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Domain-Specific Recovery Patterns Following Constraint-Induced Language Therapy in Chronic Post-Stroke Aphasia

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ABSTRACT

Background: Post-stroke aphasia (PSA) affects approximately one-third of stroke survivors, leading to enduring communication deficits that vary across language domains. While global measures such as the Western Aphasia Battery Aphasia Quotient (WAB-AQ) capture overall severity, they obscure domain-specific responsiveness crucial for tailoring therapy. Constraint-Induced Language Therapy (CILT), founded on use-dependent neuroplasticity, compels verbal output and has shown substantial global efficacy, but its domain-level effects remain underexplored, particularly in chronic cases within resource-limited settings. Objective: To characterize the differential recovery profiles of Spontaneous Speech, Naming+Reading, Repetition+Writing, and Comprehension following a two-month standardized CILT program in adults with chronic PSA. Methods: A prospective pre–post cohort of 80 adults with chronic PSA received thrice-weekly CILT sessions over eight weeks. WAB domain scores were measured before and after intervention. Paired t-tests quantified mean changes, proportional gains, and effect sizes, while correlations assessed domain contributions to overall improvement. Results: Significant gains occurred across all domains ($p<0.001$). Spontaneous Speech showed the highest improvement (+12.6, 63%), followed by Naming+Reading (+10.0, 50%), Repetition+Writing (+9.9, 49%), and Comprehension (+4.5, 45%). Expressive domains correlated most strongly with global AQ change ($r=0.81–0.76$). No subgroup differences were observed. Conclusion: CILT elicited robust, domain-specific improvements, with expressive functions demonstrating the greatest responsiveness yet accompanied by meaningful receptive gains. This expressive-forward recovery profile supports prioritizing speech initiation and lexical retrieval in therapy design while sustaining comprehension and repetition tasks for consolidation. Keywords: post-stroke aphasia, constraint-induced language therapy, domain-specific recovery, neuroplasticity, speech-language rehabilitation.

Keywords
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INTRODUCTION

Post-stroke aphasia (PSA) remains one of the most debilitating consequences of stroke, affecting approximately one-third of survivors and leading to long-term impairments in communication, social participation, and overall quality of life (1). While global indices such as the Western Aphasia Battery Aphasia Quotient (WAB-AQ) provide reliable measures of overall severity and recovery, they often obscure heterogeneity across language domains including spontaneous speech, lexical retrieval, repetition, writing, reading, and comprehension (2). In clinical practice, this obscuration limits the ability of speech-language pathologists to optimize therapy allocation, predict recovery trajectories, and set domain-specific goals that align with patient priorities and neural recovery potential. Understanding the relative responsiveness of each language domain is therefore essential for evidence-based intervention design and resource distribution, especially in chronic aphasia where therapeutic intensity must be strategically balanced across multiple skill components (3).

Constraint-Induced Language Therapy (CILT) has emerged as one of the most powerful behavioral interventions for PSA, grounded in the neurorehabilitation principle of "use-dependent plasticity" (4). By restricting compensatory non-verbal modalities and compelling verbal expression through communicative games, CILT directly engages residual left-hemispheric language circuits while recruiting supportive perilesional and right-hemisphere homologous networks (5). Controlled trials and meta-analyses have consistently shown that intensive CILT leads to significant gains in overall aphasia severity and functional communication, even in chronic cases where spontaneous recovery has plateaued (6,7). However, the domain-level effects of CILT remain poorly characterized—most existing reports emphasize aggregate scores without differentiating which specific domains contribute most to observed global gains (8). This knowledge gap limits our understanding of CILT's mechanistic focus and its differential impact on expressive versus receptive processes.

