state the opposite shape if it is white and the correct shape if it is black, the same with arrows (white arrow opposite direction, black arrow correct direction) and as quickly as possible. Before both conditions, participants did the example first. Response time, number of errors, number of self-corrections, the sum of errors and the number of self-corrections recorded for each condition. The same as for Inhibition, the final score presents the sum of response time and sum of errors converted into a scaled score using a specific conversion table.

Emotional factors

Mathematics anxiety. The Abbreviated Math Anxiety Scale (AMAS, Hopko et al., 2003) is a self-report questionnaire containing nine items adapted to middle school students. The questionnaire uses a 5-point Likert scale on which participants indicated how much anxiety they would feel in a given situation that involves mathematics (1 = *little anxiety*, 5 = *great anxiety*). The total score was the sum of all scores for each item, with a higher score corresponding to more severe MA.

Mathematical ability. The AC-MT 3 (Cornoldi et al., 2020) tests of mathematical calculation and problem-solving skills from 6 to 14 years old. This test examines different aspects of mathematical learning, written and oral calculus skills, the ability to understand and produce numbers, arithmetical reasoning skills, speed of calculation and problem-solving skills. For this study, we used five subscales (Approximate calculation, Fluency, Matrix, Inferences and Written calculation). The reason for choosing this battery was that five subscales could be assessed in a collective way. *Approximate calculation*, participants were shown an arithmetical operation and chose from a set of numbers closest to the correct result. They were allowed one and a half minutes to complete 15 exercises. For *Fluency*, participants saw the same series of operations and provided the correct answers as quickly as possible. They had three sheets, one of the additions (20 exercises), one of the subtractions (20 exercises) and one of the multiplications (20 exercises). For each sheet, they had 1 min to complete the task. The matrix subscale is a mathematical reasoning task. A series of numbers were presented in 2×2 or 2×3 matrices in which a number was missing. Children had to choose which number was missing for each matrix. Students had two and a half minutes to complete the task. The *Inferences* subscale included three different exercises where students needed to use mathematical reasoning to solve them. The first type of exercise used symbols instead of numbers. In the second exercise, computational operation is missing and students needed to add it. In the last, the third exercise, there are two operations: one complete, while in the other the result is missing. Students were required to complete the calculation using the second operation as an aid. The

total time available for the subscale was 2 min, 1 min for the first type of the exercise and 1 min for the second and the third types of the exercise. For the subscale *Written calculation*, they had eight different operations (two additions, two subtractions, two multiplications and two divisions) to be solved in 5 min. The tasks were presented in a paper-and-pencil format. Each correct answer scored one point, and the wrong answers scored zero. The sum of raw scores of all subscales was used as a final score.

The order of the sessions and the tasks (emotional, cognitive and math performance) were the same for every participant.

RESULTS

Analytic strategies

SPSS IBM 21 was used to obtain the descriptive and correlation analyses between all measures. We conducted a bivariate correlation analysis using Pearson r between math calculation, EFs (VWM, VSWM, Inhibition and Shifting) and MA for the whole sample. In addition, path analyses were done with the lavaan package (Rosseel, 2012) for R (R Core Team, 2019) to explore our third hypothesis the descriptive statistics of all tasks are reported in Table 1.

Bivariate correlations between mathematical performance, EFs and MA are presented in Table 2.

Preliminary analyses included a test of a theoretical framework for better understanding the influence of cognitive and emotional factors on math calculation. This theoretical model used cognitive factors as mediators (VWM, VSWM, inhibition and shifting). We ran a path analysis and tested model fit considering: the chi-square (χ^2), the comparative fit index (CFI), the normed fit index (NFI), the Tucker fit index (TFI) and the root mean square error of approximation (RMSEA); the chi-square difference ($\Delta\chi^2$) and the Akaike information criterion (AIC) were also used to compare the fit of alternative models (Kline, 2011). *A priori* power analysis (Gpower: Faul et al., 2007) indicated that a sample size of 63 would be sufficient to detect a significant interaction effect with a power of .95 and an alpha of .05.

