LMJ LINK MEDICAL JOURNAL OF HEALTH AND COMMUNITY RESEARCH

Crossref DOI: https://doi.org/10.61919/vpgb9798

Original Article

Effect of Task-Oriented Motor Training on Upper Limb Functional Recovery in Post-Stroke Patients: A Randomized Controlled Trial

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ABSTRACT

Background: Upper limb motor impairment affects approximately 70–80% of stroke survivors and constitutes a primary determinant of functional independence and quality of life. Task-oriented motor training (TOT) engages neuroplastic recovery through repetitive, goal-directed functional practice, yet evidence from low- and middle-income country (LMIC) rehabilitation settings remains limited. Objective: To evaluate the efficacy of structured task-oriented motor training on upper limb motor recovery, arm function, motor performance efficiency, and functional independence compared to conventional physiotherapy in subacute post-stroke patients. Methods: A single-blind, parallel-group randomized controlled trial was conducted at a tertiary care neurorehabilitation centre in Khyber Pakhtunkhwa, Pakistan. One hundred and two subacute stroke patients (2–6 months post-ictus) were allocated by computer-generated randomization to TOT (n = 51) or conventional physiotherapy (n = 51), each receiving 45–60 minutes of supervised therapy five sessions per week for six weeks. Primary outcome was the Fugl-Meyer Assessment–Upper Extremity (FMA-UE); secondary outcomes included the Action Research Arm Test (ARAT), Wolf Motor Function Test (WMFT), and Barthel Index. Intention-to-treat analysis with multiple imputation was applied; Bonferroni correction controlled for multiple comparisons. Results: Ninety-five participants completed post-intervention assessment (TOT: n = 48; control: n = 47). The TOT group demonstrated significantly greater improvements across all outcomes: FMA-UE (MD = +3.9, 95% CI: 2.5–5.3; d = 0.58), ARAT (MD = +4.4, 95% CI: 2.7–6.1; d = 0.52), WMFT (MD = −2.1 s, 95% CI: −3.2 to −1.0; d = 0.46), and Barthel Index (MD = +5.4, 95% CI: 3.2–7.6; d = 0.49); all $p < 0.0125$ after Bonferroni correction. TOT group improvements exceeded established minimal clinically important difference thresholds for all outcomes. Conclusion: Structured task-oriented motor training yields clinically meaningful, statistically robust improvements in upper limb motor recovery and functional independence following stroke, and represents an effective, low-resource-compatible rehabilitation strategy for LMIC clinical settings. Keywords: stroke; upper limb recovery; task-oriented training; motor function; neurorehabilitation; LMIC; functional independence; neuroplasticity; randomized controlled trial

"Cite this Article" | **Received**: 16 October 2025; **Accepted**: 27 December 2025; **Published**: 31 December 2025.

Author Contributions: Concept and design: EW, SA; Data collection: HK, UK, KI, AR, MN, WK; Data analysis and interpretation: EW, AN; Manuscript drafting: HK, UK, KH, WK; Critical revision and final approval: SA, EW; all authors reviewed and approved the final version for submission.. **Ethical Approval**: Institutional Review Board, [Name of Approving Institution], Approval No. SIRMS/IRB/Letter 21st/00021D. **Informed Consent**: Written informed consent was obtained from all participants; **Conflict of Interest**: The authors declare no conflict of interest; **Funding**: No external funding; **Data Availability**: Available from the corresponding author on reasonable request; **Acknowledgments**: N/A.

INTRODUCTION

Stroke is a leading cause of long-term adult disability globally, with its burden borne disproportionately by low- and middle-income countries (LMICs) where structured neurorehabilitation services remain underdeveloped and unevenly distributed (1, 2). The World Stroke Organization estimates approximately 12.2 million new stroke events annually, with stroke-attributable disability rising sharply in South Asian contexts, including Pakistan, where neurological rehabilitation is frequently confined to acute hospital management and post-acute community-based services remain largely inaccessible to the majority of survivors (1, 2). This epidemiological and infrastructural reality underscores the pressing need to identify clinically effective, low-resource-compatible rehabilitation strategies that can be incorporated into routine therapeutic practice without dependence on advanced technological infrastructure.

Upper limb motor impairment represents the most functionally consequential sequel of stroke, affecting approximately 70–80% of survivors during the acute phase, with persistent upper extremity dysfunction documented in nearly half of all cases at one year post-ictus (3). The clinical spectrum of upper limb impairmentencompassing paresis, spasticity, impaired coordination, and reduced dexteritysubstantially restricts independence in activities of daily living (ADLs) including dressing, grooming, feeding, and object manipulation (4). Reduced arm function is closely associated with diminished quality of life, social disengagement, and escalating caregiver burden, outcomes that collectively compound the public health impact of stroke, particularly in settings where formal caregiving infrastructure is limited (4). Restoration of upper limb motor function is therefore a principal objective of post-stroke rehabilitation, with functional arm recovery recognized as a primary determinant of post-stroke independence and community reintegration.

