

Network Models of Brain Connectivity Changes in Anxiety and Depression

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ABSTRACT

The mental health conditions of anxiety and depression are relatively common conditions that are becoming defined as disorders of large-scale malfunctioning of brain networks rather than localised abnormalities. Brain connectivity network models provide a valuable framework for understanding how communication among distributed neural systems is influenced across various environments. Using graph-theoretical and network neuroscience analyses of functional and structural neuroimaging data, researchers have identified consistent connectivity alterations in core brain networks, including the default mode network (DMN), salience network (SN), and central executive network (CEN). These networks are characterised by abnormal integration and segmentation, i.e., hyperconnectivity of the DMN, reduction in connectivity in executive control areas and abnormal coupling of emotional and cognitive control systems in anxiety and depression. These abnormalities are associated with significant clinical factors, including excessive rumination, diminished emotion regulation, increased risk sensitivity, and cognitive inflexibility. Network-based measures also show variation in network hubs, efficiency, modularity, and the small-world phenomenon, which may indicate a transition to less optimal information processing in anxious and depressive states. Particularly, these connection patterns have standard and disorder-specific features that support transdiagnostic models of internalising psychopathology combined with brain markers that distinguish between anxiety and depression. Generally, brain connection models provide essential information on the neurobiological pathways underlying anxiety and depression. They can be used to understand how the diagnosis can be performed more effectively, to inform treatment stratification, and to develop tailored interventions based on the individual brain network.

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1. Introduction

Human emotions result from the interaction of multiple brain systems, each involved in perception, memory, motivation, and internal control. These systems cannot operate as distinct components; instead, they work as part of a complex network that continuously processes information received from external and personal interior environments (Vohryzek et al., 2024). The development of the perception of the brain as a system of interconnected components has been particularly beneficial to the study of mental health. Psychological disorders cause extensive disruptions that extend well beyond a single brain region. Emotional regulation, attentional control, and self-directed thinking arise not just from large-scale networks but are also coordinated. When these networks are out of balance or physically or functionally affected, then mood and thinking processes can change dramatically (Lynch et al., 2024). Anxiety and sadness are the most recognised examples of network-level disturbances. Both are characterised by persistent emotional states, abnormal thinking processes, and altered physiological responses to stress, which can only be defined in terms of connection rather than isolated breakdowns. Anxiety and depression are among the world's most common mental health conditions, affecting individuals of all ages and backgrounds. It frequently occurs together, and the symptoms of anxiety, fear, depressed mood, and depression often come together (Zhu et al., 2023). In a healthy brain, numerous networks play important roles in emotional processing and regulation. The default mode network (DMN) is responsible for self-referential thinking, internalising reflection, and autobiographical memory. The SN salience network helps us recognise information that is significant for survival and directs attention to relevant stimuli. Furthermore, the central executive network is related to planning, working memory, and attentional flexibility. This combination of systems maintains a balance between internal and external requirements (Zhao et al., 2023). One of the most prevalent and incapacitating mental health disorders in the

world is anxiety and depression, which affects people belonging to all age groups and cultures. These diseases, according to global health statistics, constitute a significant share of the total disease burden, leading to reduced functioning, reduced quality of life, and increased socioeconomic costs. Nevertheless, the brain mechanisms of anxiety and depression are complex and not fully understood after years of research. Classical neuropsychiatric models have typically concentrated on dysfunctions in single brain parts, e.g., the amygdala in anxiety or the prefrontal cortex in depression. Although these region-centred methods have yielded valuable insights, they do not capture the distributed and interactive nature of brain activity that underlies human thought and mood. Over the past few years, neuroimaging and computational neuroscience have advanced, shifting the emphasis from localised brain disorders to large-scale brain networks. The human brain is a highly interconnected system in which cognitive, emotional, and behavioural processes arise from dynamic interactions among distributed neural systems.