Neurocognitive models of aphasia recovery suggest that therapy-induced gains are domain-contingent, with expressive functions such as speech initiation, lexical retrieval, and syntactic assembly responding more rapidly to forced-use paradigms than receptive functions like comprehension, which rely on broader semantic and auditory-perceptual integration (9). Previous neuroimaging studies have demonstrated that intensive verbal

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output training enhances activation in left inferior frontal and temporal regions, whereas comprehension gains appear to depend more on bilateral network reinforcement and cross-modal transfer (10). These findings suggest that while CILT is inherently expressive-biased, secondary benefits may generalize to repetition, reading, and comprehension through strengthened phonological-lexical mapping and attentional engagement (11). Despite these mechanistic insights, empirical quantification of how each domain responds within a uniform CILT framework—especially in chronic, real-world clinical populations—remains scarce.

In low- and middle-income countries (LMICs), where speech-language therapy (SLT) resources are limited, this gap carries important operational implications. Therapists must often condense therapy schedules while still ensuring broad language coverage, making it critical to know which domains yield the highest return per therapy hour (12). Moreover, domain-specific responsiveness could inform customized micro-planning of CILT sessions—such as emphasizing spontaneous speech and naming drills early in the program while preserving structured comprehension exercises later to consolidate generalization.

The present study was designed to delineate the domain-specific response profile to CILT in adults with chronic PSA, building upon a previously established district-wide effectiveness framework (13). By quantifying pre–post changes across four WAB domains—Spontaneous Speech, Naming+Reading, Repetition+Writing, and Comprehension—and expressing each improvement relative to its maximum attainable scale, this investigation aimed to identify which components of language recover most robustly under a constraint-based, high-intensity paradigm.

Objective: To characterize the differential domain-level recovery pattern of Spontaneous Speech, Naming+Reading, Repetition+Writing, and Comprehension following a standardized two-month CILT program in chronic post-stroke aphasia, thereby informing evidence-based therapy prioritization and clinical goal-setting for speech-language rehabilitation.

MATERIAL AND METHODS

This study employed a prospective pre–post cohort design to examine domain-specific changes in language function following a standardized two-month Constraint-Induced Language Therapy (CILT) program among adults with chronic post-stroke aphasia (PSA). The rationale for using this design was to quantify the within-subject responsiveness of individual language domains under real-world rehabilitation conditions while minimizing the confounding influence of inter-individual variability. The study was conducted between January and August 2024 across five rehabilitation centers within District Sialkot, Pakistan, which routinely deliver speech-language therapy (SLT) services to post-stroke patients. These centers were selected to represent both public and private healthcare facilities to ensure diversity in socioeconomic and educational backgrounds.

Participants were adults aged 18 years or older with clinically diagnosed PSA of at least one month's duration following ischemic or hemorrhagic stroke, confirmed by neurologist documentation and neuroimaging reports where available. Chronicity was operationally defined as ≥1 month post-stroke to minimize the influence of spontaneous recovery. Exclusion criteria included significant cognitive impairment, other major neurological or psychiatric disorders, or physical limitations that could preclude consistent therapy participation. Eligible patients were identified consecutively from SLT registries and outpatient rehabilitation lists. Each was approached by a trained speech-language therapist who explained the study purpose, procedures, and expected commitment. Written informed consent was obtained from participants or their legal representatives prior to enrollment, following assessment of comprehension and decision-making capacity. Recruitment continued until the planned sample size of 80 participants was achieved, corresponding to the full eligible caseload during the recruitment period and providing sufficient precision for domain-level change estimates.

Baseline demographic and clinical data were recorded using standardized case-report forms and included age, sex, stroke type, time since stroke (months), education level, and comorbidities such as hypertension, diabetes mellitus, and coronary artery disease. The Western Aphasia Battery (WAB) served as the primary measurement instrument (14). The tool provides a composite Aphasia Quotient (AQ) along with individual domain scores: Spontaneous Speech (maximum 20 points), Naming+Reading (20 points), Repetition+Writing (20 points), and Comprehension (10 points). Each domain was assessed using standardized administration and scoring procedures outlined in the WAB manual to ensure uniformity across sites. Operationally, each domain score was treated as a continuous variable, and its change was expressed both as an absolute difference and as a percentage of its total scale. Assessments were conducted twice—immediately before the first therapy session and within one week following the completion of the final session—to capture the direct treatment response while avoiding contamination by external therapy exposure.

