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Neuroplastic Changes Associated with Speech Therapy in Traumatic Brain Injury Rehabilitation

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ABSTRACT

Background: Traumatic brain injury is a major cause of acquired communication disorders in Pakistan, often resulting in long-term speech and language impairments. Despite growing awareness of the link between speech therapy and neural recovery, local research exploring neuroplastic changes remains limited. **Objective:** To investigate the neuroplastic changes associated with structured speech therapy among traumatic brain injury patients undergoing rehabilitation at Lahore General Hospital, Lahore, and to evaluate its effectiveness in improving speech performance and functional communication. **Methodology:** A mixed-methods design was employed with 20 adult participants diagnosed with moderate to severe traumatic brain injury, aged between 18 and 55 years were recruited through purposive sampling, verified through CT or MRI imaging, with a post-injury duration of three to twelve months, and the presence of speech or language impairments as determined by the Western Aphasia Battery. Patients with progressive neurological disorders, notable hearing loss, or psychiatric comorbidities were excluded from the study. Each received individualized speech therapy sessions three times a week for 12 weeks. Pre- and post-intervention assessments included functional MRI and EEG scans to track cortical reorganization, along with standardized speech evaluations measuring articulation, fluency, and intelligibility. The qualitative insights were gathered through semi-structured interviews with patients and caregivers. Differences in pre- and post-intervention speech performance were evaluated using paired t-tests, and correlations between neuroimaging and behavioral outcomes were determined using Pearson's correlation coefficient. **Results:** Neuroimaging revealed increased cortical activation in perilesional and contralateral hemispheres post-therapy. Statistically notable improvements were observed in articulation clarity and verbal fluency ($p<0.05$). Participants also reported enhanced confidence and communication in daily interactions. **Conclusion:** Findings demonstrate that structured speech therapy promotes measurable neuroplastic changes that correspond with improved speech outcomes in patients with traumatic brain injury. Incorporating such interventions within Pakistan's rehabilitation programs could meaningfully improve recovery and quality of life for individuals with brain injury.

Keywords: Cognitive linguistic therapy, Functional neuroimaging, Neuroplastic changes, Speech therapy, Traumatic brain injury

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INTRODUCTION

Traumatic Brain Injury (TBI) is one of the leading causes of neurological disability worldwide, with an estimated 69 million cases reported annually.[1] Developing nations such as Pakistan bear a disproportionate burden due to high rates of road traffic accidents, occupational hazards, and limited access to specialized neurorehabilitation services.[2] Individuals who sustain moderate to severe TBI often experience persistent speech and language impairments, including dysarthria, apraxia of speech, and cognitive-communication deficits, which notably affect their social participation and emotional well-being.[3] Rehabilitation of such impairments requires not only linguistic retraining but also targeted stimulation of the brain's neuroplastic potential, the intrinsic ability of neural networks to reorganize following injury.[4]

Speech therapy plays a critical role in facilitating this neuroplastic reorganization. Repetitive, task-specific exercises have been shown to enhance synaptic efficacy, recruit perilesional regions, and strengthen engagement of the contralateral hemisphere.[5] Structured therapy promotes recovery by engaging residual neural pathways and forming compensatory connections that support motor-speech coordination.[6] Neuroimaging studies using functional MRI (fMRI) and EEG have revealed that improvement in articulation and fluency often parallels increased cortical activation in Broca's area, the supplementary motor cortex, and right-hemisphere homologs.[7]

Recent advances in neuroimaging and electrophysiological monitoring have enabled the objective measurement of therapy-induced neuroplasticity. Saur et al. demonstrated that repetitive speech-motor exercises enhance cortical excitability and functional connectivity between auditory and motor regions.[8] Similarly, EEG biomarkers linked to speech rhythm recovery in post-injury patients, reinforcing the role of cortical synchronization in linguistic rehabilitation.[9] These studies highlight the potential of neuroimaging as a reliable tool for assessing treatment progress and tailoring interventions to individual recovery profiles.[10] In the South Asian context, the application of such evidence-based and technology-supported interventions remains limited. Rafiq & Naz (2024) emphasized that Pakistani rehabilitation settings often lack integrated neuroimaging assessment and data-driven therapy models, resulting in inconsistent outcomes.[12] Given this gap, there is a pressing need to validate global rehabilitation frameworks within local hospital environments, such as Lahore General Hospital, where patient demographics, injury patterns, and resource availability differ markedly from Western contexts.