The statistical fit for the theoretical model was: CMIN = 13.75, $df = 4$, CMIN/ $df = 3.43$, $p = .008$, CFI = .883, NFI = .860, TLI = .560, RMSEA = .154, AIC = 1976.922, BIC = 2019.078. Results showed *Mathematical performance* to be significantly directly predicted by *VSWM* ($\beta = .18$; $p = .038$), *Shifting* ($\beta = .29$; $p = .001$) and negatively by *MA* ($\beta = -.35$; $p = .000$). Indirectly, significant and negative impact on *Mathematical performance* had *MA* through measure of *Shifting* ($p = .024$). Analysis, also, showed significant paths between *VSWM* and *Shifting* ($\beta = .31$; $p = .002$) and between *Shifting* and *MA* ($\beta = -.28$; $p = .003$). Also, results showed non-significant path between *MA* and *Inhibition* ($\beta = -.09$; $p = .357$), *MA* and *VWM* ($\beta = -.11$; $p = .186$) and *MA* and *VSWM* ($\beta = -.13$; $p = .259$).

From the theoretical model we excluded all non-significant paths because we wanted to see if there will be changes in the fit indexes in a new model. Furthermore, we ran the path analysis by testing for both direct and indirect influences to show the influence of MA on math performance mediated by shifting. Model statistical fit was good: CMIN = 1.25, $df = 1$, CMIN/ $df = 1.25$, $p = .26$,

TABLE 1 Descriptive statistics of the tasks used in our study

	Mean (SD)	Minimum	Maximum	Reliability
VWM (scaled scores)	11.37 (4.22)	1	23	.90
VSWM (proportions)	0.38 (.23)	0.07	0.98	.85
Inhibition (scaled scores)	10.03 (2.33)	1	15	.80
Shifting (scaled scores)	9.67 (2.78)	4	15	.80
MA (raw scores)	21.80 (6.36)	9	38	.83
Math (ζ score)	6.15 (4.60)	-5.12	17.25	.73

Abbreviations: MA, math anxiety; SD, standard deviation; VSWM, visuospatial WM; VWM, verbal WM.

CFI = .996, NFI = .982, TLI = .976, RMSEA = .050, AIC = 1591.879, BIC = 1615.592. Results showed *Mathematical performance* to be significantly directly predicted by *VSWM* ($\beta = .20$; $p = .018$), *Shifting* ($\beta = .29$; $p = .001$) and negatively by *MA* ($\beta = -.40$; $p = .000$). Indirectly, significant and negative impact on *Mathematical performance* had *MA* through measure of *Shifting* ($p = .033$). Analysis showed significant path between *VSWM* and *Shifting* ($\beta = .32$; $p = .002$) and between *Shifting* and *MA* ($\beta = -.25$; $p = .006$). Results concerning direct and indirect influence and percentage of explained variance (R^2) are presented in Figure 2.

DISCUSSION

Researchers have investigated the influence of cognitive and emotional factors on math performance in adults (Ashcraft & Kirk, 2001) and, more recently, in primary school children (Ramirez et al., 2013), mainly leaving unexplored the middle school period and the complex interplay between factors specifically referring to cognitive processes. The most investigated aspects were the influence of WM and MA, but rarely the influence of other EFs (e.g. inhibition and shifting) on math performance (Mammarella et al., 2017). Because of the lack of literature on the sample of middle school students, we designed the present study to understand the importance of EFs and investigate the reciprocal role of cognitive (WM, inhibition and shifting) and emotional factors (MA) in mathematical performances. The goals of our study were to analyse: (1) the relationship between MA and maths performance, (2) the relationship between EFs and math performance and (3) the interplay between EFs (VWM, VSWM, inhibition and shifting) and MA on math performance.

Our first hypothesis was confirmed, and results showed a significant and negative relationship between MA and maths performance. The results are in line with previous studies in primary school

TABLE 2 Bivariate correlations between all variables considered in the sample

	1	2	3	4	5	6
1. VWM	–					
2. VSWM	.314**	–				
3. Inhibition	-.061	.106	–			
4. Shifting	.075	.332**	.348**	–		
5. MA	-.136	-.110	-.090	-.260**	–	
6. Math	.188	.335**	.137	.446**	-.492**	–

Abbreviations: MA, math anxiety; VSWM, visuospatial WM; VWM, verbal WM.

