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Parallel paths? Do state and trait math anxiety interact differently with executive functions in explaining math problem solving?

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Keywords

Math anxiety
State-trait discrepancy
Working memory
Math problem-solving
Conditional models

Abstract

Math anxiety and executive functions both impact mathematical achievement, yet their interaction shows methodological inconsistencies. Building on the theoretical framework of the state-trait discrepancy, this study evaluates these math anxiety dimensions through differentiated conceptual models applied to math problem solving: specifically, mediation for state-math anxiety and moderation for trait-math anxiety. Gender was also included due to its relevance for math anxiety and math problem solving. The sample consisted of 291 Chilean students (169 girls; mean age of 10.54 years). Results showed direct relationships between math anxiety and math problem solving, and replicated performance differences favoring males in math problem solving and state-math anxiety. Working memory mediates the state-math anxiety and math problem solving relationship consistently across genders. Trait-math anxiety moderation was significant only through verbal-working memory, with an additional interaction by gender. This moderation mechanism was exclusive to girls, indicating that a robust verbal-working memory buffered the negative effect of trait-math anxiety on math problem solving. These findings highlighted the importance of distinguishing math anxiety dimensions and underscored verbal-working memory as a key target for interventions aimed at improving math problem solving and potentially reducing gender differences related to math anxiety and math problem solving.

¿Caminos paralelos? Interacción diferencial de la ansiedad matemática estado y rasgo con los componentes de funciones ejecutivas para la resolución de problemas matemáticos

Palabras clave

Ansiedad matemática
Discrepancia estado-rasgo
Memoria de trabajo
Resolución de problemas matemáticos
Modelos condicionales

Resumen

Tanto la ansiedad matemática como las funciones ejecutivas impactan el rendimiento matemático; sin embargo, su interacción presenta inconsistencias metodológicas. Con base en el encuadre teórico de la discrepancia de ansiedad matemática estado-rasgo, se evaluaron ambas dimensiones de ansiedad matemática a través de modelos conceptuales diferenciados aplicados al rendimiento en problemas matemáticos: mediación para ansiedad matemática-estado y moderación para ansiedad matemática-rasgo. Adicionalmente, se incluyó el género por su relevancia en la ansiedad matemática y el rendimiento en problemas matemáticos. La muestra consistió en 291 estudiantes chilenos (169 niñas; edad promedio de 10.54 años). Los resultados demostraron una relación directa entre ansiedad matemática y rendimiento en problemas matemáticos y replicaron diferencias de género a favor de los niños tanto en rendimiento en problemas matemáticos como en ansiedad matemática-estado. La memoria de trabajo medió la relación entre ansiedad matemática-estado de manera consistente en ambos géneros. Además, la memoria de trabajo-verbal moderó significativamente la relación entre ansiedad matemática-rasgo y rendimiento en problemas matemáticos con interacción adicional por género. Este mecanismo de moderación fue exclusivo de las niñas, lo que sugiere que una memoria de trabajo-verbal robusta puede amortiguar el efecto negativo de la ansiedad matemática-rasgo en el rendimiento en problemas matemáticos. Estos hallazgos resaltan la importancia de distinguir las dimensiones de la ansiedad matemática y señalan a la memoria de trabajo-verbal como un objetivo clave para intervenciones que busquen mejorar el rendimiento en problemas matemáticos y reducir las brechas de género relacionadas con ansiedad matemática y rendimiento en problemas matemáticos.

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Mathematical competence is essential for academic success, employability, and quality of life (Gilmore, 2023). Consequently, research on cognitive and emotional factors influencing math skills has become central (Passolunghi et al., 2019). Math Problem Solving (MPS) is a complex process that differs from standard arithmetic because it requires building an accurate mental representation from a verbal description before selecting a strategy (Cartwright et al., 2022). This study focuses on Compare Problems, the most challenging semantic structure for elementary students (Schumacher & Fuchs, 2012). Their relational language (e.g., "more than") requires cognitive control to suppress the keyword-to-operation bias, the tendency to map relational terms directly onto arithmetic operations regardless of context (Verschaffel, 1994). Solving these tasks requires sufficient executive control to maintain quantities in mind while processing relational differences. Thus, the compare-type MPS serves as a robust variable for analyzing the interplay between affective and cognitive factors.

Performance in MPS is influenced by affective factors, particularly Math Anxiety (MA), defined as tension, apprehension, or fear during math tasks (Mammarella et al., 2023). PISA 2022 data indicate that a one-point increase in MA corresponds to an 18-point decrease in math achievement (Organisation for Economic Co-operation and Development [OECD], 2023). The MA-math performance link is explained by two models: the Debilitating Anxiety Model (DAM, Tobias, 1986), which suggests that MA impairs performance by interfering with cognitive processes, and the Deficit Model (DM, Maloney et al., 2010), which posits that weaknesses in numerical abilities cause anxiety. Both models have empirical support coexisting in the literature (Ashcraft & Krause, 2007; Cuder et al., 2023; Finell et al., 2022).

