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HOW DOES FUNCTIONAL CONNECTIVITY BETWEEN BRAIN REGIONS DIFFER IN INDIVIDUALS WITH DYSCALCULIA COMPARED TO THOSE WITHOUT?

Nurani Fatini Zulhelmy[1], Afifah Hazirah Adi Hanafi[2], Nur Aisya Imani Yuszaimi[3], Nur Farah Nabilah Winoto[4], Nur Amirah Raja Mohamed[5], Che Mohd Nasril Che Mohd Nassir[6], Mohamed Ayaaz Ahmed[7], Huriyyah Hamiemah Md Tajudin[8], Usman Jaffer[9*]

[1] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: nf.zulhelmy@live.iium.edu.my

[2] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: a.hazirahhanafi@live.iium.edu.my

[3] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: aisya.imani@live.iium.edu.my

[4] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: farah.nw@live.iium.edu.my

[5] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: amirah.rm@live.iium.edu.my

[6] Department of Anatomy and Physiology, School of Basic Medical Sciences, Faculty of Medicine, Universiti Sultan Zainal Abidin (UniSZA), 20400 Kuala Terengganu, Terengganu, Malaysia
Email: nasrilnassir@unisza.edu.my

[7] Southern Ambition 473 CC, 7764, Cape Town, South Africa
Email: ayaaz@reamz.co.za

[8] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: huriyyahamiemah02@gmail.com

[9] AbdulHamid AbuSulayman Kulliyyah of Islamic Revealed Knowledge and Human Sciences, International Islamic University Malaysia, 50728 Kuala Lumpur, Malaysia
Email: jafferu@iium.edu.my

[*] Corresponding Author

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Abstract:

Dyscalculia, a specific learning difficulty in mathematics, is characterized by impairments in number processing and arithmetic skills. This paper aims to review past and current literature on functional connectivity differences in individuals with dyscalculia compared to typically developing individuals. Our findings show altered connectivity within the intraparietal sulcus (IPS), hippocampus, including the parietal, temporal, and frontal areas. These findings provide valuable insights into the neural mechanisms underlying dyscalculia. Furthermore, this paper also provides insights from the Islamic perspective in addressing dyscalculic issues. Therefore, by having these insights researchers are able to suggest interventions for individuals with dyscalculia.

Keywords:

Dyscalculia, Brain Connectivity, Impacted Brain Region, Intervention

Introduction

The major issue regarding dyscalculia is due to its rarity, it contributes to a lack of awareness of dyscalculia compared to other learning disabilities such as dyslexia (Grant, 2017 as cited in Mahmud et al., 2020). Aquil and Ariffin (2020) stated that there are many definitions of dyscalculia due to its inconsistency and ambiguity. It is important to define dyscalculia properly, so it can be distinguished from general mathematics difficulties, thus the prevalence of genuine dyscalculia can be reported accurately (Peard, 2010).

Mahmud et al. (2020) define dyscalculia from the Diagnostic and Statistical Manual (DSM-IV) as a learning disorder that is mainly concerned with mathematics. Contrary to much research that has defined dyscalculia as general mathematical difficulty, Dowker (2005, as cited in Aquil & Ariffin, 2020) argues that dyscalculia is accurately understood as arithmetic impairment. With this, confusion in investigating dyscalculia can be reduced by using correct and specific terms to describe the condition.

According to Kunwar and Sharma (2020, as cited in Nkepah & Atanga, 2022), dyscalculia describes a range of learning difficulties affecting mathematical ability but not necessarily in every aspect of mathematics. This indicates that dyscalculia term is broad, and can describe diverse conditions that lead to various mathematics difficulties, including developmental dyscalculia, mathematical disability, numerical learning disability and number fact disorder (Emerson & Babtie, 2010, as cited in Nkepah & Atanga, 2022). For example, de Smedt, Peters and Ghesquiere (2019) define dyscalculia as a developmental disorder where it impacts how children's brains develop math skills.