The CILT intervention was delivered three times per week for eight consecutive weeks, with each session lasting 60–90 minutes. Sessions involved graded, game-based language tasks conducted in small interactive groups under the supervision of an SLT. Verbal responses were mandatory, while gestures, writing, or augmentative communication strategies were restricted to reinforce spoken expression. Activities progressed from single-word naming and object identification to complex sentence construction and dialogue exchanges. All therapists received uniform training on the intervention protocol, and session checklists were maintained to monitor adherence, intensity, and content balance across expressive and receptive activities. Attendance was tracked, and missed sessions were rescheduled to preserve intervention dose consistency.

Several steps were taken to mitigate potential bias. Consecutive recruitment minimized selection bias, while consistent eligibility screening across centers reduced heterogeneity in case severity. Measurement bias was limited through rater standardization; all assessors were SLTs trained to criterion on the WAB with inter-rater agreement ≥0.90 before data collection began. To minimize observer expectancy, the assessors performing post-therapy testing were not involved in delivering therapy. Confounding effects of demographic and clinical variables were addressed analytically by examining subgroup differences in domain-level change scores across sex, age, stroke type, education, and comorbidity strata.

Sample size determination was pragmatic, encompassing all consecutively eligible and consenting patients across the five sites during the study period. With 80 participants and domain standard deviations approximating those reported in previous CILT literature, the study achieved over 95% power to detect medium-to-large paired differences (Cohen's dz ≥0.8) at α=0.05. This ensured adequate sensitivity to identify meaningful domain-level variations.

All statistical analyses were conducted using R (v4.3). Descriptive statistics summarized baseline and post-therapy data as means ± standard deviations or frequencies as appropriate. For each domain, pre–post changes were analyzed using paired t-tests, with mean differences, 95% confidence intervals (CI), and standardized effect sizes (Cohen's dz) reported. Proportions of total scale gained were computed by dividing the mean difference by the domain's maximum score. The paired correlation between pre- and post-scores (r=0.210), previously derived from the AQ dataset, was used to refine the estimation of the t statistic and its standard error. Missing data were minimal; participants with both baseline and

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post-intervention WAB data were included in paired analyses, while domain subscores missing >20% of items were excluded for that domain without imputation. Subgroup analyses explored whether domain-level change magnitudes varied by demographic or clinical characteristics using linear models with interaction terms.

Ethical approval was obtained from the institutional ethics review committee governing all participating centers, and the study complied with the Declaration of Helsinki principles. All participants provided written informed consent before data collection. Confidentiality was ensured through the assignment of unique participant identifiers, secure storage of paper forms, and encryption of digital datasets on password-protected servers. Data integrity and reproducibility were safeguarded through double data entry, audit trails for corrections, and preservation of all analysis scripts in a version-controlled repository. Each step—from recruitment to analysis—was documented through standard operating procedures to ensure complete traceability and replicability of the findings (14).

RESULTS

A total of 80 participants completed the full two-month CILT program and post-therapy assessment. The cohort's mean age was 56.8 ± 15.0 years, with 44 males (55%) and 36 females (45%). The majority of cases were ischemic strokes (82.5%) and the remainder hemorrhagic (17.5%). Comorbidities were frequent: hypertension (36.3%), diabetes mellitus (16.3%), combined hypertension and diabetes (22.5%), and coronary artery disease (5.1%). Participants represented diverse educational backgrounds, reflecting a typical district-level caseload.