The neurobiological rationale for targeted upper limb rehabilitation is grounded in principles of experience-dependent neuroplasticity, which establish that repetitive, goal-directed, and functionally meaningful motor activity drives use-dependent cortical reorganization, adaptive sensorimotor relearning, and consolidation of functional motor circuits (5). Task-oriented motor training (TOT) operationalizes these principles through structured, repetitive practice of ecologically valid functional tasksincluding reaching, grasping, lifting, and object manipulationin a manner that promotes active engagement of the paretic limb within meaningful activity contexts (5). In contrast to conventional physiotherapy paradigms that predominantly employ passive range-of-motion exercises, stretching, and non-functional strengthening, TOT is explicitly designed to counteract learned non-usea maladaptive behavioral suppression of the affected limb arising from repeated unsuccessful movement attempts, which perpetuates functional disability beyond the level attributable to neurological injury alone (6). By engaging the paretic limb in purposeful, repetitive task practice, TOT promotes motor relearning through repetition-dependent synaptic potentiation and cortical map expansion, consistent with current models of post-stroke neuroplastic recovery (5).

The evidence supporting the efficacy of task-oriented approaches in post-stroke upper limb rehabilitation has expanded substantially over the past two decades. A Cochrane systematic review of repetitive task training after strokesynthesizing data from 33 randomized trials involving over 1,000 participantsestablished statistically significant improvements in arm-hand function and ADL performance attributable to task-specific practice relative to control conditions, providing the foundational evidence base for its inclusion in international stroke rehabilitation guidelines (7). Subsequent randomized controlled trials have extended these findings across diverse clinical protocols: Abbas and Jabeen reported significant upper limb motor recovery gains with a combined task-oriented and mirror therapy protocol compared to conventional care (8), while Akhtar and colleagues demonstrated that task-oriented training combined with progressive strengthening produced superior outcomes in hemiplegic stroke patients at both motor function and functional independence levels (9). More recently, technology-mediated formats including telerehabilitation and virtual reality-based task practice have demonstrated efficacy in extending TOT principles beyond institutional settings, with improvements in upper limb function and ADL performance documented in both high-income and LMIC contexts (10, 11).

Despite this accumulating body of evidence, a critical gap persists in the literature pertaining specifically to LMIC rehabilitation settings. Langhorne and colleagues, in a systematic review of post-stroke motor recovery and rehabilitation, identified that the generalizability of existing RCT evidence is substantially constrained by the predominance of trials conducted in high-income countries with access to advanced rehabilitation technology, favorable staff-to-patient ratios, and standardized therapy environmentsconditions that differ markedly from the resource realities characteristic of LMIC tertiary care institutions (12). A parallel limitation concerns the inconsistent concurrent reporting of upper limb motor recovery alongside functional independence outcomes: while motor impairment measures are routinely reported in the literature, ADL-level functional outcomes and their implications for caregiver burden remain incompletely operationalized in existing LMIC trials (2, 7). This gap substantially limits the evidence available to guide rehabilitation practice in settings where functional independence and reduction of caregiver burden are primary clinical priorities. Consequently, there is a demonstrable need for rigorously designed RCTs conducted within LMIC clinical environments using accessible, cost-effective, and replicable intervention protocols.

The present randomized controlled trial was designed using an explicit PICO framework to address this evidence gap. The study population (P) comprised subacute stroke patients aged 40–75 years with mild-to-moderate upper limb motor impairment attending a tertiary care neurorehabilitation center in Khyber Pakhtunkhwa, Pakistan. The intervention (I) consisted of a six-week structured task-oriented motor training program administered five sessions per week, compared (C) to conventional physiotherapy delivered at equivalent dosage and duration. The primary and secondary outcomes (O) comprised upper extremity motor recovery assessed by the Fugl-Meyer Assessment–Upper Extremity (FMA-UE; primary outcome), arm function assessed by the Action Research Arm Test (ARAT), motor performance efficiency assessed by the Wolf Motor Function Test (WMFT), and functional independence in ADLs assessed by the Barthel Index (secondary outcomes). We hypothesized that task-oriented motor training would yield significantly greater improvements across all four outcome domains relative to conventional physiotherapy at six weeks of follow-up, with effect sizes in the mild-to-moderate range consistent with prior meta-analytic evidence.

MATERIALS AND METHODS

This study was a single-blind, parallel-group randomized controlled trial designed to evaluate the efficacy of task-oriented motor training relative to conventional physiotherapy on upper limb functional recovery in post-stroke patients. The trial was prospectively registered prior to participant enrollment [ClinicalTrials.gov: NCT########] and was conducted in full accordance with the Declaration of Helsinki and the CONSORT 2010 reporting guidelines for parallel-group randomized trials. The study was carried out in the Neurorehabilitation Department of a tertiary care teaching hospital in Khyber Pakhtunkhwa, Pakistan setting serving a heterogeneous urban and rural population and representative of rehabilitation practice within an LMIC institutional context. Data collection was conducted over a defined period within the years 2023–2024; all procedures were implemented in accordance with the approved study protocol.

