ARTICULATION OF CORTICAL CONNECTIVITY

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ABSTRACT

The most intricate organ in the human body is the brain. Some brain diseases are Alzheimer's disease, Epilepsy, and Parkinson's disease. The samples are taken for normal people (Nold), Mild Cognitive Impairment (MCI) and Parkinson's disease (PD). The difference between the normal person and patients are identified by the variations in path length, clustering coefficient, small world with the support of different band levels.

Keywords-path length, small world, clustering coefficient, Parkinson's disease

I. INTRODUCTION

The hub of control of the body is the brain. It modulates speech, movement, memory, and thought. It oversees the manner in which organs work. The brain processes promptly and spontaneously when it is in prime condition. However, when concerns occur, the consequences can be catastrophic. Inflammation of the cortex can cause difficulties include vision loss, weakness, and paralysis. You may have trouble thinking clearly if you lose brain cells as a result of a stroke. Furthermore, brain tumors may inflame nerves and impair cognitive function. Some mental illnesses are inherited. Electroencephalographic (EEG) helps to measure the values in both eyes-open and eyes-closed condition [4]. Depending on the exact state of affairs, neurological illnesses reveal an array of symptoms. Damage may be partially irreparable. In other circumstances, interventions like surgery, drugs, or physical therapy could address the root cause of the issue or lessen symptoms.

In the framework of Graph Theory, structural brain networks are characterized as graphs made up of nodes (vertices) designating neural components (neurons or brain regions) and edges (synapses or axonal projections) that depict physical connections. [3].

Here Neurons are considered as vertices, connections between neurons are considered as edges. Graph Theory is made up of vertices and edges. Swiss Mathematician Euler who invented Graph Theory in 18th century [5].

Through Graph Theory, the differences in brain connectivity for Nold, MCI, PDpatients with the help of Path Length, Clustering Coefficient, and Small world has been found [1]. By identifying these problems can be rectifying by taking Medicines and treatment with the help of doctors.

II. PRELIMINARIES

Definition 2.1: A linear graph is composed of up of a pair of objects: vertices, denoted by $V = \{v_1, v_2 \ldots\}$ etc., and edges, marked by $E = \{e_1, e_2 \ldots\}$ etc. The edges are depicted as segments of lines spanning the end vertices of each edge, whereas the vertices are shown as points [2].

Definition 2.2: A Clustering Coefficient in the mathematical discipline of graph theory is a measurement of the amount that nodes in a graph prefer to cluster together A [1].

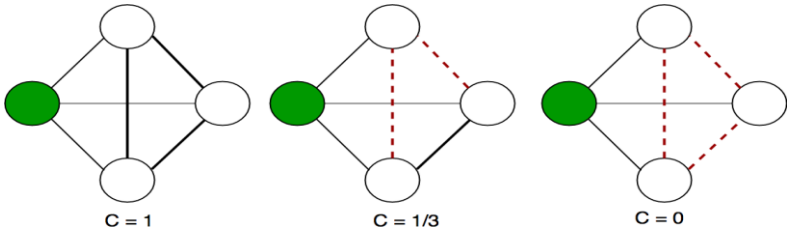


Figure 2.2 Clustering Coefficient

Definition 2.3: A path is an array of nodes in a graph where each node is connected to the one before it by an edge. The amount of edges in the path impacts the measurement of the path. [1].

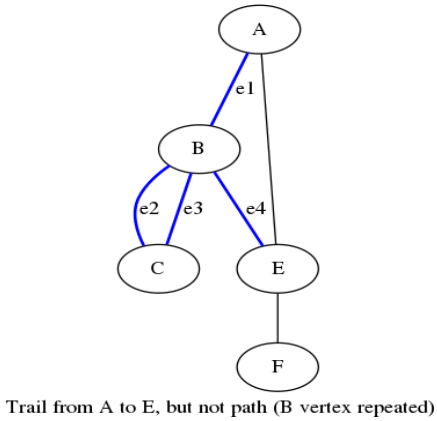


Figure 2.3 Path Length

Definition 2.4: In a small-world network, a great deal of nodes are not adjacent from one yet another, but those nearby of each node tend to be near neighbors to among yet another, and the rest of nodes may be accessed by any other node with just a few of actions. A small world network is specifically described as a structure in which the usual distance L among two randomly selected nodes (the quantity of steps needed) increases directly to the exponential of the network's node count N. [1].