Graph neuroscience: Network models of brain connectivity offer a powerful platform for studying these interactions. Instead of asking whether a particular brain region is overactive or underactive, network models investigate the mechanisms by which brain regions communicate with one another, how information is transferred across networks, and how the brain's overall structure facilitates or limits mental performance. Anxiety and depression are becoming seen as diseases of network dysregulation and not individual neuronal pathologies. Both disorders involve dysfunctions in emotional regulation, attention, memory, and decision-making, which depend on the coordinated action of various brain regions. Investigations of functional and structural neuroimaging consistently point to disruption of a large-scale network, such as the default mode network (DMN), salience network (SN), or central executive network (CEN). These networks play important roles in self-referential thought, emotion salience detection, and cognitive regulation, respectively. Mental functioning requires these networks to maintain both concentration and integration. They must be sufficiently discrete to conduct specialised operations while remaining sufficiently integrated to undertake complex, goal-directed activities. Depression and anxiety seem to have an impact on the psychological balance. In the DMN, stronger association is often linked to ongoing negative thinking habits, such as stress and anxiety. When the functioning of this system becomes dominant or more synchronised, the brain may be unable to shift to other networks, resulting in a present-focused or controlled state (Siddiqi et al., 2023). On the other hand, the CEN might be attributed to poor connectivity or a lack of coordination, which limits a person's ability to shift attention, regulate emotional states, or engage in adaptive problem-solving. Whereas the salience network commonly exhibits abnormal associative characteristics that preclude individuals from perceiving threats, eliciting unpleasant emotions, or switching between internal and external attention. The imbalances have the potential to create a self-reinforcing cycle in which unpleasant ideas receive greater attention, emotional responses increase, and control becomes more challenging (Deco et al., 2024). Network models may be used to provide a systematic response to these changes. Surprisingly, dynamic systems analysis, graph theory, and computer modelling may be utilised to map patterns of connection across the brain and study differences between patients suffering from anxiety or depression. Clustering, modularity, and centrality are graph-theoretic measures that researchers can use to assess information flow in brain networks. For example, high modularity may indicate that networks are overly segregated, which can disrupt the integration necessary for emotion regulation, whereas low modularity may indicate insufficient differentiation across networks (Voigt et al., 2023). Network efficiency, connection strength, and communication methods may help determine whether the brain has become harder, less flexible, or less capable of coordinating distributed activities. The dynamic approach to interaction enhances this theoretical framework by investigating not only fixed communication patterns but also how networks develop. Emotional states fluctuate constantly, and brain networks must adapt to meet shifting demands (Brynielsen et al., 2023). In times of depression and anxiety, these dynamic shifts might become inflexible. Network states may persist for too long in inner concentration or in more surveillance states, and movement between balanced and externally directed states may be restricted or interrupted. Dynamic models capture temporal fluctuations, providing a more comprehensive model of the brain's functional environment (Sam et al., 2023). White-matter networks serve as the physical foundation for inter-regional communication. These changes in the pathways might restrict or disrupt functional connectivity patterns. A structural plus functional intervention may be used to explain abnormal patterns of activity as being caused by underlying anatomical variations, or to imply that they are the consequence of increased or reduced interaction among structurally intact systems. This holistic approach is required to understand the emergence of emotional illnesses and the persistence of certain symptoms.

Network models have significant consequences for medical care (Vohryzek et al., 2023). Many people with anxiety and depression respond differently to treatments such as cognitive-behavioural therapy, pharmaceutical therapy, and neuromodulation therapy. Networks of interaction may be utilised to predict who will benefit the most from various strategies. For example, a patient with a high DMN hyperconnectivity may benefit from rumination therapy, while a patient with a deficiency in executive network functioning may benefit from cognitive control training. Furthermore, changes in network connectivity during therapy can be monitored, thereby allowing us to determine whether symptom improvement is attributable to restored network balance or increased flexibility in network transitions. With the constantly evolving means of analysing the problem, these network-based techniques are likely to restrict our understanding of anxiety and depression

(Chai et al., 2023). Combining imaging, behavioural, and symptom data with computational techniques may reveal patterns of connectivity associated with specific emotional or cognitive problems. These findings extend beyond basic diagnostic labels to inform the development of targeted therapies that address network disorders specific to each individual (Wei et al., 2023). Overall, the network model has completely transformed our understanding of anxiety and depression. This point of view does not seek a single brain area that might malfunction but instead focuses on general neural networks that influence perception, emotion, and behaviour. It emphasises the importance of communication within networks, the constantly changing nature of their states, and the imbalance of processes that leads to persistent emotional discomfort. Network models, which examine the brain as an interconnected system, enable more specific descriptions of these diseases and more effective treatments and preventive strategies (Yankouskaya et al., 2023). It is believed that changes in the balance and interaction of these networks are the underlying pathophysiology of most of the major symptoms reported in anxiety and depression. The default mode network, which includes regions such as the medial prefrontal cortex, the posterior cingulate cortex, and the precuneus, is predominantly activated during rest and during internally oriented cognition. Hyperconnectivity in the DMN has been linked to over-rumination, negative self-referential processing, and rumination about past failures or losses in depression. Similarly, in anxiety disorders, anomalous DMN associations have been associated with increased self-observation and worry. These results indicate that maladaptive patterns of internal thinking associated with the two diseases contribute to aberrant DMN functioning. The salience network, located in the anterior insula and anterior cingulate cortex, is critical for the identification and prioritisation of emotionally and physiologically salient stimuli. It also allows dynamic switching between the DMN and CEN in response to changing environmental requirements. It is usually reported that hyperresponsivity of the salience network occurs in anxiety, with the display of increased danger detection and emotional reactivity. Salience network failure can also be a contributing factor to the lack of emotional awareness and reactivity to positive stimuli in depression.

