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Role Of Neuroplasticity In Language Recovery After Left Hemiplegic Stroke

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Abstract
Background: Language impairments post left hemispheric stroke significantly impact the quality of life of the survivors. Neuroplasticity plays a crucial role in recovery, but the mechanisms and factors influencing this process remain incompletely understood.
Objectives: To investigate the role of neuroplasticity in language recovery after left hemispheric stroke, identify factors influencing recovery patterns, and evaluate the effectiveness of targeted rehabilitation strategies.
Methods: This prospective study included 50 patients with the first incidence of left hemispheric stroke and language deficits. Patients underwent comprehensive language assessment using standardized tools at baseline, 3 months, and 6 months post-left hemispheric stroke. Neuroplastic changes were monitored using functional neuroimaging.
Results: Significant improvement in language function was observed, correlating with neuroplastic reorganization patterns. Early intervention, intensity of therapy, and patient age were identified as key factors influencing recovery.
Conclusion: Neuroplasticity significantly influences language recovery post-stroke, with specific patterns of neural reorganization associated with better outcomes. Understanding these mechanisms can inform more effective rehabilitation strategies.

Keywords: Neuroplasticity; Stroke; Language Recovery; Aphasia; Neural Reorganization; Rehabilitation; fMRI; Speech Therapy; Brain Recovery; Neuroimaging

Introduction
Stroke remains a leading cause of disability worldwide, with left hemispheric strokes, impairing language function.[1] Damage to regions supplied by the middle cerebral artery often results in aphasia, significantly affecting communication and daily life. However, the brain exhibits remarkable neuroplasticity, enabling language recovery despite injury to critical regions like Broca's and Wernicke's areas.[2,3]
Neuroimaging studies reveal that language recovery involves both perilesional tissue in the left hemisphere and the recruitment of homologous right-hemispheric regions. Yet, the precise mechanisms of this neural reorganization, recovery predictors, and optimal rehabilitation strategies remain incompletely understood.[2,4]
Current rehabilitation outcomes vary widely, highlighting the need for more targeted, evidence-based interventions. Identifying reliable prognostic factors and optimizing therapy timing and intensity are crucial to improving recovery. The economic and social burden of post-stroke aphasia is substantial, affecting individuals, families, and healthcare systems, making effective rehabilitation increasingly vital.
This study aims to bridge knowledge gaps by investigating neural mechanisms underlying language recovery, identifying factors influencing recovery potential, and evaluating targeted interventions. Using clinical assessments and advanced neuroimaging, we seek to elucidate patterns of neural reorganization and develop evidence-based rehabilitation protocols. Our findings could enhance clinical practice, improve patient outcomes, and advance understanding of neuroplasticity in stroke recovery.

Aim And Objectives
The aim of this study is to investigate neural reorganization patterns, the impact of intensity and timing of rehabilitation, reliable predictors of recovery, and the effectiveness of targeted therapy in promoting neuroplasticity following left hemispheric stroke.

Objectives:
- To investigate patterns of neural reorganization during language recovery in patients with left hemispheric stroke using functional neuroimaging.
- To evaluate the relationship between rehabilitation intensity and language recovery outcomes in post-left hemispheric stroke aphasia patients.
- To determine the impact of early intervention timing on neural plasticity and language recovery after left hemispheric stroke.

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- To identify predictive factors for successful language recovery based on clinical and neuroimaging parameters.
- To assess the effectiveness of targeted language therapy protocols in promoting beneficial neuroplastic changes.

Methodology
Hypotheses
Research Hypothesis: Language recovery follows specific neural reorganization patterns influenced by rehabilitation intensity and timing, clinical and neuroimaging parameters predict outcomes, and targeted therapy promotes greater neuroplastic changes than standard care.

Null Hypothesis: Neural reorganization, rehabilitation intensity, and intervention timing do not affect language recovery; clinical and neuroimaging parameters do not predict outcomes, and targeted therapy offers no advantage over standard care.

Material and Method
This prospective longitudinal study involves 50 patients recruited from the Department of Neurology and Rehabilitation at the Institute of Applied Medicines & Research. All patients provided written informed consent.

Outcome Measures
Each patient underwent clinical and neuroimaging assessment of language impairment.

