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| Research Article / Araştırma Makalesi |

The Role of Number Sense Performance in the Relationship Between Math Anxiety and Math Achievement Among Second-Grade Primary School Students

İlkokul İkinci Sınıf Öğrencilerinde Matematik Kaygısı ile Matematik Başarısı Arasındaki İlişkide Sayı Hissi Performansının Rolü[1]

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Keywords
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Abstract

Purpose: This study investigates the role of number sense performance in the relationship between math anxiety and math achievement among second-grade primary school students.

Design/Methodology/Approach: The study sample consisted of 138 second-grade students from a school representing a middle socioeconomic status. Data were collected using a math anxiety scale, a math achievement test, and a number sense test. The data were analyzed through descriptive statistics, Pearson correlation, mediation, and moderation analyses.

Findings: The results revealed a strong positive correlation between number sense performance and math achievement (r = .64) and a moderate negative correlation between math anxiety and math achievement (r = -.34). Mediation analysis indicated that number sense performance partially mediated the relationship between math anxiety and math achievement. On the other hand, moderation analysis showed that number sense did not have a significant moderating effect on this relationship. Slope analysis suggested that students with high number sense performance were less affected by math anxiety.

Highlights: These findings highlight that number sense is a significant predictor of early mathematical achievement and that math anxiety indirectly influences achievement through this skill. The findings indicate that number sense-based interventions in early education may significantly enhance academic achievement by fostering both cognitive development and affective factors.

Öz

Çalışmanın amacı: Bu çalışma, ilkokul ikinci sınıf öğrencilerinde matematik kaygısı ile matematik başarısı arasındaki ilişkide sayı hissi performansının rolünü incelemektedir.

Materyal ve Yöntem: Çalışma grubunu, orta sosyoekonomik düzeydeki bir okuldan 138 ikinci sınıf öğrencisi oluşturmaktadır. Veriler, matematik kaygı ölçeği, matematik başarı testi ve sayı hissi testi aracılığıyla toplanmıştır. Veriler, betimleyici istatistik, Pearson korelasyon, aracılık ve düzenleyicilik analizleriyle değerlendirilmiştir.

Bulgular: Analizler sonucunda, sayı hissi performansı ile matematik başarısı arasında güçlü pozitif (r = .64), matematik kaygısı ile matematik başarısı arasında ise orta düzeyde negatif bir ilişki (r = -.34) bulunmuştur. Aracılık analizi, sayı hissi performansının matematik kaygısı ile matematik başarısı arasındaki ilişkide kısmi bir aracı rol oynadığını göstermiştir. Ancak düzenleyicilik analizi, sayı hissinin bu ilişki üzerinde anlamlı bir düzenleyici etkisi olmadığını ortaya koymuştur. Eğim analizi, yüksek sayı hissi performansına sahip öğrencilerin matematik kaygısından daha az etkilendiğine işaret etmektedir.

Önemli Vurgular: Elde edilen bulgular, sayı hissinin, erken matematiksel başarının önemli bir yordayıcısı olduğunu ve matematik kaygısının bu beceri aracılığıyla başarıyı dolaylı olarak etkilediğini göstermektedir. Bu sonuçlar, erken yaşta yapılacak sayı hissi temelli müdahalelerin, hem bilişsel gelişimi hem de duyuşsal faktörleri destekleyerek akademik başarıyı artırmada kritik rol oynayabileceğini ortaya koymaktadır.

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INTRODUCTION

Mathematical skills are increasingly acknowledged as essential for academic and professional success in today's world (Kenderov, 2022). Educational scientists, mathematics educators, neuroscientists, and psychologists have conducted extensive research over recent decades to identify the processes that influence mathematics teaching and learning. Research into the mechanisms underlying the acquisition of mathematical skills highlights a foundational construct that is believed to be innately present yet shaped and refined through experience: number sense (see Feigenson et al., 2004; Lipton & Spelke, 2003; Xue & Spelke, 2000). Before defining this core skill and examining its relationship with mathematical performance, it is equally important to highlight math anxiety (MA)—an affective factor that plays a significant role in mathematics learning and interacts with cognitive processes. This issue has received growing attention, as MA can adversely affect children's academic achievement and future employment opportunities (Ramirez et al., 2016). In light of these considerations, the present study aims to investigate the relationship between number sense performance, MA, and math achievement in young children. Understanding the interplay among these variables is crucial for developing targeted instructional interventions for students who experience difficulties with mathematical competencies and contributes to the early identification of at-risk students by highlighting key predictive factors.

Number sense performance and math achievement

In neurocognitive psychology research, number sense is defined as the ability to mentally represent and manipulate numbers and quantities (Dehaene, 2001). Within the educational paradigm (Jordan et al., 2010; National Council of Teachers of Mathematics, 1989; Reys et al., 1999), it is characterized as both the ability and disposition to develop effective strategies—applying a comprehensive understanding of numbers and operations to flexibly perform mathematical evaluations and navigate numerical situations. These mathematical skills include counting; number knowledge (comparing numerical magnitudes and distinguishing quantities); number transformations; calculations based on reference points or without them; estimations (making approximate or precise estimates by utilizing reference points); and number patterns (identifying, repeating, and extending numerical relationships) (Jordan et al., 2010; Reys et al., 1999). Although these definitions provide distinct perspectives, number sense is generally characterized by the use of diverse numerical representations; such as recognition of relative and absolute number magnitudes; selection and use of reference points; decomposition and recomposition of numbers; understanding the relational effects of operations on numbers; and the ability to perform flexible and accurate mental calculations and estimations (Reys & Yang, 1998). A consensus among neurocognitive scientists and educators highlights that number sense is strongly associated with math achievement (Caviola et al., 2020; Geary et al., 2012; Jordan et al., 2010; Mazzocco et al., 2011; Nelwan et al., 2021; Olkun, 2015; Olkun et al., 2017; Reys et al., 1999).