The state-trait discrepancy

Anxiety is conceptualized along state and trait dimensions (Lazarus, 2001). State-MA is a temporary, situation-specific reaction, while trait-MA is a stable personality trait (Mammarella et al., 2023; Pelegrina et al., 2024). These dimensions relate differently to mathematical outcomes, a phenomenon known as the state-trait discrepancy (Bieg et al., 2015; Roos et al., 2015). Studies show that state-MA, by reducing cognitive resources in real time, often exerts a stronger immediate impact on mathematical achievement (Daker et al., 2022; Orbach et al., 2020). This aligns with findings that the correlation between state-MA and performance remains significant even when controlling for trait-MA (Cohen et al., 2021). While some studies find no link between trait-MA and math skills (Orbach et al., 2019a, 2019b), others show that trait-MA can predict math success beyond the effects of state-MA (Pelegrina et al., 2024).

Trait-MA is more strongly associated with avoidance behaviors and long-term mathematical difficulties (Wang et al., 2020). Unlike a temporary state, trait-MA's stable nature allows for the development of management or compensatory strategies over time (Demedts et al., 2022). Thus, although related, both MA dimensions operate through distinct pathways that may be sensitive to context and individual characteristics.

Executive functions and math problem solving

The interference with cognitive resources described in the state-trait discrepancy suggests involvement of Executive Functions (EFs), mental processes crucial for goal-directed tasks (Diamond, 2013). Core EFs components include inhibition (suppressing irrelevant information), shifting (changing attention or adopting new perspectives), and working memory (WM; holding and manipulating information) (Diamond, 2013; Miyake et al., 2000). WM comprises distinct components, including verbal and visuospatial subsystems, which serve different information modalities and may be differentially engaged depending on task demands (Baddeley, 2012). Meta-analyses show a moderate association (r = .36 – .37) between EFs and math skills (Cortés Pascual et al., 2019; Spiegel et al., 2021). This relationship likely occurs because specific EFs components aid different mathematical domains; WM, for instance, is more strongly linked to MPS (r = .35) than to other domains (Peng et al., 2016). Theoretically, the constrained and unconstrained skills model suggests that while automated numerical skills (constrained) require fewer resources, unconstrained skills like MPS demand greater cognitive control due to their inherent complexity (De Smedt, 2022; Spiegel et al., 2021). Compare-type MPS tasks, therefore, provide a sensitive context for examining EFs' deployment under MA.

Connecting MA, EFs, and MPS: the research gap

The combined effects of MA and EFs on math performance have become a key focus (Cohen et al., 2021; Orbach et al., 2019b, 2020). Previous research has explored this relationship using different conditional models; however, most studies have focused on general math achievement or basic arithmetic, often using composite scores that blend procedural fluency with reasoning. Some studies report that EFs, particularly WM, mediate the MA-mathematical achievement link (Finell et al., 2022; Justicia-Galiano et al., 2017; Pelegrina et al., 2024), suggesting that anxiety impairs performance by consuming cognitive resources. Others find moderation effects, with inhibition and shifting buffering or amplifying this relationship (Cuder et al., 2023; Orbach et al., 2020). However, these interactions remain notably unexplored within MPS, and it remains unclear whether these mediation and moderation models hold for complex problem-solving tasks.

Furthermore, a critical gap remains. To our knowledge, only two studies have analyzed the interaction between MA, EFs, and math achievement while distinguishing state and trait-MA (Orbach et al., 2020; Pelegrina et al., 2024). Crucially, these studies applied similar models to both MA dimensions despite their conceptual differences. Theoretically, state-MA, as a transient response in specific situations (Cohen et al., 2021; Orbach et al., 2019a, 2020), may act as a situational distractor that compromises executive resources in real time, consistent with mediation. In contrast, trait-MA is a stable disposition that individuals may learn to manage or compensate for over time (Demedts et al., 2022; Sorvo et al., 2017), suggesting it interacts with EFs

through moderation, where EFs components potentially act as buffers. Exploring these different pathways could help clarify why some studies report that high WM increases vulnerability to anxiety (Ramirez et al., 2013), while others suggest it provides protection (Soltanlou et al., 2019), as these discrepancies often emerge from trait-like measures that do not account for the immediate interference of state-MA.

An additional layer of complexity arises from gender differences, for which evidence remains inconsistent. While self-report studies often find higher MA scores in females (Hart & Ganley, 2019), research differentiating MA dimensions shows that females generally report higher trait-MA (Bieg et al., 2015; Orbach et al., 2020). In Chile, where this study's sample was drawn, research also identifies higher state-MA in girls (Fernández-Blanco et al., 2024). Regarding math performance, while large-scale meta-analyses find no significant gender gap (Lindberg et al., 2010), Chilean data show a persistent gap favoring boys that widens with age (OECD, 2023; Perez Mejias et al., 2021). These localized disparities suggest that the interaction between MA and EFs in explaining MPS may be sensitive to gender, yet this factor has not been integrated into models that distinguish between state and trait-MA. This leaves a need to investigate whether state- and trait-MA relate to EFs through different mechanisms while accounting for gender as a potential moderator.

The present study

This study aims to provide evidence on how state- and trait-MA, modeled separately according to their conceptual distinctions, relate to EFs (WM, inhibition, and shifting) and MPS, while also considering gender effects. It was hypothesized that state-MA will affect MPS through a mediation mechanism involving EFs, reflecting its resource-depleting nature in real time (Cohen et al., 2021; Orbach et al., 2019a, 2020). Trait-MA was expected to interact with EFs as a moderator, consistent with its stable nature (Demedts et al., 2022; Orbach et al., 2019b). Regarding the role of gender, it was further hypothesized that this variable will moderate the interactions between the two dimensions of MA and EFs. Addressing these relationships concurrently within compare-type MPS allows for a more nuanced understanding of how affective and cognitive factors interact to determine mathematical success.

