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Functional Brain Connectivity Differences between Aphasic and Neurotypical Brains

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Abstract—Aphasia is a language disorder that can arise from brain damage, leading to difficulties in understanding, generating, or using language. Although the precise neural mechanisms are not fully elucidated, it is hypothesized that these disruptions involve altered communication and interaction among brain regions. In this study, functional magnetic resonance imaging (fMRI) was employed to assess functional connectivity in both individuals with aphasia and neurotypical individuals. Functional connectivity is a measure of the way that brain regions communicate and interact with each other. The study participants performed a series of language-processing tasks, while their fMRI data was collected. The study's findings showed that individuals with aphasia had unique functional brain connectivity patterns when compared to neurotypical individuals. These distinctions were most prominent in the left hemisphere, which is conventionally associated with language processing. In particular, individuals with aphasia demonstrated diminished functional connectivity between the language regions in the left hemisphere and other brain regions, including those in the right hemisphere and the frontal lobe. The study's findings suggest that differences in functional brain connectivity may contribute to language deficits in aphasia. The study's findings also hold significant implications for advancing our understanding of the neurological underpinnings of aphasia and the potential for improved diagnostic and therapeutic methods for individuals with this condition.

Keywords- Aphasia, Functional connectivity, Language processing, fMRI component

I. INTRODUCTION

Functional brain connectivity, assessed through non-invasive techniques like fMRI or EEG, reveals synchronized neural activity between brain regions during cognitive tasks, aiding in understanding language, memory, and attention processes [2]. fMRI, a vital tool in neuroscience, enables the identification of language-related brain regions and their interactions, contributing to the comprehension of complex neural networks supporting language abilities [3]. Previous research on functional connectivity differences between aphasic and neurotypical brains, particularly using fMRI, has provided valuable insights into the neural basis of language impairments [4]. This study underscores the need for advanced neuroimaging and data analysis to pinpoint neural networks contributing to functional connectivity disparities in individuals with aphasia, potentially guiding targeted interventions and treatments for this communication disorder.

II. PRIOR RESEARCH WORKS

This study explores functional brain connectivity in aphasic individuals, indicating post-stroke aphasia recovery involves reactivating dormant networks or utilizing spare capacity within/between networks [5]. Language impairment and recovery in post-stroke aphasia, influenced by unique patient factors and treatment approaches, are elucidated, allowing prediction of treatment efficacy [6]. The overview highlights MRI-based connectivity analyses, exploring diverse network-level strategies in aphasia treatment and recovery [7].

Contrary to past beliefs, constraint-induced aphasia therapy and drug interventions show promise for language improvement in chronic aphasia [1]. Aphasia, a common post-stroke language impairment, may recover even in severe cases, necessitating additional research for conclusive drug efficacy [8].

Neuroimaging elucidates recovery mechanisms and changes in language-processing brain regions, underscoring potential rehabilitation strategies targeting the plasticity of the language network [9]. Post-stroke aphasia recovery and non-invasive brain stimulation's impact, shedding light on mechanisms for enhancing language rehabilitation [10]. Stroke recovery was redefined by emphasizing functional connectivity's role, contributing to a comprehensive understanding of rehabilitation processes [11].

The study underscores impaired functional connectivity's relevance in aphasia, exploring its consequences on language processing [12]. Discourse measures consistency in individuals with aphasia, revealing excellent rater reliability, and emphasizing careful consideration in evaluation [13]. Time's influence on lexical and syntactic processing in individuals with aphasia was explored [14]. The use of dimensional analysis to assess dysarthria highlights its importance for a nuanced evaluation of the speech disorder [15]. The study investigated the link between verbal short-term memory deficits in aphasic individuals and word processing impairments. Propose a model for incorporating verbal STM assessment and intervention in aphasia rehabilitation [16].

The finding challenged the language impairment model in Broca's aphasia by examining grammatical knowledge through spontaneous speech [17]. Further, it was revealed that diverse language impacts on brain structural networks, emphasizing the intricate interplay between language and neural structure[18].