2. Literature Review

The number of studies on anxiety and depression in the network has increased significantly as researchers attempt to understand how macro participatory brain connection structure impacts emotional and mental health. For many years, researchers have highlighted that anxiety and depression are not isolated problems, but rather the result of extensive systemic changes in function and structural networks (Wang et al., 2023). According to the researchers, depression typically comes with a stronger functional connectivity of DMN with one another and in the brain between the medial prefrontal cortex and the posterior cingulate cortex. This natural tendency has been suggested to promote extensive self-absorption and rumination. Studies have also shown that DMN abnormalities can occur in anxiety disorders, although often in the form of improper interactions between the DMN and the salience network rather than greater internal coherence in isolation (Ajith et al., 2024). These findings suggest that DMN disturbances have a general role in internalising symptoms, but these changes occur with anxiety and depression. Another major focus of the researcher was on the salience network (SN). Researchers emphasised that stressed individuals exhibit hyperconnectivity in the anterior insula and dorsal anterior cingulate, which process danger signals and physiological feelings (Gao et al., 2023). This stronger association has been predicted to cause exaggerated nervousness and anxiety. The literature on depression reveals even more shifting SN patterns. Some researchers observed a stronger association with sad mood, whereas others found less influence of the salience network on cognitive-control regions. These disparities have led scientists to hypothesise that disturbances in salience networks may be subtype-dependent, emotion-dependent, or anxiety-related (Venkatapathy et al., 2023). Apart from this, both disorders show impairment of the frontoparietal control network (FPN). Scholars have demonstrated that damaged connections within this network affect executive control, attentional switching, and mood regulation. Researchers have claimed that the FPN connection reduces the brain's ability to regulate activity in both the SN and DMN. Based on these results, scholars proposed the "triple network model," which claims that anxiety and depressive illnesses result from improper interaction between the DMN, SN, and FPN (Langenecker et al., 2024). The model also claims that the salience network can not sufficiently coordinate changes in internal thought and outward attention, resulting in rumination-threat bias cycles. In addition, network-level structural connectivity research supports this relationship (Long et al., 2023). Using diffusion tensor imaging, researchers concluded that anxiety and depression have associations with decreased integrity of white matter pathways such as the uncinate fasciculus and cingulum bundle. These neural networks facilitate communication between the prefrontal and limbic regions, and their degeneration may underlie impaired emotion regulation (Yang et al., 2023). Furthermore, researchers have demonstrated that decreased fractional anisotropy is associated with greater symptom severity, supporting the notion that structural disconnection results from functional disruption of critical networks (Cai et al., 2024). The amygdala, the brain's emotional processing region, also shows consistent modifications. Scholars argued that the amygdala's significant interest influences anxiety disorders in the insula, prefrontal regions, and sensory areas, which promotes inappropriate responses to perceived threat (Cabello-Toscano et al., 2023). In depression, however, researchers have produced conflicting results; some studies reported amygdala hyperconnectivity in the presence of negative feedback, while others found hypoconnectivity with frontal regulators. The reward network, similar to the

emotional network, has been extensively studied. Researchers found that depression is characterised by impaired communication between the ventral striatum and the orbitofrontal cortex, leading to diminished hedonic experience and motivational deficits (Ke et al., 2023). Many researchers often show intact or slightly enhanced reward connections to networks. However, studies observed that comorbid anxiety-depression leads to more significant disruptions, indicating that reward network modifications might be accelerated when several symptom systems combine. Researchers found that anxiety and depression have been associated with lower overall performance of brain networks, which means that communication between brain regions becomes less coordinated and more dispersed (Dallmer-Zerbe et al., 2023). Network models suggest that a disruption of the salience network impairs optimal coordination between emotional and cognitive systems. The higher-order cognitive tasks of working memory, attentional control, and goal-directed behaviour are facilitated by the central executive network, which includes the dorsolateral prefrontal cortex and parietal areas. Less linkage and efficiency in this network is common both in anxiety and depression. These impairments relate to deficiencies in concentration, decision-making, and cognitive flexibility, which are characteristic features of these diseases.

Notably, less robust executive control can limit a person's ability to regulate emotional responses elicited by limbic and salience-related systems. In addition to finding evidence of altered connections amongst individual areas or networks, network neuroscience methods examine global properties of brain structure. The degree of a node, clustering coefficient, path length, modularity, and small-worldness are graph-theoretical metrics that enable researchers to assess the efficiency of information integration and segregation in the brain. Anxiety and depression studies observed that there are complaints in the network efficiency and modular organisation, indicating that there is a transition to less efficient information processing. For example, reduced global efficiency can indicate reduced ability to communicate rapidly across networks, and changes in modularity can reflect excessive functional segregation or aberrant integration between networks. Another major addition that network models have enabled is the discovery of network hubs, highly connected points that are central to coordinating information flow. Changes in the distribution of hubs and hub connections have been observed in prefrontal, limbic and midline regions in anxiety and depression. Disruption of these hubs can have far-reaching effects on brain function, making localised abnormalities highly significant across the system. Researchers have suggested evidence of altered network modularity and reduced hub strength in prefrontal regions among patients, which disrupts cognitive and emotional information integration. The researchers based their conclusions on these data, claiming that anxiety and depression were symptoms of large-scale deficiencies in brain structure rather than isolated anomalies. It has been demonstrated that mindfulness training, cognitive-behavioural therapy, and antidepressant medication can restore connectivity within core networks (Dunlop et al., 2023). Other research has shown that when receiving effective depression therapy, there has been a reduction in DMN hyperconnectivity, as well as a decrease in ruminating. Researchers suggested that increased anxiety symptoms are connected with increased FPN connectivity, as seen by improved top-down modulation of fear circuits. The findings suggest that network plasticity can predict treatment effectiveness. The researchers claimed that people with a high genetic risk of developing depression display DMN and control network imbalances even before they emerge (Sun et al., 2023). Stress research has shown that chronic stress disrupts the connection between both systems via the amygdala and prefrontal cortex, leading to anxiety and depressive disorders. This kind of research illustrates that network defects may be created long before clinical diagnosis. Scholars generally agreed that anxiety and depression represent network disorders (Zhao et al., 2024). Evidence consistently indicates that inappropriate interactions among the DMN, SN, FPN, limbic pathways, and reward circuits lead to emotional dysregulation, cognitive inflexibility, and maladaptive behaviour (Tura & Goya-Maldonado, 2023). According to the reviewed research, network models provide a more complete and physiologically informed perspective on the causes of anxiety and depression than the region-based model. Network techniques offer promising insights into diagnosis, prevention, and targeted therapy by revealing interactions among brain systems (Xia et al., 2023).