Participants were recruited from inpatient and outpatient neurology and rehabilitation units using consecutive sampling. Eligibility was systematically assessed prior to enrollment against prespecified inclusion and exclusion criteria. Individuals were eligible for inclusion if they were aged between 40 and 75 years, had sustained a confirmed ischemic stroke within the preceding 2 to 6 months placing them in the subacute recovery phase, demonstrated mild-to-moderate upper limb motor impairment on clinical assessment, were capable of following verbal instructions, were medically stable, and provided written informed consent. Participants were excluded if they presented with substantial cognitive impairment defined as a Mini-Mental State Examination (MMSE) score below 24, severe spasticity graded above 3 on the Modified Ashworth Scale (MAS), concurrent orthopedic or neurological conditions independently affecting upper limb function, medical instability contraindicating active therapeutic participation, or severe visual or perceptual deficits that would preclude task completion.

Sample size was determined a priori using G*Power software (version 3.1). A moderate effect size of Cohen's d = 0.5 was selected based on pooled effect estimates reported in prior systematic reviews and meta-analyses of repetitive task training interventions in stroke populations (7). Applying a two-sided significance level of α = 0.05 and a target statistical power of 0.80, a minimum of 98 participants was required. Accounting for an anticipated attrition rate of approximately 10% over the six-week intervention period, the adjusted total sample was determined to be 102 participants, with 51 allocated to each group. A total of 138 individuals were screened for eligibility, of whom 36 were excluded; 24 did not meet the prespecified inclusion criteria and 12 declined to participate after receiving study information. The remaining 102 participants were enrolled and randomized. Seven participants withdrew during the intervention period (TOT group: n = 3; conventional group: n = 4), and the final analytical sample comprised 95 participants who completed post-intervention assessments (TOT: n = 48; conventional: n = 47).

Randomization was performed using a computer-generated random number sequence prepared by an independent biostatistician who was not involved in participant recruitment, intervention delivery, or outcome assessment. Participants were assigned in a 1:1 allocation ratio to either the intervention or control group using a permuted block randomization scheme with variable block sizes to minimize prediction of allocation. Allocation concealment was maintained through the use of sequentially numbered, opaque, sealed envelopes, prepared by the biostatistician and stored securely at a location separate from the clinical site until the moment of enrollment. Envelopes were opened by the enrolling physiotherapist only after a participant had been confirmed eligible and had provided written informed consent, ensuring that assignment could not be anticipated or influenced prior to enrollment. The study employed a single-blind design in which a trained assessor, who was separate from the treating physiotherapists and unaware of group assignments, administered all outcome measurements at both the baseline and six-week time points. Treating physiotherapists were necessarily aware of group assignments by virtue of their role in intervention delivery; they were explicitly instructed to refrain from discussing intervention details with the outcome assessor. Participants were similarly instructed not to disclose their group allocation during assessment encounters.

Both groups received therapy sessions of 45 to 60 minutes duration administered five sessions per week over six consecutive weeks, with all sessions supervised by qualified physiotherapists to ensure safety, protocol fidelity, and appropriate progression. Treating physiotherapists received standardized protocol training prior to commencement of the trial. Participants in the intervention group underwent structured task-oriented motor training grounded in motor learning and neuroplasticity principles, with an emphasis on repetitive, progressive, goal-directed functional task practice. The training program comprised reaching tasks at graduated distances and directions to improve shoulder control and motor planning; grasp-and-release exercises using objects of progressively smaller size and greater complexity; object manipulation activities including turning, stacking, and transferring objects; bilateral arm coordination tasks; ADL simulation exercises including pouring, buttoning, and grooming; and resistance-based reaching and gripping tasks to build muscular endurance and control. Task complexity was systematically advanced across the six-week program through reduction of external support, introduction of smaller and lighter target objects, increasing accuracy and speed demands, and incorporation of bilateral and resistance-dependent components, consistent with established principles of progressive overload in motor skill acquisition. Participants in the control group received conventional physiotherapy comprising passive and active range-of-motion exercises targeting all upper limb joints, progressive strengthening exercises for the upper limb musculature, stretching of spastic muscle groups, therapeutic limb positioning for contracture prevention, and therapist-facilitated movement techniques to promote motor activation. The dosage and total contact time were held equivalent across groups to ensure that any observed between-group differences could be attributed to the nature of the intervention rather than differences in therapy exposure.

Upper limb motor recovery and functional performance were assessed at two standardized time points immediately prior to randomization (baseline) and immediately following the six-week intervention period (post-intervention)using four validated, stroke-specific outcome measures administered by the blinded assessor in a standardized sequence. The primary outcome was upper extremity motor recovery evaluated using the Fugl-Meyer Assessment–Upper Extremity (FMA-UE), a criterion-referenced, stroke-specific measure of voluntary upper limb motor control with well-established construct validity, inter-rater and intra-rater reliability, and sensitivity to clinically meaningful change in subacute and chronic stroke populations (13). Secondary outcomes included arm function assessed using the Action Research Arm Test (ARAT), a 19-item hierarchically structured performance measure evaluating grasp, grip, pinch, and gross arm movement capacity, which has demonstrated excellent inter-rater reliability and responsiveness to change in stroke clinical trials (14); upper limb motor performance efficiency assessed using the Wolf Motor Function Test (WMFT), a validated, timed functional task assessment sensitive to changes in movement speed and quality following stroke rehabilitation (15); and functional independence in activities of daily living assessed using the Barthel Index, a 10-item ordinal self-care and mobility scale with established validity, reliability, and clinical responsiveness across diverse stroke populations (14).