Clinical assessments were completed using the following assessment tools:
- Western Aphasia Battery (WAB): Primary assessment tool to track changes in language capabilities, including spontaneous speech, auditory comprehension, repetition, and naming. A licensed Speech and Language Pathologist administered it.
- Boston Naming Test: Detailed evaluation of word-finding abilities
- Token Test: Assessment of auditory comprehension.
- Communicative Effectiveness Index (CETI) and Assessment of Living with Aphasia (ALA) to evaluate functional communication and the practical impact of recovery on daily life.
- Montreal Cognitive Assessment (MoCA): Monitoring overall cognitive status and identifying changes that might influence language recovery.
- Stroke Aphasic Depression Questionnaire: Assessment of psychological factors affecting recovery.

All assessments are documented using standardized forms and entered into a secure electronic database within 24 hours of completion.

Neuroimaging assessment was done with a Siemens Prisma 3-Tesla MRI scanner equipped with a 64-channel head coil. Functional MRI sequences are performed while participants complete specific language tasks to activate key language networks. Resting-state fMRI was taken to evaluate functional connectivity patterns, diffusion tensor imaging assessed white matter tract integrity, and standard structural sequences for anatomical reference. Participants underwent practice sessions outside the scanner to familiarize themselves with the language tasks and ensure consistency. During scanning, visual stimuli are presented through MRI-compatible goggles, and responses are recorded using a specialized response system. Real-time monitoring ensures data quality and participant compliance with tasks. Image processing relies on specialized software packages, including SPM12 for functional image analysis, FSL for structural analysis, and custom MATLAB scripts for advanced processing.[24]

Rehabilitation factors:
- Intensity of therapy (measured in hours per week)
- Timing of intervention initiation (days post-stroke)
- Type of therapy received (traditional versus specialized approaches).

Inclusion criteria
- First incidence of left hemispheric stroke confirmed by neuroimaging
- Age range: 30–70 years
- Right-handed dominance (verified by Edinburgh Handedness Inventory)
- Presence of language deficits of varying severity
- Acute onset of stroke (less than 7 days) before enrolment
- Medically stable for safe participation
- Sufficient cognitive ability for informed consent and study engagement

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- Normal or corrected-to-normal vision and hearing for accurate assessment

Exclusion Criteria

- History of previous stroke or other neurological conditions
- Pre-existing developmental speech or language disorders
- Significant psychiatric conditions requiring current treatment
- Severe cognitive impairment preventing meaningful participation
- History of substance abuse within the past year
- Severe visual or auditory impairments beyond normal correction
- Unstable medical conditions interfering with participation
- Current enrolment in other clinical trials

Data Analysis

Data analysis was conducted using SPSS version 27.0 and R statistical software. The data was tested for normality using Shapiro Wilk test. Repeated measures ANOVA test was used to evaluate changes in language function across different assessment time points. Post-hoc analyses with Bonferroni correction for multiple comparisons identified significant changes between specific time points, providing a detailed understanding of recovery trajectories. Mixed-effects models acknowledged for individual variation in recovery patterns such as time and therapy intensity. Correlation analysis examined relationships between formal language test scores and functional communication outcomes. Neuroimaging data was Analyze through SPM12 software in MATLAB.

Results

The 50 patients recruited in the study had a mean age of 58.4 (12.3) years with 28 female and 22 male participants. Patients had an average of 12.5 (4.2) days post the stroke incidence. The demographics are mentioned in Table 1.

Analysis of Language Recovery

The analysis of primary language outcomes focused on changes in Western Aphasia Battery- Revised (WAB-R) scores across the study period. Repeated measures analysis of variance (ANOVA) was conducted to examine changes in the Aphasia Quotient (AQ) at baseline, 1 month, 3 months, and 6 months post-stroke. The results revealed significant improvement over time, as shown in Table 2.

Functional Communication (CETI)

Secondary outcome analysis examined functional communication measures and quality of life indicators. The Communicative Effectiveness Index (CETI) showed improvements in practical communication abilities, as detailed in Table 4.

Quality of Life(SAQOL-39)

Quality of life, assessed using the Stroke and Aphasia Quality of Life Scale-39 (SAQOL-39), demonstrated improvement across multiple domains seen in Table 5.
Correlation analysis between outcomes revealed significant relationships between formal language measures and functional communication abilities as seen in Table 6.