Dyscalculia can be detected as early as during childhood (Kuhl et al., 2021). Price and Ansari (2013, as cited in Aquil & Ariffin, 2020) stated the prevalence of dyscalculia ranges from 3% to 6.5%, making it as common as dyslexia in various studies conducted in different countries,

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hence making dyscalculia a global concern. Not only that, the study found that there is a high comorbidity between dyscalculia and dyslexia, causing people who have dyslexia to develop dyscalculia too (Kaufman & Aster, 2012, as cited in Aquil & Ariffin, 2020; Peters et al., 2018). In terms of prevalence among genders, Jacobson (2024) found that dyscalculia occurs equally in males and females. In contrast, some studies have shown that this problem is more common among girls (Lewis & Fisher, 2016, as cited in Mahmud et al., 2020). Elhakeem et al. (2025) also discovered a slightly higher frequency of dyslexia in girls than in boys, while other studies discovered a similar prevalence of dyslexia in older primary school students of both genders. Thus, it can be seen that dyscalculia varies among genders and ages, although most likely can be noticed at an early age.

Learning Support Service (2015) as cited in Aquil and Ariffin (2020) mentioned characteristics of a person diagnosed with dyscalculia which included: 1) deficiency in number sense, 2) weak number operation and understanding, 3) using fingers as the only method to calculate, 4) struggles in money management, 5) difficulty in time-related issue, and 6) weak memory and sequencing problems. In addition, due to the importance of learning mathematics in school, signs of children with dyscalculia can be identified: 1) struggles to understand and recall basic arithmetic operations, 2) troubles in understanding concepts of word problems and other non-mathematical calculation, 3) struggle with academic assignments, homework and examinations, 4) struggle to maintain expected grade in mathematical subjects, and 5) difficult to understand visual-spatial learning like charts and graphs (Jacobson, 2024).

Therefore, this paper aims to develop a deeper understanding on dyscalculia focusing on the functional connectivity between brain regions that differ in individuals with dyscalculia compared to those without.

Methodology

The search strategy for this review was comprehensive and standardized, utilizing mainly Google Scholar as the academic search engine. Furthermore, the literatures were compiled through Research Gate, Frontier, Science Direct and Springer Nature library database. To ensure comprehensive search, Boolean operators (AND, OR) were used alongside the relevant keywords, including "physiological mechanism of dyscalculia," "academic arithmetic disability," and dyscalculia in children."

Inclusion and Exclusion Criteria

To ensure the most relevant publications, the first criteria was the publication date. All literatures were published between January 2018 to December 2025, with focus on children subjects. Furthermore, the literatures included were articles with original findings, article reviews, case studies and book chapters. The excluded publications were thesis papers and student dissertations as well as grey literature. It is also noteworthy to mention that all publications were in English language.

Data Extraction

A standardized form was developed for the data extraction process. This form enabled comprehensive synthesis of data, including the research designs, objectives of study research findings and limitations of research. As such, the information was organized into meaningful paragraphs.

Findings

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Neural Basis of Numerical and Arithmetic Processing

de Smedt et al. (2019) explained that children typically develop number skills through two core processes: numerical magnitude processing and arithmetic ability. Numerical magnitude processing refers to the capacity to understand and manipulate numerical size in both symbolic and non-symbolic forms (Scalise & Ramani, 2021). Arithmetic, meanwhile, involves the execution of basic mathematical operations such as addition, subtraction, multiplication, and division.

Differences in Functional Connectivity

de Smedt et al. (2019) found that children with dyscalculia exhibit significantly reduced brain activation in the intraparietal sulcus (IPS), a key region associated with numerical processing, compared to typically developing children. This reduced activation suggests disruptions in the development of neural networks specialised for number processing. Similarly, Xiang et al. (2016, as cited in Molise & Kakoma, 2024) identified abnormalities in the parietal and occipital lobes, which are associated with visuospatial processing, and in the left inferior frontal gyrus, which supports language-related mathematical tasks.

