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fNIRS-based functional connectivity estimation using semi-metric analysis to study decision making by nursing students and registered nurses

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This study aims to investigate the generalizability of the semi-metric analysis of the functional connectivity (FC) for functional near-infrared spectroscopy (fNIRS) by applying it to detect the dichotomy in differential FC under affective and neutral emotional states in nursing students and registered nurses during decision making. The proposed method employs wavelet transform coherence to construct FC networks and explores semi-metric analysis to extract network redundancy features, which has not been considered in conventional fNIRS-based FC analyses. The trials of the proposed method were performed on 19 nursing students and 19 registered nurses via a decision-making task under different emotional states induced by affective and neutral emotional stimuli. The cognitive activities were recorded using fNIRS, and the emotional stimuli were adopted from the International Affective Digitized Sound System (IADS). The induction of emotional effects was validated by heart rate variability (HRV) analysis. The experimental results by the proposed method showed significant difference (FDR-adjusted $p = 0.004$) in the nursing students' cognitive FC network under the two different emotional conditions, and the semi-metric percentage (*SMP*) of the right prefrontal cortex (PFC) was found to be significantly higher than the left PFC (FDR-adjusted $p = 0.036$). The benchmark method (a typical weighted graph theory analysis) gave no significant results. In essence, the results support that the semi-metric analysis can be generalized and extended to fNIRS-based functional connectivity estimation.

Graph theory has been widely employed in neuroimaging studies such as functional magnetic resonance imaging (fMRI), electroencephalographic (EEG) and functional near-infrared spectroscopy (fNIRS) to better understand the functional connectivity (FC) under various neurological conditions[1–4]. According to the graph theory, a brain network may be described as a graph consisting of nodes, and the connections between the nodes are known as edges[5]. A collection of nodes in a brain network forms a brain region while the strength or synchronicity of the connectivity is usually represented by the weight of the edges. The number of edges connected to a node is referred to as a degree. To quantitatively evaluate the information transmission ability in a network, the shortest path length plays a crucial role in defining network efficiency at both local and global levels[3].

In conventional graph theory analysis, the shortest path length is always defined as the minimum sum of the distance between two nodes[6], providing the most preferable route for information to be passed from one node to another. In real-world networks, the shortest path is not always the direct distance because the distance from one node to another via a circuitous (indirect) path may be less than the length of the direct path[7]. This phenomenon violates the transitive property and forms a semi-metric network[8], as shown in Fig. 1. Previous studies on fMRI[7,9] have shown improvement in graphical network processing performance in information sharing

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