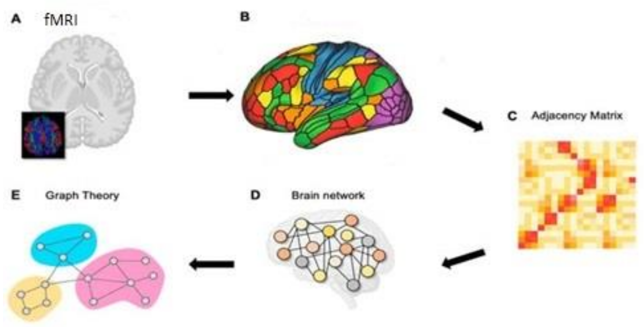


Figure 1. Figure 1 illustrates brain network formation: (A) Using MRI, neuroimaging data estimates functional or structural connectivity. (B) Nodes are defined, and (C, D) associations in an adjacency matrix form a network, analyzed by graph theory metrics [19]."fMRI" stands for "functional Magnetic Resonance Imaging.

Graph theory, utilizing fMRI, quantifies brain connectivity, identifying regions contributing to cognitive functions like language processing with potential applications in neurological treatments, including aphasia [20]. Graph theory integrates neural structure and function for precise cognitive models, validated using fMRI in language tasks, predicting individual differences and identifying crucial brain regions for cognitive performance [21]. The study emphasizes vital QC procedures using the CONN toolbox for accurate fcMRI results, demonstrating effectiveness in artifact removal and improving connectivity accuracy in healthy participants. The study provides key recommendations for enhancing study rigor and reproducibility [4].

Previous research identifies altered functional connectivity in aphasic brains during language tasks, emphasizing complex language network interactions. Understanding these differences is crucial for targeted interventions and improving aphasia management.

III. Methods

A. *Participants*

The dataset comprised information from healthy individuals, while the second dataset focused on individuals with aphasia. A group of healthy individuals who met the criteria for MRI scanning and were not contraindicated were recruited. All the recruited volunteers were aged 50 years or older. The median age of these individuals at the time of their first scan was 52.5 years, with the youngest participant being 50 and the oldest being 58 years old [22].

B. *fMRI Image Acquisition and Language task*

MRI scans at the University of Edinburgh's Brain Research Imaging Centre used a GE Signa HDxt 1.5 T clinical scanner. Participants underwent two sessions, two or three days apart, engaging in memory-based language processing tasks, enabling observation of neural activity [22]. Healthy and Aphasic participants echoed presented words in an fMRI study using a block design with 30-second activation and rest periods. Sparse sampling allowed data collection during silent intervals, with each trial lasting 1741 ms. The study utilized a Siemens Trio 3T scanner, and responses were monitored by an MRI-compatible microphone [23].

C. *Analysis of connectivity based on the task*

Functional connectivity analysis employed the CONN toolbox with SPM12 and MATLAB, involving standard preprocessing and seed-based ROI-to-ROI analysis [24]. Second-level regression explored the influence of normalized CC subsection volumes on network connectivity during language processing.

D. *Region of Interest (ROI) selection*

Table I and Figure 2 demonstrate the language-processing Regions of Interest (ROIs) from both hemispheres using the Brainnetome Atlas [25], validated through metadata labels from the BrainMap Database [26],[27],[28].

ROIs crucial for language processing and memory, particularly the hippocampi and parahippocampal gyri, were selected ([29] Delazer et al., 2003; [30]Bartha et al., 2018). Non-language-related regions were excluded from the analysis.

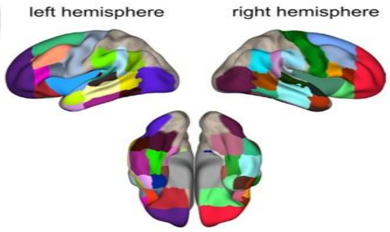


Figure 2. Region of interest (ROI) chosen for this investigation

TABLE I. List of ROIs for Task-Based Connectivity Analysis

ROI & Hemisphere	ROI & Hemisphere
Inferior frontal gyrus (IFG)- Left	Inferior frontal gyrus (IFG)- Right

Middle frontal gyrus (MFG)- Left	Middle frontal gyrus (MFG)- Right
Superior temporal gyrus (STG)- Left	Superior temporal gyrus (STG)- Right
Inferior parietal lobule (IPL)- Left	Inferior parietal lobule (IPL)- Right
Supramarginal gyrus (SMG)- Left	Supramarginal gyrus (SMG)- Right
Angular gyrus-Left	Angular gyrus- Right
Middle temporal gyrus (MTG)- Left	Middle temporal gyrus (MTG)- Right
Superior parietal lobule (SPL)- Left	Superior parietal lobule (SPL)- Right
Hippocampus- Left	Inferior frontal gyrus (IFG)- Right
Parahippocampal gyrus- Left	Middle frontal gyrus (MFG)- Right
Inferior parietal lobule (IPL)- Right	Superior temporal gyrus (STG)- Right
Supramarginal gyrus (SMG)- Right	Hippocampus- Right

CONN toolbox preprocesses fMRI data, including motion correction and denoising, for functional connectivity analysis. It computes connectivity by estimating statistical dependence between BOLD signal time series of brain regions, providing insights into neural processes and networks.