Previous studies have demonstrated that early number sense skills are stronger predictors of later math performance than either intelligence or working memory (e.g., Decarli et al., 2023; Friso-van den Bos et al., 2014; Mazzocco et al., 2011). For instance, a recent longitudinal study conducted by Decarli and colleagues revealed that the core number sense ability—defined as the approximate number system—measured in 60 infants at 12 months of age served as a distinct predictor of their mathematical proficiency at age four, independent of general intelligence and inhibitory control (Decarli et al., 2023). Moreover, some researchers argue that impaired number sense may underlie mathematical difficulties, suggesting that its deficiency could be a contributing factor to math-related learning challenges (e.g., Butterworth, 2010; Butterworth & Laurillard, 2010; Halberda et al., 2008; Olkun et al., 2015; Starr et al., 2013; Wilson & Dehaene, 2007). Additional evidence indicates that improvements in mathematical skills may coincide with developments in number sense, pointing to a potentially bidirectional relationship between the two constructs (e.g., Elliott et al., 2019; Mussolin et al., 2014). Conversely, other studies have questioned this association, reporting no significant correlation between number sense performance and children's mathematical achievement (e.g., Price et al., 2012; Sasanguie et al., 2012). Taken together, these findings underscore the need for further research to clarify the nature and extent of the relationship between number sense and math achievement in early childhood.

MA and math achievement

MA can be defined as a feeling of tension, worry, or even fear that interferes with performing mathematical tasks and solving mathematical problems (Ashcraft & Faust, 1994). Alternatively, it is characterized as behavioral, attitudinal, or emotional responses that negatively impact an individual's performance during the learning, application, or assessment of mathematics (McMinn & Aldridge, 2020). MA is characterized by negative emotions toward mathematics and may lead individuals to avoid math courses and math-related careers (Pizzie & Kraemer, 2017). Research has consistently shown that MA is significantly associated with math achievement (Bayırlı et al., 2021; Miller & Bichsel, 2004; Mutlu et al., 2017; Namkung et al., 2019; Sarı & Ekici, 2018; Şad et al., 2016). Importantly, MA not only undermines students' current performance but may also have long-term consequences by hindering the process of learning mathematics (Pantoja et al., 2020; Soltanlou et al., 2019; Szczygieł et al., 2024). For example, Pantoja and colleagues (2020) found that MA levels in first-grade students strongly predicted their math achievement up to third grade. Thus, MA can pose a significant obstacle to mathematical development. Regarding the directionality of the relationship between MA and math achievement, three theoretical frameworks have been proposed (Carey et al., 2016): (1) the Deficit Theory, which posits that poor performance in mathematics leads to increased anxiety; (2) the Debilitating Anxiety Model, suggesting that anxiety contributes to avoidance of learning mathematics, thereby resulting in lower achievement; and (3) the Reciprocal Theory, which views the relationship as bidirectional, where prior math achievement influences levels of MA and vice versa. Research findings indicate that both variables are likely in a vicious cycle (e.g., Foley et al., 2017; Gunderson et al., 2018;

Namkung et al., 2019; Ramirez et al., 2018; Szczygieł et al., 2024). In other words, low math achievement can lead to math anxiety, while high math anxiety can lead to low math performance.

MA typically emerges in childhood and begins to develop during the early years of primary education. As children grow older, MA levels tend to increase, generally peaking around ages 9 or 10, after which they stabilize—though symptoms may persist throughout the school years and even into adulthood (Koch, 2018). Notably, the impact of MA on children's fundamental mathematical skills appears to differ from that observed in adults and is shaped by a more intricate network of interactions (Justicia-Galiano et al., 2017). For instance, a recent meta-analysis reported a general trend of improvement in MA from primary through late secondary education, while the association between MA and math performance became more pronounced and negative during the later stages of compulsory schooling (i.e., grades 9 and 10) (Brunner et al., 2023). Similar findings have been documented in prior meta-analyses (e.g., Barroso et al., 2021; Bayırlı et al., 2021; Şad et al., 2016; Zhang et al., 2019). Although the adverse effects of MA on math performance have been observed as early as the initial school years (see Szczygieł & Pieronkiewicz, 2021), the relationship appears less consistent in children compared to adults—possibly due to the limited scope and number of previous studies focusing specifically on younger age groups.

MA and number sense performance

Although the negative effects of MA on individuals' math performance are well documented, the role of number sense performance—one of the underlying cognitive processes potentially mediating these effects—has yet to be fully clarified (Sarı & Szczygieł, 2023; Szczygieł, 2021). It is hypothesized that poor number sense skills may increase the likelihood of initial failure and negative learning experiences in mathematics education, potentially triggering MA (Lindskog et al., 2017; Maldonado Moscoso et al., 2020). Some studies examining the relationship between number sense performance and MA suggest that MA directly impairs number sense, which may contribute to lower math achievement (e.g., Ak & Ertekin, 2020; Maldonado Moscoso et al., 2020; Sarı & Szczygieł, 2023). Conversely, other studies have reported no significant correlation between number sense skills and MA (e.g. Braham & Libertus, 2018; Szczygieł, 2021). Overall, it is believed that MA may negatively influence number sense skills at early ages, thereby shaping math achievement over the long term. Moreover, the enhancement or maintenance of advanced number sense skills is considered a protective factor that may help support math performance in individuals with high levels of MA (Braham & Libertus, 2018).