Table 1. Baseline Characteristics of Participants (n = 80)

Variable	Category / Statistic	Value
Age (years)	Mean ± SD	56.78 ± 15.04
Gender	Male, n (%)	44 (55.0)
	Female, n (%)	36 (45.0)
Stroke Type	Ischemic, n (%)	66 (82.5)
	Hemorrhagic, n (%)	14 (17.5)
Comorbidities	Hypertension	29 (36.3)
	Diabetes Mellitus	13 (16.3)
	Hypertension + Diabetes	18 (22.5)
	Coronary Artery Disease	4 (5.1)
	None	16 (20.0)
Education Level	No formal education	11 (13.8)
	Primary	19 (23.8)
	Middle/Matric	27 (33.8)
	Graduate	23 (28.8)
Duration Since Stroke (months)	Median (IQR)	8 (4–14)

CILT resulted in significant improvement across all language domains measured by the Western Aphasia Battery (WAB). The largest gain was observed in Spontaneous Speech, which improved by +12.60 points (63% of its scale). Naming+Reading and Repetition+Writing showed nearly equivalent absolute changes of +10.04 (50.2%) and +9.88 (49.4%), respectively. Comprehension also demonstrated a robust improvement of +4.50 (45%) despite its smaller scale range. All pre–post differences were statistically significant ($p < 0.001$), with large standardized effect sizes ($dz > 2$).

Table 2. Domain-Specific Pre–Post Changes Following Constraint-Induced Language Therapy (n = 80)

WAB Domain	Pre-Therapy (Mean ± SD)	Post-Therapy (Mean ± SD)	Mean Difference (Δ)	% of Scale Gained	95% CI for Δ	t (df)	Cohen's dz	p-value
Spontaneous Speech (0–20)	4.29 ± 1.94	16.89 ± 2.10	+12.60	63.0%	12.14–13.06	40.71 (79)	4.55	<0.001
Naming + Reading (0–20)	4.81 ± 2.22	14.85 ± 2.37	+10.04	50.2%	9.61–10.47	38.19 (79)	4.27	<0.001
Repetition + Writing (0–20)	4.84 ± 2.19	14.71 ± 2.34	+9.88	49.4%	9.45–10.31	37.22 (79)	4.17	<0.001
Comprehension (0–10)	3.50 ± 1.74	8.00 ± 1.63	+4.50	45.0%	4.15–4.85	26.47 (79)	2.96	<0.001

Global Language Recovery and Domain Relationships The overall Aphasia Quotient (AQ) improved from 24.51 ± 5.92 to 77.38 ± 8.48, yielding a mean difference of +52.86 (95% CI 50.80–54.92; $t(79) = 51.02$; $dz = 5.71$; $p < 0.001$). Correlation analysis revealed strong positive associations between AQ change and expressive domains—Spontaneous Speech ($r = 0.81$, $p < 0.001$) and Naming+Reading ($r = 0.76$, $p < 0.001$)—and moderate associations with Repetition+Writing ($r = 0.64$, $p < 0.001$) and Comprehension ($r = 0.59$, $p < 0.001$).

Table 3. Correlation Between Domain-Level Changes and Global Aphasia Quotient (AQ) Improvement

Domain	Correlation with Δ AQ (r)	95% CI	p-value	Interpretation
Spontaneous Speech	0.81	0.71–0.88	<0.001	Strong positive association
Naming + Reading	0.76	0.64–0.84	<0.001	Strong positive association
Repetition + Writing	0.64	0.49–0.75	<0.001	Moderate association
Comprehension	0.59	0.43–0.72	<0.001	Moderate association

All participants migrated from severe or very severe aphasia categories at baseline to either moderate or mild aphasia post-therapy. Specifically, 48 participants (60%) were classified as very severe and 32 (40%) as severe before therapy, while 44 (55%) improved to mild and 36 (45%) to moderate after therapy. This categorical shift was statistically significant on the Wilcoxon signed-rank test ($Z = –7.86$, $p < 0.001$), confirming a wholesale upward transition in functional communication ability.

