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Arithmetic and reading skills mediate the link between math and reading anxiety and word problem solving

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Children's ability to solve arithmetic word problems (AWP), which require integrating mathematical and linguistic information, has been associated with academic achievement and future life outcomes. AWPs demand numerical cognition, literacy skills, and emotional factors such as math anxiety (MA) and reading anxiety (RA) may further be related to performance by disrupting these foundational abilities. This study examined the pathways through which MA and RA are associated with AWP performance among 717 third-grade students, using a structural equation modeling (SEM) approach. MA showed negative associations with AWP performance, both directly and indirectly via reduced arithmetic fact fluency. In contrast, RA was not directly associated with AWP performance but showed significant indirect association via reading fluency, reading comprehension, and a serial path from reading fluency to comprehension. These findings highlight the differential pathways through which MA and RA relate to AWP solving, with arithmetic and reading-related skills serving as key mediators. Notably, while MA showed both direct and indirect associations, RA was related to performance exclusively through indirect reading-related skill pathways. Results underscore the multi-componential nature of AWP solving mechanisms and support a holistic view that considers numeric, linguistic, and emotional factors concurrently.

Keywords Arithmetic word problems, Math anxiety, Reading anxiety, Arithmetic fact fluency, Reading fluency, Reading comprehension

Arithmetic word problems (AWP) have been extensively studied due to their critical role in academic achievement[1,2] and future success[3,4]. Solving these problems requires a combination of cognitive, numerical, and linguistic skills[5,6] and is associated with emotional factors, such as stress and anxiety[7–11,13]. Despite extensive research on the factors associated with AWP performance, a gap remains regarding the specific associations between reading anxiety (RA) and math anxiety (MA) and performance. This gap is particularly evident when examining the mediating roles of reading fluency, reading comprehension, and arithmetic fluency, essential cognitive skills that are associated with AWP performance[1,12,13].

The present study aims to address this gap by proposing a unified multi-pathway model that explores the interplay between emotional and cognitive factors in AWP performance among middle elementary school children. Specifically, it explores whether reading fluency and reading comprehension mediate the associations between RA and performance, while arithmetic fluency mediates the association between MA and performance. This study provides a novel multi-pathway approach by evaluating cognitive and affective pathways within a unified model, offering deeper theoretical insights into the mechanisms through which different types of anxiety are related to AWP solving holistically.

Understanding these mechanisms can illuminate important contextual factors for learners across domains, helping to reduce barriers to learning and identify potential mechanisms of weakness. Studies highlight the need for multicomponent models to capture complex cognitive mechanisms underlying behavior[15,16]. By integrating multiple factors, this study offers a more comprehensive understanding of human behavior and performance in AWP solving.

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The importance of arithmetic word problems in developing mathematical skills

Arithmetic word problems are verbal descriptions of problem situations that require mathematical operations on given numerical data to find a solution. They play an important role in connecting mathematics with daily life[12,17]. AWP are associated with the application of mathematical concepts and skills, enhancement of problem-solving abilities, use of mathematics to understand the world, and increased motivation for mathematical learning[1,17,18]. Beyond academic settings, children's AWP competence has been shown to be associated with future employment opportunities and wages[3,19]. Moreover, problem-solving ranks among the top four most in-demand 21st-century skills essential for workplace success[4].

Thus, AWP may help students apply mathematical concepts in everyday life while supporting more advanced mathematics learning[20]. As a result, AWP are a central focus in key educational frameworks[21–24]. Yet, these problems are also the challenging components of primary school mathematics[2], with success rates often up to 30% lower than numerically formatted problems[25]. Data from the National Center for Education Statistics[26] reveals that only 41% of fourth graders achieve proficiency in AWP, while 19% perform at a basic level, underscoring widespread challenges with word problems. Teachers identify word problems as the most critical and challenging of 15 mathematical skills[27].

Research shows that AWP can present a significant challenge for students due to their complexity, as they require integrating mathematical reasoning with contextual narratives to generate accurate solutions, unlike simple arithmetic expressions[5,6,12]. Indeed, it had been shown that students consistently perform worse on AWP than on numerical arithmetic tasks[25,28], highlighting the increased complexity of translating linguistic information into mathematical notation.

The challenges in solving arithmetic word problems: numerical cognition

AWP requires numerical abilities that operate across multiple levels of numerical cognition[15] and are related to AWP performance through both domain-general and domain-specific cognitive processes[1]. Essential components of numerical cognition relevant to solving AWP include basic numerical skills such as processing magnitudes and arithmetic fluency[1].

Basic numerical abilities involve the foundational understanding of number symbols, their relationships, and their applications[15,29]. Core components of these abilities include symbolic and non-symbolic magnitude comparison[15,30,31]. Symbolic magnitude comparison, such as determining which digit is larger (e.g., comparing 6 and 3), has been consistently linked to mathematical achievement[30–34]. It is widely regarded as a measure of numerical fluency[29,30] and is related to arithmetic fluency[35,36], which itself is associated with AWP performance[1]. Meta-analytic findings emphasize the strong association between symbolic numerical magnitude processing and mathematical achievement, highlighting its utility as a screening tool for school-aged children[37]. Thus, comparing symbolic numerical information serves as a useful indicator of individual numerical skills[30,31].

Another key component of numerical cognition is arithmetic fluency[15,29], which refers to the ability to retrieve arithmetic facts (e.g., addition, subtraction, multiplication, division) quickly and accurately[15,38,39]. Automatic retrieval is thought to reduce cognitive load, allowing for more efficient engagement in higher-order thinking[40,41]. Accordingly, it is considered a cornerstone of advanced mathematical competencies, and has been linked to broader mathematical achievement[42] and, particularly, AWP-solving proficiency in elementary school[1,35,42,43]. Furthermore, arithmetic fluency may reflect an understanding of arithmetic operations and the ability to generalize operational rules, which in turn supports the creation of word-problem models[1].