3. Methodology

3.1 Research Strategy

The study employs a quantitative, cross-sectional neuroimaging design to assess brain connectivity changes associated with anxiety and depression, using network neuroscience models. Graph-theoretical analysis of functional and anatomical brain connectivity is used to reveal the abnormality in large-scale brain networks. It is used to examine the differences between the features of networks among individuals with anxiety and depression, and healthy control participants and the correlation between network features and levels of symptoms.

3.2 Participants

Advertisement and referrals are used to recruit participants in outpatient mental health clinics and the general population. The sample consists of three clusters, namely individuals having anxiety disorders, those having major

depressive disorder and healthy control participants who never had psychiatric or neurological illnesses. Diagnoses are made using standardised clinical interviews, according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) criteria, by the clinician. Clinical group inclusion criteria will include individuals between the ages of 18 and 55 years of age, right-handedness to reduce variation in hemispheres and a primary diagnosis of anxiety/depression. The exclusion criteria are comorbid severe psychiatric conditions (e.g., schizophrenia or bipolar disorder), substance abuse, neurological pathology, traumatic brain injury history, and magnetic resonance imaging contraindications. The clinical groups are matched with healthy controls for age, gender, and education level.

3.3 Clinical Assessment

The severity of the symptoms is assessed using validated psychometric instruments. Symptoms of anxiety are evaluated with the help of the State-Trait Anxiety Inventory (STAI) or Beck Anxiety Inventory (BAI). However, the symptoms of depression are reviewed with the help of the Beck Depression Inventory-II (BDI-II) or the Hamilton Depression Rating Scale (HDRS). Other measures include questionnaires assessing rumination, emotion management strategies, and perceived stress to capture transdiagnostic aspects of symptoms. These ratings are used in the correlational analyses through measures of network connection. The source of the neuroimaging data is as follows: The data were acquired using a 3-T MRI scanner. Diffusion-weighted imaging (DWI) is used to measure structural connection, whereas the resting-state functional MRI (rs-fMRI) measures functional connectivity. The instructions provided to participants during rs-fMRI acquisition are to remain still, with eyes open or closed, which are standard instructions; they should not perform any cognitive tasks. T1-weighted anatomical images are high-resolution images that are obtained to perform spatial normalisation and brain parcellation. Functional images are created using echo-planar imaging sequences to capture the entire brain's blood-oxygen-level-dependent (BOLD) signals. Diffusion images are acquired with multiple gradient directions, enabling fine reconstruction of white matter tracts.

3.4 Anatomical Processing

Neuroimaging data are subsequently preprocessed by identifying cortical and subcortical structures through anatomical processing.
Preprocessing of Neuroimaging Data: The Neuroimaging data is further preprocessed by the identification of the cortical and subcortical structures via anatomic processing. Standard neuroimaging software programmes, such as SPM, FSL, or CONN, are used to preprocess functional MRI data. The preprocessing steps include slice-timing correction, motion correction, spatial normalisation to a standard brain template, smoothing, and temporal filtering. Motion artefacts are effectively controlled by excluding subjects with extreme head motion and by applying nuisance regression to minimise motion artefacts and physiological noise. Programs that process structural diffusion data include MRtrix or the Diffusion Toolbox of FSL. Preprocessing includes correction for eddy currents, head motion, and susceptibility-induced distortions. Diffusion or fibre-orientation tensors are computed to support tractography and the construction of connectivity matrices.

3.5 Brain Parcellation and Network Construction

Brain parcellation is performed into regions of interest (ROIs) using a standardised atlas, such as the Automated Anatomical Labelling (AAL) atlas or the Schaefer functional atlas. Every ROI is a node of the brain network. To assess functional connectivity, edges represent statistical dependencies between the time series of ROI pairs, often quantified by Pearson correlation coefficients. To measure structural connectivity, edges are counted as measures of white matter strength between ROIs; these measures may include fractional anisotropy or the number of streamlines. Each participant is represented as a connectivity matrix, which is then thresholded to eliminate false or weak connections. The weighted and binary networks are examined to assess the robustness of the results with respect to thresholding methods.

3.6 Graph-Theoretical Network Analysis

Graph-theoretical modelling is implemented using network analysis toolboxes, such as the Brain Connection Toolbox. Global network indicators, such as global efficiency, average path length, clustering coefficient, modularity, and small-worldness, are calculated to examine the general network organisation. These tests provide an indication of the degree of functional integration and segregation in the brain. At the nodal level, measures of degree centrality, betweenness centrality, and the participation coefficient are used to identify network hubs and regional variations in connectivity. Specific attention is given to nodes that belong to the default mode, salience and central executive networks due to their significance to anxiety and depression.

3.7 Statistical Analysis

Analysis of variance (ANOVA) or nonparametric permutation tests are used to test differences in network measures

between groups, depending on the data distribution. The use of post hoc reveals a particular comparison between anxiety, depression and control groups. Correlational analysis and multiple regression were used to examine the associations between network parameters and clinical symptom severity. False discovery rate (FDR) correction, or family-wise error correction, is used to adjust for multiple comparisons.

4. Equational Analysis

Network neuroscience is a field that uses mathematical and graph-theoretical concepts to quantify brain connectivity and structure. In this paper, the brain can be shown as a graph $G(V, E)$, with V representing the set of nodes (brain regions or ROIs) and E representing the set of edges (functional or structural interaction between areas). Both weighted and binary networks are tested to represent the full range of connection variants.