Figure 2.4 Small world

Definition 2.5: In a weighted graph, each branch has an allocated numerical weight. As a result, a weighted graph is a particular kind of labeled graph where the labeling are values, which are typically assumed to be positive [5].

Definition 2.6: If a graph's edges are given weights, it is alleged to possess a weighted graph; otherwise, it is said to be an unweighted graph. Each edge has a weight, which is a numerical value [5].

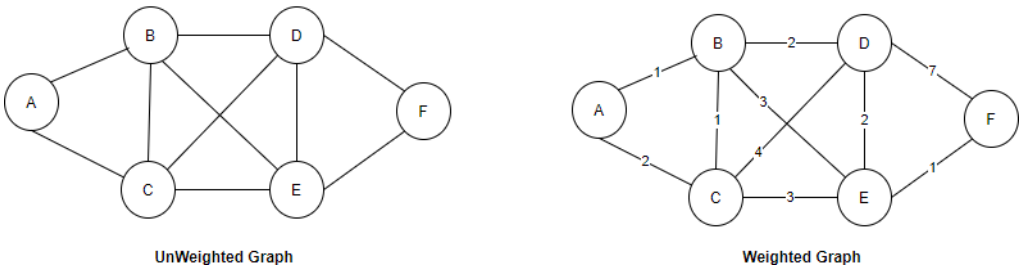
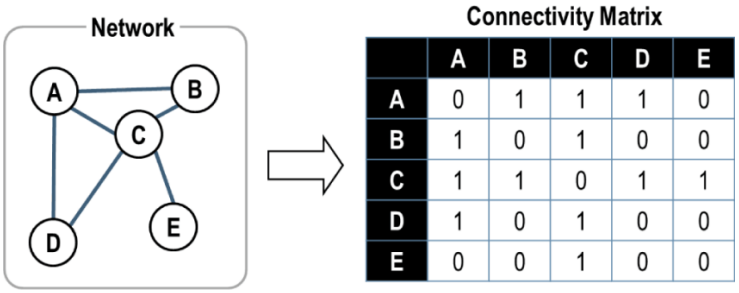


Figure 2.5 Unweighted and Weighted graph

Definition 2.7: The nodes of a graph are represented by the rows and columns of the connection matrix, which is thought of as a square array. The first entry show there's is an edge connecting two nodes. An undirected graph's adjacency matrix is symmetric. [2].



	A	B	C	D	E
A	0	1	1	1	0
B	1	0	1	0	0
C	1	1	0	1	1
D	1	0	1	0	0
E	0	0	1	0	0

Figure 2.6 Connection Matrix

Definition 2.8: If G has a (u,v)-path, then both vertices u and v are said to be related. An similarity relations over the set of vertex V signifies a connection. This means that each of u and v link together if and only if each u and v constitute the same set V_i. V is then divided into nonempty subsets V_1, V_2... V_w. The $G[V_1]$, $G[V_2]$,..., $G[V_w]$ subgraphs are referred to as the $G[V]$ components. G is connected if it contains precisely one component; otherwise, it is disconnected. The number of components of G is indicated by the symbol $w(G)$. [5].