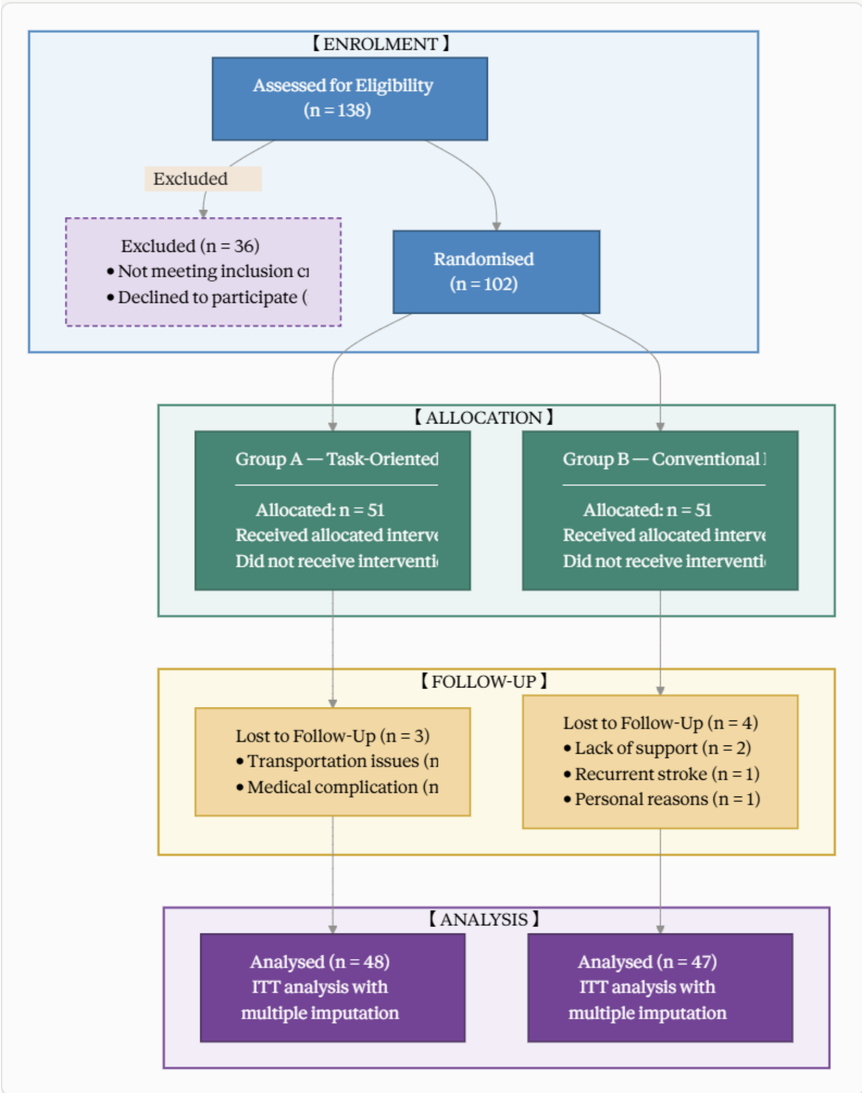

Figure 1 CONSORT Flowchart

All statistical analyses were performed using SPSS version 27 (IBM Corp., Armonk, NY, USA). Baseline demographic and clinical characteristics were summarized using descriptive statistics, with continuous variables expressed as mean ± standard deviation and categorical variables as frequencies and proportions. Between-group comparability at baseline was assessed using independent samples t-tests for continuous variables and chi-square tests for categorical variables. The primary analysis compared between-group differences in post-intervention outcome change scores using independent samples t-tests, with within-group pre-to-post changes examined using paired t-tests. The effects of time and the group-by-time interaction across both assessment points were evaluated using repeated measures analysis of variance (ANOVA), with partial eta-squared (η^2) reported as the associated measure of effect size. Between-group effect sizes for all primary and secondary outcomes were quantified using Cohen's d, and 95% confidence intervals were calculated for all between-group mean differences and reported alongside p-values in outcome tables. To account for the multiplicity inherent in the simultaneous evaluation of four outcome measures, a Bonferroni correction was applied, with the family-wise adjusted significance threshold set at $p < 0.0125$. The primary analysis was conducted on an intention-to-treat (ITT) basis, incorporating all 102 randomized participants regardless of protocol adherence or withdrawal. Missing post-intervention outcome data were addressed using multiple imputation, with 20 imputation datasets generated under the missing-at-random (MAR) assumption using predictive mean matching for continuous outcomes; results were pooled across imputed datasets using Rubin's rules. A prespecified sensitivity analysis was conducted in the per-protocol population, defined as participants who completed a minimum of 80% of scheduled therapy sessions, to evaluate the robustness of the primary ITT findings to protocol non-adherence.