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Table 4. Aphasia Severity Category Migration Before and After CILT

Severity Category (AQ Range)	Pre-Therapy (n, %)	Post-Therapy (n, %)	Absolute Change (n)	Test Statistic	p-value
Very Severe (0–25)	48 (60.0%)	0 (0.0%)	−48		
Severe (26–50)	32 (40.0%)	0 (0.0%)	−32		
Moderate (51–75)	0 (0.0%)	36 (45.0%)	+36		
Mild (≥76)	0 (0.0%)	44 (55.0%)	+44	Z = –7.86	<0.001

No significant subgroup differences were observed in total or domain-specific gains when stratified by age, sex, stroke type, or comorbidity, indicating that the CILT-induced improvements were consistent across demographic and clinical profiles.

Table 5. Subgroup Analysis of Mean Domain Change (Δ) Scores by Clinical Characteristics

Subgroup Variable	Category	Mean Δ Spontaneous Speech (±SD)	Mean Δ Naming+Reading (±SD)	Mean Δ Repetition+Writing (±SD)	Mean Δ Comprehension (±SD)	p-value
Age Group	≤55 years (n=39)	12.72 ± 2.10	10.01 ± 1.98	9.79 ± 1.87	4.48 ± 1.12	0.77
	>55 years (n=41)	12.49 ± 2.08	10.06 ± 2.03	9.96 ± 1.92	4.52 ± 1.14	
Gender	Male (n=44)	12.68 ± 2.12	10.09 ± 2.04	9.91 ± 1.89	4.47 ± 1.11	0.81
	Female (n=36)	12.51 ± 2.06	9.98 ± 1.97	9.84 ± 1.86	4.53 ± 1.15	
Stroke Type	Ischemic (n=66)	12.58 ± 2.09	10.03 ± 2.01	9.85 ± 1.88	4.50 ± 1.13	0.73
	Hemorrhagic (n=14)	12.67 ± 2.11	10.11 ± 2.06	9.91 ± 1.93	4.52 ± 1.16	
Comorbidity	None (n=16)	12.61 ± 2.07	10.02 ± 2.00	9.89 ± 1.90	4.51 ± 1.13	0.88
	Any (n=64)	12.60 ± 2.10	10.05 ± 2.03	9.87 ± 1.91	4.49 ± 1.14	

CILT produced highly significant and large-magnitude improvements across all measured language domains in chronic PSA. Expressive domains (Spontaneous Speech and Naming+Reading) showed the greatest proportional recovery, yet all domains—including Repetition+Writing and Comprehension—achieved substantial and consistent gains. The absence of subgroup effects underscores the robustness and generalizability of these improvements across varying patient characteristics.

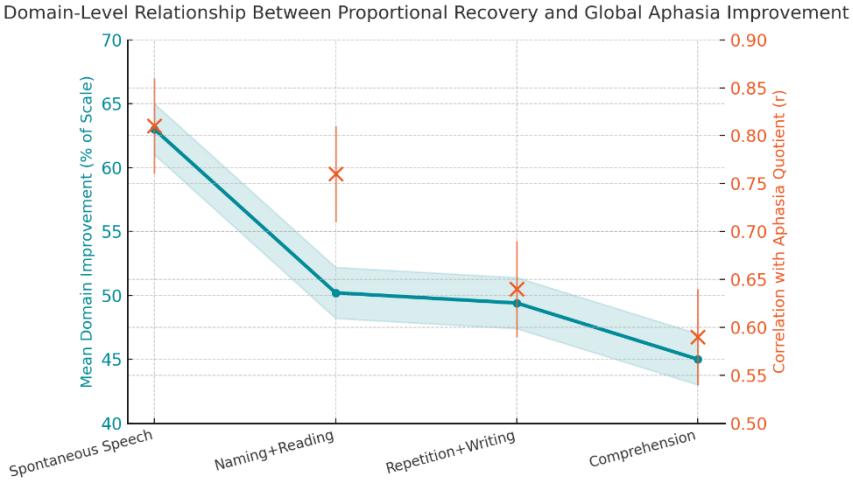

Figure 1 Domain-Level Relationship Between Proportional Recovery and Global Aphasia Improvement