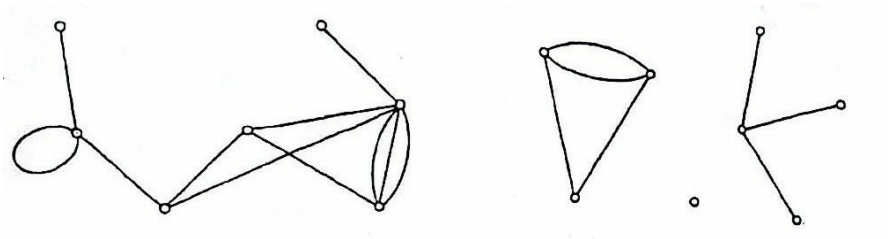


Figure 2.7 Connected and disconnected graph

Definition 2.9: The mind is a sophisticated organ that manages every bodily function as well as thoughts, emotions, motor abilities, vision, respiration, temperature, and hunger. The central nervous system, sometimes known as the CNS, is comprised of the brain and the spinal cord that emanates from it [6].

Definition 2.10: Central nervous system condition that affects mobility and frequently includes tremors. Parkinson's symptoms are brought on by a decrease in dopamine levels due to nerve cell destruction in the brain. [7].

III. A GRAPH THEORITICAL ANALYSIS OF CORTICAL CONNECTIVITY FROM EEG DATA

The goal of graph theory is to succinctly describe the characteristics of complicated networks. A scientific description of various brain functions has been claimed to result from a thorough understanding of anatomical connections between cortical areas (also known as the "human connectome"), particularly in terms of their dynamics and hierarchy. Due to the difficulty in obtaining a full description of the human connectome, it has primarily been used to explain brain graphs derived from anatomical, morphological, and neural imaging approaches.

Path length assessments are further linked to illness severity as determined by the MMSE (Mini-Mental State Examination) and other sophisticated neuropsychological exams. An elevated MMSE correlated with an elevated clustering coefficient and a shorter typical path length, according to electroencephalographic (EEG) research. The findings were explained by a less ideal, or small-world like, structure of networks in the PD group.

A. Preconditioning and Dataset Acquisition

Subjects were sitting and at ease in a quiet, dark room throughout the EEG recordings, which were done when they were at rest, with their gaze shut, and under "no task" parameters (for at least 5 minutes). 19 electrodes on the scalp (Fp1, Fp2, F7, F8, F3, F4, T3, T4, C3, C4, T5, T6, P3, P4, O1, O2, Fz, Cz, and Pz) placed in accordance with the International 10-20 system were used to record EEG signals. Skin/electrode impedances were dropped below 5 KΩ for the downward and upward electrooculography channels, which served to track the eye rotations. The EEG recordings were band-pass filtered from 0.1 to 47 Hz using a finite impulse response filter and the sampling rate frequency was set up at 256 and 512 Hz. Imported EEG data were fragmented in 2 second duration epochs, identifying and extracting visible artifacts (i.e., eye movements, cardiac activity, and scalp muscle contraction) using an independent component analysis (ICA) procedure. ICA is a blind source decomposition algorithm that enables the separation of statistically independent sources from multichannel data. It has been proposed as an effective method for separating ocular movement and blink artifacts from EEG data. ICA was performed using the Infomax ICA algorithm as implemented in the EEGLAB.

B. Graph analysis

A network is a set of nodes (vertices) and links (edges) among sets of nodes that serves as a mathematical description of a real-world complicated system. In enormous scale neural networks, nodes typically represent brain areas, whereas links, based on the dataset, reflect anatomical, functioning, or efficient connectivity. Two core measures of graph theory were computed: characteristic path length (L) and clustering coefficient (C). They can be divided into measurements informing on characteristics relating to network cohesion and segregation, respectively, given the data that they provide. Segregation (or specialization) describes the extent to which the components of the network form distinct clusters. The ability of the network in its entirety to collaborate and share data is referred to as integration. L is reported in the following:

$$L = \frac{1}{n}\sum_{i \subset N} L_i$$

$$= \frac{1}{n}\sum_{i \subset N} \frac{\sum_{j \subset N, j \neq i} d_{ij}}{n-1}$$

Where L_i is the average distance between nodes i and all other nodes.