In summary, when studies examining the antecedents of math achievement—particularly MA and number sense performance (Braham & Libertus, 2018; Lindskog et al., 2017; Sarı & Szczygieł, 2023; Szczygieł, 2021)—are considered collectively, it becomes evident that certain underlying mechanisms remain unclear. In particular, the relationship between MA and number sense performance, and the role this relationship plays in shaping math achievement, has yet to be fully elucidated (see Braham & Libertus, 2018; Mononen et al., 2022; Szczygieł, 2021). Consequently, there is a need for further research to better understand the mechanisms underpinning the stronger association between MA and math achievement in young children. In this context, De Smedt and colleagues (2013) argue that identifying which early cognitive and affective predictors significantly influence the development of math achievement—and understanding when and how these predictors exert their effects—can inform educational practices and curriculum design, as well as guide the development of effective early interventions.

In this context, the primary aim of the present study is to examine whether number sense performance mediates the relationship between MA and math achievement. The theoretical model tested for this purpose is presented in Figure 1. The second aim is to evaluate whether number sense performance moderates the relationship between MA and math achievement; this theoretical model is shown in Figure 2. Finally, the study seeks to determine whether number sense performance and math achievement differ between children with low and high levels of MA. Investigating differences in math performance between young children with low and high MA is important, as previous studies suggest students with higher levels of MA at later educational stages (e.g., middle school, high school, and university) may be at greater risk for poor math performance compared to those with lower levels of MA (e.g., Maloney et al., 2010; Maloney et al., 2011; Sarı & Szczygieł, 2023; Skagerlund et al., 2019).

As a result, in line with previous studies (e.g., Lindskog et al., 2017; Skagerlund et al., 2019), it is anticipated that MA will be directly associated with math achievement, and that number sense performance may partially mediate this relationship. In other words, number sense performance may help explain how MA exerts its negative effect on math achievement. Furthermore, consistent with the findings of Braham and Libertus (2018), it is expected that children with higher levels of MA and lower number sense performance will perform more poorly on math tasks than children with lower levels of MA and higher number sense performance.

