ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. XI, Issue 12/ March 2024

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

A Comprehensive Review on Dyscalculia, Mathematics Anxiety, and Working Memory: Exploring Their Interrelations and Implications for Mathematics Performance[1]

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Abstract

This review article provides a comprehensive examination of three interrelated domains—dyscalculia, mathematics anxiety, and working memory—and their impact on mathematics performance, particularly in children. Dyscalculia is characterized as a specific learning disorder that manifests as persistent difficulty in understanding numbers and performing arithmetic operations. The article details the various types of dyscalculia, emphasizing developmental, acquired, and pseudo-dyscalculia subtypes, and notes contributing factors such as genetic predispositions, neurobiological anomalies in parietal brain regions, and cognitive deficits (e.g., working memory, attention, and executive functions). Mathematics anxiety is explored as a critical emotional factor, disrupting performance by overwhelming cognitive resources. Research findings indicate that math anxiety negatively affects mathematical problem-solving, especially by interfering with working memory processes. In children with dyscalculia, co-occurring math anxiety can further intensify learning challenges, creating a negative feedback loop that impairs both skill acquisition and willingness to engage in mathematical tasks. Working memory, which involves the temporary storage and manipulation of information, is highlighted as crucial for arithmetic success. Deficits in working memory are frequently found in children with dyscalculia and are exacerbated by math anxiety. Consequently, targeted interventions—ranging from direct instruction and the Concrete–Representational–Abstract (CRA) approach to cognitive-behavioral techniques and working memory training—are recommended to address both the cognitive and emotional dimensions of mathematical learning difficulties. Overall, the article underscores the importance of early and comprehensive intervention, including individualized instructional strategies that incorporate emotional regulation. By addressing dyscalculia, mathematics anxiety, and working memory deficits in tandem, educators, parents, and clinicians can foster better mathematical outcomes and more positive attitudes toward learning in affected children.

Keywords: Dyscalculia, Mathematics Anxiety, Working Memory, Mathematics Performance , Early Intervention, Neurocognitive Factors

INTRODUCTİON

Mathematics learning difficulties manifest in diverse ways, ranging from mild challenges in numerical fluency to severe deficits in arithmetic and problem-solving

[1] This article was produced from İhsan Söylemez's doctoral thesis titled "The Effect of Activities Designed to Remove Mathematics Anxiety on the Mathematics Performance, Mathematics Anxiety and Working Memory of Children at Risk of Discalculia".
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skills. Among the specific learning disorders related to mathematics, *dyscalculia* has attracted considerable scholarly attention. This difficulty not only disrupts children's ability to process numbers and perform basic arithmetic but also affects their broader educational journey and socioemotional well-being. In parallel, *mathematics anxiety* stands out as a critical emotional factor that undermines mathematical performance by impairing cognitive resources, particularly working memory. When children experience both dyscalculia and mathematics anxiety, the synergistic effect can further compromise their academic outcomes. Additionally, *working memory*—a cognitive system responsible for the transient storage and processing of information—has been repeatedly identified as a key component in mathematical learning and performance. This review aims to offer a comprehensive examination of (a) dyscalculia and its core characteristics, (b) the concept of mathematics anxiety, (c) the role of working memory in mathematics, (d) the confluence of dyscalculia and mathematics anxiety in children, and (e) the impact of this interplay on mathematics performance.

DYSCALCULİA

Definition and Core Characteristics

Dyscalculia derives from the Latin roots "dis-" (denoting difficulty or impairment) and "calculi" (meaning stones or calculation) and refers to a specific learning disorder characterized by a persistent difficulty in acquiring basic numerical and arithmetic skills (Butterworth et al., 2011; Haberstroh & Schulte-Körne, 2019; Kucian & von Aster, 2015). Individuals with dyscalculia often struggle to develop a firm sense of number magnitude, execute arithmetic operations, and engage in mathematical reasoning aligned with the normative developmental trajectory for their age and educational background (Chodura et al., 2015; Landerl et al., 2004). These struggles extend beyond simple calculation difficulties, involving conceptual gaps in understanding numbers, quantities, and spatial representations (Butterworth, 2010; Haberstroh & Schulte-Körne, 2019).