The language-based challenges in solving arithmetic word problems

Mathematical tasks necessitating extensive language processing, such as solving AWP, are closely associated with linguistic competencies[1,44,57]. Successful AWP solving relies on a comprehensive understanding of linguistic elements, enabling students to accurately interpret the problem's linguistic structure and devise an effective solution strategy[45,46]. These linguistic elements include word decoding, reading fluency, vocabulary, syntax, text structure, and especially overall reading comprehension[11,12,14,28,45,47]. Reading comprehension involves both linguistic and cognitive processes that support word decoding and meaning extraction[48], which are essential for interpreting the textual elements of word problems[49].

AWP pose a particular linguistic challenge because, unlike standard numerical problems with fixed structures (e.g., $X \pm Y = Z$), AWP varies in wording, character order, and the representation of numerical values (e.g., "seven" vs. "7")[17,50], as well as in the requirement to retrieve specific numerical information from a linguistic story[38,42,56].

Thus, solving AWP involves not only numerical understanding but also the integration of linguistic and mathematical processing, making it a multi-faceted cognitive task[6,17,38,47].

Solving AWP entails several key operations that integrate linguistic and numerical skills[51], acting as foundational bridges between the mathematical and linguistic domains[52]. These linguistic and numerical skills facilitate the translation of text into mathematical procedures. First, mapping semantic evidence to mathematical models by extracting relevant information from problem statements and converting it into equations[53,54], as well as, understanding algebraic symbols and mathematical notation accurately[43,54,55]. These translation processes of converting natural language into mathematical equations, are supported by the ability to understand semantic structures and identify quantitative relationships[6,17,42,49,5257]. The use of realistic or everyday contexts in AWPs may further support students' understanding[58]. Beyond these translation processes, a major challenge lies in constructing a mental model of the problem situation[58]. This involves understanding the scenario described and mentally simulating it in a way that aligns with the mathematical operations needed for solution. Constructing such a model requires integrating linguistic interpretation with formal symbolic conversion[58].

Together, these operations illustrate the multi-componential nature of AWP solving. Students must coordinate multiple cognitive processes, linguistic and numerical, in order to effectively interpret, represent, and solve the problem[5,6,12,52,58,].

Anxiety and arithmetic word problems

When tackling mathematical problems, emotions, particularly negative ones[13] such as anxiety[7,59], may significantly shape the individual's problem-solving abilities[8,9]. Negative emotions have been shown to exert deleterious effects on performance[13], as they can impair focus, disrupt logical thinking, and lead to impulsive decisions[960,61,62]. Moreover, such emotions may interfere with the efficient use of strategies needed to accomplish a cognitive task[13]. Two specific forms of anxiety have been linked to poor performance in solving AWP: math anxiety[8,9,63] and reading anxiety[11,64].

MA is characterized by feelings of fear, tension, and apprehension in mathematical contexts[40]. According to the 2022 PISA report, approximately six out of ten students report worrying about their ability to succeed in mathematics classes[10,65]. Over time, MA can limit math-related career opportunities[66,67], as highly math-anxious individuals may develop impaired numerical skills due to prolonged avoidance of math-related tasks.

MA has been negatively associated with math achievement[7,63,69,70]. Some studies attribute this effect to increased avoidance of math-related activities[62,70], while others emphasize the potential interference of MA with working memory during mathematical processing[8,39,71]. However, other findings suggest that working memory and MA may each be independently associated with math performance, rather than MA operating through working memory[69]. In line with this, a recent meta-analysis by Namkung et al.[72] found no moderating effect of working memory on the relation between math anxiety and math performance. The authors noted that the limited number of studies addressing all three constructs, as well as the use of working memory tasks unrelated to math, may partly explain this null finding[72]. Given these mixed findings, we included working memory as a control variable in our study.

Either way, the evidence underscores the widespread nature of MA. MA has diverse origins and operates through various cognitive and neural mechanisms (for more detailed information, see[62]. In particular, the intrusive thoughts associated with MA can impair cognitive resources necessary for solving complex problems, ultimately reducing the performance[61,62].

Several studies have examined the relationship between MA and math performance, particularly in the context of AWP among elementary school children. Gunderson et al.[70] found that MA predicts future math performance, while math performance, in turn, predicts MA, indicating a reciprocal relationship. Ching[8] reported that MA related to AWP performance beyond non-verbal intelligence, working memory, number skills, and general and test anxieties. Ramirez et al.[61] found that MA is associated with reduced use of advanced problem-solving strategies, which may relate to lower AWP performance. Doz et al.[9] demonstrated that MA is linked to AWP proficiency both directly and indirectly via perceived task difficulty. Sorvo et al.[63] found that MA is linked to lower arithmetic fluency, which has also been associated with AWP performance[1]. Building on these findings, the present study explores whether MA is associated with AWP solving directly or indirectly through arithmetic fact fluency.

Reading anxiety, like MA, involves negative emotions and physiological responses during reading tasks[64], often manifesting as fear or apprehension when processing text[73]. Solving AWP requires reading comprehension skills[11,12,14], making it important to examine RA's role in both reading comprehension and AWP solving. Research has shown that higher RA levels are linked to poorer performance on reading comprehension[74] and word reading tests[73,75].

Few studies examined both RA and MA in the context of math, particularly AWP solving. Pollack et al.[64] explored the relationship between RA, MA, and math competence, finding a unidirectional, cross-domain pattern in which RA and motivation were associated with math competence (measured as a composite score including arithmetic fluency, calculations, and word problems). However, their reading measures included word reading (like in our study) but did not account for RC, an important skill necessary for AWP solving[11,12,14]. The novelty of the present study lies in its examination of RA, MA and cognitive abilities as distinct factors within SEM framework. This approach provides a more detailed view of how each factor is related to AWP performance. Compared to Pollack et al.[64] who used a composite measure of math competence and focused only on word reading, our study includes RC, a skill particularly relevant to AWP solving[11,12,14] and examines each component separately. These elements offer a more holistic perspective on the interplay between affective and cognitive factors involved in AWP performance.