Method

Participants

A non-probabilistic convenience sample of 291 students from six urban primary schools with high social vulnerability (School Vulnerability Index [IVE] > 70%) in Talca, Chile, participated in the study. Mean age was 10.54 years (SD = 0.54); 169 were girls (58.08%) and 122 boys (41.92%). A total of 154 students were in 4th grade (52.92%) and 137 in 5th grade (47.08%). Participation was voluntary with parental consent and individual assent. Children with a diagnosed cognitive impairment that prevents independent completion (n = 5) were excluded from the final data analysis.

Procedure

Data was collected from March to August 2024, in three sessions during school hours. Researchers recruited participants through visits to participating schools, obtaining parental consent and student assent. In Session 1, students completed the trait-MA questionnaire in a group setting (approximately 20 minutes). Session 2 involved state-MA administration before and after the MPS task (averaging 5 minutes for each questionnaire and 45 minutes for the task). In Session 3, students completed EFs tasks individually (approximately 25 minutes) with task order counterbalanced (independent t-tests confirmed no significant order effects, all $p > .05$). The study was approved by the Scientific Ethics Committee of the University of Talca (Folio 10-2023, date: 5/07/2023).

Instruments

Gender: Participant gender was retrieved from school administrative records, compiled from information provided by families, and coded as a binary variable (0 = *Boys*; 1 = *Girls*).

Math anxiety: The Chilean validated version of the *State-Math Anxiety Questionnaire* (state-MAQ) (Fernández-Blanco et al., 2024; Orbach et al., 2020) was used to measure state-MA. This 12-item self-report instrument includes six items administered pre- and post-math task, rated on a 4-point Likert scale (0 = *Not at all* to 3 = *Very much*; e.g., "I am worried about whether I will be able to solve the tasks correctly"). Total scores were calculated by summing scores from both completed questionnaires, as recommended, to obtain a comprehensive measure of state-MA (Orbach et al., 2019b, 2020), yielding a total range of 0 to 36. The Chilean validated version of the trait-Math Anxiety Questionnaire (trait-MAQ) (Fernández-Blanco et al., 2024; Orbach et al., 2019a), which included 14 items rated on a 5-point Likert scale (0 = *Never* to 4 = *Always*; e.g., "I get very nervous when I have to do math homework"), was used to assess trait-MA. Total scores range from 0 to 56, with higher scores indicating higher anxiety levels. Reliability was acceptable for both ($\omega \geq .8$).

Executive functions: EFs were assessed using standardized digital tasks: Backward Corsi Block-Tapping Task (Corsi, 1972) for visuospatial-WM, Auditory Memory subtest of the Woodcock-Muñoz III Battery (Muñoz-Sandoval et al., 2005) for verbal-WM, and Hearts & Flowers task (Diamond et al., 2007) for inhibition and shifting. For inhibition and shifting, performance was indexed using the Inverse Efficiency Score (IES), where higher values indicate lower efficiency. Reliability for EFs tasks was adequate ($\alpha \geq .75$). Detailed descriptions of the stimuli, trial structures, and scoring procedures are provided in Appendix A.

Math Problem Solving: MPS was evaluated using a custom MPS comparison task, aligned with the Chilean curriculum and adapted from previous research (Lubin, 2013; Schumacher & Fuchs, 2012). The task was administered using a paper-and-

pencil booklet. Participants were instructed to read each problem carefully and provide the answer; no time limit was imposed to reduce the influence of test-taking speed. The task consisted of eight single-step verbal problems, with two problems for each basic arithmetic operation (addition, subtraction, multiplication, and division). To account for academic progression, tasks were grade-leveled (4^{th}-5^{th}) by adjusting numerical range and vocabulary while preserving problem structure. Each problem followed a three-sentence structure: a statement of the first variable, a description of the relationship with the second variable, and the final question (e.g., "Florencia baked 327 cheese empanadas. Natalia baked 110 more cheese empanadas than Florencia. How many cheese empanadas did Natalia bake?"). Performance was computed as overall accuracy, representing the proportion of correctly solved problems (ranging from 0 to 1). In the current sample, the task showed acceptable internal consistency (ω = .76).

Data analysis

Data was processed using SPSS v.25 (IBM Corp., 2017), complemented by the PROCESS macro v4.3 (Hayes, 2022), and the *pwr* package (Champley, 2020) in R version 4.3.2 (R Core Team, 2023). Regarding sample size adequacy, sensitivity analysis (α = .05, power = .8) indicated detectable effects of $r = .16$ and $d = .33$. For complex associations estimated via conditional process analysis, Fritz and MacKinnon (2007) indicate that for bias-corrected bootstrapping, a sample size of $N = 148$ is sufficient to detect medium-sized effects with .8 power. The sample size exceeds this threshold, providing sufficient power for the hypothesized models.

Descriptive statistics were computed, and independent two-tailed *t*-tests were used to assess gender differences. Cohen's *d* was calculated for significant comparisons, using conventional benchmarks (small = 0.2, medium = 0.5, large = 0.8; Cohen,1988). Bonferroni correction was used to control Type I error in multiple comparisons.

