World Academy of Science, Engineering and Technology
International Journal of Educational and Pedagogical Sciences
Vol:18, No:02, 2024

Investigating the Neural Heterogeneity of Developmental Dyscalculia

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Abstract : Developmental Dyscalculia (DD) is defined as a particular learning difficulty with continuous challenges in learning requisite math skills that cannot be explained by intellectual disability or educational deprivation. Recent studies have increasingly recognized that DD is a heterogeneous, instead of monolithic, learning disorder with not only cognitive and behavioral deficits but so too neural dysfunction. In recent years, neuroimaging studies employed group comparison to explore the neural underpinnings of DD, which contradicted the heterogenous nature of DD and may obfuscate critical individual differences. This research aimed to investigate the neural heterogeneity of DD using case studies with functional near-infrared spectroscopy (fNIRS). A total of 54 aged 6-7 years old of children participated in this study, comprising two comprehensive cognitive assessments, an 8-minute resting state, and an 8-minute one-digit addition task. Nine children met the criteria of DD and scored at or below 85 (i.e., the 16th percentile) on the Mathematics or Math Fluency subtest of the Wechsler Individual Achievement Test, Third Edition (WIAT-III) (both subtest scores were 90 and below). The remaining 45 children formed the typically developing (TD) group. Resting-state data and brain activation in the inferior frontal gyrus (IFG), superior frontal gyrus (SFG), and intraparietal sulcus (IPS) were collected for comparison between each case and the TD group. Graph theory was used to analyze the brain network under the resting state. This theory represents the brain network as a set of nodes--brain regions—and edges—pairwise interactions across areas to reveal the architectural organizations of the nervous network. Next, a single-case methodology developed by Crawford et al. in 2010 was used to compare each case's brain network indicators and brain activation against 45 TD children's average data. Results showed that three out of the nine DD children displayed significant deviation from TD children's brain indicators. Case 1 had inefficient nodal network properties. Case 2 showed inefficient brain network properties and weaker activation in the IFG and IPS areas. Case 3 displayed inefficient brain network properties with no differences in activation patterns. As a rise above, the present study was able to distill differences in architectural organizations and brain activation of DD vis-à-vis TD children using fNIRS and single-case methodology. Although DD is regarded as a heterogeneous learning difficulty, it is noted that all three cases showed lower nodal efficiency in the brain network, which may be one of the neural sources of DD. Importantly, although the current "brain norm" established for the 45 children is tentative, the results from this study provide insights not only for future work in "developmental brain norm" with reliable brain indicators but so too the viability of single-case methodology, which could be used to detect differential brain indicators of DD children for early detection and interventions.

Keywords : brain activation, brain network, case study, developmental dyscalculia, functional near-infrared spectroscopy, graph theory, neural heterogeneity
Conference Title : ICELS 2024 : International Conference on Education and Learning Sciences
Conference Location : Washington, United States
Conference Dates : February 26-27, 2024