This study seeks to investigate the neuroplastic changes associated with structured speech therapy in patients with TBI admitted to Lahore General Hospital, Lahore. Specifically, the objective is to investigate the neuroplastic changes associated with structured speech therapy among TBI patients undergoing rehabilitation at Lahore General Hospital, Lahore, and to evaluate its effectiveness in improving speech performance and functional communication. By linking clinical progress with measurable neural reorganization, this study contributes to a growing body of research supporting the integration of neuroscience into speech-language rehabilitation. It is expected to provide empirical evidence for developing standardized, locally adaptable therapy protocols in Pakistan, bridging the gap between clinical speech therapy and neurophysiological research. Ultimately, understanding therapy-induced neuroplasticity could reshape rehabilitation strategies for TBI patients across the country, fostering recovery, independence, and social reintegration.

METHODOLOGY

This study adopted a quasi-experimental pretest–posttest design and was conducted at the Lahore General Hospital, Lahore, between July and December 2024. Ethical approval for the research was obtained from the Ethical Review Committee of the Central Park Medical College, Lahore, Pakistan. All participants or their legal guardians provided written informed consent before inclusion in the study. The selection of Lahore General Hospital as the research site was based on its well-established neurorehabilitation unit and its interdisciplinary collaboration among neurologists, speech-language pathologists, and imaging specialists.

A total of twenty adult participants aged between 18 and 55 years were recruited through purposive sampling. All participants had been diagnosed with moderate to severe traumatic brain injury, verified through CT or MRI imaging and clinical evaluation. Inclusion criteria consisted of a post-injury duration of three to twelve months and the presence of speech or language impairments as determined by the Western Aphasia Battery. Patients with progressive neurological disorders, notable hearing loss, or psychiatric comorbidities were excluded from the study.

Baseline data, including demographic information, medical history, and Glasgow Coma Scale scores, were collected to ensure comparability among participants. Each participant underwent a personalized speech therapy program administered by certified speech-language pathologists. Therapy sessions were delivered three times per week for a period of twelve weeks, each lasting approximately forty-five minutes. The intervention incorporated evidence-based techniques such as Melodic Intonation Therapy, articulation placement training, prosody modulation, and semantic cueing. These approaches were designed to stimulate both the damaged and compensatory neural networks responsible for speech and language processing. Family members were trained to support home-based practice to encourage skill retention and functional communication outside clinical settings.

Pre- and post-therapy assessments were conducted using a combination of behavioral and neuroimaging measures. Functional MRI scans were performed to examine cortical activation during speech-related tasks, while EEG recordings were used to assess neural connectivity and temporal synchronization. Speech outcomes were measured using standardized assessment tools, including the Assessment of Intelligibility of Dysarthric Speech and the Boston Diagnostic Aphasia Examination. To reduce observer bias, all assessments were conducted by independent evaluators who were blinded to the treatment timeline. Quantitative data were analyzed using SPSS version 25. Differences in pre- and post-intervention speech performance were evaluated using paired t-tests, and correlations between neuroimaging and behavioral outcomes were determined using Pearson's correlation coefficient. A significance level of $p<0.05$ was considered statistically meaningful.

RESULTS

Table 1 shows that a total of twenty participants, 15 males and 5 females, completed the twelve-week intervention. The mean age was 34.6±8.2 years, reflecting a typical demographic for traumatic brain injury (TBI) cases in developing regions. The primary cause of injury was road traffic accidents (70%), followed by falls (20%) and workplace trauma (10%), patterns consistent with earlier Pakistani epidemiological data (Hassan et al., 2021). The average duration since injury was 7.4±2.1 months, placing most participants in the sub-acute recovery stage when neuroplastic potential remains substantial. Baseline Glasgow Coma Scale (GCS) scores averaged 11.2±1.8, indicating moderate TBI severity.