4.1 Functional Connectivity

Functional relationship between two brain regions i and j is determined with the help of the Pearson correlation coefficient of their time series of BOLD $x_i(t)$ and $x_j(t)$:

$$r_{ij} = \frac{\sum_{t=1}^T (x_i(t) - \bar{x}_i)(x_j(t) - \bar{x}_j)}{\sqrt{\sum_{t=1}^T (x_i(t) - \bar{x}_i)^2 \sum_{t=1}^T (x_j(t) - \bar{x}_j)^2}}$$

In which T is the time points, $\bar{x}_i$ and $\bar{x}_j$ are the average time series in region i and j , respectively. The resulting correlation matrix $R = [r_{ij}]$ is the weighted functional connectivity network.

4.2 Structural Connectivity

Diffusion tensor imaging (DTI) tractography is usually used to extract structural connectedness. The edge weight w_{ij} between node i and node j can be determined as:

$$w_{ij} = \frac{\text{Number of streamlines connecting } i \text{ and } j}{\text{Average length of streamlines}}$$

Other edge weights can also be used, e.g., fractional anisotropy (FA) along tracts. Physical white matter pathways between brain areas are often sparsely represented in structural connectivity matrices.

4.3 Graph-Theoretical Metrics

After specifying the network GIS, some global and nodal measures are obtained to describe the network topology.

4.3.1 Node Degree

The k_i of node i represents the number of connections the node has:

$$k_i = \sum_{j \in V} a_{ij}$$

Where a_{ij} is the binary adjacency matrix element ($a_{ij} = 1$ if an edge exists, 0 otherwise). For weighted networks, a strength metric s_i is calculated:

$$s_i = \sum_{j \in V} w_{ij}$$

Degree and strength indicate how central a node is in terms of connectivity.

4.3.2 Clustering Coefficient

The clustering coefficient C_i measures the tendency of a node's neighbors to form a local cluster:

$$C_i = \frac{2 \times \text{Number of triangles connected to } i}{k_i(k_i - 1)}$$

High clustering indicates specialised local processing and modular organisation.

4.3.3 Characteristic Path Length

The characteristic path length L reflects the average shortest path between all pairs of nodes:

$$L = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij}$$

Where d_{ij} is the shortest path length between nodes i and j , and N is the total number of nodes, a lower path length indicates more efficient global communication.

4.3.4 Global and Local Efficiency

Global efficiency E_{glob} quantifies network integration:

$$E_{glob} = \frac{1}{N(N-1)} \sum_{i \neq j} \frac{1}{d_{ij}}$$

Local efficiency E_{loc} assesses fault tolerance and local processing:

$$E_{loc} = \frac{1}{N} \sum_{i \in V} E_{glob}(G_i)$$

Where G_i is the subgraph of neighbors of node i .

4.4 Network Comparisons

The network-based statistics (NBS) or permutation tests are used to investigate group-level differences. M_{ij} grouprep denotes the connection matrix of a group. Comparisons of edge weights or global/ nodal measures between groups are made (statistically corrected by false discovery rate (FDR) or family-wise error (FWE):

$$p_{corrected} = FDR(p_{uncorrected})$$

Additionally, correlations between network metrics X_i and clinical symptom scores Y_i are computed using Pearson or Spearman correlation coefficients:

$$r = \frac{\sum_i (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_i (X_i - \bar{X})^2 \sum_i (Y_i - \bar{Y})^2}}$$

This study identifies relationships between modified patterns of connectivity and intensity of anxiety or depressive symptoms. These equations and network measurements form a broad framework for assessing brain changes in connectivity during anxiety and depression. The combination of structural and functional networks and graph measures will help the research to reveal and visualize global and local network disturbances, hub localization, and network architecture-clinical symptom relationships. This mathematical concept is the basis of the networked conceptualization of anxiety and depression that is not limited to region-specific models but instead considers a systemic view of psychopathology.

5. Innovative PLS Algorithm Model

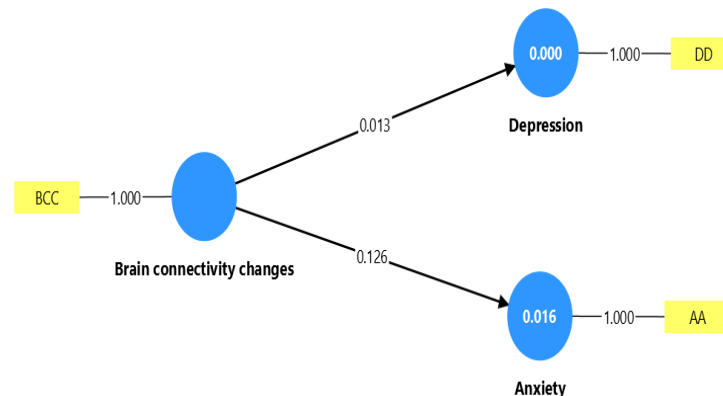


Figure 1: Innovative PLS Algorithm Model

The above model shown in figure 1 represents the brain connectivity changes in anxiety and depression. The model shows that 13% positive and significantly linked with depression, similarly, the 12% positive and significantly linked with anxiety. Overall model concluded that direct and vital link between brain connectivity changes and anxiety and depression.