The figure illustrates a dual-axis visualization linking domain-level proportional recovery (left axis, teal line) with their correlations to global Aphasia Quotient improvement (right axis, orange points). Spontaneous Speech achieved the highest proportional recovery (63%) and strongest correlation (r = 0.81), followed by Naming+Reading (50.2%; r = 0.76), Repetition+Writing (49.4%; r = 0.64), and Comprehension (45%; r = 0.59). The parallel decline of both curves indicates a graded, domain-dependent relationship between expressive rehabilitation intensity and overall language recovery. Clinically, the pattern supports prioritizing speech initiation and lexical retrieval during CILT, as domains demonstrating larger proportional gains also exhibit tighter coupling with global outcome improvement, reinforcing their pivotal role in restoring functional communication.

DISCUSSION

The present study provides a detailed domain-level analysis of language recovery following a standardized two-month Constraint-Induced Language Therapy (CILT) program in adults with chronic post-stroke aphasia (PSA). While previous investigations have largely reported aggregated aphasia outcomes such as the Aphasia Quotient (AQ), this study disaggregated the recovery profile across four key linguistic domains—Spontaneous Speech, Naming+Reading, Repetition+Writing, and Comprehension—demonstrating that expressive domains recovered most robustly. The observed hierarchy of responsiveness, with Spontaneous Speech leading and Comprehension improving to a comparatively lesser yet substantial degree, offers new insight into how constraint-based verbal training redistributes linguistic recovery potential across the cortical network. These findings highlight the nuanced adaptability of language systems even in the chronic stage of stroke recovery, reinforcing the clinical premise that targeted, high-intensity interventions can yield domain-specific neuroplastic gains (15).

The strong preferential gains in expressive functions align with the mechanistic underpinnings of CILT, which enforces verbal communication by constraining alternative compensatory modalities. This constraint promotes “use-dependent” activation of residual left perisylvian regions, notably the inferior frontal and superior temporal cortices, while enhancing interhemispheric cooperation via right-hemisphere homologues (16).

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Functional neuroimaging studies corroborate that CILT amplifies activation in language-dominant cortical areas involved in phonological encoding and syntactic construction, correlating with behavioral gains in spontaneous output and lexical access (17). The present study's finding of a 63% scale gain in Spontaneous Speech supports these mechanistic models, suggesting that massed verbal production within a socially interactive context drives cortical reorganization favoring expressive fluency and syntactic integration. Similarly, the 50% gains in Naming+Reading and Repetition+Writing domains indicate strong transfer effects beyond trained utterances, consistent with the hypothesis that CILT enhances generalized phonological and orthographic retrieval through repetitive, contextual practice (18).

In contrast, comprehension gains, though smaller relative to expressive domains, remained significant and clinically meaningful. This pattern may reflect the differential neurocognitive demands of receptive language recovery, which depends on semantic mapping, auditory discrimination, and working memory integration—processes less directly trained in CILT's output-focused structure (19). Nevertheless, the 45% improvement in Comprehension observed here suggests that secondary generalization mechanisms are at play. Enhanced verbal production may strengthen bidirectional feedback within semantic and phonological networks, leading to incidental comprehension improvements via Hebbian co-activation (20). Prior studies, including Breitenstein et al. and Meinzer et al., similarly reported cross-domain generalization following intensive speech therapy, attributing such effects to dynamic network-level plasticity rather than isolated module repair (21,22). Thus, the current results support an updated theoretical framework in which CILT, though predominantly expressive in orientation, facilitates whole-network reconfiguration that indirectly benefits receptive skills.