Types of Dyscalculia

Multiple subtypes of dyscalculia have been discussed in the literature, each emphasizing particular cognitive or developmental domains (Butterworth, 2005; Chodura et al., 2015). *Developmental dyscalculia*, the most common form, typically arises from innate or genetic factors affecting numerical processing regions in the brain (Landerl et al., 2004; Rykhlevskaia et al., 2009). Within developmental dyscalculia, researchers categorize subtypes such as *verbal dyscalculia* (difficulties in retrieving arithmetic facts verbally), *practognostic dyscalculia* (issues with manipulating quantities in practical contexts), *lexical/graphical dyscalculia* (problems reading and writing numerals or symbols), *ideognostik dyscalculia* (challenges conceptualizing novel mathematical relations), and *operational dyscalculia* (difficulties executing arithmetic operations) (Košč, 1974; Metikasari et al., 2019; Sokol et al., 1991).

Acquired dyscalculia, though less prevalent, emerges following brain trauma or neurological insults, such as strokes or head injuries (Nkepah & Atanga, 2022). In contrast, *pseudo-dyscalculia* or *"false dyscalculia"* mimics the symptoms of dyscalculia but is not driven by underlying neurobiological factors; instead, it may be due to factors like poor instruction, limited exposure to mathematical concepts, attention deficits, or insufficient working memory capacity (Aster & Shalev, 2007; Butterworth et al., 2011; Krön, 2023).

Prevalence and Diagnostic Issues

Prevalence estimates for dyscalculia vary, partly due to methodological inconsistencies, varying definitions, and assessment tools used across studies (Barbaresi et al., 2005; Morsanyi et al., 2018). Nonetheless, the literature generally indicates that approximately 3% to 7% of the population may have dyscalculia (Gross-Tsur et al., 1996; Shalev & Von Aster, 2008). The diagnostic process involves comprehensive evaluation protocols, often including standardized achievement tests, teacher observations, psychoeducational assessments, and measures of cognitive functions such as working memory (Arx et al., 2016; Haberstroh & Schulte-Körne, 2019). The risk of underdiagnosis or misdiagnosis remains high when co-occurring conditions—such as dyslexia or attention-deficit/hyperactivity disorder (ADHD)—complicate clinical pictures (Landerl & Moll, 2010; Luoni et al., 2022).

Etiological Factors in Dyscalculia

The etiology of dyscalculia is complex, involving a confluence of genetic, neurobiological, and cognitive factors. Twin studies and familial aggregation patterns highlight the inherited susceptibility to dyscalculia (Butterworth, 2010; Kovas & Plomin, 2007). Neuroimaging research underscores significant structural and functional atypicalities in parietal regions associated with numerical processing (Kaufmann & von Aster, 2012; Price et al., 2007). On the cognitive level, deficits in domain-general capabilities—particularly working memory, attention, and executive functions—can exacerbate numerical difficulties (Kunwar, 2021; Price & Ansari, 2013). Some children with dyscalculia exhibit poor performance in tasks requiring the maintenance, manipulation, and updating of numerical information, signifying that working memory shortcomings play a major role in the manifestation of dyscalculia (Attout & Majerus, 2014; Szűcs et al., 2013).

Dyscalculia Symptoms and Impact on Daily Life

Although dyscalculia is often conceptualized as a disorder of basic arithmetic, its repercussions extend to broader domains such as spatial navigation, temporal processing, and financial management (Aquil & Ariffin, 2020; Butterworth et al., 2011). Many children with dyscalculia struggle to estimate quantities accurately, follow multi-step procedures, and retrieve basic arithmetic facts from memory. Consequently, their daily functioning can be significantly impacted, not only academically but also in routine tasks such as reading clocks, budgeting, and understanding measurements (Chinn, 2020; Landerl & Moll, 2010).

MATHEMATİCS ANXİETY

Concept and Significance

Mathematics anxiety refers to the feelings of tension, worry, or fear experienced when encountering mathematics-related activities, thereby hindering performance by reallocating cognitive resources away from arithmetic and problem-solving tasks (Ashcraft & Moore, 2009; Hembree, 1990; Maloney & Beilock, 2012). It can develop in learners of all ages, genders, and cultural backgrounds, suggesting that both environmental and cognitive-emotional variables—such as stereotype threats, self-efficacy beliefs, and teaching approaches—interact to generate anxiety (Beilock et al., 2010; Luttenberger et al., 2018).