Zhang et al.[11] found that MA fully mediates the relationship between RA and AWP solving among third-grade Chinese children. Their findings suggest that MA may not only be directly associated with AWP solving but may also mediate how RA relates to AWP performance.

While their study offered valuable into affective pathways, it left several gaps that the current study aims to address. First, reading fluency was not included in their model, despite its foundational role in supporting both RC and the successful decoding of AWP[48], much like arithmetic fluency supports broader math performance. Second, although Zhang et al.[11] assessed RC, it was limited to sentence-level tasks involving picture matching, which may not fully capture the demands of AWP solving. In contrast, our study uses short text-based RC, which more closely mirrors the linguistic and inferential demands of AWP, offering potentially improved ecological validity.

Moreover, Zhang et al.[11] did not identify the mediating role of RC. This may reflect a gap, as previous studies suggest that reading-related skills could be vulnerable to anxiety and potentially associated with AWP performance[4140,74]. The pathway, where RA linked to AWP via reading abilities like reading fluency and comprehension, has received limited attention.

The current study aims to address this gap by proposing a unified model that simultaneously examines the roles of MA, RA, and key cognitive skills in AWP performance. By incorporating arithmetic fluency, reading fluency, and reading comprehension as mediators, and including verbal and visual working memory as well as symbolic magnitude comparison as control variables, our SEM captures both cognitive and emotional pathways within a single, large-scale framework ($N = 717$), offering greater statistical power than prior studies. Taking a holistic approach allows for the simultaneous evaluation of multiple interrelated pathways, providing a more comprehensive view of the mechanisms associated with AWP solving.

The current study

In line with the multi-component framework of numerical cognition[15], overall mathematics achievement is understood to involve the integration of various skills and knowledge required for solving complex, contextualized problems. Previous studies emphasize the critical importance of mathematical cognition, language skills, and reading comprehension in this process[5,6,12,16,52]. At the same time, research highlights the associations between MA and mathematical performance, including AWP solving[7–9,35,61,69]. Notably, MA has been reported to mediate the association between RA and AWP performance[11], while a cross-domain study found that RA was predictive of AWP competence[64]. Both MA and RA have been shown to be associated with learning experiences and behaviors, potentially influencing performance at different levels[7–9,11,15,35,60,6173,7475].

Thus, a multi-component approach is important for understanding the interconnected cognitive and affective factors involved in AWP solving.

Despite these important findings, the pathways through which RA and MA are associated with AWP solving remain underexplored to our knowledge within a unified multi-componential framework. The present study aims to address this gap by proposing a unified model with different pathways, which provides a comprehensive view of the relationships between MA, RA, AWP, and if and how this relation operates via arithmetic fluency, reading fluency and reading comprehension. As highlighted in the literature above, these three cognitive skills function as foundational bridges between the mathematical and linguistic domains, facilitating the translation and conversion of text into mathematical procedures[1,6,52] and the construction of a mental model of the problem[58].

This rationale supports the study's integrative framework, which emphasizes the need to consider both linguistic and numerical domains concurrently. Thus, the multi-pathway model examined in this study can reflect the dynamic interplay between cognitive and affective processes, which can either facilitate or reduce mathematical performance[62] and AWP solving success[61].

Based on this background, we formulated four hypotheses: (A) Arithmetic fluency will mediate the relationship between math anxiety and word problem-solving performance[163]. (B) Reading comprehension will mediate the relationship between reading anxiety and word problem-solving performance[11,12,14,74]. (C) Reading anxiety will be indirectly associated with arithmetic word problem-solving performance through a serial mediation pathway: reading anxiety will be associated with reading fluency, which in turn will be associated with reading comprehension, which will be associated with AWP performance[1,73,74,75]. (D) The central hypothesis, derived from hypotheses A–C, posits that understanding AWP performance requires examining all pathways simultaneously and holistically, rather than in isolation. While individual analyses of each pathway are possible, they do not capture the complex interactions between emotional and cognitive factors. Recent research underscores the necessity of multi-componential models to better explain complex cognitive mechanisms, as such models offer a more integrated account of human performance and behavior[15,16].

By integrating these multiple components, the current study aims to deepen our understanding of the cognitive and emotional dimensions of AWP-solving and can help reveal the underlying mechanisms involved in AWP performance.

The study enables the examination of the pathways through which math and reading anxiety are associated with AWP solving, with arithmetic and reading-related skills serving as key mediators. Notably, while MA has been shown to demonstrate both direct and indirect associations with AWP performance[1,9,63], it remains important to explore whether RA is related to AWP performance exclusively through indirect pathways involving academic skills, an issue with important theoretical and educational implications.

Methods

Sample size

Power analysis was conducted using G*Power[77,78]. For multiple regression, assuming a medium effect size ($f^2 = 0.1$), power > 95%, an alpha level of 0.05, and four predictors, the required sample size was 158 participants. Structural equation modeling (SEM) typically requires a minimum sample size of 100–150[79]. The current SEM sample included 717 participants, accounting for missing data. As the study is part of a larger research project conducted at the Edmond J. Safra Brain Research Center for the Study of Learning Disabilities at the University of Haifa, we included all participants for whom data had already been collected.

Participants and ethics

The study included 717 third-grade participants, 348 boys, and 369 girls. All participants were Hebrew speakers. All data were collected after receiving approvals from the Chief Scientist of the Israeli Ministry of Education (12,126), the Ethics Committee for Human Research in the Faculty of Education (452/21). The informed consent form was signed by the parents of the children who participated in the study. All methods were performed in accordance with relevant guidelines and regulations.