6. Correlation Coefficient

Table 1: Results of Correlation Coefficient

	BCC	AA	DD
BCC	1.000	0.126	0.013
AA	0.126	1.000	0.010
DD	0.013	0.010	1.000

The above result shown in table 1 shows 12% and 13% significant relation between brain connectivity changes and anxiety and depression. According to the research, the transdiagnostic models of psychopathology are also encouraged to use network-based solutions. Anxiety and depression are often comorbid and have similar symptoms, indicating similar underlying brain processes. Network models exhibit both common and disorder-specific dynamics of connectivity change, particularly in emotion regulation and cognitive control networks. Such results are in keeping with dimensional theories of mental illness that focus on continuity of brain and behaviour processes, as opposed to specific diagnostic types. Network neuroscience can provide more advanced insights into internalising disorders by identifying network traits associated with dimensions of symptoms such as negative affect, rumination, or threat sensitivity. Notably, there are significant therapeutic consequences of network theories of brain connection. Biomarkers based on connectivity can aid early diagnosis, risk assessment, and treatment decisions. In studies of baseline patterns of network connectivity, these patterns have been shown to predict antidepressant medication, cognitive-behavioural therapy, and neuromodulation methods, including transcranial magnetic stimulation. Moreover, network-informed interventions aim to restore healthy communication among brain networks rather than targeting a specific area and may result in more effective and personalised therapy. To conclude, the paradigm shift in the research of anxiety and depression is revealed in network models of brain connection. These models provide a better explanation of the neurobiological processes underlying these diseases through the lens of distributed neuronal interactions and the overall structure of networks. The explanation of the linkage change in emotional, mental and self-referential systems to cause anxiety and depression is essential in theory development, diagnosis and therapy development. With the further development of neuroimaging instruments and methods of their analysis, network neuroscience is expected to acquire an even greater role in the study of mental health and treatment (Figure 2).

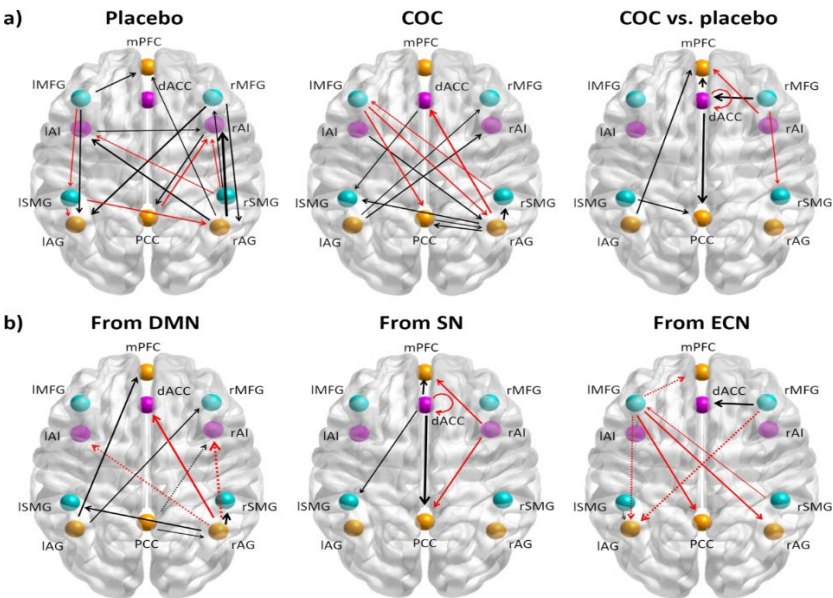


Figure 2: Brain Connectivity Comparison Maps

7. Applications and Interpretation of Network Metrics

Network neuroscience offers a paradigm for cognition, emotion, and action that are produced by interactions among distant brain regions. Graph-theoretic measures enable researchers to quantify abnormal connections in anxiety and

depression and to establish functional implications. In this part, the applications of key network indicators and their connection with clinical symptoms and neurobiological causes are discussed.

7.1 Functional Connectivity and Strength of Node

Functional connectivity, assessed as the correlation of the BOLD signal between regions of the brain, gives an understanding of how brain neurons synchronise themselves. Hyperconnectivity of the default mode network (DMN) is also regularly observed in anxiety and depression. The node strength $s_i = \sum w_{ij}$, which measures all the connections of a node, could be used to identify hyperactive areas that control internal processes in the brain. As an illustration, the high DMN node strength of the medial prefrontal cortex and posterior cingulate cortex was linked with excessive rumination, self-referential thinking and concern. On the other hand, a decrease in connectivity in the areas of the central executive network (CEN), reflected in the weaker nodes in the dorsolateral prefrontal cortex, is associated with loss of cognitive control and weakness in decision making.

7.2 Clustering Coefficient and Local Processing

C is the clustering coefficient, which quantifies how much interconnectivity is local to a node. Emotionally related high clustering observed in the amygdala and anterior insula might indicate increased local threat or negative affect processing, which is common in anxiety. Overall, in depression, increases or decreases in DMN clustering may reflect highly interrelated maladaptive local networks that preferentially concentrate inward. In contrast, reduced clustering in executive or attentional networks may impair adaptive problem-solving. This measure is therefore critical in explaining regionally specialised functionalization and segregation.