Continuous variables were centered before moderation and moderated mediation analyses. A simple mediation model (Model 4) was used to assess the indirect role of EFs in the state-MA-MPS relationship. For the trait-MA-MPS relationship, a simple moderation model (Model 1) was used to test whether EFs components acted as moderators. For significant models, gender was included as an additional moderator (Model 2 for dual moderation and Model 59 for moderated mediation). Indirect effects and the index of moderated mediation were evaluated with 95% confidence intervals (CIs) using bootstrapping with 5,000 samples. Effects were significant if CIs did not contain zero. The conceptual structure follows standard PROCESS templates (Hayes, 2022).

Results

Descriptive statistics and bivariate correlations

Descriptive statistics and bivariate correlations are presented in Table 1. All variables approximated normal distributions, except switching, which was log10-transformed for analyses to meet assumptions (Bryne, 2010). Hearts & Flowers metrics differ because inhibition is reported in raw form, whereas switching uses transformed values.

Gender was significantly correlated with almost all study variables. The strongest associations involved MPS and state-MA, with males showing higher MPS scores and females reporting higher state-anxiety. Both state- and trait-MA were negatively associated with MPS. All EFs showed the expected relationship with MPS. Positive correlations were observed with WM measures. Negative correlations were observed for inhibition and shifting, as higher IES values indicate lower efficiency. Finally, state-MA was negatively associated with WM, and trait-MA with inhibition.

Gender-based comparisons

Gender differences are presented in Table 2. Bonferroni-corrected *t*-tests revealed that only state-MA and MPS remained significant. Girls reported higher state-MA than boys ($d = .45$), whereas boys outperformed girls in MPS ($d = .83$). No significant gender differences emerged for trait-MA or EFs.

Table 1

Descriptive statistics and bivariate correlations

Variables	Mean (SD)	Correlations						
		2.	3.	4.	5.	6.	7.	8.
1. Gender	-	.22**	.11*	-.15**	-.13*	.09	.13*	-.38**
2. state-MA	14.77 (9.7)		.28**	-.16*	-.16**	-.02	-.02	-.34**
3. trait-MA	32.46 (8.13)			-.11	.03	-.12*	-.11	-.18**
4.Visuospatial-WM	3.43 (3.68)				.29**	-.15**	-.18**	.36**
5. Verbal-WM	17.22 (4.8)					-.25**	-.26**	.4**
6. Inhibition	1082.84 (177.4)						.65**	-.17**
7. Shifting	3.14 (0.09)							-.2**
8. MPS	0.55 (0.25)							

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

Table 2

Gender differences in the study variables

Variables	Gender	Mean	*SD*	t	*p*-values	Cohen's *d*
state-MA	F	16.56	9.71	-3.78	*< .01*	*0.45*
	M	12.3	9.17			
trait-MA	F	33.24	8.51	-1.92	.06	0.23
	M	31.39	7.47			
Visuospatial-WM	F	2.95	3.56	2.62	.01	0.31
	M	4.09	3.75			
Verbal-WM	F	16.68	4.35	2.29	.02	0.27
	M	17.98	5.28			
Inhibition	F	1096.76	172.47	-1.58	.12	0.19
	M	1063.55	182.98			
Shifting	F	3.15	0.09	-2.25	.02	0.27
	M	3.13	0.08			
MPS	F	0.47	0.24	6.96	*< .01*	*0.83*
	M	0.66	0.21			

Note. Bonferroni correction was applied to adjust for multiple *t*-test comparisons within the same sample. α was set at 0.0071.

Table 3

Mediation analysis of EFs components linking state-MA to MPS

Predictors	β	SE	t	β std.	CI 95%
			visuospatial-WM (M1)		
State-MA (X)	-.06	.02	-2.83	-0.16*	-0.11; -0.02
			R^2 = .03, F = 8.01*		
			verbal-WM (M2)		
State-MA (X)	-.08	.03	-2.66	-0.15*	-0.13; -0.02
			R^2 = .02, F = 7.09*		
			inhibition (M3)		
State-MA (X)	-.26	1.08	-0.24	-0.01	-2.38; 1.85
			R^2 < .001, F = 0.06		
			shifting (M4)		
State-MA (X)	<.01	<.01	0.29	0.02	< -0.01; 0.001
			R^2 < .001, F = 0.08		
			Math Problem Solving (Y)		
State-MA (X)	-.01	<.01	-5.11	-0.26*	< -0.01; < -0.01
Visuospatial-WM (M1)	.01	<.01	4.15	0.22*	< 0.01; 0.02
Verbal-WM (M2)	.01	<.01	5.06	0.27*	< 0.01; 0.02
Inhibition (M3)	.00	<.01	-0.47	-0.03	< -0.01; < 0.01
Shifting (M4)	-1.19	.19	-1.01	-0.07	-0.56; 0.18
			R^2 = .29, F = 23.78*		

* p < .01.

Conditional models of indirect associations

Model selection followed the theoretical distinction between MA dimensions. State-MA is examined through a mediation model to capture its role as a task-related process that may tax specific EFs during problem-solving. In contrast, trait-MA is examined through moderation models to explore how this stable predisposition interacts with EFs.

Mediation of executive function components linking state Math anxiety to mathematical problem-solving performance

Mediation analysis, summarized in Table 3 and Figure 1, confirmed that state-MA had a significant negative direct effect on MPS. State-MA also had a significant negative impact on visuospatial WM and verbal-WM, but no significant effect was observed on inhibition or shifting, excluding them as mediators.

The effects of state-MA on MPS were partially mediated by visuospatial- and verbal-WM. The total indirect effect through both mediators represented 23% of the total state-MA effect (Table 4).