** $p \leq .01$.

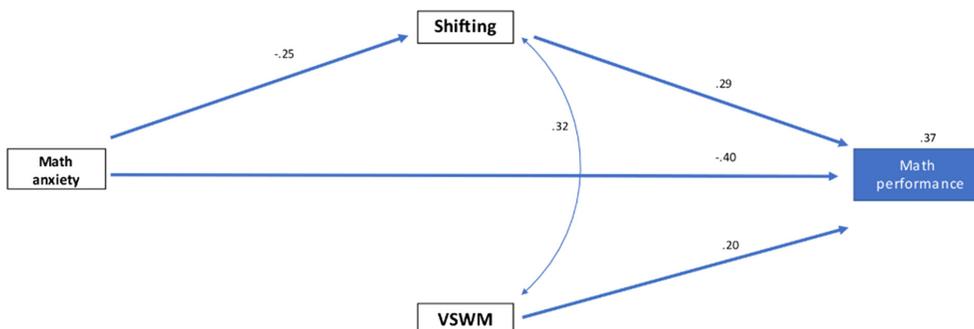


FIGURE 2 Final model

students (Vukovic et al., 2013), in middle school students (Madjar et al., 2018) and with adults (Ashkenazi & Danan, 2017).

The second hypothesis of the study was partially confirmed by cognitive factors (VWM, VSWM, inhibition and shifting) having a significant and positive relationship with math performance in middle school students. Results showed a positive relationship between VSWM and math performance and between shifting and math performance, but not a significant relationship between VWM and math performance. Giofrè et al. (2018) showed that VWM and VSWM could be split regarding their predictive influence on reading and mathematics. The results of their study indicated the importance of VSWM for math, and the importance of VWM in reading. Also, some of the previous studies can be used to explain our results, for example, the studies that underline the impact on math performance by depressing specifically VSWM resources (Soltanlou et al., 2019). The authors showed how MA primarily impacts the visual component (e.g. Trezise & Reeve, 2018). The study with a sample of 14-year-old female students (Trezise & Reeve, 2014) showed an association between high worry, low WM and poor algebra results, also between low worry, high WM and high results in algebra tasks but without the impact of high worry with moderate WM. On the other hand, Wong and Szücs (2013) showed that maths tasks presented in a written format can inherently engage the visual components and had shown that format influences strategies that participants would choose (Katz et al., 2000).

In respect to inhibition, studies on pre-schoolers showed a significant relationship between inhibition and math performance in preschool children (Clark et al., 2010). The study of Bull and Scerif (2001) on primary school students who had lower mathematical abilities indicated that students had major difficulties with inhibition of learned strategy and switching to a new one. Moreover, Orbach et al. (2020), with a sample of fourth- and fifth-grade students, showed the negative influence of state-MA on math performance through core EFs (inhibition, cognitive flexibility, WM capacity, a global measure of core EFs). Some of the studies also addressed this relationship in samples of middle school students showing the role of inhibition of math performance (St Clair-Thompson & Gathercole, 2006).

A non-significant relationship between inhibition and math performance was observed in our study. The explanation of this result could be due to the type of task proposed in the NEPSY II evaluation. The Inhibition and Shifting tasks were based on the same type of material but with an increasing level of WM required. While in the 'inhibition' test participants were presented with a series of black and white shapes (circles and squares) or black and white arrows (pointing in a given direction) and participants had to say as quickly as they could the opposite shape or direction, the Shifting test required participants to state the opposite shape if it is white and the correct shape if it is black. The necessity to compare the rule and modify the strategies according to the material, different from the first task, implies a more challenging performance in this last assignment. In this more challenging case, a significant relationship between shifting and math performance was observed.

The third hypothesis has been partially confirmed, too. The indirect influence of MA through the cognitive measures was significant just for the measure of shifting but not for VWM, VSWM and inhibition. In other words, our results indicated that only shifting mediated the relations between MA and maths performance in middle school students. Previous studies investigated the mediating role of WM in primary school (Justicia-Galiano et al., 2017) and middle school students (Owens et al., 2012), but not the mediating role of other EFs. Another possible explanation is related to the nature of the math tasks used in our study. MA reducing the capacity of shifting and relying on WM decrease math performance. Because of the negative influence of MA that consumes capacity for shifting, participants showed lower results on the math tasks where they needed to shift from one strategy to another. It is important to note that, as math tasks, we used five different tasks that involve various computational operations (addition, subtraction, multiplication and division) and inferences that require more involvement of shifting.