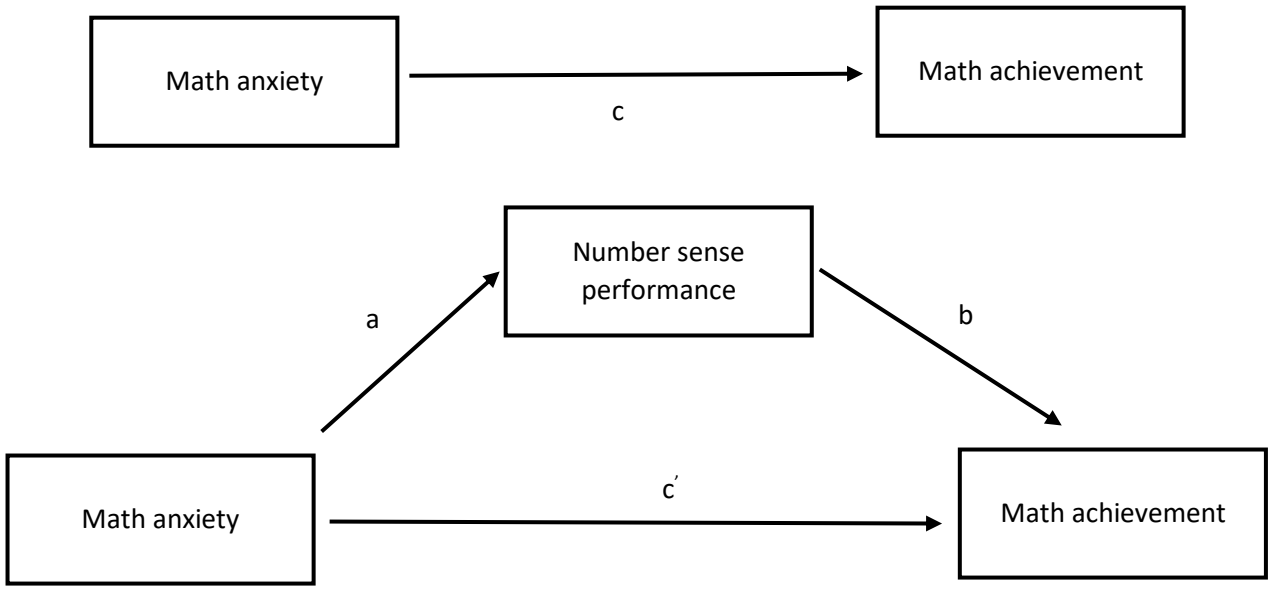

Figure 1. Mediation Model

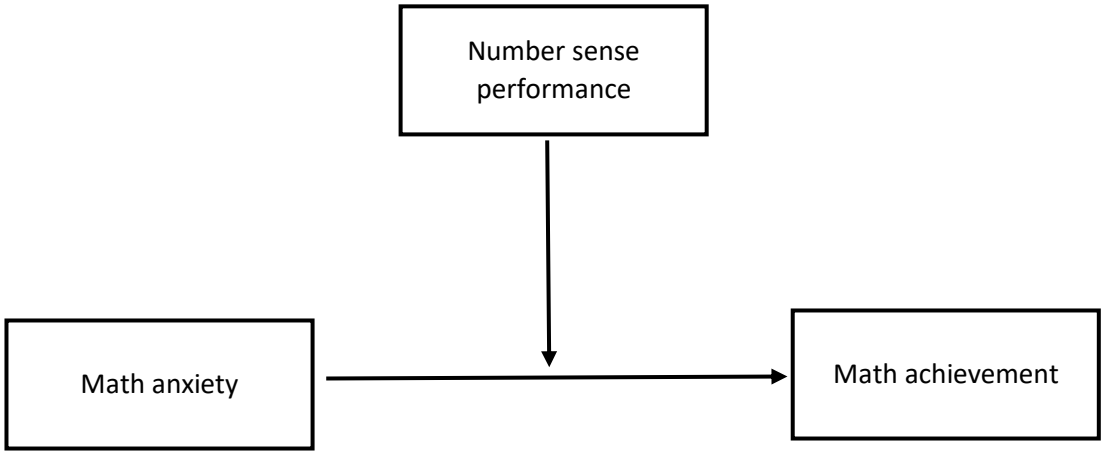

Figure 2. Moderation Model

METHOD/MATERIALS

Participants

The study sample comprised second-grade elementary school students. This age group was selected based on evidence that the early years of primary education represent a critical period for the development of fundamental mathematical skills (Wu et al., 2014) and mark the initial onset of MA (e.g., Barroso et al., 2021; Harari et al., 2013; Szczygieł & Pieronkiewicz, 2021). The minimum required sample size was calculated as 100 using the G*Power 3.1 software (Faul et al., 2009), based on the following parameters: $\alpha = 0.05$, $\beta = 0.80$, $r = -0.28$, and a two-tailed test. The effect size ($r = -0.28$) was derived from the meta-analysis conducted by Barroso et al. (2021). In total, data were collected from 141 second-grade students attending a school with a middle socioeconomic status located in the Central Anatolia Region. Following the exclusion of data from three students identified as outliers, the final sample consisted of 138 participants: 78 girls (56.5%) and 60 boys (43.5%).This sample size was deemed sufficient to ensure adequate statistical power for testing the study's hypotheses.

Data Collection Instruments

Three instruments were employed for data collection in this study: the Math Anxiety Scale, the Math Achievement Test, and the Number Sense Test.

Math Anxiety Scale: Developed by Mutlu and Söylemez (2018) to assess MA in elementary school students, this scale comprises 13 items, including 5 positively worded and 8 negatively worded items. It is designed as a three-point Likert scale, with scores

ranging from 13 (minimum) to 39 (maximum). Students were allotted one class period (40 minutes) to complete the scale. Mutlu and Söylemez (2018) reported a Cronbach's alpha (α) of 0.75 for the scale's reliability. In the present study, the Cronbach's alpha was 0.78. Confirmatory factor analysis yielded the following fit indices: $\chi^2/df = 100.739/62 = 1.63$, RMSEA = 0.068, RMR = 0.031, GFI = 0.90, CFI = 0.91, NFI = 0.81, NNFI = 0.89, and AGFI = 0.85. The χ^2/df and RMR values indicate good fit, while RMSEA, CFI, and GFI values suggest acceptable fit. Although NFI, NNFI, and AGFI values fall slightly below conventional thresholds, prior literature considers values between 0.80 and 0.89 acceptable (Cole, 1987; Doll et al., 1994; Segars & Grover, 1993). Thus, the scale's goodness-of-fit indices are deemed acceptable.

Math Achievement Test: Developed by Fidan (2013) for second-grade students, this test consists of 15 items. Students were given one class period (40 minutes) to complete the test. Correct answers were scored as 1, and incorrect answers as 0. Fidan (2013) reported a Kuder-Richardson-20 (KR-20) reliability coefficient of 0.92. In the present study, the KR-20 coefficient was 0.85.

Number Sense Test: It was developed by Palabıyık (2022) for second-graders. The test consists of 23 questions. However, since questions 20, 21, 22, and 23 contain subquestions, the subquestions in these items were evaluated separately, and the test was scored out of a total of 27 items in this study. Students were allotted one class period (40 minutes) to complete the test. Correct answers were scored as 1, and incorrect answers as 0. Palabıyık (2022) reported a KR-20 reliability coefficient of 0.86. In the present study, the KR-20 coefficient was 0.89.

Data Analysis

Prior to conducting the data analysis, the dataset was examined for outliers, as the presence of extreme values can distort the normality distribution and lead to misinterpretation of statistical results (Gürbüz, 2021). A univariate outlier analysis was performed, resulting in the identification and removal of three data points classified as outliers. Subsequently, a multivariate outlier analysis was carried out using Mahalanobis distance calculations. In accordance with the criterion proposed by Tabachnick and Fidell (2012)—where data points significant at the $p < .01$ level should be excluded—no multivariate outliers were detected in the dataset.

Following outlier removal, multicollinearity was assessed using Variance Inflation Factor (VIF) values. As recommended by O'Brien (2007), VIF values below 10 indicate no multicollinearity concerns. The computed VIF values were as follows: number sense performance (VIF = 1.72), MA (VIF = 1.14), and math achievement (VIF = 1.77). These values fall well within acceptable limits.