Table 1 describes the Demographic details of the sample

Characteristics	Mean (SD)	n (%) Range
Age (years)	58.4 (12.3)	30-70
Gender (female)		28 (56%)
Gender (male)		22 (44%)
Education (years)	14.2 (3.8)	8-22
Time post-stroke (days)	12.5 (4.2)	5-21
Baseline WAB-AQ score	48.6 (22.4)	12-82

Table 2 shows the WAB-AQ scores at different time points

Time Point	Mean WAB-AQ (SD)	Mean Change from Baseline	95% CI	p-value
Baseline	48.6 (22.4)	-	-	-
1 Month	62.4 (20.8)	13.8	10.2-17.4	<0.001
3 Months	72.8 (18.6)	24.2	20.1-28.3	<0.001
6 Months	78.4 (16.2)	29.8	25.4-34.2	<0.001

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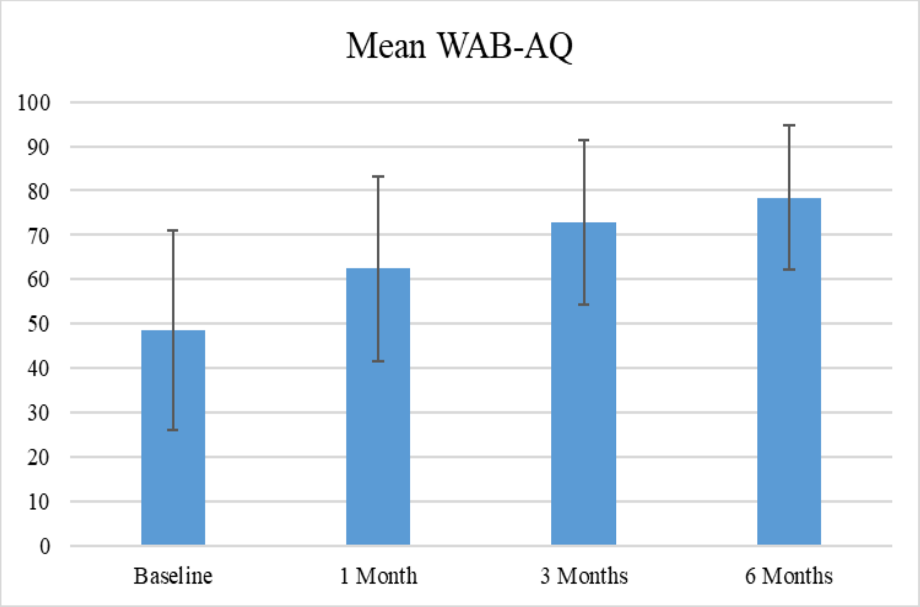
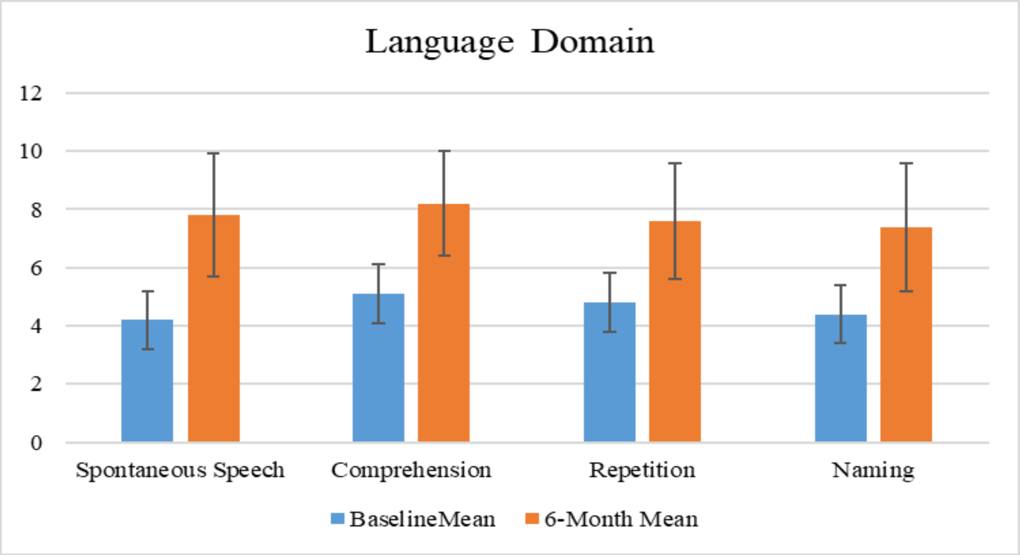