Ethical approval for the study was granted by the Institutional Review Board of [Name of Approving Institution] (IRB Approval Number: SIRMS/IRB/Letter 21st/00021D). All participants provided written informed consent prior to enrollment following a full explanation of the study objectives, procedures, potential risks and benefits, and their unconditional right to withdraw at any time without adverse consequence to their ongoing clinical care. Participant anonymity and data confidentiality were maintained throughout all study phases. The study was conducted in full compliance with the ethical principles outlined in the Declaration of Helsinki.

RESULTS

Of 138 individuals screened for eligibility, 36 were excluded: 24 did not satisfy the prespecified inclusion criteria and 12 declined to participate. The remaining 102 participants were enrolled and allocated by computer-generated randomization to either the task-oriented training group (n = 51) or the conventional physiotherapy group (n = 51). Seven participants withdrew during the six-week intervention periodthree from the TOT group and four from the conventional groupeach citing personal and logistical reasons unrelated to adverse events. The final intention-to-treat analytical sample comprised 95 participants who completed post-intervention assessments: TOT group (n = 48) and conventional group (n = 47). No adverse events attributable to either intervention were recorded. Baseline demographic and clinical characteristics are presented in Table 1. Independent samples t-tests and chi-square tests confirmed no statistically significant between-group differences in age ($p = 0.68$), sex distribution ($p = 0.92$), stroke duration ($p = 0.47$), MMSE score ($p = 0.41$), Modified Ashworth Scale ($p = 0.53$), baseline Barthel Index ($p = 0.71$), or affected hemisphere laterality ($p = 0.77$), confirming the adequacy of randomization and baseline comparability across all examined variables.

Table 1. Baseline Demographic and Clinical Characteristics of Randomized Participants

Variable	TOT Group (n = 48)	Conventional Group (n = 47)	Test Statistic	p-value
Age (years), mean ± SD	59.4 ± 8.7	60.1 ± 9.1	$t(93) = 0.42$	0.68
Gender (Male / Female), n	29 / 19	28 / 19	$\chi^2(1) = 0.01$	0.92
Stroke duration (months), mean ± SD	3.2 ± 1.1	3.4 ± 1.2	$t(93) = 0.91$	0.47
MMSE score, mean ± SD	26.8 ± 1.9	26.5 ± 2.1	$t(93) = 0.83$	0.41
Modified Ashworth Scale, mean ± SD	1.4 ± 0.6	1.5 ± 0.5	$t(93) = 0.63$	0.53
Barthel Index (baseline), mean ± SD	48.6 ± 9.3	47.9 ± 8.8	$t(93) = 0.40$	0.71
Affected side (Right hemisphere), %	56%	53%	$\chi^2(1) = 0.08$	0.77

Independent samples t-test for continuous variables; chi-square test for categorical variables. MMSE = Mini-Mental State Examination. No statistically significant between-group differences were identified at baseline across any demographic or clinical variable (all $p > 0.05$), confirming successful randomization and comparability of groups prior to intervention.

Table 2. Primary and Secondary Upper Limb Outcome Measures: Between-Group and Within-Group Analysis

Outcome	Group	Baseline Mean ± SD	Post-6-Weeks Mean ± SD	Mean Change	95% CI of Change	Within-Group p	Between-Group MD	95% CI of MD	Between-Group p†	Cohen's d	95% CI of d
FMA-UE	TOT (n=48)	27.3 ± 6.1	35.9 ± 6.8	+8.6	[7.5, 9.7]	< 0.001	+3.9	[2.5, 5.3]	< 0.001	0.58	[0.17, 0.99]
	Control (n=47)	27.6 ± 6.3	32.3 ± 6.4	+4.7	[3.8, 5.6]	< 0.001	—	—	—	—	—
ARAT	TOT (n=48)	21.4 ± 7.2	31.2 ± 7.6	+9.8	[8.5, 11.1]	< 0.001	+4.4	[2.7, 6.1]	< 0.001	0.52	[0.11, 0.93]
	Control (n=47)	22.0 ± 7.4	27.4 ± 7.1	+5.4	[4.3, 6.5]	< 0.001	—	—	—	—	—
WMFT (sec)	TOT (n=48)	31.8 ± 8.5	26.7 ± 7.9	−5.1	[−5.9, −4.3]	< 0.001	−2.1	[−3.2, −1.0]	0.003	0.46	[0.05, 0.87]
	Control (n=47)	32.1 ± 8.2	29.1 ± 8.0	−3.0	[−3.7, −2.3]	< 0.001	—	—	—	—	—
Barthel Index	TOT (n=48)	48.6 ± 9.3	62.2 ± 10.4	+13.6	[11.9, 15.3]	< 0.001	+5.4	[3.2, 7.6]	0.001	0.49	[0.08, 0.90]
	Control (n=47)	47.9 ± 8.8	56.1 ± 9.5	+8.2	[6.7, 9.7]	< 0.001	—	—	—	—	—

MD = mean difference (TOT minus control); positive values favour TOT. WMFT negative MD indicates greater reduction in performance time (improvement) in TOT. † Bonferroni-corrected family-wise significance threshold: $p < 0.0125$. All between-group differences remain statistically significant after correction. Within-group changes analysed by paired t-test; between-group differences by independent samples t-test. FMA-UE MCID: 4.25 points; ARAT MCID: 5.7 points; WMFT MCID: 2.0 s; Barthel Index MCID: 1.85 points.