Means and standard deviations were calculated for all variables included in the analysis. Normality of scale and test distributions was evaluated through skewness and kurtosis indices (see Table 1). Prior to conducting the mediation and moderation analyses, Pearson product-moment correlation coefficients were computed to assess the bivariate relationships among variables (see Table 2). All descriptive and inferential analyses were performed using IBM SPSS Statistics v22. To examine whether number sense performance served as a mediating or moderating variable in the relationship between MA and math achievement, the PROCESS Macro (v4.2) was employed. Mediation was tested using Model 4 (Hayes, 2022), with 5,000 bootstrap resamples and a 95% confidence interval. The indirect effect was considered significant if the bootstrap confidence interval did not contain zero. Moderation was assessed using Model 1 (Hayes, 2022).

FINDINGS

This section presents the descriptive statistics, correlation analyses, and findings related to the mediation and moderation effects based on the data collected from second-grade students.

Descriptive Statistics

Descriptive statistics for the scores obtained from the Math Anxiety Scale, Math Achievement Test, and Number Sense Test administered to second-grade students are presented in Table 1.

Table 1. Descriptive Statistics of the Variables

	N	$\overline{X}$	SD	Skewness	Kurtosis	Min.	Max.
Number sense performance	138	9.8	6.0	0.32	-0.92	0	27
Math achievement	138	9.4	3.8	-0.61	-0.43	0	15
Math anxiety (MA)	138	18.9	4.0	0.86	0.09	13	35

Note: SD = Standard Deviation; Min. = Minimum value; Max. = Maximum value

As shown in Table 1, the mean score for number sense performance was 9.8 (SD = 6.0), with a positive skewness of 0.32 and a negative kurtosis of -0.92, indicating a left-skewed and platykurtic distribution. The mean score for math achievement was 9.4 (SD = 3.8), with a negative skewness value of -0.61, suggesting that most students achieved relatively high scores on the math

achievement test. The mean score for MA was 18.9 (SD = 4.0), with a positive skewness of 0.86. This right-skewed distribution indicates that the majority of students reported low to moderate levels of anxiety, whereas a smaller proportion of students reported high levels of anxiety. Overall, the descriptive statistics indicate that all three variables exhibit distributions that are approximately normal.

In the second phase of the study, correlational analyses were conducted to examine the relationships among the study variables. The results are presented in Table 2.

Table 2. Correlation Results Among Number Sense Performance, Math Achievement, and Math Anxiety

Variables	1	2	3
1. Number sense performance	-		
2. Math achievement	0.64**	-	
3. Math anxiety (MA)	-0.30**	-0.34**	-

*Note: **p<.01*

The results presented in Table 2 indicate a strong positive association between number sense performance and math achievement (r = .64, p < .01), suggesting that students with higher fluent number sense tend to perform significantly better in mathematics. A moderate negative correlation was observed between number sense performance and MA (r = –.30, p < .01), implying that students with greater numerical proficiency reported lower levels of anxiety related to mathematics. Additionally, a moderate inverse relationship was found between MA and math achievement (r = –.34, p < .01), indicating that elevated anxiety is linked to lower performance in mathematics. Together, these findings provide preliminary support for the proposed mediation and moderation models, wherein number sense performance may play a pivotal role in explaining or altering the influence of MA on achievement.

Testing the Mediating Effect of Number Sense Performance

The results of the mediation model examining whether number sense performance (M) mediates the relationship between math anxiety (X) and math achievement (Y) are presented in Figure 3.

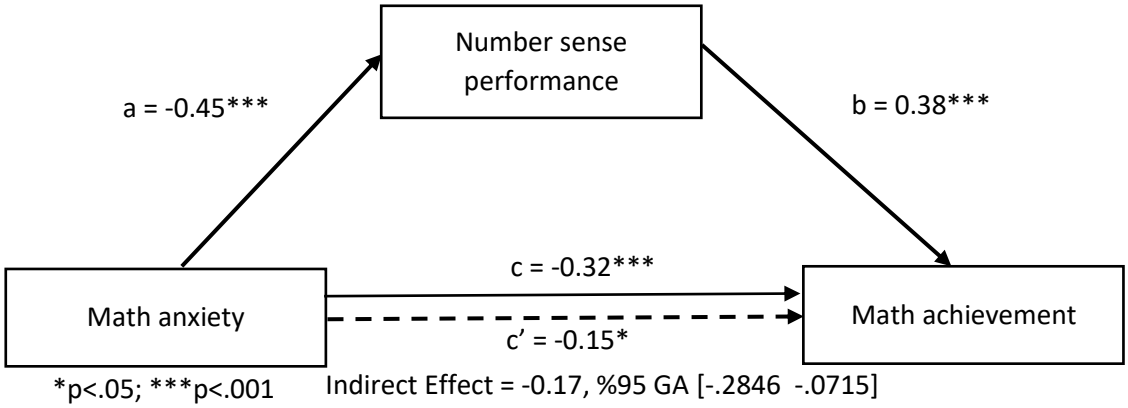

Figure 3. Mediation Model of Number Sense Performance in the Relationship Between Math Anxiety and Math Achievement

As illustrated in the mediation model presented in Figure 3, math anxiety (MA) (X) significantly predicted number sense performance (M), a = –.45, p < .001, and number sense performance significantly predicted math achievement (Y), b = .38, p < .001. The total effect of MA on math achievement was statistically significant, c = –.32, p < .001. These results provide evidence for a partial mediation, with both the direct effect (c' = –.15, p < .05) and the indirect effect ($a \times b$ = –.17, 95% CI [–.2846, –.0715]) reaching statistical significance. The confidence interval for the indirect effect does not include zero, supporting the mediation hypothesis. In summary, higher levels of MA are associated with lower number sense performance, which in turn positively predicts math achievement. While MA has a direct negative effect on math achievement, it also exerts an indirect effect via number sense performance, thereby supporting a partial mediation model.