The idea of interaction routes and their excursion lengths is the foundation for most integration measurement techniques. Any distinct set of edges which joins both nodes together is called a path, and the quantity of hops in an a binary graph or the total of the edge lengths in a weighted graph determines

how long a path is. A network's distinctive path length represents the mean of all lengths across the whole network. The average length of the shortest path among a pair for nodes relates to the distance (also sometimes known as the "shortest path length"). Functional integration is facilitated by small path lengths that enable interaction at minimal phases, reducing the impacts of sound or signal deterioration. The nervous system's functional integration, to use non-mathematical terminology, is the capacity to quickly incorporate specific data from dispersed brain parts. The lengths of the pathways reflect the likelihood of functional integration occurring among different brain regions, with shorter paths indicating a higher likelihood. The node's clustering coefficient C, is reported as follows:

$$L = \frac{1}{n}\sum_{i \subset N} C_i$$

$$= \frac{1}{n}\sum_{i \subset N} \frac{2t_i}{k_i(k_i - 1)}$$

Here C_i denotes the node i's clustering coefficient ($C_i = 0$ for $k_i < 2$).

IV. GRAPH THEORY APPLICATIONS IN FUNCTIONAL BRAIN NETWORK ARCHITECTURE

In the near future, this strategy may assist create new, customized therapeutic/rehabilitative tactics. Network science and graph theory tactics are invaluable to understanding age-related brain function and dysfunction and in particular, to map the neural network from structure to function, examine the way cognitive processes arise through their structural substrates, as well as better assess the link among structural modifications and functional derangement.

A. Graph Theory Methodology

The "network science of the brain" contends that the brain of an individual is perhaps the most intricate collection of interconnected networks in all of science. The term "Connectome" refers to the human brain's connectivity matrix. Prior work has used graph theory to analyze EEG data to examine how the cerebral cortex organizes itself as people age, especially on a straight line which links normal aging (Nold), mild cognitive impairment (MCI), and Parkinson's disease (PD).

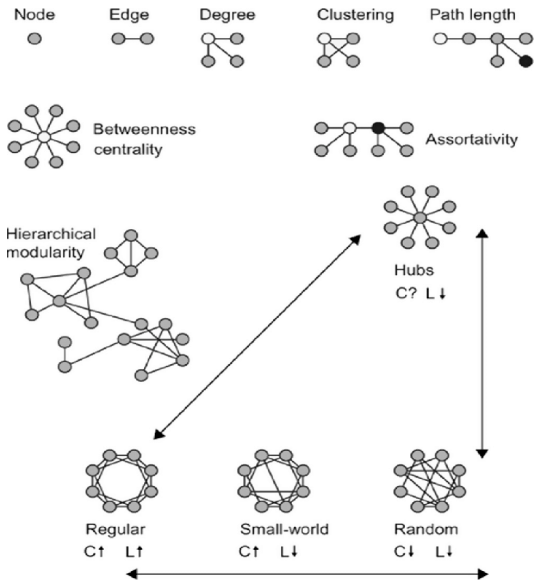


Figure 4.1 Comprehension of Graph Theory concepts

Neural interconnectivity has been determined by the eLORETA program using an individual analysis in the regions of interest (ROIs) specified in accordance with the accessible Brodmann areas for the left and right hemispheres. For all of the following pairs of ROIs: delta (2-4 Hz), theta (4-8 Hz), alpha 1 (8-10.5 Hz), alpha 2 (10.5-13 Hz), beta 1 (13-20 Hz), beta 2 (20-30 Hz), and gamma (30-45 Hz), intracortical LagR, derived through "all nearest voxels" or the ones in a sphere of 19mm radius, was separately computed.

B. Parameters derived by Graph Theory

Whereas integration defines a network's ability for being attached and share data, segregation pertains to the extent to which its parts form different clusters and is characterized by the clustering coefficient (C), whereas integration is determined by its characteristic path length (L) coefficient.