Üstün et al. (2021) further reported heightened activation of the hippocampus in children with dyscalculia during symbolic comparison tasks, indicating reliance on memory as a compensatory mechanism. Increased activation was also observed in frontal regions, including the anterior cingulate cortex and medial prefrontal cortex, suggesting greater cognitive effort during numerical tasks. Importantly, activation of the IPS was present in both dyscalculic and typically developing children, reinforcing its fundamental role in numerical cognition.

Arithmetic Processing and Working Memory

According to de Smedt et al. (2019), arithmetic development involves a gradual transition from counting-based strategies to more efficient methods such as fact retrieval and problem decomposition. This process engages multiple brain regions, including the parietal cortex for numerical representation, the prefrontal cortex for working memory and attention, the temporoparietal cortex for arithmetic fact retrieval, and the occipitotemporal cortex for visual symbol processing.

These findings align with Peters et al. (2018), who highlighted the contribution of working memory and naming speed to arithmetic performance. Their study demonstrated that as arithmetic proficiency increases, neural activation shifts from frontal regions associated with problem-solving to parietal regions associated with memory retrieval, reflecting a developmental change in cognitive strategy.

Molise and Kakoma (2024) further emphasised that learners with dyscalculia often experience deficits in working memory, which comprises the phonological loop, visuospatial sketchpad, and central executive. Impairments in these components can hinder the processing of verbal instructions, spatial representation of numbers, and sustained attention, thereby affecting arithmetic performance.

Structural Brain Differences

Beyond functional connectivity, McCaskey et al. (2020) identified structural differences in the brains of children with developmental dyscalculia (DD). Using voxel-based morphometry, the

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study revealed reduced grey matter volume in regions including the intraparietal sulcus, frontal cortex, occipitotemporal cortex, and superior parietal lobes. Reduced white matter volume was also observed in the temporoparietal regions and left frontal lobe. Notably, these differences remained stable from childhood into adolescence, suggesting that neural deficits associated with dyscalculia persist over time rather than resolving with development.

Collectively, these findings indicate that difficulties in numerical and arithmetic processing among individuals with dyscalculia are closely linked to both functional and structural differences in brain connectivity.

Factors Contributing to Dyscalculia

Molise and Kakoma (2024) identified neurological abnormalities as a primary contributor to dyscalculia, including atypical brain development resulting from genetic conditions, prenatal complications, or early neurological insult. Genetic disorders such as Down syndrome and prenatal factors such as maternal substance exposure or oxygen deprivation during birth may adversely affect brain structure and function.

Conversely, Bugden and Ansari (2014, as cited in Mahmud et al., 2020) argued that the brains of individuals with dyscalculia function differently rather than being structurally atypical. Supporting this view, Mutlu, Çalışkan, and Yasul (2022) noted that there is no definitive consensus on the causes of dyscalculia. Instead, evidence suggests a multifactorial origin involving neurological dysfunction, working memory deficits, and environmental or cultural influences. Overall, the literature indicates that dyscalculia arises from an interaction between biological and non-biological factors.

Methods of Identifying Dyscalculia

Neuroimaging techniques, particularly functional magnetic resonance imaging (fMRI), have been widely used to identify dyscalculia. Mateu-Estivill et al. (2024), for example, examined resting-state functional connectivity among 19 children with DD and 23 typically developing children using rs-fMRI and functional connectivity multivariate pattern analysis. Similarly, Üstün et al. (2021) employed fMRI to investigate neural activation during symbolic and non-symbolic numerical comparison tasks.

In addition to neuroimaging, Aquil and Ariffin (2020) highlighted both qualitative and quantitative diagnostic approaches. Quantitative methods rely on standardised mathematical assessments, while qualitative methods include discrepancy, severity, and resistance-to-treatment models, which are supported by diagnostic frameworks such as the DSM-IV and the World Health Organization. A comprehensive diagnostic approach combining behavioural assessment and neuroimaging is therefore essential to accurately identify dyscalculia.