Testing the Moderating Effect of Number Sense Performance

The statistical data concerning the moderation model, which examines whether number sense performance (W) moderates the relationship between math anxiety (X) and math achievement (Y), are presented in Table 3.

Table 3. Regression Analysis Results Indicating the Moderating Effect (N = 138)

Variables	β	S.E.	t	p	LLCI	ULCI
Math Anxiety (X)	-0.14	0.07	-2.20	0.00**	-0.2721	-0.0149
Number Sense Performance (W)	.038	0.04	8.82	0.03*	0.2945	0.4646
X*W (Interaction)	0.02	0.010	1.58	0.11	-0.0039	0.0353

Note: *p < .05; **p < .01; SE: Standard Error; LLCI: Lower Limit of Confidence Interval; ULCI: Upper Limit of Confidence Interval

The results of the moderation analysis (Table 3) revealed that both math anxiety (MA) and number sense performance were significant predictors of math achievement. Specifically, MA was found to have a significant negative effect on math achievement (β = -0.14, *p* = .00), whereas number sense performance exhibited a significant positive effect (β = 0.38, *p* = .03). However, the interaction term between MA and number sense performance was not statistically significant (β = 0.02, *p* = .11), indicating that number sense performance does not moderate the relationship between MA and math achievement. In other words, the strength or direction of the relationship between MA and achievement does not significantly change at varying levels of number sense. To further investigate whether the relationship between number sense performance and math achievement varies across different levels of MA (i.e., low, moderate, and high), a simple slopes analysis was conducted. The resulting interaction patterns are illustrated in Figure 4.

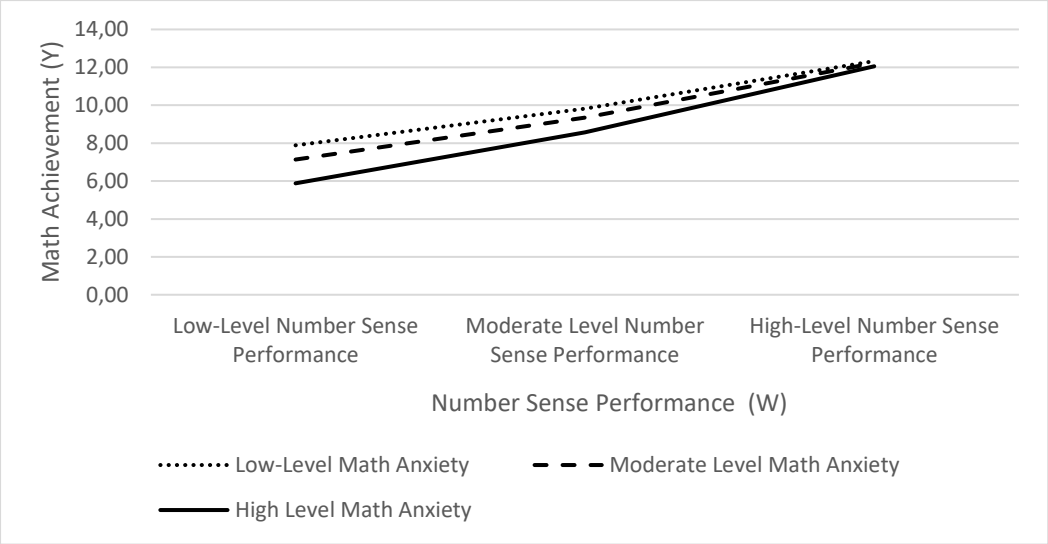

Figure 4. Simple Slope Analysis Graph of the Relationship Between Number Sense Performance and Math Achievement

As illustrated in Figure 4, the simple slope analysis of the relationship between number sense performance and math achievement indicates that math achievement scores differ based on levels of math anxiety (MA), particularly among students with low and moderate levels of number sense performance. Specifically, in these groups, students with higher MA tend to have lower math achievement compared to their peers with moderate or low anxiety levels. In contrast, among students with high number sense performance, math achievement scores appear relatively stable and do not significantly differ across varying levels of MA. These results suggest that high number sense performance may buffer the negative effects of MA on achievement, while such a protective effect is not evident among students with lower or moderate number sense skills.

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Mathematics is a multifaceted domain encompassing a broad spectrum of cognitive subdomains. Analyzing specific mathematical competencies is crucial for advancing our understanding of affective processes—particularly MA—and its relationship to performance outcomes, as well as for exploring how task characteristics may modulate this relationship (Mielicki et al., 2022). Investigating MA during the early years of schooling not only clarifies the interplay between emotional factors and academic performance, but also informs the development of targeted interventions aimed at alleviating anxiety and enhancing achievement (Ramirez et al., 2013). In this context, the present study examines the interrelations among number sense performance, math achievement, and MA in second-grade primary school students. Specifically, it investigates whether number sense performance mediates and/or moderates the relationship between MA and math achievement, thereby contributing to a more nuanced understanding of affective–cognitive dynamics in early mathematics education.