Research procedure

All sessions were conducted individually with an experimenter in a quiet room at the school. Testing was spread over two sessions within a 2- to 5-day period. Across the sessions, students completed the following tasks: (1) math anxiety and (2) reading anxiety questionnaires, and (3) arithmetic fact fluency, (4) reading fluency, (5) reading comprehension, and (6) arithmetic word problems. As this study is part of a larger research project, the task order and structure were dictated by the broader study design. The order of tasks was randomized across participants, and importantly, the anxiety questionnaires were never administered immediately before or after the tasks relevant to the current study. This design minimized the risk that anxiety self-assessments would prime participants or directly influence their subsequent performance on the arithmetic and reading tasks.

Reading comprehension, MA, and RA were administered digitally via Qualtrics. The arithmetic fact fluency, reading fluency and arithmetic word problems were compiled with paper and pencil. Additionally, three control variables were collected: verbal working memory (administered orally), visual working memory (administered via E-Prime), and symbolic magnitude comparison (administered via Qualtrics; see Table 1 in the Results section).

Research materials

Control variables

Control criteria included verbal and spatial working memory, as well as symbolic magnitude comparison[32,80,81,82], to account for cognitive factors that may be associated with both reading and mathematics performance (see Table 1). Specifically, verbal and visual-spatial working memory are essential cognitive skills for mathematics, particularly for AWP solving[8,17,29,82,83]. Symbolic magnitude comparison serves as a longitudinal predictor of children's mathematical achievement[30–34].

Digit span test – backward (WISC lll)[85]. This task measures verbal working memory performance. The participant was asked to repeat aloud a sequence of digits in reverse order. The task began with a two-digit sequence, increasing by one digit every two trials, for a total of seven blocks. The administration stopped when two incorrect answers were received at a span length within a block. The participant's span is the longest number of sequential digits that can accurately be remembered. The reliability of this assignment is $\alpha = 0.88$.

Corsi block backwards. The task measured visuospatial working memory. This computerized version of the Corsi blocks task[86,87] is assessed for reversed-recall order. An array of 9 cubes is displayed on the screen. Each time a sequence of cubes of increasing difficulty was blackened. The participant was asked to recall the displayed sequence by indicating the cubes with the computer mouse, inverted (backward) to the displayed one. Two trials per length are given (between 2 and 8 blocks). The task ended when the participant completed all the blocks or made two consecutive errors within the same block. The reliability for the backwards task is $\alpha = 0.75$.

Symbolic magnitude comparison. This measure, adapted from the numeracy screener test[30], required participants to compare pairs of magnitudes ranging from 1 to 9 in a symbolic format. Participants identified the larger number in each pair of single-digit numbers. Numerical magnitudes were counterbalanced for the side of presentation. Easier items with smaller ratios were presented first, followed by more challenging items with larger ratios, to sustain motivation. Performance was evaluated by calculating the total number of correct responses completed within a 1-minute time limit. The symbolic task demonstrated high reliability, with Cronbach's alpha of $\alpha = 0.94$.

Key variables

Math anxiety was measured using a computerized questionnaire based on the abbreviated math anxiety scale[91]. The questionnaire, designed to assess math anxiety in school children, consists of eight questions about their feelings toward math. Participants listen to the statements (for example How anxious do you feel when you start learning a new topic in math? How anxious do you feel when you are given math homework to submit for the next lesson? (and are asked to rate their agreement on a five-point Likert-type scale, ranging from 1 (never concerned) to 5 (always concerned). The total score represents the sum of the items, with higher scores indicating higher levels of math anxiety. The reliability of this questionnaire is $\alpha = 0.83$.

Research variables	Mean (Sd)	Skewness	Kurtosis	Min–max	*N*
Key research variables					
Math anxiety	17.06 (7.09)	0.63	−0.30	8–36	663
Reading anxiety	14.87 (5.77)	0.78	0.19	4–35	663
Arithmetic fact fluency	55.54 (17.65)	0.42	0.33	0–122	708
Reading fluency	38.91 (11.66)	0.14	0.63	0–78	708
Reading comprehension	7.16 (2.32)	−0.77	−0.11	0–10	689
Arithmetic word problems	3.15 (2.23)	0.28	−0.98	0–8	705
Control variables					
Symbolic comparison	34.17 (7.42)	−0.22	1.12	4–56	662
Visual working memory	4.21 (1.25)	−0.61	0.57	0–8	651
Verbal working memory	3.30 (0.83)	0.41	0.49	0–6	653

Table 1. Descriptive statistics for key research measures and control variables.

Reading anxiety was measured using a computerized questionnaire developed by Katzir et al.[75] to assess reading-related anxiety in children. Although it was developed independently from the AMAS[91], the reading anxiety scale shares a similar structure and item phrasing, allowing for meaningful comparison. The scale includes seven items reflecting children's feelings in reading situations (e.g., *"How anxious do you feel when you have to read a page with a lot of words and no illustrations?"*). Participants listened to each item and rated their response on a five-point Likert-type scale, ranging from 1 (never concerned) to 5 (always concerned). The total score was calculated by summing the items, with higher scores indexing higher levels of reading anxiety. The reliability of this questionnaire is $\alpha = 0.75$.

Arithmetic fact fluency was assessed using the *WJ-III math fluency test*[93]. Children were instructed to complete as many simple single-digit addition, subtraction, and multiplication facts within 3 min, skipping those they could not answer. Their score was based on the number of correct responses provided within the allotted time. Each correct answer was scored one point, with a maximum possible score of 151. The reliability of this task was $\alpha = 0.97$.

Reading Fluency was assessed using The TOWRE test[88,89], based on[90], by measuring how quickly and accurately participants can read aloud 104 single words within 45 s. The words are presented in increasing order of difficulty. The reliability of this task is $\alpha = 0.94$. Scores are calculated based on the number of correct words provided in 45 s.