The significance of mathematics anxiety lies in its far-reaching consequences. Research shows that mathematics anxiety is negatively associated with mathematics achievement (Barroso et al., 2021; Ma & Xu, 2004). Students with heightened math anxiety often exhibit reduced motivation to engage with mathematical tasks, form negative attitudes toward the subject, and are less likely to pursue math-related courses or careers (Ashcraft & Krause, 2007; Kyttälä & Björn, 2021). Additionally, math anxiety constrains core cognitive processes—particularly working memory—by overwhelming the mental workspace with worry-related thoughts (Suárez-Pellicioni et al., 2015).

Underlying Factors and Mechanisms

A host of factors can precipitate or intensify math anxiety, including adverse experiences in early math education (e.g., repeated failures, harsh critiques), gender stereotypes, negative parental or teacher attitudes, and cultural pressures emphasizing the importance of mathematical competence (Choi & Han, 2020; Dowker et al., 2016). Academic environments that rely excessively on timed tests or rote memorization can inadvertently boost stress levels and strengthen avoidance behaviors (Cavanaugh, 2007; Finlayson, 2014). On a cognitive level, math anxiety disrupts performance by commandeering working memory resources. The anxious individual's constant rumination on potential failure or negative evaluations leaves fewer cognitive resources available for mathematical computations (Ashcraft, 2002; Ashcraft & Kirk, 2001).

Effects on Performance and Learning

Math anxiety has clear negative implications for arithmetic processing, conceptual understanding of mathematical principles, and overall problem-solving capabilities (Ashcraft & Moore, 2009; Bosmans & Smedt, 2015). When anxiety is high, children often avoid math-related activities, reducing the frequency and depth of their mathematical practice. This avoidance leads to minimal exposure to critical math concepts, compounding conceptual gaps over time (Beilock & Carr, 2005; Choe et al., 2019). Moreover, for individuals who already have inherent cognitive vulnerabilities or learning difficulties—such as dyscalculia—the co-occurrence of math anxiety can produce a vicious cycle, wherein performance deficits provoke more anxiety, and anxiety further hampers performance (Ashcraft & Krause, 2007; Wu et al., 2012).

Mitigating Mathematics Anxiety

Research has identified various strategies for mitigating math anxiety, including:

- **Cognitive-Behavioral Interventions:** Techniques that alter negative thoughts and reframe maladaptive beliefs about mathematics can minimize anxiety (Liu, 2023; Pizzie et al., 2020).
- **Expressive Writing and Reflection:** Encouraging learners to write about their anxieties can help reduce intrusive thoughts (Park et al., 2014).
- **Supportive Instructional Environments:** Ensuring a low-pressure setting that values process over correctness promotes engagement (Finlayson, 2014; Furner & Duffy, 2022).

- **Relaxation and Mindfulness Training:** Structured relaxation methods—like deep breathing—can lessen physiological arousal (Rubinsten et al., 2018).
- **Teacher Professional Development:** Because teacher math anxiety can influence student outcomes, training teachers to manage their own anxiety proves beneficial (Beilock et al., 2010).

WORKİNG MEMORY

Definition and Theoretical Perspectives

Working memory is a limited-capacity cognitive system responsible for the transient storage, manipulation, and updating of information used in various higher-order processes such as comprehension, reasoning, learning, and problem-solving (Adams et al., 2018; Baddeley, 1992; Baddeley & Hitch, 1974; Cowan, 2001). One widely recognized model proposes multiple components: (1) the central executive, which allocates attention and manages information; (2) the phonological loop, which retains verbal data; and (3) the visuospatial sketchpad, which maintains spatial and visual representations (Baddeley, 2003; Guo et al., 2021). More recent discussions incorporate an episodic buffer and emphasize the interplay between long-term memory and working memory (Baddeley, 2003).

Importance in Learning and Academic Achievement

Working memory capacity robustly predicts reading comprehension, language processing, and arithmetic skills (Alloway et al., 2009; Chen et al., 2016; Holmes & Adams, 2006). For instance, storing and manipulating partial sums while performing multi-step calculations relies heavily on an intact working memory system. Children with lower working memory capacity may struggle to keep pace with instruction that requires them to hold numerical information in mind across multiple arithmetic steps (Swanson, 2006; Raghubar et al., 2010). Importantly, research suggests that working memory is even more predictive of later academic performance in children with learning difficulties than general intelligence (Alloway, 2009).