Math Anxiety, Number Sense Performance, and Math Achievement

Consistent with the proposed hypothesis, a strong and positive correlation was observed between number sense performance and math achievement (r = .64). This result aligns with a substantial body of research that identifies number sense as a foundational cognitive mechanism underlying mathematical competence (e.g., De Smedt et al., 2013; Geary, 2011; Jordan et al., 2010; Nelwan et al., 2021), as well as with findings from prior meta-analyses (Chen & Li, 2014; Fazio et al., 2014; Schneider et al., 2017). The strength of this association suggests that number sense plays a pivotal role in the mathematical development of second-grade students. Supporting the growth of this skill during early schooling may be crucial for fostering long-term academic success, especially given its integrative function across multiple mathematical domains.

Although number sense skills are generally thought to make a significant contribution to mathematical development, some researchers have reported evidence showing no significant correlation between these two variables (e.g., Price et al., 2012; Sasanguie et al., 2012). Inconsistencies in the literature may be related to differences in the types of tasks employed—such as symbolic versus non-symbolic comparison tasks, math achievement tests, or arithmetic performance tests (e.g., Caviola et al., 2019; Halberda et al., 2008; Nelwan et al., 2021; Olkun, 2015)—as well as to the age of the participants studied (e.g., Olkun, 2015). For instance, meta-analyses conducted by Fazio et al. (2014) and Chen and Li (2014) revealed that the correlation between number sense skills and math achievement appears strongest prior to formal schooling (r = .40), while this association weakens during primary education (r = .25) and further declines in adolescence and adulthood (r = .22 for ages 17 and older). These findings underscore the importance of age-related cognitive sensitivity and task design in interpreting the functional role of number sense across developmental trajectories.

Another finding from the study is that math anxiety (MA) showed moderate, negative correlations with both number sense performance (r = −.30) and math achievement (r = −.34). The observed correlations align with coefficients reported in previous cross-sectional studies (Ak & Ertekin, 2020; Sarı & Ekici, 2018; Mutlu et al., 2017) and meta-analyses (Barroso et al., 2021; Hembree, 1990; Namkung et al., 2019; Zhang et al., 2019), which have typically ranged from r = -0.25 to -0.40. Similarly, meta-analyses conducted in Türkiye have reported comparable average effect sizes (e.g. Bayırlı et al., 2021; Şad et al., 2016). For instance, the meta-analysis by Bayırlı and colleagues (2021), which synthesized findings from 29 studies conducted in Türkiye, identified a significant moderate negative relationship between MA and math achievement, with an average effect size of -0.36.

It is known that MA emerges in early childhood and tends to peak around ages 9 to 10 (Koch, 2018; Szczygieł & Pieronkiewicz, 2021). In the present study, the fact that most second-grade students reported low to moderate levels of anxiety suggests that MA may already begin to affect mathematical performance even in the early years of primary school. However, some studies have reported no significant relationship among MA, number sense, and math achievement (Braham & Libertus, 2018; Krinzinger et al., 2009; Szczygieł, 2021; Thomas & Dowker, 2000; Van den Bussche et al., 2020). These inconsistencies may be attributed to factors such as differences in the age of participants (children, adolescents, adults), the measurement tools employed (e.g., symbolic vs. non-symbolic number sense tasks; math achievement vs. arithmetic fluency tests; MA scales based on differing theoretical models), or contextual variables related to test administration (e.g., timed vs. untimed formats).

The Mediating and Moderating Role of Number Sense Performance

The most salient finding of the present study, in line with our prediction, is that number sense performance functions as a complex cognitive mechanism that not only contributes directly to math achievement but also regulates its relationship with an affective factor such as MA. In this context, the mediation analysis revealed that number sense performance plays a partial mediating role in the relationship between MA and math achievement. Specifically, while MA negatively affects number sense performance, number sense performance positively predicts math achievement. Moreover, both the direct and indirect effects were found to be statistically significant, supporting the notion that number sense partially transmits the adverse impact of anxiety on math achievement. The presence of both significant direct and indirect effects indicates that math anxiety (MA) influences achievement through two complementary pathways: (1) directly, consistent with cognitive-interference and processing-efficiency accounts that anxiety disrupts working memory and attentional control (Ashcraft & Faust, 1994; Ashcraft & Krause, 2007; Eysenck & Calvo, 1992; Eysenck et al., 2007), and (2) indirectly, aligning with evidence that MA undermines foundational number-sense processes and working-memory–dependent numerical processing (Maldonado Moscoso et al., 2020; Skagerlund et al., 2019). Furthermore, the findings are consistent with previous research suggesting that MA negatively affects core skills such as number sense (Maldonado Moscoso et al., 2020; Sarı & Szczygieł, 2023; Skagerlund et al., 2019). Although this study employed a cross-sectional design, the observed direct and indirect effects of MA on math achievement and number sense performance, as well as the direct effect of number sense on math achievement, are in line with findings from prior longitudinal studies (Cargnelutti et al., 2017; Pantoja et al., 2020; Szczygieł et al., 2024). For instance, Cargnelutti et al. (2017) demonstrated a strong negative association between MA and math achievement in second and third grades, and showed through longitudinal analyses that MA measured in second grade independently predicted math performance in third grade. Similarly, Szczygieł et al. (2024) found that math achievement at Time 1 predicted MA at Time 2, while MA at Time 1 also predicted math achievement at Time 2. Additionally, the authors noted that MA at baseline (Time 0) was predicted by general anxiety and symbolic numerical representation, an indicator of number sense skills. Collectively, these findings suggest that MA can negatively affect children's math achievement as early as second grade. Moreover, the identified mediating role of number sense underscores that anxiety can adversely impact not only math achievement but also foundational cognitive skills, highlighting the complex interplay between affective and cognitive processes in early mathematics education.