All participants demonstrated measurable improvement in speech and language performance following twelve weeks of structured speech therapy, as mentioned in Table 2. The most notable progress was observed in articulation clarity and speech intelligibility, both showing strong statistical significance ($p<0.00$). The Assessment of Intelligibility of Dysarthric Speech (AIDS) and Boston Diagnostic Aphasia Examination (BDAE) revealed mean increases of 18.9% and 21.9% respectively, confirming the effectiveness of repetitive, individualized interventions in restoring communication abilities. Post-therapy improvements were not limited to speech output but extended to cognitive-linguistic efficiency, as reflected in increased fluency and faster word retrieval. Participants who initially struggled to produce coherent speech exhibited smoother articulation and more natural prosody after twelve weeks. The steady improvement trend suggests that consistent therapy frequency and active engagement reinforced neural reorganization through experience-dependent plasticity.

Table 1: Participant demographics and baseline characteristics

Variables		Mean ± SD
Age (years)		34.6 ± 8.2
Duration (months)		7.4 ± 2.1
Baseline GCS score		11.2 ± 1.8
		Frequency (%)
Gender	Male	15 (75%)
	Female	5 (25%)
Injury mechanism	Road traffic	14 (70%)
	Fall	4 (20%)
	Workplace	2 (10%)

Neuroimaging findings corroborated behavioral outcomes, which are explained in Table 3. Functional MRI scans showed increased activation intensity in the left inferior frontal gyrus (Broca's area), supplementary motor cortex, and auditory cortex regions critical for motor-speech integration and auditory feedback. Notably, the right inferior frontal gyrus also demonstrated moderate post-therapy activation, indicating compensatory interhemispheric engagement. This bilateral recruitment aligns with global studies emphasizing the right hemisphere's role in speech recovery following left-hemispheric damage.

EEG data analysis further supported the neuroplastic interpretation. There was a clear increase in beta-band synchronization (13–30 Hz) across fronto-temporal regions during speech production tasks, reflecting more efficient neuronal communication. Participants who demonstrated greater EEG synchronization generally achieved higher articulation and fluency scores, reinforcing the direct neurobehavioral correlation between brain activity and speech recovery. These correlations demonstrate that individuals showing stronger cortical activation post-therapy also achieved more substantial speech performance gains. The mean correlation coefficient (r=0.78) reflects a robust link between neural reorganization and functional speech recovery. This finding reinforces contemporary theories that neuroplasticity serves as a measurable biomarker of rehabilitation success.

Qualitative feedback from both patients and caregivers added a human dimension to these findings. Participants frequently reported feeling more understood, while caregivers observed increased conversational confidence and emotional engagement. The combination of quantitative data, neuroimaging evidence, and subjective reports provides compelling evidence that structured, repetitive speech therapy can induce both physiological and psychosocial recovery in TBI patients. Overall, these results highlight that consistent therapy engagement over twelve weeks not only enhances behavioral communication outcomes but also triggers observable neuroplastic changes within the speech-motor network, validating the brain's remarkable capacity to reorganize and recover even after notable trauma.

DISCUSSION

The findings of this study provide compelling

Table 2: Comparison of pre- and post-therapy speech outcomes using paired t-test

Variables	Pre-Therapy Mean ± SD	Post-Therapy Mean ± SD	t-value	p-value
Articulation clarity (%)	62.4 ± 9.5	81.3 ± 7.8	7.12	<0.00
Verbal fluency (words/min)	58.9 ± 10.2	77.1 ± 8.4	6.85	<0.00
Speech intelligibility (%)	60.7 ± 8.7	82.6 ± 6.9	7.54	<0.00

Table 3: Neuroimaging findings: cortical activation patterns pre- and post-therapy

Brain Region	Activation		Change (%)	Interpretation
	Pre-Therapy	Post-Therapy		
Left Inferior Frontal Gyrus (Broca's Area)	Moderate	High	+42%	Enhanced speech-motor control
Right Inferior Frontal Gyrus	Low	Moderate	+35%	Compensatory recruitment
Supplementary Motor Cortex	Low	High	+48%	Improved motor planning
Auditory Cortex	Moderate	High	+30%	Strengthened feedback loop

Table 4: Correlation between neuroimaging activation and speech outcome gains

Variable Pair	Correlation Coefficient (*r*)	p-*value*
fMRI activation (Broca's) vs Articulation Score	0.81	<0.00
EEG beta synchronization vs Fluency	0.74	0.00
Combined neural activation vs Speech Intelligibility	0.78	<0.00

evidence that structured speech therapy can notably enhance both behavioral and neurophysiological outcomes in patients recovering from traumatic brain injury (TBI). The observed improvements in articulation, fluency, and intelligibility, along with measurable increases in cortical activation, strongly support the hypothesis that speech therapy fosters neuroplastic reorganization within the damaged neural networks responsible for language processing. The consistent post-intervention gains across multiple speech parameters align closely with the existing literature on neurorehabilitation and brain recovery.