Connections to Emotional Regulation and Cognitive Control

Beyond academic domains, working memory plays a significant role in emotional regulation and attentional control (Barkus, 2020; Yang, 2022). When stress or anxiety arises, working memory resources must balance task-related processing with the management of emotional stimuli. Individuals with higher working memory capacity may be better able to suppress negative thoughts or intrusive worries, potentially mitigating the detrimental effect of anxiety on performance (Ashcraft & Moore, 2009; Finell et al., 2022).

DYSCALCULİA AND MATHEMATİCS ANXİETY İN CHİLDREN

Intersections of Cognitive and Affective Vulnerabilities

Children diagnosed with dyscalculia commonly exhibit deficits in number sense, arithmetic fluency, and complex problem-solving (Butterworth, 2010; Landerl et al., 2004). These academic difficulties can induce heightened levels of frustration, insecurity, and negative self-perception, which in turn fuel mathematics anxiety (Kucian et al., 2018; Rubinsten & Tannock, 2010). Indeed, research indicates that math anxiety prevalence is significantly higher among children with dyscalculia compared to typically developing peers (Beilock et al., 2010; Maloney & Beilock, 2014).

Mathematics anxiety in dyscalculic children often manifests as avoidance behaviors—such as reluctance to participate in math lessons or refusal to attempt tasks—even when they have the potential to succeed at simpler numerical activities (Barroso et al., 2021; Gunderson et al., 2011). Such avoidance exacerbates existing skill gaps (Mutlu et al., 2022). Over time, repeated episodes of failure or fear of failure produce a cyclical pattern: poor performance intensifies math anxiety, which further undermines performance (Rubinsten & Tannock, 2010).

Empirical Evidence on the Dyscalculia-Anxiety Link

Neuroimaging studies show that both dyscalculia and math anxiety may involve atypical activations in the amygdala, a region implicated in emotional processing (Kucian et al., 2018). Additionally, difficulties in retrieving arithmetic facts or conceptualizing basic numeric relationships contribute to more frequent error-making. These errors fuel children's math-related negative affect, heightening their anxiety (Ashcraft, 2002; Mutlu et al., 2016, 2017).

Mutlu and Akgün (2017) note that ongoing struggles with mathematics can lead to strong emotional responses and attitudes. In particular, children with dyscalculia who lack customized intervention often report significant anxiety during school assessments and even in everyday tasks involving estimation, financial transactions, or time management. This interplay between cognitive deficits (dyscalculia) and emotional factors (math anxiety) signals a need for multifaceted intervention plans that address both skill deficits and affective components.

THE ROLE OF WORKİNG MEMORY İN DYSCALCULİA AND MATHEMATİCS ANXİETY

Working Memory Deficits in Dyscalculia

Several studies confirm that dyscalculic children frequently show marked deficits in working memory, especially in tasks requiring the temporary storage and manipulation of numeric or spatial information (Attout & Majerus, 2014; Szűcs et al., 2013). These deficits are visible across different components of working memory: some children struggle more with verbal (phonological) loops, while others exhibit difficulties with the visuospatial sketchpad (Landerl et al., 2004; Luoni et al., 2022). Such limitations create obstacles for performing multi-step arithmetic computations, retrieving math facts, and maintaining newly introduced concepts in short-term storage long enough for thorough processing (Raghubar et al., 2010).

Studies by Mutlu et al. (2022) highlight that teachers often fail to recognize these complex interrelations among working memory deficits, dyscalculia, and poor math performance, leading to generalized or inadequate forms of remediation. The authors emphasize the importance of individualized strategies that target not only arithmetic instruction but also the development of cognitive processes—particularly working memory skills.

Impact of Mathematics Anxiety on Working Memory

Math anxiety induces intrusive worries that occupy cognitive resources, thereby reducing the working memory capacity required to effectively process math tasks

(Ashcraft & Moore, 2009; Ramirez et al., 2013). This interference effect is particularly detrimental for children whose working memory capacity is already compromised by dyscalculia (Rubinsten & Tannock, 2010; Witt, 2012). For these children, the combination of a limited memory store and persistent anxious thoughts creates a significant barrier to successful arithmetic processing (Ashcraft & Kirk, 2001; Kucian et al., 2018).

Some studies demonstrate that even children with relatively strong working memory skills can become hindered in the presence of math anxiety if that anxiety escalates to the point of monopolizing mental resources (Evans et al., 2020; Ramirez et al., 2016). Thus, to foster mathematical growth, interventions must address not only skill-based components but also the emotional-cognitive synergy that drives performance.