Another notable finding of the study is that the hypothesized interaction term in the moderation analysis was not statistically significant. Although number sense performance was found to partially mediate the relationship between MA and math achievement, it did not serve as a moderating factor. The lack of statistical significance in the interaction effect may be attributable to sample homogeneity or limitations inherent in the measurement instruments. However, consistent with the theoretical prediction, slope analyses revealed that students with high number sense performance appeared to be less affected by the negative impact of MA on achievement. This pattern suggests a buffering effect that goes beyond the classical moderation hypothesis. It may be posited that advanced number sense skills help students maintain their achievement levels in the presence of heightened anxiety. This interpretation is partially supported by Braham and Libertus (2018), who proposed that strong number sense may serve as a protective factor against the detrimental effects of MA. Moreover, the differentiation in math achievement scores across levels of MA (low, moderate, high) within low and moderate number sense performance groups echoes previous findings (Ashkenazi & Cohen, 2021, 2023; Maki et al., 2024; Maldonado Moscoso et al., 2020; Nunez-Pena & Suarez-Pellicioni, 2014; Passolunghi et al., 2016; Sarı & Szczygieł, 2023; Skagerlund et al., 2025). These studies collectively indicate that children with high levels of MA tend to demonstrate lower performance on math tasks (Maki et al., 2024; Skagerlund et al., 2025; Sarı & Szczygieł, 2023), face greater difficulty solving complex problems (Maki et al., 2024), and possess less precise representations of numerical magnitude—often making more errors in symbolic processing (Ashkenazi & Cohen, 2023; Maloney et al., 2010, 2011; Nunez-Pena & Suarez-Pellicioni, 2014; Sarı & Szczygieł, 2023).

Several limitations of the present study warrant a cautious interpretation of the findings. First, the cross-sectional design restricts the ability to infer causal relationships among MA, number sense performance, and math achievement. Whether anxiety influences the development of number sense, or whether weak number sense contributes to heightened anxiety, remains unclear and can only be examined in greater detail through longitudinal or experimental research designs. Second, the exclusive use of a self-report scale to measure MA may introduce subjective bias, particularly in younger age groups where emotional awareness and self-expression skills may still be developing (see Cargnelutti et al., 2017; Primi et al., 2020). Third, the sample was drawn from a single school representing middle socioeconomic status, which may limit the generalizability of the findings to other age groups, socioeconomic backgrounds, or cultural contexts. Fourth, unmeasured variables such as teacher practices (see Hunt & Sarı, 2019; Sarı & Aksoy, 2016), parental attitudes toward mathematics (see Sarı & Hunt, 2020; Türk & Bedir, 2021), classroom climate, and students' prior mathematical experiences (see Quintero et al., 2022) could have influenced the observed relationships. Finally, collecting data at only a single time point does not capture how these factors may evolve or interact over time. Together, these limitations suggest that the present findings should be interpreted within their specific context and highlight the need for further research to enable broader generalizations. Importantly, rather than diminishing the value of the study, these limitations offer a roadmap for future research directions aimed at deepening our understanding of the complex interplay among affective and cognitive factors in early mathematics education.

In conclusion, this study holistically examined the relationships among MA, number sense performance, and math achievement, yielding several important findings. Number sense performance emerged as a strong predictor of math achievement in second-grade primary school students. MA was found to negatively affect math achievement both directly and indirectly through number sense, which served as a partial mediating variable in this relationship. Although the moderating role of number sense was not statistically significant, slope analyses suggested that students with higher number sense performance may be less vulnerable to the adverse effects of anxiety. These results underscore the importance of designing systematic interventions aimed at enhancing number sense, particularly during the early years of primary education. Such interventions may not only support cognitive development and improve students' math achievement (e.g., Kucian et al., 2011; Sarı & Olkun, 2024; Wilson et al., 2006) but also indirectly strengthen their ability to manage negative emotions related to mathematics (e.g., Ng et al., 2022; Passolunghi et al., 2020). Furthermore, comprehensive support programs that target both cognitive and affective domains could be especially beneficial for children exhibiting higher levels of MA. These programs might combine anxiety-reduction strategies with practices designed to foster number sense development. Future research should investigate the interplay between number sense and affective variables in greater depth, across different age groups and among populations at developmental risk (e.g., children with mathematical learning difficulties or those from lower socioeconomic backgrounds). Such work could provide valuable insights for early diagnosis and the prevention of mathematical difficulties. Given that the dual role of number sense—as both a mediating and protective factor in mathematical development—has been explored in only a limited number of studies (e.g., Cargnelutti et al., 2017; Pantoja et al., 2020; Szczygieł et al., 2024), there remains a need for longitudinal research to clarify these dynamics. Focusing on developmental trajectories over time may help overcome the limitations inherent in cross-sectional and correlational designs, ultimately allowing for more robust causal interpretations.

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Statements of publication ethics

We hereby declare that the study has not unethical issues and that research and publication ethics have been observed carefully.

Researchers' contribution rate

Conceptualization MHS, BÖ, Data curation MHS, BÖ, Formal analysis BÖ, Investigation MHS, Methodology MHS, BÖ, Writing – original draft MHS, Writing – review & editing MHS, BÖ.

Ethics Committee Approval Information

The Research Ethics Committee of the Nevşehir HBV University (date and number = 2025/2025.05.164) authorized the recruitment, tasks, and overall procedure. The research was conducted on a voluntary basis and no reward or money was paid to the participants.

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