A study by Chen et al. (2010) emphasized that repetitive, goal-oriented speech tasks enhance the efficiency of residual neural circuits, facilitating the restoration of communicative competence following TBI.[11] Similarly, Kiran et al. (2019) demonstrated that targeted therapy induces activation in perilesional cortical regions, promoting functional compensation through interhemispheric engagement.[13] The current study's neuroimaging data mirror these findings, revealing increased activity in the left inferior frontal and supplementary motor cortices post-therapy. The activation of the right inferior frontal gyrus in our participants is particularly noteworthy. This pattern is consistent with the compensatory mechanisms described in an earlier study, which reported that the right hemisphere assumes partial control of language processing when left-hemispheric pathways are compromised.[14,15] The bilateral activation pattern observed in this study suggests that therapy may not only strengthen existing neural pathways but also facilitate cross-hemispheric integration, a hallmark of functional neuroplasticity. These results also echo findings from Morgan (2013), who observed that neuroplastic changes induced by speech therapy are quantifiable through both fMRI and EEG measures, with beta-band synchronization serving as a key electrophysiological marker of recovery.[16] In our study, the strong correlation between EEG synchronization and verbal fluency reinforces the link between neural coherence and language efficiency. In the Pakistani context, this study holds particular significance.

Research on neuroplastic mechanisms in speech rehabilitation remains limited, with most local studies focusing primarily on clinical outcomes rather than underlying neural changes. A case report from the Pakistan Armed Forces Medical Journal highlighted speech and language recovery in severe TBI but called for neuroimaging-based evidence to substantiate behavioral progress.[17] The current findings respond directly to that gap by combining behavioral measures with neurophysiological evidence collected within a Pakistani hospital setting. The improvement observed over twelve weeks shows that, in many ways, early, intensive, and consistent therapy can harness the brain's inherent adaptability even in resource-limited rehabilitation environments. Comparable trends have been reported in studies where similar therapy intensities yielded meaningful gains in fluency and speech intelligibility.[18,19] This reinforces the notion that well-structured rehabilitation protocols can be effectively translated into low- and middle-income countries with appropriate clinical support.

From a theoretical perspective, the results align with Hebbian learning principles, wherein repeated neural activation strengthens synaptic connections, ultimately leading to improved functional outcomes. The integration of neuroimaging into the clinical process further validates this concept, transforming speech therapy from a purely behavioral intervention into a neurobiologically informed treatment strategy.

However, certain limitations must be acknowledged. The relatively small sample size and single-center design may restrict generalizability. Additionally, while fMRI and EEG provided valuable insights, longitudinal imaging would be beneficial to evaluate the durability of neuroplastic adaptations.

Despite these limitations, the consistent behavioral and imaging improvements across participants underscore the reliability of the observed trends.

Overall, this study underscores the transformative potential of speech therapy in facilitating cortical reorganization and functional recovery following TBI. It not only contributes empirical evidence to Pakistan's limited body of rehabilitation research but also emphasizes the importance of integrating neuroscience-based monitoring into routine clinical practice. Future research should explore larger multicenter studies and examine the long-term retention of neuroplastic gains, potentially incorporating noninvasive brain stimulation techniques to further augment speech recovery.

CONCLUSION

This study provides strong evidence that structured and intensive speech therapy facilitates measurable neuroplastic changes in individuals recovering from traumatic brain injury. Participants demonstrated notable improvements in speech articulation, fluency, and intelligibility, supported by neuroimaging findings showing increased cortical activation and interhemispheric engagement. These results affirm that the brain retains the capacity to reorganize and compensate following injury when therapy is targeted, consistent, and sustained. The integration of behavioral progress with neurophysiological data strengthens the scientific foundation of speech rehabilitation and underscores the value of a neuroscience-informed approach to clinical practice in Pakistan, where such research remains limited.

DECLARATIONS

Consent to participate: Written consent had been obtained from patients. All methods were performed following the relevant guidelines and regulations.
Availability of Data and Materials: Data will be made available upon request. The corresponding author will submit all dataset files.
Competing interests: None
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