Reading comprehension was assessed using the *Developmental TAMAR*[95], based on the original *TAMAR*[94]. This computerized test consists of two short texts, each followed by five multiple-choice questions. Participants were instructed to read each text and then answer the questions by selecting the correct response from four options on the computer. The maximum time allowed to complete the test was 10 min. The score was the sum of the correct answers, with a reliability coefficient of $\alpha = 0.76$.

Arithmetic word problems test[92] consists of eight problems assessing problem-solving skills involving change, combination, comparison, and equalization relationships. The test includes five one-step problems (e.g., "*There are 31 cars in a parking lot. If 8 of the cars are new, how many are old?"* and *"Each of the 4 jars on the shelf contains 8 chocolate cookies. How many chocolate cookies are there in total?"*) and three two-step problems (e.g., *"Ruth has 22 fewer marbles than Daniela, who has 35. How many marbles do they have together?" and "Dan bought 3 green pencils and 5 blue pencils. How much did Dan pay if each pencil costs 3 shekels?"*). Problems are printed on an A4 sheet, and participants solve them independently within a six-minute time limit.

Scoring includes two components: equation production and solution. In one-step problems, each component is worth 1 point (maximum 2 points). In two-step problems, each component can receive up to 2 points (maximum 4 points per problem), allowing for partial credit. The number of operations or steps used did not influence the score. For example, in the pencil problem, participants could apply a factorization strategy (e.g., $(3 + 5) \times 3$) or a distributive approach (e.g., $(3 \times 3) + (5 \times 3)$). Both were scored equally, provided that the equation demonstrated a correct understanding of the problem and the final answer was accurate.

Partial credit in two-step problems was awarded as follows:

- For equation production, 2 points were given if both parts of the problem were correctly represented (regardless of whether two or more steps were used), 1 point for partial or incomplete representation, and 0 points for incorrect or missing equations.
- For solution, 2 points were awarded for a fully correct numeric answer, 1 point for a plausible but incomplete result (e.g., a correct intermediate answer or a minor error after a correct setup), and 0 points for an incorrect or missing response.

This scoring approach focused on conceptual understanding and solution accuracy, not on the specific problem-solving strategy or number of steps used. Participants were neither penalized nor rewarded for using more than two steps, as long as their reasoning was mathematically valid.

The reliability of equation production is $\alpha = 0.78$, solutions $\alpha = 0.81$, and the overall reliability of the task is $\alpha = 0.91$. The test's validity is supported by its significant positive correlations with other cognitive and mathematical skills: reading fluency ($r = .43$, $p < .001$), arithmetic fact fluency ($r = .52$, $p < .001$), reading comprehension ($r = .49$, $p < .001$), visual working memory ($r = .15$, $p = .003$), and verbal working memory ($r = .23$, $p < .001$), symbolic magnitude comparison ($r = .18$, $p < .001$). These correlations indicate that the arithmetic word problems test effectively measures arithmetic word problem-solving abilities while reflecting interrelated cognitive and academic skills.

Data analysis plan

All data were analysed using IBM SPSS (Version 27) and AMOS (Version 27), with additional mediation analyses conducted in R (Version 4.5.0).

We first conducted descriptive statistics and bivariate Pearson correlation analyses in SPSS to examine the distribution, central tendency, and interrelations among the main study variables: math anxiety, reading anxiety, arithmetic fact fluency, reading fluency, reading comprehension, and arithmetic word problem performance. Skewness and kurtosis were also examined to assess the normality of distributions.

To test the hypothesized mediation model, we estimated a saturated Structural Equation Model (SEM) in AMOS. This model examined how reading and mathematics anxiety predicted arithmetic word problem-solving performance through three cognitive skill mediators: arithmetic fact fluency, reading fluency, and reading comprehension. Verbal working memory, visual working memory, and symbolic magnitude comparison were included as control variables.

Model fit was assessed using standard fit indices, including the chi-square statistic (χ^2), the Comparative Fit Index (CFI), the Tucker–Lewis Index (TLI), the Incremental Fit Index (IFI), and the Normed Fit Index (NFI).

Standardized regression weights (β) and their associated p-values were used to evaluate the significance and strength of direct paths.

To test the indirect effects, we used bootstrapping procedures in R with 5,000 resamples, generating bias-corrected 95% confidence intervals (CIs). Indirect effects were considered statistically significant if their 95% CI did not include zero. These analyses enabled robust testing of multiple mediation pathways between anxiety and arithmetic word problem-solving via relevant cognitive skills.

Results

Descriptive statistics were conducted for all research variables. The descriptive statistics are presented in Table 1.

Correlation analysis

The correlation matrix demonstrates the negative relationships between anxiety measures and cognitive skills, i.e. reading comprehension, arithmetic fact fluency, reading fluency and arithmetic word problems. Table 2 displays the Pearson correlation matrix for the key variables. Specifically, math anxiety was strongly and positively correlated with reading anxiety ($r = .61$, $p < .001$) and negatively correlated with arithmetic fluency ($r = -.24$, $p < .001$), reading fluency ($r = -.14$, $p < .001$), reading comprehension ($r = -.19$, $p < .001$), arithmetic word problems ($r = -.38$, $p < .001$). Reading anxiety had significant negative correlations with reading fluency ($r = -.20$, $p < .001$), reading comprehension ($r = -.30$, $p < .001$), arithmetic fluency ($r = -.13$, $p < .001$), and arithmetic word problems ($r = -.30$, $p < .001$).

Additionally, the correlations analysis showed positive correlations between the cognitive skills themselves. Arithmetic fact fluency was positively correlated with reading fluency ($r = .51$, $p < .001$), comprehension ($r = .32$, $p < .001$), and arithmetic word problems ($r = .52$, $p < .001$(. Reading fluency was positively correlated with reading comprehension ($r = .47$, $p < .001$), and arithmetic word problems ($r = .43$, $p < .001$), and reading comprehension was positively correlated with arithmetic word problems ($r = .49$, $p < .001$).