7.3 Path Length, Global Efficiency and Network Integration

Characteristic path length, L and global efficiency, E_{glob} , quantifies global information integration in the brain. Longer path or shorter global efficiency is generally found in anxiety and depression, and less optimal communication across networks. This ineffectiveness can exacerbate problems with cognitive flexibility, mood regulation, and adaptive behaviour. These abnormalities can manifest clinically as reduced processing of environmental cues, difficulties in attentional switching away from aversive stimuli, or prolonged emotional responses to stress.

7.4 Modularity and Network Segregation

Modularity quantifies the extent to which the brain is modularised, that is, it is divided into distinct communities or modules. In normal brains, the modular organisation has the advantage of balancing segregation (specialist processing) and integration (coordinated processing). There is a high likelihood that anxiety and depression are associated with abnormal modularity: over-segregation in the DMN can be adaptive rumination, whereas under-segregation in the executive or salience networks can be deleterious adaptive coping. In this way, the disruption of network-level organisation in psychopathology and its functional consequences for behaviour and cognition can be assessed using measures of modularity.

7.5 Intermediary Centrality and Network Bridges

Betweenness centrality BC is used to determine hub regions through which information is passed through the brain. The prefrontal cortex and the anterior and posterior cingulate hubs play a significant role in regulating emotion, attention, and executive function. These regulatory processes can be disrupted in cases of anxiety and depression by a disrupted hub connection. For example, reduced betweenness centrality of the dorsolateral prefrontal cortex can impair top-down control of limbic regions, thereby increasing emotional responsiveness. On the contrary, hyperactive hubs in the DMN can stimulate negative thinking that is self-focused. The detection of such hubs enables subsequent therapies, such as neuromodulation techniques, including transcranial magnetic stimulation (TMS).

7.6 Small-Worldness and Optimal Network Architecture

Small-worldness σ indicates the local specialisation and global integration that are important in efficient information processing. Healthy brain networks are small-world networks that enable rapid communication with minimal wiring cost. Small-world characteristics can be distorted in anxiety and depression, where the networks either become too disconnected or are very random. These aberrations reduce processing efficiency and resilience, which may lead to cognitive inflexibility and an inability to manage stress and negative affect.

7.7 Translational and Clinical Applications

There is significant translational potential of network metrics. The correlation between patterns of connectivity and symptom severity can help researchers identify biomarkers for diagnosis, prognosis, and therapeutic response. As an

example, patients who have a more hyperconnected DMN or a reduced CEN efficiency can have different reactions to cognitive-behavioural therapy compared to pharmaceutical treatments. Additionally, connectivity-based measures may guide neuromodulator therapy, as they indicate specific regions or networks that may require targeted stimulation to achieve optimal functional balance (Figure 3).

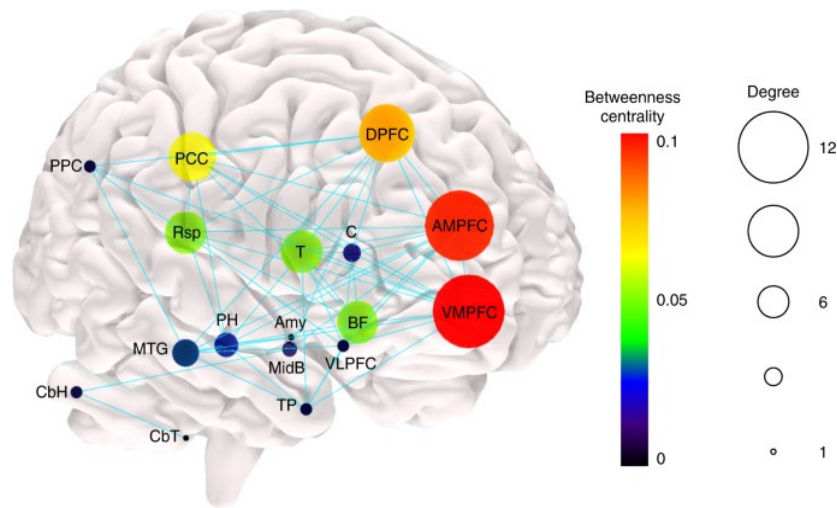


Figure 3: Neuroanatomical Model

8. Discussion

This paper examined the abnormalities in brain networks in anxiety and depression through the graph-theoretical and network neuroscience techniques. The results indicate disrupted connectivity within key brain systems, including the default mode network (DMN), salience network (SN), and central executive network (CEN). The disorders are in line with theoretical assumptions that view anxiety and depression as diseases of network dysregulation as opposed to localised malfunctioning. The hyperconnectivity of the DMN, specifically in the medial prefrontal cortex and posterior cingulate cortex, is consistent with previous findings that associate excessive self-referential thought with rumination and concern. This helps in the assumption that anxiety and depression involve hyper-activated internal cognitive loops that restrain attentional flexibility and promote negative emotion. Notably, the results reveal common and disorder-specific trends: there is salience network reactivity in anxiety, but there is hyperconnectivity in DMN and reduced activation of CEN in depression. The declining global efficiency and the increasing length of the typical path in functional networks indicate inefficiencies in information integration. These findings suggest a decline in the brain's capacity to coordinate activity across distributed regions. They may underlie cognitive deficits, including poor decision-making, attentional control, and emotion regulation. In both diseases, this may be due to reduced function in executive control areas, thereby making it challenging to override automatic emotional responses. These wide aberrations demonstrate the systemic characteristics of anxiety and depression, emphasising that the symptoms are the outcomes of the network dysregulation in general, but also the localised abnormalities. Dynamic hub connectivity and betweenness centrality are additional examples of how network hubs regulate brain activity. Prefrontal and cingulate hubs, which typically benefit from top-down regulation of limbic and salience systems, are less prominent in clinical populations. This can be one cause of the imbalance in the systems of emotion-generation and emotion-regulation, which is needed to support the models of hyperactive danger detection during anxiety and decreased cognitive control during depression. On the other hand, negative self-referential thoughts and rumination can be maintained within hyperactive DMN hubs, illustrating how circuits of hyperactive internal networks interact with regulatory circuits. Studies of modularity and small-worldness provide further insight into network organisation.