The mean clustering coefficient is calculated for each node in the graph. It is a measurement of the propensity for local cluster formation among network parts. The shortest weighted path length among two nodes, started with the specification of L, is delimited by the weighted characteristic path length Lw.

The proportion across normalized C and L - Cw and Lw according to the frequency bands is known as the small-world (SW) parameter. The balance among a network's local connectedness and global integration is expressed by the SW coefficient. Small-world organization is somewhere around regular networks or lattices and random networks, where the entire shortest path length is linked to a low amount of local clustering and the high level of clustering is linked to a lengthy path length. This suggests that very few additional steps are required to connect nodes, and that most nodes have a limited number of direct interconnections.

V. EEG STUDY FOR PARKINSON'S DISEASE

The recording of the first human EEG was performed in 1924 by German physician Hans Berger. Since then relative band power has become an established measure to quantify deviations from normal oscillatory brain activity. Several minutes of EEG signal, usually recorded under resting state condition and in an 'eyes closed' (EC) setting, are filtered into four to seven non-overlapping frequency bands covering a range from 0.5Hz up to 70Hz. Then, for each of those bands, the relative signal power is calculated.

High density EEG machines available today provide up to 256 individual electrodes recording brain activity at a frequency of 1000Hz or higher.

Behind Alzheimer's disease, Parkinson's disease (PD) is perhaps the most prevalent age-associated neurodegenerative condition. It is predicted to impact 2% or less of people over 65. It takes skilled professionals to diagnose Parkinson's disease, particularly in its early stages. Therefore, a crucial first step is to develop methods for identifying initial fluctuations in brain function that are as simple to use as measuring one's own arterial blood pressure.

	1	2	3	4	5	6
AGE	65	66	72	68	65	66
BASELINE	0.98	1.03	0.96	0.97	0.98	0.965
T_0	0.97	1.04	0.975	0.956	0.98	0.997
T_1	0.985	1.06	0.985	0.93	0.978	0.98
T_2	0.97	1.06	0.985	0.991	0.997	0.98

Table 5.1 Small World parameter for Parkinson's disease (PD)

	1	2	3	4	5	6
AGE	65	66	72	68	65	66
NOLD	1.005	1.002	1.02	0.998	1.01	0.99
MCI	1.001	1.003	1	1	1.02	0.99
PD	1.001	1.003	1	1	1.01	0.99

Table 5.2 Small world parameter for Parkinson's disease in Eyes open condition

	1	2	3	4	5	6
AGE	65	66	72	68	65	66
NOLD	1.025	1.025	0.99	0.998	1.002	1.001
MCI	1.02	1.02	0.99	0.999	1.002	1.001
PD	1.001	1.003	1	1	1	0.99