Interventions

Computer-Based Interventions

Computer-assisted learning has shown promise in supporting learners with dyscalculia. Singh (2022) demonstrated the effectiveness of the BrainOmatics programme in improving visuospatial working memory in an eight-year-old child over 15 intervention sessions. Games such as *Adams Apple* were particularly effective, as they directly targeted visuospatial processing. Although the findings are limited by the single-case design, they highlight the

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potential of technology-based interventions in enhancing cognitive skills relevant to mathematics.

Parental Support and Motivation

Parental involvement plays a crucial role in supporting children with dyscalculia. Delgado et al. (2019) emphasised the use of didactic materials and information and communication technology (ICT) to create engaging learning environments. Motivation and emotional support were identified as key factors in sustaining learning, as meaningful learning occurs when new information is linked to prior knowledge and supported by positive attitudes.

Discussion

Application to Current Educational Issues

Early identification of dyscalculia is essential for effective intervention. Indicators include difficulties with basic numerical concepts, symbolic and non-symbolic differentiation, number sequencing, and arithmetic operations (Noël & Karagiannakis, 2022). Suganya and Sarath (2022) further outlined challenges such as number reversal, difficulty reading analogue clocks, and confusion with arithmetic symbols, which can guide educators in designing targeted interventions.

Instructional and Therapeutic Approaches

Sensory Integration Therapy (SIT) has been shown to be effective in improving arithmetic performance among children with dyscalculia (Suganya & Sarath, 2022). By engaging multiple sensory systems through play-based activities, SIT supports working memory and attention, although it may require specialised resources and trained practitioners.

Explicit instruction and heuristic-based strategies have also demonstrated strong outcomes. Gersten et al. (2009, as cited in Noël & Karagiannakis, 2022) identified explicit modelling, drill practice, and heuristic approaches as highly effective. The COSMOS heuristic model, which encourages structured problem-solving through visualisation and reflection, promotes flexible thinking and peer discussion, supporting deeper mathematical understanding.

Visual representation, when combined with explicit instruction, further enhances comprehension by aligning with the brain's spatial organisation of numerical information (Kucian, 2017).

Islamic Perspective

Individuals with dyscalculia are recognised as part of the disabled community and are entitled to dignity, respect, and support. Islam affirms human equality, as stated in the Qur'an (49:13), and encourages the pursuit of knowledge to better understand the diversity of Allah's creation (Qur'an 30:22). Advances in neuroscience, such as fMRI, exemplify this pursuit and enable more effective support for individuals with learning difficulties.

Islam also emphasises compassion and social responsibility. Supporting learners with dyscalculia through structured teaching strategies, patience, and encouragement reflects the Islamic principle of alleviating hardship, as highlighted in the hadith narrated in Sahih Muslim (Hadith 2699). Educational interventions such as step-by-step modelling and supportive

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learning environments embody these values by reducing cognitive burden and fostering inclusion.

Recognising individual challenges also cultivates gratitude and resilience. The Qur'an reminds believers that Allah intends ease rather than hardship (Qur'an 2:185), encouraging empathy and perseverance. Integrating Islamic principles with educational practice therefore reinforces both moral responsibility and effective teaching.

Conclusion
Dyscalculia presents complex challenges that extend beyond numerical difficulties, affecting academic performance, emotional well-being, and self-esteem. Early identification of symptoms, including deficits in numerical understanding, sequencing, and working memory, is essential for timely intervention. Evidence-based approaches such as Sensory Integration Therapy, heuristic problem-solving models, explicit instruction, and computer-based interventions have demonstrated effectiveness in supporting learners with dyscalculia, particularly when tailored to individual needs.

A holistic approach that combines educational strategies, parental involvement, and compassionate teaching practices can foster academic success and social inclusion. By recognising neurological diversity and implementing structured, supportive interventions, educators and families can empower individuals with dyscalculia to reach their full potential and navigate a numerically demanding world with confidence.

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