IMPLİCATİONS FOR INTERVENTİON AND INSTRUCTİON

Targeted Approaches for Dyscalculia

Interventions designed for dyscalculic learners traditionally include structured, sequential teaching methods and visual scaffolds, helping students build foundational number sense (Chin & Fu, 2021; Shalev & Von Aster, 2008). *Direct instruction*, involving explicit and systematic practice in small incremental steps, appears especially effective (Gersten et al., 2009; Kroesbergen & Van Luit, 2003; Swanson & Jerman, 2006). *Schematic or concrete-to-abstract (CRA)* instructional sequences can further help children link tangible experiences to symbolic representations (Rojo & Wakim, 2023).

Mutlu and colleagues (Mutlu & Akgün, 2017; Mutlu et al., 2022) highlight a “Multiple Filter Model” for diagnosing mathematics learning difficulties, emphasizing collaborative data gathering (teacher observations, screening tools, cognitive assessments) and individualized remedial frameworks. They argue that comprehensive diagnostic processes can yield more precise interventions, particularly for learners whose dyscalculia coincides with significant working memory weaknesses or high math anxiety.

Addressing Math Anxiety in Dyscalculic Children

Alleviating math anxiety in children with dyscalculia necessitates strategies that target both cognitive skills and affective responses (Furner & Duffy, 2022; Kucian et al., 2018). Effective approaches may include:

- **Therapeutic Interventions:** Cognitive-behavioral therapy (CBT) techniques, mindfulness, and relaxation methods that reduce the emotional burden related to math tasks (Pizzie et al., 2020; Samuel & Warner, 2019).
- **Positive Classroom Climate:** The teacher’s role is vital in shaping how students perceive and approach mathematics. Reducing time pressure, offering consistent feedback, and presenting supportive error-correction can reduce anxiety (Beilock et al., 2010; Mutlu et al., 2022).
- **Parental Engagement:** Given the generational transmission of math anxiety, parental awareness programs and collaborative homework support can minimize negative emotional spillover at home (Cosso et al., 2022; Zhang, 2023).

- **Gradual Exposure and Mastery Experiences:** Structured practice allowing students to repeatedly experience success in progressively challenging tasks can boost self-efficacy and lessen avoidance (Ashcraft & Moore, 2009; Ramirez et al., 2016).

Enhancing Working Memory within Mathematics Instruction

Because of the intricate interplay of working memory, math anxiety, and dyscalculia, interventions that bolster working memory could substantially improve mathematical performance (Kroesbergen & Dijk, 2015; Raghubar et al., 2010). Such interventions may feature:

- **Working Memory Training Programs:** Digital platforms or small-group sessions focused on tasks like updating, backward digit span, or n-back tasks (Alloway & Passolunghi, 2011; Holmes et al., 2009; Klingberg et al., 2005).
- **Metacognitive Techniques:** Teaching children to self-monitor and strategically manage their cognitive load, such as by breaking down multi-step problems or articulating mental steps aloud (Furner & Duffy, 2022; Ozlü Ünlü et al., 2022).
- **Supportive Resources:** Visual aids, manipulative materials, and step-by-step scaffolding to lighten working memory demands (Amelia & Supena, 2022; Rojo & Wakim, 2023).

CONCLUSİON

Dyscalculia is a multifaceted learning disorder that disrupts a child's ability to process, represent, and manipulate numerical information. Co-occurring mathematics anxiety adds an emotional burden, thereby amplifying cognitive load and reducing academic success. This confluence becomes even more detrimental when coupled with limited working memory capacity, as working memory plays a central role in short-term information management and problem-solving. The evidence suggests that early, targeted, and comprehensive interventions—encompassing explicit instruction, working memory supports, and emotional regulation strategies—can mitigate the negative consequences of dyscalculia and math anxiety on mathematics performance.

Future research should continue to investigate personalized educational interventions, particularly those tailored to learners who exhibit the combined cognitive-affective challenges associated with dyscalculia and math anxiety. Moreover, broadening teacher training and parental guidance programs would strengthen the quality and consistency of the support system available to affected children. Ultimately, bridging the gap between empirical research and classroom practice holds promise for enabling children with dyscalculia to achieve more positive trajectories in mathematics learning and overall academic development.

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