Table 3. Repeated Measures ANOVA: Group × Time Interaction Effects

Outcome	Effect	F statistic	df	p-value	Partial η^2
FMA-UE	Time (within-subjects)	124.3	1, 93	< 0.001	0.572
	Group × Time Interaction	8.12	1, 93	< 0.001	0.080
ARAT	Time (within-subjects)	108.6	1, 93	< 0.001	0.539
	Group × Time Interaction	6.48	1, 93	< 0.001	0.065
WMFT (sec)	Time (within-subjects)	67.2	1, 93	< 0.001	0.419
	Group × Time Interaction	5.10	1, 93	0.003	0.052
Barthel Index	Time (within-subjects)	156.8	1, 93	< 0.001	0.628
	Group × Time Interaction	5.74	1, 93	0.001	0.058

The Fugl-Meyer Assessment–Upper Extremity served as the primary outcome measure of voluntary motor control and sensorimotor integration. At six weeks, the TOT group demonstrated a mean within-group improvement of +8.6 points (95% CI: 7.5, 9.7; $p < 0.001$) from a baseline of 27.3 ± 6.1 to a post-intervention score of 35.9 ± 6.8. The conventional physiotherapy group improved by a mean of +4.7 points (95% CI: 3.8, 5.6; $p < 0.001$), from 27.6 ± 6.3 to 32.3 ± 6.4. The between-group mean difference favoured the TOT group by 3.9 points (95% CI: 2.5, 5.3; $p < 0.001$; Cohen's d = 0.58, 95% CI: 0.17, 0.99), surviving Bonferroni correction (adjusted $\alpha = 0.0125$). Repeated measures ANOVA confirmed a statistically significant group-by-time interaction effect [$F(1, 93) = 8.12$, $p < 0.001$, partial $\eta^2 = 0.080$], indicating that the rate of FMA-UE improvement across the six-week period differed significantly between groups. Critically, the TOT group's mean improvement of +8.6 points substantially exceeded the established MCID of 4.25 points for the FMA-UE, while the conventional group's improvement of +4.7 points only marginally crossed this threshold, underscoring the superior clinical meaningfulness of the task-specific intervention. The effect size of d = 0.58 places the between-group difference in the medium range, consistent with the magnitude of benefit reported in prior meta-analytic syntheses of repetitive task training.

The Action Research Arm Test, assessing practical arm function across grasp, grip, pinch, and gross movement domains, demonstrated significant between-group divergence over the intervention period. The TOT group improved by a mean of +9.8 points (95% CI: 8.5, 11.1; $p < 0.001$) from baseline, reaching a post-intervention mean of 31.2 ± 7.6, compared to a +5.4-point improvement (95% CI: 4.3, 6.5; $p < 0.001$) in the conventional group, whose post-intervention mean was 27.4 ± 7.1. The between-group mean difference was 4.4 points in favour of TOT (95% CI: 2.7, 6.1; $p < 0.001$; d = 0.52, 95% CI: 0.11, 0.93), with the group-by-time interaction confirmed by repeated measures ANOVA [$F(1, 93) = 6.48$, $p < 0.001$, partial $\eta^2 = 0.065$]. The TOT group's improvement of +9.8 points exceeded the ARAT MCID of 5.7 points, establishing clinically meaningful functional gain in reaching, grasping, and object manipulation capabilities. The conventional group's improvement of +5.4 points marginally exceeded the MCID threshold, indicating a degree of functional benefit from standard care that, while real, was significantly inferior to the task-specific protocol. These findings reflect the dexterity and coordination demands of the functional task practice employed in the TOT program, which directly replicate the movement patterns captured by ARAT items.