Structural equation model (SEM) analysis

To examine the complex relationships among anxiety measures, mediating skills, and arithmetic word problem-solving, a saturated structural equation model (SEM) was estimated (Fig. 1). The model demonstrated excellent fit indices: $\chi^2 = 0.000$, NFI = 1.00, CFI = 1.00, TLI = 1.00, IFI = 1.00, indicating a perfect model fit.

The SEM results revealed that math anxiety had a significant negative direct effect on arithmetic fluency ($\beta = -0.17$, $p < .001$) and on arithmetic word problems ($\beta = -0.21$, $p < .001$) but was not significantly related to reading fluency or reading comprehension. Conversely, reading anxiety significantly predicted lower reading fluency ($\beta = -0.18$, $p < .001$) and reading comprehension ($\beta = -0.22$, $p < .001$), but did not directly predict arithmetic fluency, or arithmetic word problem performance.

In terms of cognitive skill predictors, arithmetic fluency was a strong positive predictor of arithmetic word problems ($\beta = 0.29$, $p < .001$). Similarly, reading comprehension was positively associated with arithmetic word problems ($\beta = 0.28$, $p < .001$), and reading fluency predicted reading comprehension ($\beta = 0.38$, $p < .001$) and arithmetic word problems ($\beta = 0.08$, $p = .025$). Arithmetic fluency was not directly associated to reading comprehension (see Table 3).

Indirect effects

Significant indirect effects were also observed (see Table 4), supporting the hypothesized mediation paths: Math anxiety had an indirect negative effect on arithmetic word problem-solving through arithmetic fluency (indirect effect = –0.018, 95% CI [–0.025, –0.007]). Reading anxiety showed several significant indirect effects on arithmetic word problems: via reading fluency (indirect effect = –0.012, 95% CI [–0.012, –0.0003]), via reading comprehension (indirect effect = –0.021, 95% CI [–0.035, –0.014]), via a serial mediation through reading fluency → reading comprehension (indirect effect = –0.01, 95% CI [–0.012, –0.002]).

These results highlight the differential pathways through which math and reading anxiety are associated with arithmetic word problem-solving, with arithmetic and reading-related skills serving as key mediators. Notably, while math anxiety exerted both direct and indirect effects, reading anxiety was related to arithmetic word problem-solving exclusively through indirect reading skill pathways.

Discussion

The value of multi-component cognitive models is well established in both scientific and pedagogical literature[15,16,95]. Building on this foundation, the present study innovatively investigates arithmetic word

Variables	1	2	3	4	5	6
1. Math anxiety	–	0.61***	−0.24***	−0.14***	−0.19***	−0.38***
2. Reading anxiety		–	−0.13***	−0.20***	−0.30***	−0.30***
3. Arithmetic fact fluency			–	0.51***	0.32***	0.52***
4. Reading fluency				–	0.47***	0.43***
5. Reading comprehension					–	0.49***
6. Arithmetic word problems						–

Table 2. Pearson correlation matrix for the key research variables. Notes. ***$p < .001$, **$p < .01$, *$p < .05$.

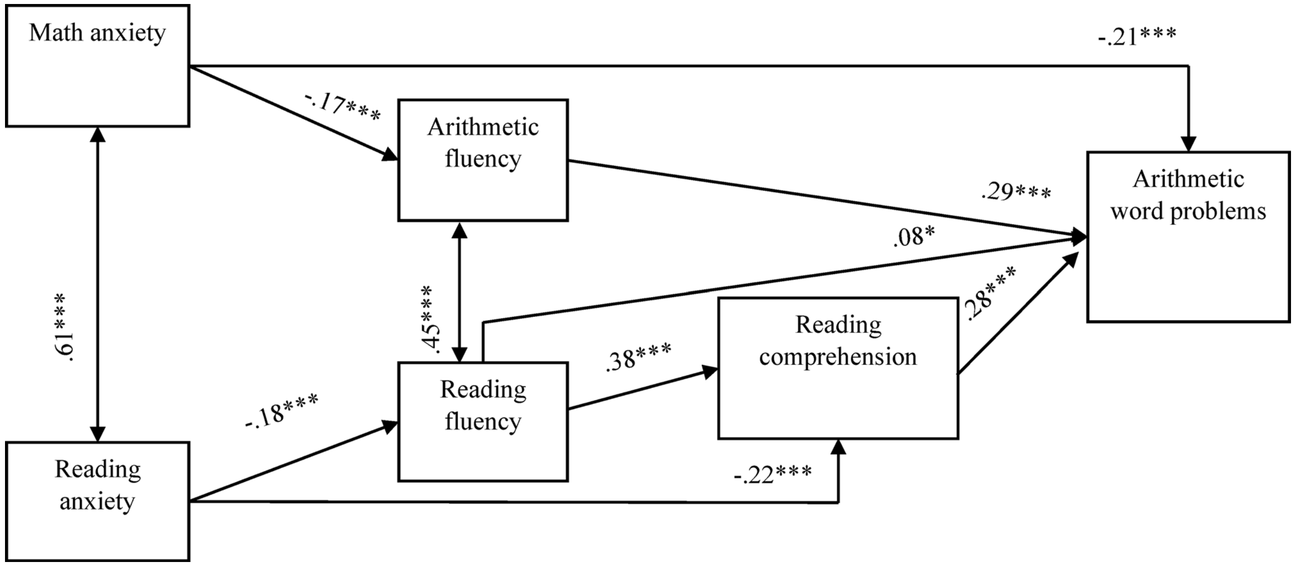

Fig. 1. Structural Equation Model (SEM) analysis. *Note.* Standardized regression weights. *$p<.05$., **$p<.01$, ***$p<.001$.

problem performance through a unified, multi-component, multi-pathway model that holistically integrates a complex set of processes: numeric, linguistic, and emotional. The findings emphasize a critical point: to better understand AWP performance, it is important to examine the interplay of these factors simultaneously rather than in isolation.