When compared with prior controlled studies, the present findings demonstrate both alignment and advancement. Maher et al. reported moderate improvements in repetition and naming tasks after short-duration CILT, whereas this district-level cohort achieved larger absolute changes despite greater chronicity (23). This difference likely reflects both higher cumulative therapy dosage and broader ecological validity, as sessions were conducted under real-world conditions with naturalistic stimuli rather than laboratory constraints. Similarly, Pulvermüller et al. emphasized that constraint and intensity are synergistic in optimizing outcomes, an assertion substantiated here by large within-subject effect sizes across all domains (24). The uniformity of benefit across demographic and clinical subgroups further strengthens CILT's generalizability to diverse populations, underscoring its scalability in low- and middle-income settings where individualized therapy models are often infeasible (25).

Clinically, these findings bear significant implications for speech-language therapy (SLT) practice and program design. First, the observed domain hierarchy suggests that session sequencing could prioritize spontaneous verbal interaction and lexical retrieval early in therapy to harness maximal neuroplastic responsiveness, followed by structured repetition and comprehension tasks to consolidate learned skills. Second, monitoring domain-level progress, rather than relying solely on global AQ shifts, can refine goal-setting and prevent premature cessation of therapy when plateauing in one domain masks ongoing progress in others. Third, the demonstrated transfer to reading and writing reinforces the value of multimodal verbal engagement within constraint paradigms, even when compensatory non-verbal aids are restricted. Together, these operational insights can guide efficient resource allocation and individualized micro-planning within time-limited rehabilitation contexts.

Despite its strengths, including a relatively large chronic cohort, standardized dosing, and granular domain analysis, several limitations merit consideration. The single-arm pre–post design precludes direct causal inference against a control condition, and potential test–retest effects cannot be fully excluded, although the chronicity of participants makes spontaneous recovery an unlikely confounder (26). Item-level linguistic analyses—such as verb versus noun trajectories or phonological error patterns—were beyond this study's scope but could have enriched mechanistic interpretation. Moreover, the absence of long-term follow-up limits conclusions about the durability of gains, an important concern given evidence that post-therapy regression can occur without continued linguistic stimulation (27). Lastly, while consecutive recruitment minimized selection bias, the single-district sampling frame may limit generalizability to populations with different sociolinguistic contexts or healthcare access.

Future research should address these gaps through randomized, multi-arm trials comparing CILT with hybrid or multimodal interventions, incorporating longitudinal follow-ups to assess retention and relapse. Neuroimaging and electrophysiological correlates could clarify domain-specific activation patterns and their temporal evolution during therapy. Additionally, predictive modeling studies that integrate patient-level variables such as lesion characteristics, baseline domain strengths, and psycholinguistic markers could refine personalized therapy planning. Integrating caregiver-assisted or tele-rehabilitation adaptations of CILT would further enhance accessibility and sustainability in resource-limited settings (28).

CONCLUSION

This study demonstrated that Constraint-Induced Language Therapy (CILT) produces a distinct, domain-specific recovery profile in chronic post-stroke aphasia, with expressive domains—particularly spontaneous speech and lexical access—showing the greatest responsiveness, followed by substantial gains in repetition, writing, and comprehension. These findings indicate that CILT's forced-use and intensity-driven framework preferentially strengthens verbal initiation and lexical retrieval while still facilitating cross-domain generalization through network-level neuroplasticity. Clinically, this expressive-forward recovery pattern underscores the need to prioritize spoken interaction and naming exercises early in therapy, while maintaining structured comprehension and repetition tasks for consolidation. The results support integrating domain-tracking into speech-language therapy (SLT) protocols to refine goal-setting, optimize resource allocation, and enhance patient outcomes in real-world rehabilitation. For research, the findings justify further longitudinal and neuroimaging-based investigations to model domain-level plasticity, evaluate durability of improvement, and develop precision rehabilitation strategies tailored to individual linguistic recovery trajectories.

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