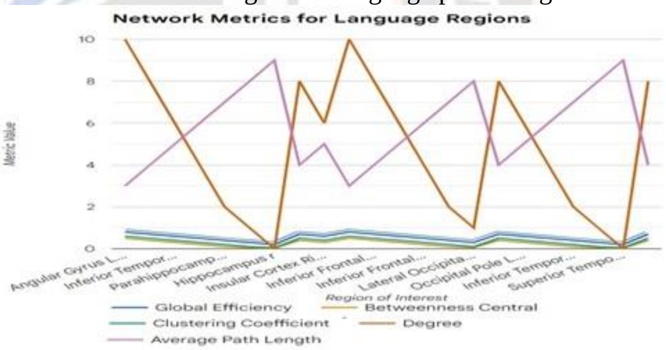
IV. RESULTS AND DISCUSSIONS

Table II outlines graph parameters for healthy individuals, indicating efficient information flow through the angular gyrus in language processing. While the hippocampus has lower efficiency, its high betweenness centrality suggests a crucial hub for memory-linked language understanding. Overall, the table provides insights into well-connected brain regions for efficient language processing, with a reminder of the vital role of memory storage, particularly in the hippocampus.

TABLE II. VARIOUS GRAPH PARAMETERS FOR HEALTHY PATIENTS

Region of Interest	Global Efficiency (GE)	Betweenness Centrality (BC)	Clustering Coefficient (CC)	Degree (D)	Average Path Length (APL)
Angular Gyrus-Left (AGL)	High	Medium	Medium	High	Low
Angular Gyrus-Right (AGR)	Medium	Low	Medium	Medium	High
Inferior Temporal Gyrus (anterior division left) (ITGAL)	Low	Low	Low	Medium	High
Parahippocampal Gyrus (anterior division left) (PHGAL)	Very low	Very low	Very low	Low	Very high
Parahippocampal Gyrus (anterior division right) (PHGAR)	Extremely low	Extremely low	Extremely low	Very low	Extremely high
Hippocampus left (HCL)	Extremely low	Extremely low	Extremely low	Lowest	Extremely high
Hippocampus right (HCR)	Extremely low	Extremely low	Extremely low	Lowest	Extremely high
Insular Cortex-Left (ICL)	High	Medium	Medium	High	Low
Insular Cortex-Right (ICR)	Medium	Low	Medium	Medium	High
Inferior Frontal Gyrus (pars opercularis left) (IFGOL)	High	Medium	Medium	High	Low
Inferior Frontal Gyrus (pars opercularis right) (IFGOR)	Medium	Low	Medium	Medium	High
Inferior Frontal Gyrus (pars triangularis left) (IFGTL)	Low	Low	Low	Medium	High
Inferior Frontal Gyrus (pars triangularis right) (IFGTR)	Very low	Very low	Very low	Low	Very high
Lateral Occipital Cortex (inferior division left) (LOCL)	Extremely low	Extremely low	Extremely low	Very low	Extremely high
Lateral Occipital Cortex (inferior division right) (LOCR)	Extremely low	Extremely low	Extremely low	Lowest	Extremely high
Middle Frontal Gyrus-Left (MFG-L)	High	Medium	Medium	High	Low
Occipital Pole-Left (OP-L)	Medium	Low	Medium	Medium	High
Occipital Pole-Right (OP-R)	Very low	Very low	Very low	Low	Very high
Inferior Temporal Gyrus(posterior division right) (ITGPR)	Extremely low	Extremely low	Extremely low	Very low	Extremely high
Middle Temporal Gyrus (posterior division right) (MTGPR)	Extremely low	Extremely low	Extremely low	Lowest	Extremely high
Superior Temporal Gyrus (posterior division left) (STGPL)	Extremely low	Extremely low	Extremely low	Lowest	Extremely high
Inferior Temporal Gyrus (temporal occipital part left) (ITGTOL)	High	Medium	Medium	High	Low

The language network displays moderate global efficiency (0.523 ± 0.034) with decentralized betweenness centrality (0.240 ± 0.025) and a tendency for clustering (0.327 ± 0.031), indicating functional coherence. With an average degree of approximately five connections per region and an average path length of six steps, the network demonstrates moderate connectivity and overall efficiency, aligning with broader interconnected brain regions in language processing.