Using a large sample of third-grade children and a structural equation modeling framework, we examined how RA is related to AWP performance via reading fluency and reading comprehension, and how MA is related to AWP performance directly and indirectly via arithmetic fluency. To enhance the validity of the findings, we statistically controlled verbal and visual working memory[8,17,29,83,69,84] and symbolic magnitude comparison[31–34], which are known to be related to reading and arithmetic performance.

Our results reveal distinct patterns of association, highlighting how different types of anxiety (RA and MA) are linked with AWP performance through their negative associations with key cognitive skills: reading fluency, reading comprehension, and arithmetic fluency. These cognitive skills were positively associated with word problem solving, emphasizing the importance of viewing AWP performance through a holistic lens. Considering emotional and cognitive factors together offers a more comprehensive understanding of the mechanisms underlying individual differences in AWP performance.

Our findings revealed a complex interplay between MA and AWP performance, emphasizing both direct and indirect mechanisms. Higher levels of MA were consistently associated with poorer problem-solving outcomes, aligning with previous studies[8,9,11,62,70], suggesting that MA may interfere with mathematical performances.

One key pathway through which MA is associated with AWP solving is via arithmetic fluency, a foundational skill linked to broader mathematical achievement[42]. Fluency in arithmetic facts is particularly important for elementary school students solving AWP[1,35,43], and prior research indicates that MA contributes to deficits in this area, further impairing problem-solving performance[163]. In addition to its cognitive associations, MA is often linked to behavioral tendencies such as avoidance of math-related tasks[11], which may reduce opportunities for skill acquisition and practice[40]. Additionally, in anxiety-provoking situations, individuals with MA often tend to ruminate on stress-related thoughts rather than the task at hand[62], thereby diminishing the cognitive resources necessary for problem-solving[40,41].

The findings further underscore the role of RA in AWP performance, emphasizing the linguistic complexity inherent in solving word problems. Although RA was not directly associated with AWP performance, it showed indirect associations through multiple pathways: via reading fluency, via reading comprehension, and through a serial mediation path from reading fluency → reading comprehension. These findings reinforce the notion that RA relates to AWP performance primarily through its associations with literacy-related skills pathway[73,74,75], supporting the view that reading comprehension and fluency form a distinct cognitive pathway, beyond general cognitive load effects[41].

Word problems require not only numerical competence but also strong linguistic and comprehension skills to extract meaning from text and translate it into appropriate mathematical representations[1,11,12,14,45,47,4996]. Anxiety-related disruptions in reading processes may interfere with this translation, ultimately impair problem-solving[11,41,74]. Beyond translating text into equations, successful AWP solving also requires constructing a mental model of the described situation. This process involves mentally simulating the scenario described in the text and aligning it with the appropriate mathematical operations. Crucially, this requires the integration of linguistic understanding with formal symbolic reasoning, highlighting the need for both linguistic and numerical skills to effectively interpret and solve word problems. These deep mental representational processes highlight the need to view AWP performance as the product of both linguistic and numerical skills.

Relation examined		
Key variables	***B***	***P***
Math anxiety → Arithmetic fluency	− 0.17	< 0.001
Math anxiety → Reading fluency	0.03	0.51
Math anxiety → Reading comprehension	0.05	0.26
Math anxiety → Arithmetic word problems	− 0.21	< 0.001
Reading anxiety → Arithmetic fluency	0.03	0.42
Reading anxiety → Reading fluency	− 0.18	< 0.001
Reading anxiety → Reading comprehension	− 0.22	< 0.001
Reading anxiety → Arithmetic word problems	− 0.01	0.72
Arithmetic fluency → Arithmetic word problems	0.29	< 0.001
Arithmetic fluency → Reading comprehension	0.07	0.12
Reading fluency → Reading comprehension	0.38	< 0.001
Reading fluency → Arithmetic word problems	0.08	0.025
Reading comprehension→ Arithmetic word problems	0.28	< 0.001
Math anxiety ↔ Reading anxiety	0.61	< 0.001
Reading fluency ↔ Arithmetic fluency	0.45	< 0.001
Verbal working memory→ Arithmetic fluency	0.16	< 0.001
Verbal working memory→ Reading fluency	0.16	< 0.001
Verbal working memory→ Reading comprehension	0.03	0.38
Verbal working memory→ Arithmetic word problems	0.08	0.02
Visual working memory→ Arithmetic fluency	0.10	0.003
Visual working memory→ Reading fluency	0.08	0.03
Visual working memory→ Reading comprehension	0.10	0.006
Visual working memory→ Arithmetic word problems	0.10	0.002
Symbolic comparison→ Arithmetic fluency	0.36	< 0.001
Symbolic comparison→ Reading fluency	0.16	< 0.001
Symbolic comparison→ Reading comprehension	0.05	0.23
Symbolic comparison→ Arithmetic word problems	0.03	0.39
Verbal working memory↔ Reading anxiety	− 0.17	< 0.001
Verbal working memory↔ Math anxiety	− 0.17	< 0.001
Verbal working memory↔ Visual working memory	0.21	< 0.001
Verbal working memory↔ Symbolic comparison	0.23	< 0.001
Visual working memory↔ Reading anxiety	− 0.09	0.02
Visual working memory↔ Math anxiety	− 0.15	< 0.001
Visual working memory↔ Symbolic comparison	0.19	< 0.001
Symbolic comparison↔Reading anxiety	− 0.05	0.17
Symbolic comparison↔Math anxiety	− 0.13	0.001

Table 3. Standardized path coefficients and covariances in the model.