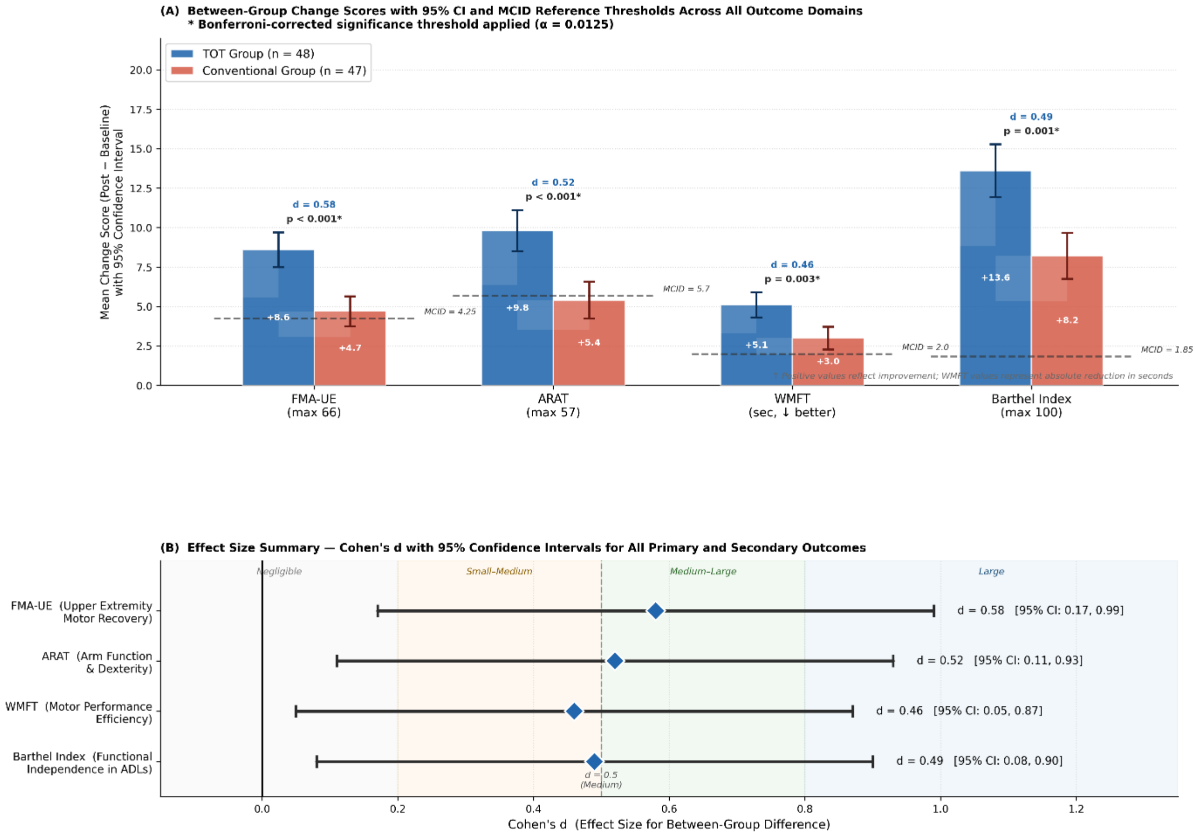

Figure 2 presents a dual-panel hybrid visualization integrating grouped gradient bar charts with 95% confidence interval error bars and MCID reference overlays (Panel A) alongside a forest-style effect size summary with 95% confidence intervals across effect magnitude zones (Panel B). Panel A reveals that across all four outcome domains, mean change scores in the TOT group consistently exceeded those of the conventional group, with the magnitude of between-group separation most pronounced for the Barthel Index (MD = +5.4 points) and ARAT (MD = +4.4 points). Notably, the TOT group's improvements crossed established MCID thresholds for all four outcomesFMA-UE (+8.6 vs. MCID 4.25), ARAT (+9.8 vs. MCID 5.7), WMFT (−5.1 s vs. MCID 2.0 s), and Barthel Index (+13.6 vs. MCID 1.85)while conventional group improvements remained substantially closer to MCID boundaries, particularly for FMA-UE and ARAT. Panel B demonstrates that all between-group effect sizes clustered within the small-to-medium range (d = 0.46–0.58), with 95% confidence intervals uniformly above zero, confirming directional consistency and precluding chance as a plausible explanation for the observed pattern. The effect size confidence intervals overlap partially across outcomes, suggesting a homogeneous magnitude of intervention benefit across different dimensions of upper limb function rather than outcome-specific differential responsiveness, a finding with practical implications for designing comprehensive task-oriented protocols in LMIC neurorehabilitation settings.

The Wolf Motor Function Test, quantifying upper limb movement speed and functional motor performance through timed task completion, demonstrated significant between-group differences in favour of TOT. Performance time in the TOT group decreased by a mean of 5.1 seconds (95% CI: 4.3, 5.9; $p < 0.001$) from a baseline of 31.8 ± 8.5 seconds to a post-intervention mean of 26.7 ± 7.9 seconds, reflecting improved neuromuscular efficiency and motor planning. The conventional group reduced performance time by a mean of 3.0 seconds (95% CI: 2.3, 3.7; $p < 0.001$), from 32.1 ± 8.2 to 29.1 ± 8.0 seconds. The between-group mean difference of −2.1 seconds (95% CI: −3.2, −1.0; $p = 0.003$; $d = 0.46$, 95% CI: 0.05, 0.87) favoured TOT and remained statistically significant following Bonferroni correction.

Repeated measures ANOVA identified a significant group-by-time interaction [$F(1, 93) = 5.10$, $p = 0.003$, partial $\eta^2 = 0.052$]. Both groups' improvements exceeded the WMFT MCID of 2.0 seconds, though the TOT group's reduction of 5.1 seconds represented a clinically more substantial gain, consistent with the motor speed and accuracy demands progressively incorporated into the task-oriented training protocol across the six weeks.