A moderated mediation model revealed that these indirect effects did not differ by gender, indicating that the mediating role of WM is consistent for both boys and girls. The indices of moderated mediation were non-significant for both verbal-WM (Index = 0.0007, 95% CI[-0.0010, 0.0026]) and visuospatial-WM (Index= -0.0003, 95% CI[-0.0016, 0.0011]).

Table 4

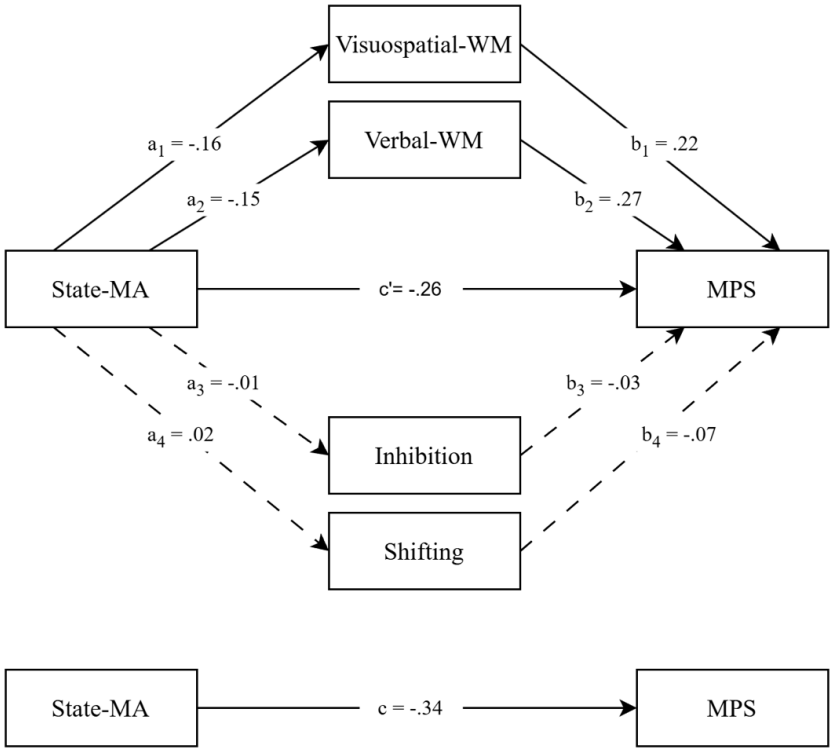
Analysis of the mediating effect of EFs components between state-MA and MPS

EF Component Mediator	Total Effect (std.)	Direct Effect (std.)	Indirect Effect (std.)	Ratio of indirect to total effect
visuospatial-WM	c = -0.34	c' = -0.26	a_1*b_1 = -0.036	0.11
verbal-WM			a_2*b_2 = -0.042	0.12
Total			$\sum_{i=1}^{4} a_i b_i$ = -0.079	-0.23

Note. Only significant mediators' indirect effects and the total indirect effect are shown. Non-significant mediators are omitted.

Figure 1

Full mediation model of EFs components between state-MA and MPS



Note. Solid lines represent significant paths (a, b, and c'), while dashed lines indicate non-significant paths. The direct effect (c) is shown separately below.

Table 5

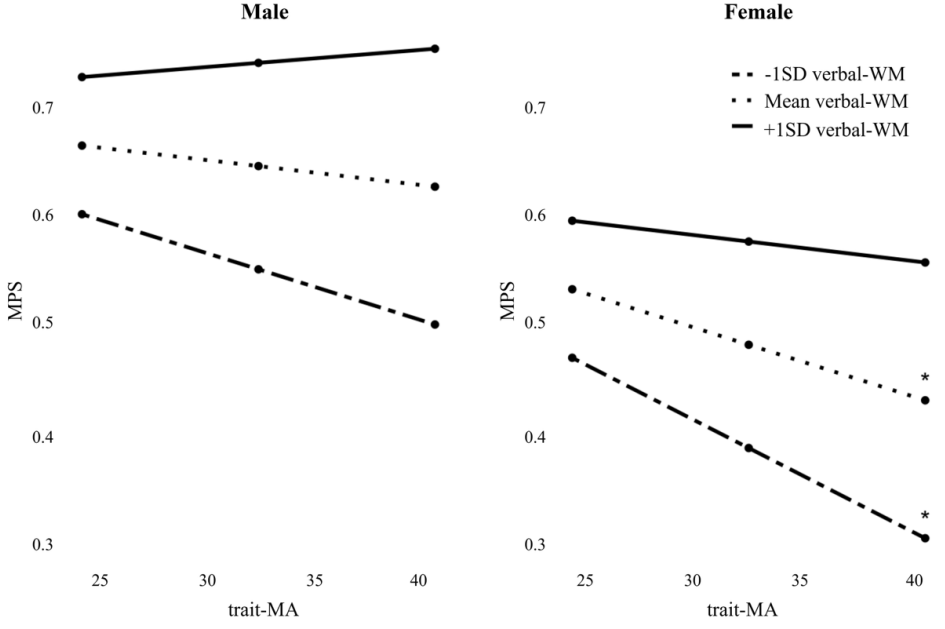
Moderation of EFs components between trait-MA and MPS