To the best of our knowledge, this is the first study that simultaneously investigated EFs and MA and evaluated the mediating role of shifting in the relation between MA and maths performance in middle school students. These data seem to reflect a change in the developmental trajectory resulting in a specific role of shifting, during this specific developmental stage, compared to other EFs (St Clair-Thompson & Gathercole, 2006). Various studies with a sample of primary school students showed

a negative correlation between arithmetic ability and shifting (Bull et al., 1999; Bull & Scerif, 2001; McLean & Hitch, 1999). Latzman et al. (2010), with a sample of male adolescents, showed that higher levels of performance on shifting tests were related to higher math performance. Finally, we can speculate that the influence of EFs on math performance may change in middle school students underlining the critical role of shifting in this developmental stage (Miyake & Friedman, 2012).

Although our findings shed further light on the mediating role of EFs between MA and maths performance, this study also shows some limitations that should be taken into account in further research. First, we did not measure general anxiety as a control variable of MA. The control variable will give a clearer view how MA influences math performance. Second, task impurity is a major issue with EF components. In our study, we used a unique task from which we derived the measures of inhibition and shifting that can be confounding given the level of task impurity (Denckla, 1994; Miyake et al., 2000), and we used a VWM task including numbers that can increase specific anxiety in children who already feel difficulties with math. It is worth noting, that in an additional analysis, we did not find differences in terms of VWM tested on numbers and letters for students with high MA ($F_{(1,26)} = .288$, $p = .596$, $\eta_p^2 = 3.889$). As a third aspect, we did not consider individual resources, such as self-concept, self-efficacy, motivation and ego resilience which have been shown important to mediate the relation between MA and maths performance (Donolato et al., 2020; Mammarella et al., 2018).

EFs are important for developing math skills and their decrease can cause a delay in math learning (Bull & Lee, 2014). Our study confirmed the importance of VSWM and shifting for maths performance in middle school students and the necessity for the studies investigating WM separately from inhibition and shifting (Cragg et al., 2017). Whether students with low arithmetic skills are tested, difficulties in shifting may be expected, thus future studies should longitudinally investigate the influence of shifting on math performance. Also, it would be important to investigate the role of shifting as moderator by considering the complexity of the math tasks, in order to understand whether the moderation effect is influenced by the WM demands of the math task used.

Educational implications

The study has several implications for math acquisition during secondary school. First, intervention programmes designed to increase math performance should be targeted at emotional and cognitive factors at the base of this type of achievement, focusing on exercises that can promote emotional control during tasks and awareness of how emotion and EFs could influence performance. Overall, metacognitive exercises may be used to increase awareness about strategies to solve math tasks (Passolunghi et al., 2020). Second, students often report receiving less emotional support during the transition into adolescence (Larson et al., 1996; National Research Council, 2004). Third, we deem as crucial for teachers to be aware of the early signs of MA and to promote intervention to train emotions, WM and EFs that base achievement to drive students to positive school adjustment. These findings highlight the importance of (1) raising awareness on the importance of math learning and all the factors that could promote or hinder math acquisition and (2) providing training on effective ways to contrast MA and ameliorate the classroom climate and equal educational opportunities for all students (Pellizzoni et al., 2019, 2020).

To conclude, further longitudinal and experimental studies should be carried out to better determine the direction between cognitive and emotional factors and their influence on math performance by considering individual resources and environmental factors.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

AUTHOR CONTRIBUTION

Marija Živković: Conceptualization; Data curation; Formal analysis; Writing – original draft; Writing – review & editing. **Sandra Pellizzoni:** Methodology; Writing – original draft; Writing – review & editing. **Irene Cristina Mammarella:** Conceptualization; Formal analysis; Writing – review & editing. **Maria Chiara Passolunghi:** Conceptualization; Supervision; Writing – review & editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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