Indirect paths	Indirect effect	95% CI
Math anxiety → Arithmetic fluency → Arithmetic word problem	− 0.018	− 0.025, − 0.007
Reading anxiety → Reading fluency → Arithmetic word problem	− 0.012	− 0.012, − 0.0003
Reading anxiety → Reading comprehension → Arithmetic word problem	− 0.021	− 0.035, − 0.014
Reading anxiety → Reading fluency → Reading comprehension → Arithmetic word problem	− 0.01	− 0.012, − 0.002

Table 4. Examination of indirect effects.

The model revealed a reciprocal association between reading fluency and arithmetic fluency, highlighting a potential bidirectional relationship between foundational skills in the reading and math domains. This cross-domain relation is particularly notable, as it bridges reading and numerical fluency components. It suggests that fluency in one domain may support or reinforce fluency in the other, possibly due to overlapping cognitive mechanisms such as rapid automatized naming (RAN), which facilitates the retrieval of verbal symbols from visual input[97], a process relevant to both reading and math. Previous study with younger Hebrew-speaking children have shown that reading fluency often develops earlier than arithmetic fluency[76] . This has been explained by instructional progression, as reading fluency in Hebrew is typically established by the end of first grade, whereas arithmetic fluency continues to develop through third grade[99,100]. However, our findings suggest that the relationship is not unidirectional, and improvements in either type of fluency could potentially benefit the other. Well-established fluency promotes learning by freeing up cognitive resources[40,41] for the execution of complex tasks, such as AWP solving[1,35,42,43]. While this reciprocal pattern underscores the interconnected nature of basic academic skills, the precise cognitive and instructional processes driving this cross-domain linkage remain beyond the scope of the current study and warrant further exploration.

The present findings can rely on broader research showing that negative emotions can have deleterious effects on arithmetic performance. For example, Lemaire[13] demonstrated that negative emotional states impair performance by disrupting the effective use of strategies, even when individuals have access to the same strategies and apply them to the same problems. These emotional effects were particularly evident on more demanding tasks, where cognitive load is higher[40,41]. Although strategy use was not directly assessed in our study, the observed associations between anxiety and reduced AWP performance, via cognitive mediators, are consistent with the idea that negative emotions may interfere with the cognitive processes underlying problem-solving.

AWP solving requires simultaneous comprehension of textual descriptions and understanding of numerical operations[1,6,17,38,47,52101], creating a cognitive load that is particularly sensitive to the effects of anxiety[11,41,73]. Both RA and MA may impair this process through distinct yet interconnected pathways. Given that AWP sits at the intersection of language and mathematics, it demands the integration of multiple skills. Our findings support the view of AWP as a multi-componential process shaped by both cognitive and emotional factors[52], particularly through mechanisms that translate text into mathematical representations[1,6,7,17,38,52], formation of a mental situation model[58] and negative emotions that can have deleterious effects on arithmetic performance[13] like RA and MA[11,64].

In summary, the present study offers a novel contribution by identifying distinct cognitive pathways through which RA and MA relate to AWP performance. Using a unified multi-pathway model, we show that RA is associated with AWP performance through reading-related skills, while MA exerts both direct and indirect effects via arithmetic fluency. This holistic framework reveals the complex interplay of emotional, linguistic, and numerical mechanisms in word problem solving. Furthermore, the study highlights RA and MA as potential early indicators of difficulties in AWP, emphasizing the importance of early detection and support.

Theoretically, these findings highlight the value of a multi-component approach that integrates cognitive and emotional factors, as they collectively contribute to solving word problems. They highlight the importance of examining all components simultaneously, as focusing on a single pathway in isolation may overlook key interactions. A comprehensive, holistic perspective is therefore essential.

Practically, this suggests that interventions should address not only cognitive-academic skills but also emotional dimensions. Solving arithmetic word problems requires both anxiety reduction and the strengthening of reading and math-related abilities. In line with Lemaire[13], negative emotions such as math and reading anxiety can have deleterious effects on performance and undermine effective strategy use. Interventions should thus aim to reduce anxiety while simultaneously supporting literacy and mathematical development, ensuring an integrated approach to improving problem-solving outcomes.

Future research should further explore how numerical cognition processes interact with both anxiety pathways at different developmental stages. It may also be valuable to investigate whether these pathways differ depending on the type of word problem (e.g., one- vs. two-step problems) or students' preferred strategies. Although strategy use was not directly assessed here, understanding how different forms of anxiety relates to strategy choice could inform instructional practices and educational support. In addition, studies might consider interventions focused on reducing RA and MA, alongside supporting both literacy and mathematical components, to better understand their potential associations with AWP performance.

While the present study offers valuable insights into the interplay between emotional and cognitive factors in AWP performance, several limitations should be acknowledged. First, cross-sectional design limits the ability to draw causal conclusions about the developmental direction of the observed relationships. Although the structural equation model identifies potential pathways, longitudinal data are needed to clarify the directionality and temporal dynamics among anxiety, fluency skills, comprehension, and problem-solving performance. Second, although our SEM included multiple control variables and showed excellent fit, unmeasured factors, such as strategy use, classroom environment, teacher-student relationships, socioeconomic status, or other emotional variables beyond anxiety, may also influence the results. Finally, the study focused on Hebrew-speaking third-grade students, which may limit the generalizability of the findings to other age groups, languages, or educational contexts.

Data availability

The data generated and analyzed during this study are not publicly available due to privacy and ethical restrictions protecting the confidentiality of study participants. Access to the data may be provided upon reasonable request, subject to appropriate ethical and legal approvals. The datasets generated and analyzed during the current study are available from the corresponding author, Orly Rubinsten, upon reasonable request.

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Author contributions

D.T. wrote and edited the main manuscript and was responsible for manuscript preparation. D.T., T.K., S.D and O.R. contributed to the methodology. M.B.Y. collected the data. D.T. and S.D. analyzed and interpreted the data. T.K., O.R., D.T and M.B.Y. contributed to the conceptualization. T.K. and O.R. supervised the study. All authors reviewed and approved the final version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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