Model	Predictors	β	SE	t	β std.	CI 95%
		Math Problem Solving (Y)				
1	trait-MA (X)	-.005	.002	-2.671	-0.146*	-0.0079; -0.0012
	visuospatial-WM (W1)	.023	.004	6.238	0.343**	0.016; 0.0312
	X*W1	.001	.001	0.852	0.048	-0.0005; 0.0013
		R^2 = .15, F = 16.79**; ΔR^2 = 0.002, F = 0.73				
2	trait-MA (X)	-.006	.002	-3.673	-0.192**	-0.0091; -0.0028
	verbal-WM (W2)	.022	.003	7.917	0.417**	0.0163; 0.0271
	X*W2	.001	<.001	2.396	0.125*	0.0001; 0.0015
		R^2 = .21, F = 26.07**; ΔR^2 = 0.016, F = 5.74*				
3	trait-MA (X)	-.006	.002	-3.613	-0.208**	-0.0099; 0.0029
	inhibition (W3)	<.001	<.001	-3.524	-0.213**	-0.0004; -0.0001
	X*W3	<.001	<.001	0.752	0	0.0000; 0.0000
		R^2 = 0.07, F = 7.56**; ΔR^2 = 0.002, F = 0.57				
4	trait-MA (X)	-.007	.002	-3.72	-0.215**	-0.0101; -0.0031
	shifting (W4)	-.66	.164	-4.02	-0.237**	-0.983; -0.3364
	X*W4	-.02	.022	-0.908	-0.058	-0.063; 0.0232
		R^2 = .08, F = 8.85**; ΔR^2 = 0.003, F = 0.82				

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

Figure 2

Gender-specific moderation of the trait-MA–MPS relationship by verbal-WM



Note. Asterisks indicate verbal-WM levels at which higher trait-MA significantly impairs MPS.

Moderation of executive function components in the relationship between trait Math anxiety and mathematical problem-solving performance

Simple moderation models tested whether each EFs component moderated the relationship between trait-MA and MPS. Results are presented in Table 5.

Trait-MA exhibited a significant negative direct effect on MPS across models. While visuospatial-WM, inhibition, and shifting did not moderate the trait-MA- MPS link, verbal-WM did. A multiple regression including all centered EFs components confirmed that only the trait-MA and verbal-WM interaction remained significant ($\beta = .11$, $p = .04$). Conditional effects of trait-MA on MPS were examined at low (−1SD), average (mean), and high (+1SD) verbal-WM levels. Results indicated that the negative association between trait-MA and MPS was strongest at low ($\beta = -.33$, $p < .001$), remained significant at average ($\beta = -.19$, $p < .001$), and was not significant at high levels of verbal-WM ($\beta = -.06$, $p = .41$).

A subsequent model tested the joint moderation of verbal-WM and gender. Results showed that the interaction between trait-MA and verbal-WM remained significant ($\beta = .16$, $p = .02$), while the trait-MA and gender interaction was non-significant ($\beta = -.04$, $p = .23$). Including both moderators significantly increase explained variance ($\Delta R^2 = .22$, $F = 4.506$, $p = .01$). As illustrated in Figure 2, conditional effects were examined for both genders, revealing a significant negative association between trait-MA and MPS only in females with low ($\beta = -.33$, $p < .001$) or average verbal-WM ($\beta = -.2$, $p = .001$). These findings suggest that higher verbal-WM buffers the detrimental effect of trait-MA on MPS, specifically in girls.

Discussion

This study examined how state- and trait-MA differentially relate to MPS through distinct mechanisms involving EFs. Consistent with the state-trait anxiety model (Roos et al., 2015), the results provide empirical support for this distinction. The moderate correlation observed between both constructs ($r = .31$) aligns with previous literature (Orbach et al., 2020) and, together with the lack of significant correlations between trait-MA and most EFs, reinforces the state-trait discrepancy (Robinson & Clore, 2002). While trait-MA reflects generalized beliefs, state-MA captures the immediate emotional reaction that directly taxes cognitive resources. This divergence justifies the different executive pathways observed in the mediation and moderation models.

Regarding the initial hypothesis that situational anxiety is resource-depleting, the results confirmed that the adverse effect of state-MA on MPS was mediated by WM. Contrary to expectations, this mediation mechanism remained stable across the sample, with gender not moderating the indirect paths. This lack of moderation helps clarify the role of gender in the state-MA-WM link, an area where recent meta-analyses found insufficient data for a definitive conclusion (Finell et al., 2022), suggesting that situational state-MA depletes cognitive resources similarly in boys and girls.

The mediating role of WM in the state-MA-MPS link aligns with the DAM, which posits that anxiety impairs performance by interfering with cognitive resources (Ashcraft & Kirk, 2001). State-MA negatively impacted verbal- and visuospatial-WM, suggesting it disrupts performance by consuming cognitive resources required for problem-solving. These results support previous studies that have established a mediating role for WM in the MA-math performance relationship (Finell et al., 2022; Ganley & Vasilyeva, 2014; Owens et al., 2008; Pelegrina et al., 2024). Although modest, the magnitude of these indirect effects contrasts to meta-analytic findings (Caviola et al., 2022), which considered them negligible. However, as Caviola et al. (2022) suggest, this discrepancy may stem from the assessment type; while meta-analyses often rely on generalized self-reports, the state-MA measure used, in immediate proximity to the task, likely captures situational interference more effectively, providing a more specific assessment of the DAM mechanisms.

The mediating effect observed for verbal- and visuospatial-WM contributes to the limited research differentiating these WM modalities in the MA-math performance relationship (Owens et al., 2008; Živković et al., 2022). Furthermore, the absence of mediation by inhibition and shifting suggests that, at this developmental stage, WM acts as the primary executive resource. This is consistent with evidence suggesting that WM often absorbs the influence of other executive components when evaluated simultaneously in mathematical tasks (Cragg et al., 2017; Miyake & Friedman, 2012).