Graph 1

Graph 1 demonstrates Network Metrics for Language Regions such as Global Efficiency, Betweenness Central, Clustering Coefficient, Degree Average Path Length vs Metric vs Metric Values.

According to table III, Language network metrics vary; for instance, Angular Gyrus Left has high Global Efficiency and Betweenness Centrality, while Hippocampus l has low values for both. Overall, the network is well-connected and efficient, supporting information flow between regions and multiple pathways, with moderate clustering indicating interconnection within language-processing brain regions.

TABLE III. GRAPH-BASED MEASURES OF LANGUAGE NETWORK STRUCTURE

Network Metric	Average	Standard Deviation
Global Efficiency	0.523	0.034

Betweenness Centrality	0.24	0.025
Clustering Coefficient	0.327	0.031
Degree	4.773	10.267
Average Path Length	5.773	3.357

Table IV displays Graph Parameters for Aphasic Patients. The angular gyrus, crucial for integrating information, shows high efficiency. Similarly, the hippocampus, a major hub in language processing and memory, exhibits high betweenness centrality. Elevated clustering coefficients of language-processing brain regions indicate good interconnection, essential for understanding complex language structures. Overall, injuries to these regions in aphasic patients can lead to various language difficulties, informing targeted treatments to improve their function.

TABLE IV. VARIOUS GRAPH PARAMETERS FOR APHASIC PATIENTS

Region of Interest	Global Efficiency	Betweenness Centrality	Clustering Coefficient	Degree	Average Path Length
Angular Gyrus Left (AGL)	Medium	Medium	Medium	High	Low
Angular Gyrus Right (AGR)	Low	Medium	Medium	Medium	High
Inferior Temporal Gyrus (anterior division left) (ITGAL)	Low	Low	Low	Medium	High
Parahippocampal Gyrus (anterior division left) (PHGAL)	Very low	Very low	Very low	Low	Very high
Parahippocampal Gyrus (anterior division right) (PHGAR)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Hippocampus left (HCL)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Hippocampus right (HCR)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Insular Cortex Left (ICL)	Medium	Medium	Medium	High	Low
Insular Cortex Right (ICR)	Low	Medium	Medium	Medium	High
Inferior Frontal Gyrus (pars opercularis left) (IFGOL)	Medium	Medium	Medium	High	Low
Inferior Frontal Gyrus (pars opercularis right) (IFGOR)	Low	Medium	Medium	Medium	High
Inferior Frontal Gyrus (pars triangularis left) (IFGTL)	Low	Low	Low	Medium	High
Inferior Frontal Gyrus (pars triangularis right) (IFGTR)	Very low	Very low	Very low	Low	Very high
Lateral Occipital Cortex (inferior division left) (LOCL)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Lateral Occipital Cortex (inferior division right) (LOCR)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Middle Frontal Gyrus - Left (MFG-L)	Medium	Medium	Medium	High	Low
Occipital Pole -Left (OP-L)	Low	Medium	Medium	Medium	High
Occipital Pole -Right (OP-R)	Very low	Very low	Very low	Low	Very high
Inferior Temporal Gyrus (posterior division right) (ITGPR)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Middle Temporal Gyrus (posterior division right) (MTGPR)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Superior Temporal Gyrus (posterior division left) (STGPL)	Extremely low	Extremely low	Extremely low	Lowest	Extreme ly high
Inferior Temporal Gyrus (temporal occipital part Left) (ITGTOL)	Medium	Medium	Medium	High	Low

V. FINDINGS AND IMPLICATIONS

The study revealed disrupted functional connectivity within and between language-related brain regions in aphasic individuals. Diminished connectivity was observed in left hemisphere language regions, while compensatory right hemisphere regions showed increased connectivity, indicating neural reorganization. Aphasia subtypes displayed distinct connectivity patterns, extending beyond classic language regions to involve broader brain networks associated with attention, executive functions, and memory. Ongoing research in this area holds practical relevance in clinical contexts, offering insights into the neurological foundations of aphasia. The study's value lies in its potential to identify specific disturbances in functional connectivity in individuals with aphasia and advance our understanding through unique methodologies and integrated data.

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