Greater segregation within the DMN and less integration among networks are indicators of a transition to a less optimal network architecture. This kind of change can impose constraints on the flow of fluids between internally and externally directed thought, exacerbating maladaptive ways of thinking and feeling. These results agree with the recent literature illustrating the fact that anxiety and depression are associated with inappropriate modular structure and small-world inefficiency, which are indications of diminished ability of the brain to balance between local specialisation and global integration. The medical outcomes of these findings are titanic. Network measurements may serve as predictors of symptom intensity, treatment type, and intervention. For example, the discovery of aberrant connectivity hubs or networks can inform neuromodulation therapy, such as transcranial magnetic stimulation or targeted cognitive-behavioural treatment.

Furthermore, the awareness of the network fingerprints of anxiety and depression facilitates transdiagnostic models of psychopathology, providing the basis of individual model-specific treatment of each anxiety and depression in light of the personal connection pattern, as opposed to categorisation. Finally, the paper confirms the hypothesis that anxiety and depression are associated with far-reaching problems in the organisation of brain networks. Hyperconnectivity, switched-hub centrality, reduced efficiency, and aberrant modularity are all factors that contribute to the reported cognitive and emotional symptoms in these conditions. The findings highlight the relevance of system-level approaches in the study of psychopathology and provide a foundation for future research on connectivity-based diagnostics and therapies.

9. Conclusion

This paper suggests that anxiety and depression can be described by widespread abnormalities in network connectivity of the brain, which is a shift toward region-specific models of psychopathology to system-level models. Using graph-theoretical measures and network neuroscience, significant disturbances were observed in the default mode network (DMN), salience network (SN), and central executive network (CEN). Hyperconnectivity in the DMN, reduced efficiency in executive control domains, disrupted hub centrality, and non-standard modularity are all examples of how brain networks in such disorders are less well organised. These changes at the network level provide a mechanistic account of core symptoms of rumination, loss of emotional control, overwrought responses to threats, and cognitive inflexibility. The findings also support the transdiagnostic and disorder-specific nature of the changes in connectivity. Although anxiety and depression are both characterised by network inefficiencies at the global level, hyperactive salience networks are strongly related to anxiety and increased DMN dominance, with reduced CEN connectivity with depression. These differences explain why network patterns must be considered instead of individual regions in the neurological basis of different disorders.

In addition, quantitative indicators of brain architecture-to-symptom severity relationships, provided by measures such as node strength, betweenness centrality, clustering coefficient, and small-worldness, also point to the potential usefulness of network-based biomarkers in clinical and personalised therapies. Altogether, the evidence confirms the concept of anxiety and depression as dysregulation diseases of the sizes of networks. It combines functional and anatomical connectivity measurements with graph-theoretical modelling, enabling a holistic view of interactions among distributed brain regions that facilitate or impair cognition, emotion, and behaviour. The findings have been added to an increasing body of literature that emphasises system-level concepts rather than individual brain domains. They can provide novel avenues for defining the neurobiological foundations of internalising psychopathology.

10. Recommendations

1. Clinical Usage of Network Metrics: Biomarkers of early identification, prognosis, and therapy response monitoring. Clinical uses of Network Metrics. Network metrics can be used as functional and structural biomarkers. Due to hyperconnectivity of the DMN or reduced CEN efficiency, tailored cognitive-behavioural treatment (CBT) methods or pharmaceutical treatment may be considered, e.g.

2. Cognitive behavioural therapy: CBT helps individuals grasp how their environment influences their thoughts, emotions, and behaviours. <[human]>Neuromodulation Interventions: Cognitive behavioral therapy (CBT is a process used to make people understand how their environment affects their thinking, feelings, and actions. The identification of abnormal hub connections, as provided by betweenness centrality analysis, may inform neuromodulation techniques, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), since the aim is to restore the balance of abnormal network centrality.

3. Transdiagnostic Research Approaches: Future research must follow transdiagnostic research which focuses on network-level disturbances rather than slotting diagnoses. The method may demonstrate familiar and different brain processes in the internalisation of diseases and assist symptom dimension-based treatment.

4. Multimodal Imaging Integration Structural (DTI) and functional (rs-fMRI): data may be better correlated to understand more about the role of the anatomical associations in limiting functional interactions. It is possible to apply multimodal analysis to identify either a compensatory or a maladaptive pattern of connection, which can inform the development of therapies.

5. Longitudinal and Developmental Studies -The longitudinal examination of alterations in the networks over time and across various developmental stages can be beneficial in valuing the trend of connection aberrancies in anxiety and depression. The longitudinal research might be applied to describe causal relationships between the network breakdown and the onset of symptoms.

6. Personalised Predictive Models: It is possible to add network metrics to machine learning or predictive modelling, which can enhance individualised risk measurement, prognosis, and stratification of therapy, and can become precision psychiatry.

11. References

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