The hypothesized moderating role of EFs in the trait-MA-MPS link was partially confirmed. The negative association between trait-MA and MPS was moderated only by verbal-WM, with the adverse effect strongest for participants with low verbal-WM and non-significant for those with high verbal-WM. This finding contributes to the debate on whether WM capacity acts as a source of vulnerability or protection (Caviola et al., 2022). While the choking-under-pressure explanation suggests that high-WM individuals are more vulnerable due to their reliance on WM-intensive strategies (Ramirez et al., 2013), the present results support a buffering account, in which higher verbal-WM capacity serves as a protective factor against the detrimental effects of trait-MA (Owens et al., 2014; Soltanlou et al., 2019). Given the verbal nature of the MPS task, verbal-WM may regulate intrusive thoughts, such as negative self-talk, thereby supporting performance (Cartwright et al., 2022). The present results indicate that, in highly demanding MPS tasks, children with lower verbal-WM may lack the cognitive margin needed to manage the intrusive thoughts while solving problems, thereby becoming more susceptible to the detrimental effects of trait-MA. Crucially, this buffering mechanism provides a plausible cognitive explanation for why approximately 77% of students with high MA maintain typical or high math achievement (Devine et al., 2018). These findings suggest that math success in anxious children may depend less on eliminating anxiety than on the availability of verbal-WM resources to mitigate its interference.

Although moderation by verbal-WM emerged in the general model, this protective effect was specific to girls, con-

firming the hypothesized moderating role of gender for the trait-anxiety dimension. This suggests a more complex interplay for girls, for whom verbal-WM efficiency becomes critical in buffering the impact of stable anxious predispositions. In the Chilean educational context, characterized by persistent gender gaps (OECD, 2023; SIMCE, 2023), these results suggest that disparities may stem from the differential way in which girls must utilize cognitive resources to manage affective interference. Notably, while gender differences appeared in affective and math performance variables, they were absent in EFs, suggesting that differences likely stem from contextual or affective factors rather than inherent cognitive differences. In this light, verbal-WM capacity operates as a compensatory mechanism specifically for girls, allowing them to mitigate the interference of trait-MA to maintain mathematical performance.

Limitations and future directions

This study has some limitations to consider. First, the cross-sectional design limits causality inference (Maxwell & Cole, 2007), a common issue in mediation analyses. However, our choice of mediation model is based on theoretical and empirical evidence aligned with the DAM (Ashcraft & Krause, 2007; Finell et al., 2022). To address causality concerns, a reverse model from MPS to state-MA was tested and was non-significant, providing preliminary support for the proposed pathway. Future longitudinal research is needed to provide more robust evidence of these causal links. Second, although a validated real-time self-report for state-MA was utilized, future studies should combine subjective and physiological indicators (e.g., heart rate, skin conductance) to better capture autonomic arousal during math tasks. Third, general anxiety or reading comprehension were not controlled for, which have been previously suggested to interact with MA and EFs to influence math success (Cartwright et al., 2022; Daker et al., 2022). Finally, the scope is limited by using a single math problem type and a restricted age range, limiting generalizability across mathematical domains and developmental stages. Future research should include broader mathematical domains (e.g., geometry, mental calculation) and wider age groups to examine the development of these executive-affective interactions across different stages of mathematical learning.

Practical implications

The findings may have practical implications for mathematical education. Results highlight the importance of a differentiated approach to MA, as state- and trait-MA may require distinct interventions. Because state-MA acts as a situational distractor that consumes WM resources (mediation), educators could focus on reducing immediate emotional tension before tasks to prevent this cognitive blocking. Regarding trait-MA, the moderating role of verbal-WM, particularly in girls, suggests that managing verbal cognitive load could be critical. Simplifying linguistic instructions or segmenting complex word problems may help students preserve cognitive resources and mitigate the negative effects of trait-MA. This may facilitate the use of available WM resources for mathematical thinking rather than for anxiety-related interference. In this sense, by providing targeted cognitive support that specifically protects the performance of highly anxious girls, such interventions represent a grounded and practical strategy to help address the persistent gender gap in mathematical performance reported in Chile and Latin American countries.

Conclusions

This study provides empirical support for a theoretically grounded distinction between state and trait-MA, showing differential associations with MPS via WM. Findings offer a possible framework for better understanding the diverse patterns reported in the literature regarding the interaction between MA and executive resources. State-MA was partially mediated by WM regardless of gender, whereas the negative effect of trait-MA on MPS was moderated by verbal-WM and was significant only among girls. These findings highlight verbal-WM as a key protective factor, particularly for girls with trait-MA. Boys outperformed girls exclusively in math-related variables: state-MA and MPS, replicating gender differences among Chilean students. Ultimately, this study contributes to the field by underscoring the importance of adopting differentiated analytical approaches grounded in the theoretical nature of MA dimensions and the need for precision in conceptualizing and addressing MA in research and education.

Author contributions

Conceptualization: A.F.B., C.R.B.
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Data curation: A.F.B.
Formal analysis: A.F.B., C.R.B., V.S.
Supervision: C.R.B., V.S.
Investigation: A.F.B.
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Writing – Review & editing: A.F.B., C.R.B., M.D., V.S.