Table 5.3 Small world parameter for Parkinson's disease in Eyes close condition

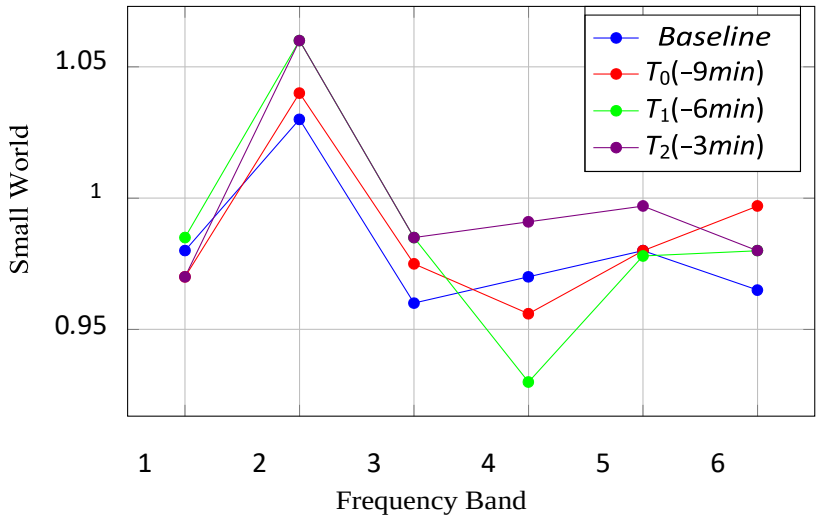


Figure 5.1 [x axis (1 as Delta, 2 as Theta, 3 as Alpha 1, 4 as Alpha 2, 5 as Beta 1, 6 as Beta 2)]

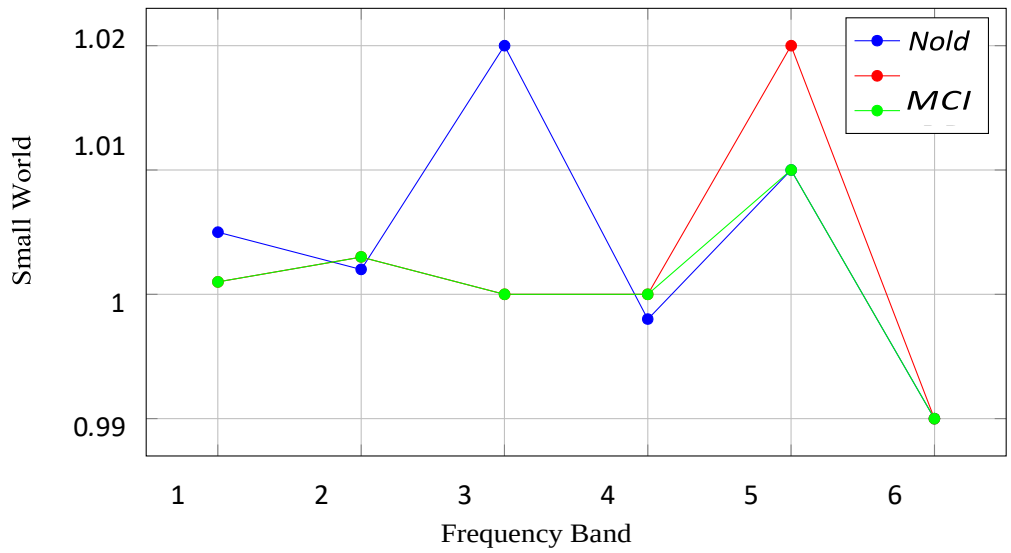


Figure 5.2 [x axis (1 as Delta, 2 as Theta, 3 as Alpha 1, 4 as Alpha 2, 5 as Beta 1, 6 as Beta 2)] Eyes opened

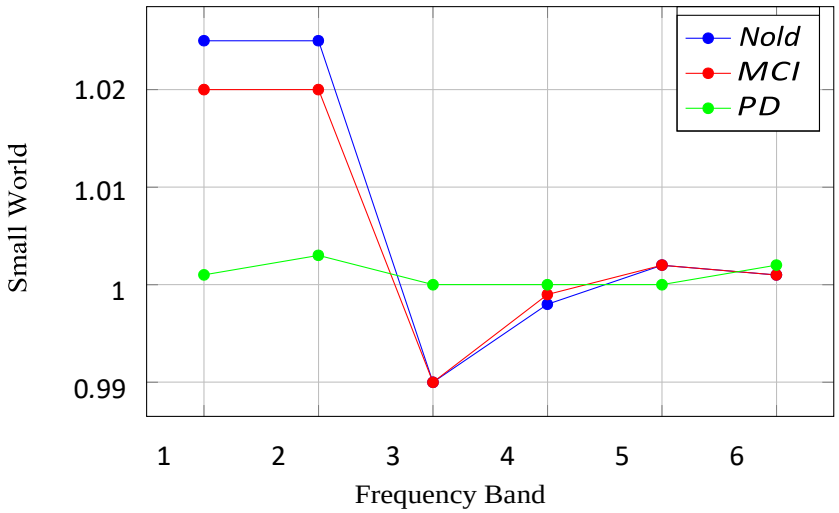


Figure 5.3 [x axis (1 as Delta, 2 as Theta, 3 as Alpha 1, 4 as Alpha 2, 5 as Beta 1, 6 as Beta 2)] Eyes closed