Graph showing mean WAB-AQ values at different time points

Table 3 presents the analysis of specific language components:

Language Domain	**Baseline Mean(SD)**	**6-MonthMean (SD)**	**Effect Size (d)**	**p-value**
Spontaneous Speech	4.2 (2.8)	7.8 (2.1)	1.46	<0.001
Comprehension	5.1 (2.4)	8.2 (1.8)	1.28	<0.001
Repetition	4.8 (2.6)	7.6 (2.0)	1.32	<0.001
Naming	4.4 (2.5)	7.4 (2.2)	1.24	<0.001



Graph showing means of Language Domian at different time points

Table 4 shows the CETI scores at baseline and 6-months post-stroke

Communication Context	**Baseline Score (SD)**	**6-MonthScore (SD)**	**Change Score**	**p-value**
Basic Needs	3.2 (1.4)	7.8 (1.2)	4.6	<0.001
Conversation	2.8 (1.6)	6.9 (1.4)	4.1	<0.001
Complex Communication	2.4 (1.5)	6.2 (1.6)	3.8	<0.001
Social Interaction	2.6 (1.4)	6.8 (1.3)	4.2	<0.001

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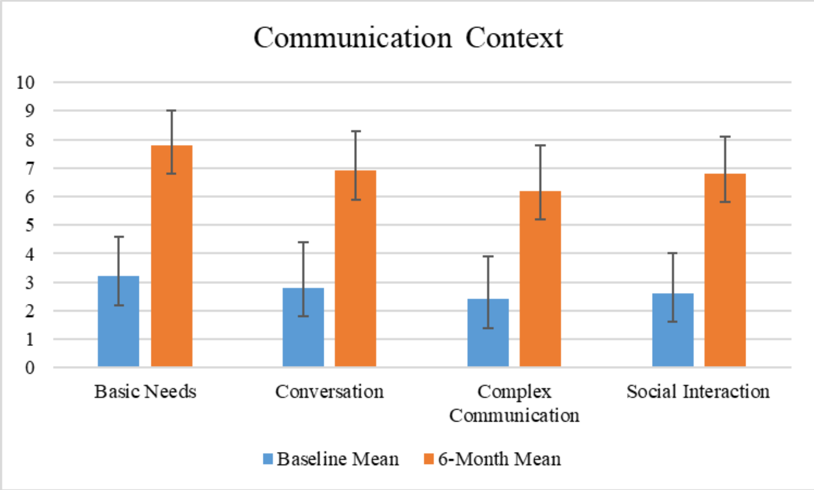
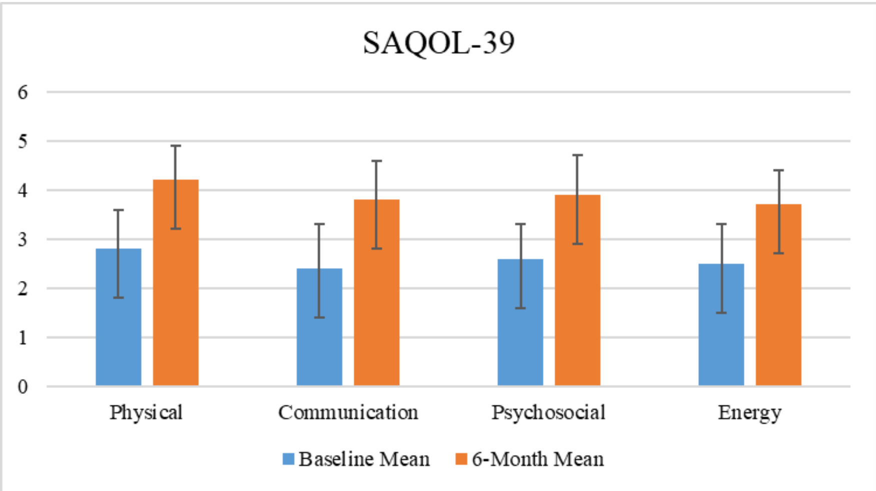


Graph showing the CETI scores at different time points

Table 5 shows SAQOL-39 scores at baseline and 6 months post-stroke.