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Declaration of interests

The authors declare that there is no conflict of interest.

Data availability statement

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

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Appendix A
Detailed description of executive function tasks

All tasks were administered digitally. Before each task, standardized instructions and a practice block with immediate feedback were provided to ensure rule comprehension.

Visuospatial working memory: Corsi block-tapping task

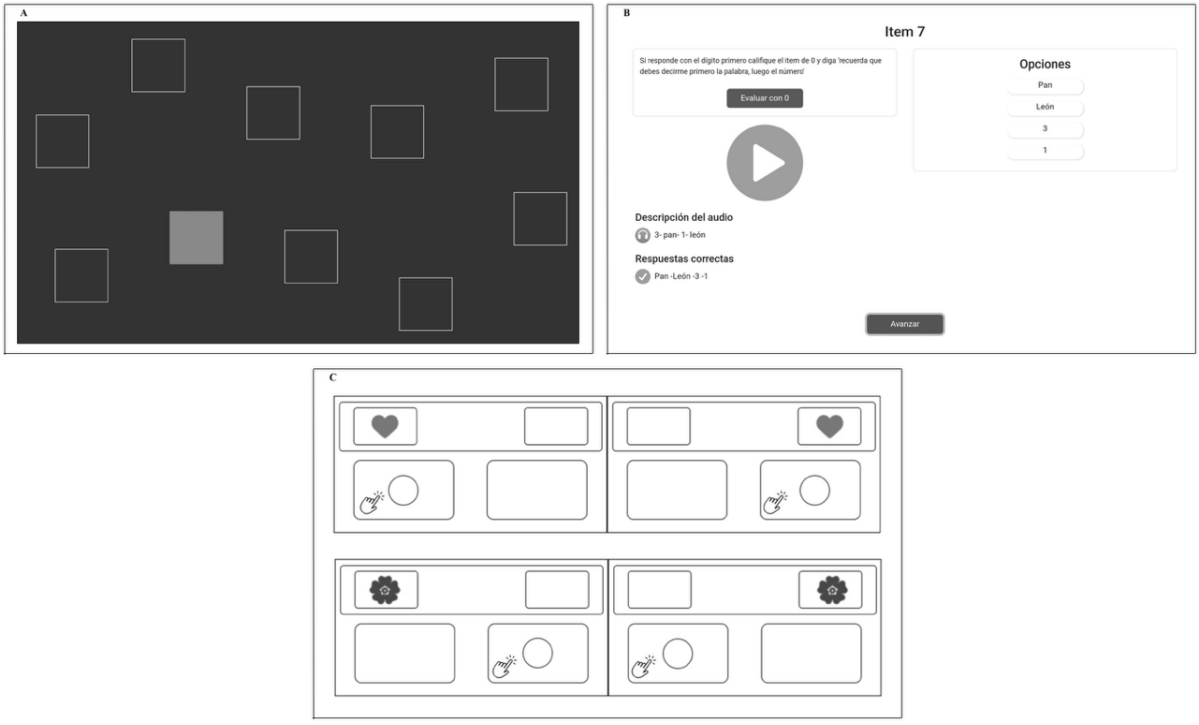
Visuospatial working memory was assessed using the backward condition of the Corsi Block-Tapping Task (Corsi, 1972) (Figure A1, Panel A). Participants were required to reproduce spatial sequences of blocks displayed on a screen in reverse order. The task began with sequences of two blocks and increased in length up to nine blocks. One point was awarded for each correctly reproduced sequence. The procedure followed a standard discontinuation criterion, where the task ended after two consecutive failures at the same span length. The final score was the total number of correct sequences completed before the task was discontinued (after two consecutive failures at the same span length).

Verbal working memory: auditory memory subtest

Verbal working memory was assessed with the Auditory Memory subtest of the Woodcock-Muñoz III Battery (Muñoz-Sandoval et al., 2005) (Figure A1, Panel B). Participants listened to sequences of words and digits and were instructed to recall the words first, and then the digits, both in the correct order. Each trial was scored from 0 to 2 (2 points if both components were correct; 1 point if only one was correct; 0 points if neither was correct or if the order was incorrect). The task was discontinued after two consecutive trials with a score of 0. The final score was the sum of points across all trials until the stopping criterion was met.

Figure A1

EFs Task Stimuli Examples



Note. All tasks are depicted in grayscale, whereas the actual tasks involve colors. Panel A. the Corsi Block-Tapping Task. Panel B. Auditory Memory Subtest. Panel C. H&F.

Inhibition and shifting: hearts and flowers task

Both inhibition and shifting were assessed using the Hearts & Flowers (H&F) task (Diamond et al., 2007) (Figure A1, Panel C). The task consists of three blocks: (1) a congruent block (hearts), where participants press a button on the same side as the stimulus; (2) an incongruent block (flowers), where they must press the button on the opposite side of the stimulus (e.g., if a flower appears on the right, the participant must press the left button); and (3) a mixed block, which requires alternating between heart and flower rules. Performance on the incongruent block (12 items) was used to index Inhibition, while performance on the mixed block (33 items) was used to index Shifting. A standardized maximum response window was applied to each trial; if no response was given, the item was marked as incorrect. For both components, performance was calculated using an inverse efficiency score (IES), which is the average reaction time for correct responses divided by the accuracy rate (IES = RT / Accuracy). According to this calculation, higher IES values indicate lower executive performance efficiency (i.e., slower responses and/or higher error rates).