The SW index data for comparisons among each factor Group (PD, Nold) and Band (delta, theta, alpha 1, alpha 2, beta 1, beta 2, and gamma) were evaluated using the statistical analysis of variation (ANOVA) design.

As shown in Figures 5.1, 5.2 and 5.3 the ANOVA used to evaluate the SW index revealed a significant correlation over the two components, Group (PD, MCI, and Nold) and Band (delta, theta, alpha 1, alpha 2, beta 1, beta 2, and gamma). When contrasted to controls, the SW index for Parkinson's disease exhibited decreased values (a more organized network) in theta and higher values (a less ordered network) in alpha 2.

The findings demonstrated that people with Parkinson's disease, especially in the theta band (4–8 Hz), displayed a more regulated frequencies low EEG pulse structure (lower value of SW) than

matched in age healthy controls. In contrast, people with Parkinson's displayed greater random organization (higher value of SW) within the high-frequency signals alpha band (10.5–13 Hz) compared to age-matched healthy participants.

When individuals with Parkinson's disease were idle, their EEG spectral examination showed a rise in lower bands of frequency and a decrease in quicker frequencies, indicating a slowdown of cerebral function.

According to other studies, theta-frequency EEG cerebral inputs are related to a dysfunctional coordination of the brain's motor networks resulting in tremor or sensorimotor integration.

The SW rise in the alpha 2 frequency for the higher-frequency band in individuals with Parkinson's disease might be considered as a possible indicator of a cognitive deterioration in the initial stages of PD. The biological mechanisms of the thalamo-cortical and cortico-cortical loops, that stimulate and block the conveyance of signals and their interpretation of data from sensory movement, are reflected in the high frequency alpha rhythm (10.5–13 Hz).

Multiple investigations indicate which a decline in alpha frequency is associated to increase a disorganized network which indicates cognitive decline and a reduction in cerebral lobe synchronization and integration.

An alteration of these pulses may be regarded as an EEG indication of modified mental processes and poor information interpretation. The alpha wave is often a vital part of standard EEG activity at resting. According to research by Vecchio and colleagues, a rise in the alpha SW parameter, which is generated through EEG information, may differentiate among a senior citizen with a normal cognitive state and one who has Parkinson's disease. In fact, they noticed that this diseased situation raised the SW index within the alpha frequency instead of the usual state.

The onset of motor impairment in people with Parkinson's disease may be indicated by a rise in SW in alpha 2 frequencies which denotes an irregular networks structure. Path length value in the alpha 2 frequency decreased in patients with Parkinson's relative to control individuals that would indicate an extra haphazard networks setup.

As a result, structural interruptions represented by a smaller SW value in the theta frequency range and greater values in the alpha band might be seen as indicators of PD-specific motor dysfunction and a decline in cerebral network efficiency.

VI. CONCLUSION

This study shows revealed Parkinson's individuals and controls show distinct little word structures in their relaxing brains. The findings imply that Parkinson's disease affects the nervous system's cortex connections worldwide, changing its fundamental physiological organization, while this modulation may be connected to alterations in the motor network and other nearby cortical regions' synaptic efficiency. Evaluating this parameter could be helpful for the early diagnosis and treatment of Parkinson’s disease (PD). Through small world and band signals the problem in brain can be detected. Findings from small world indicate that smaller values in the theta, which band and greater values in the alpha band signify functional interruptions. It could help clarify how much there are tremor dominant and non-tremor dominant variants of Parkinson's disease (PD).

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