SAQOL-39 Domain	Baseline Mean (SD)	6-MonthMean (SD)	Mean Change	Effect Size
Physical	2.8 (0.8)	4.2 (0.7)	1.4	1.12
Communication	2.4 (0.9)	3.8 (0.8)	1.4	1.08
Psychosocial	2.6 (0.7)	3.9 (0.6)	1.3	1.04
Energy	2.5 (0.8)	3.7 (0.7)	1.2	0.96



Graph showing SAQOL-39 scores at different time points

Table 6 showing correlation between different measures of language and communication.

Measure Pair	Correlation Coefficient	p-value
WAB-AQ vs CETI	0.72	<0.001
WAB-AQ vs SAQOL-Communication	0.68	<0.001
Naming vs Basic Needs	0.64	<0.001
Comprehension vs Social Interaction	0.70	<0.001

Discussion

This study analysed language recovery after a left hemispheric stroke, highlighting the role of neuroplasticity. Language abilities improved significantly over six months, with the fastest progress in the first three months. Different language functions recovered at different rates. Brain scans showed changes in activation, shifting from the left hemisphere to both hemispheres, especially in key language areas. These neural changes matched language improvements, confirming their role in recovery. Identifying clinical and brain-based predictors may help improve stroke rehabilitation outcomes.

Recovery from aphasia following a stroke typically follows a structured trajectory characterized by three distinct

phases. In the initial month post-stroke, patients often experience rapid improvements in language function, largely attributed to spontaneous neural plasticity and the effects of early rehabilitation interventions[1][3]. This phase is marked by a linear recovery pattern, particularly in expressive language capabilities. Between one and three months, recovery continues but at a moderated pace. During this period, variability in recovery rates becomes more pronounced, influenced by individual factors such as initial stroke severity and cognitive reserve. While automatic speech may show quicker recovery, complex comprehension and discourse abilities tend to progress more slowly[2][3].From three to six months, the rate of improvement generally slows further, although continued gains are observed. This phase reflects a combination of ongoing neural reorganization and adaptation of perilesional tissue[3]. The recovery of different language components varies, with phonological and receptive abilities often showing sustained improvement up to six months, while semantic and syntactic improvements plateau earlier[4].
The initial severity of stroke is identified as the most robust predictor of language recovery outcomes. Other significant factors include age, intensity of therapy[5][6] and the location and extent of brain lesions. The brain's capacity for structural reorganization plays a critical role in recovery[3][7]. Adaptations in perilesional tissue contribute to functional recovery by supporting new neural connections. Enhanced functional integration leads to more efficient neural networks that facilitate improved communication among remaining language areas[4][7].
There exists a strong correlation between neural reorganization and behavioural language recovery. Early changes in brain activity often precede observable improvements in language function. Successful outcomes are contingent upon effective communication within the remaining language networks rather than mere compensatory strategies. Individual recovery pathways vary significantly; some rely predominantly on left hemisphere reorganization while others engage right hemisphere structures more extensively[6][8].
In summary, this study enhances our understanding of neuroplasticity in language recovery after left hemispheric stroke, and focuses on predictable yet individualized recovery patterns. Neuroimaging shows systematic language network reorganization, correlating with functional improvements. Findings highlight the importance of early, intensive, and personalized rehabilitation, guiding treatment planning, and patient stratification. This research provides a foundation for improving rehabilitation outcomes, emphasizing the brain's remarkable capacity for adaptation and recovery.

Future Recommendations

Future research should focus on large-scale longitudinal studies, refined neuroimaging protocols, and improved assessment tools for subtle language deficits. Investigating individual recovery variability, cognitive reserve, and therapy impact on neural reorganization is essential. Advancing automated analysis, remote monitoring, and integrated assessment platforms will enhance both clinical practice and accessibility, improving rehabilitation outcomes for stroke survivors.

Several key directions emerge for future development:

- Refinement of assessment protocols
- Development of targeted interventions
- Enhancement of prognostic tools
- Implementation of evidence-based guidelines
- Advancement of theoretical models

Limitations of the Study

One of major limitations of this study was a lack of longer follow up and loss of patients due to decreased compliance to follow up. The study did not provide an intervention per se to the patients enrolled. No specific rehabilitation was found to be superior than other. A comparison of different approaches of speech related therapy could have been done. The geographical constraint was also a limitation of this study.

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