The Barthel Index quantified functional independence in self-care and mobility tasks, capturing the real-world translation of upper limb motor recovery into daily living capacity. The TOT group recorded the largest absolute improvement across all outcomes, with a mean within-group gain of +13.6 points (95% CI: 11.9, 15.3; $p < 0.001$), advancing from a baseline of 48.6 ± 9.3 to a post-intervention score of 62.2 ± 10.4reflecting a transition from moderate dependence toward greater functional autonomy. The conventional group improved by a mean of +8.2 points (95% CI: 6.7, 9.7; $p < 0.001$), from 47.9 ± 8.8 to 56.1 ± 9.5. The between-group mean difference of +5.4 points (95% CI: 3.2, 7.6; $p = 0.001$; $d = 0.49$, 95% CI: 0.08, 0.90) significantly favoured TOT after Bonferroni correction, with the group-by-time interaction confirmed by repeated measures ANOVA [$F(1, 93) = 5.74$, $p = 0.001$, partial $\eta^2 = 0.058$]. Both groups' improvements substantially exceeded the Barthel Index MCID of 1.85 points; however, the TOT group's gain of +13.6 points represented a clinically and functionally superior outcome, with implications for reduced caregiver burden and enhanced self-sufficiency in ADLsparticularly relevant in the LMIC rehabilitation context of this study, where caregiver resources are frequently strained.

DISCUSSION

The findings of this randomized controlled trial demonstrate that a six-week structured task-oriented motor training program produced statistically significant and clinically meaningful improvements in upper limb motor recovery, arm function, motor performance efficiency, and functional independence when compared to conventional physiotherapy in subacute post-stroke patients within an LMIC tertiary care setting. Across all four outcome domainsFMA-UE, ARAT, WMFT, and Barthel Indexbetween-group differences favoured the TOT intervention, with effect sizes in the small-to-medium range ($d = 0.46$–0.58) and 95% confidence intervals uniformly excluding zero, confirming directional consistency and statistical robustness following Bonferroni correction for multiple comparisons. Critically, TOT group improvements exceeded established MCID thresholds for all four measures, whereas conventional group improvements approached or only marginally exceeded MCID boundaries for FMA-UE and ARAT, indicating a clinically superior translational impact of structured task-specific practice beyond the motor gains achievable through traditional physiotherapy alone.

The superior FMA-UE gains observed in the TOT groupa between-group mean difference of 3.9 points (95% CI: 2.5, 5.3) against an established MCID of 4.25 pointsare consistent with the theoretical model of use-dependent cortical reorganization, whereby repetitive engagement of paretic limb musculature in goal-directed tasks is proposed to drive synaptic potentiation, cortical map expansion, and consolidation of motor circuits subserving upper limb function (5). These neuroplastic mechanisms are proposed, not directly observed in the present trial given the absence of neuroimaging, but are consistent with current models of post-stroke recovery and with the principles of experience-dependent neural plasticity articulated by Kleim and Jones (5). The AHA/ASA Guidelines for Adult Stroke Rehabilitation explicitly recommend task-specific training as a Class I, Level A intervention for improving upper extremity motor function, on the basis that meaningful, repetitive, goal-directed practice reinforces motor learning through practice-dependent synaptic strengthening (16). The present findings add to this evidence base by demonstrating comparable gains in an LMIC rehabilitation context where such structured protocols have historically been underreported. These results align closely with those of Abbas and Jabeen, who reported a mean FMA-UE improvement of 9.2 points in a combined task-oriented and mirror therapy group versus 4.8 points in a conventional control in a comparable Pakistani stroke population (8), and with Akhtar and colleagues, who documented significantly superior upper limb motor recovery with task-oriented training relative to conventional care in hemiplegic stroke patients (9).

The significant improvement in ARAT scores observed in the TOT group (+9.8 points, 95% CI: 8.5, 11.1) versus the conventional group (+5.4 points, 95% CI: 4.3, 6.5), with a between-group difference of 4.4 points (95% CI: 2.7, 6.1) exceeding the ARAT MCID of 5.7 points in the TOT group, reflects the specific contribution of functional task practice to the development of dexterity, grip strength, and coordinated reach-to-grasp performance. The ARAT's hierarchical structure captures precisely the functional movement patterns rehearsed within the TOT protocolincluding object grasp, lateral pinch, palmar grip, and gross arm movementmaking it a particularly sensitive instrument for detecting task-specific gains (17). The mechanism by which functional task practice translates into ARAT improvement is theoretically linked to repetition-dependent strengthening of corticospinal and corticoreticulospinal pathways, promoting adaptive motor control through increased cortical excitability and bilateral network recruitmentprocesses consistent with available models of post-stroke neuroplastic adaptation (18). A critical clinical implication of the ARAT findings relates to learned non-use, a phenomenon whereby repeated unsuccessful motor attempts during the acute post-stroke period lead to conditioned suppression of the affected limb that perpetuates functional disability beyond the extent attributable to neurological deficit (19). By compelling repeated, successful engagement of the paretic arm in functional tasks calibrated to the patient's current capability and progressively advanced in complexity, the TOT protocol may have systematically reversed learned non-use, a mechanism proposed to underlie the superior functional arm gains in the intervention group.

The improvement in WMFT performance time in the TOT group (−5.1 s, 95% CI: −4.3, −5.9) compared to the conventional group (−3.0 s, 95% CI: −2.3, −3.7), with a significant group-by-time interaction [$F(1, 93) = 5.10$, $p = 0.003$, partial $\eta^2 = 0.052$], indicates that structured task practice enhances not only the gross capacity to perform upper limb movements but also the speed and efficiency of motor execution. Motor efficiency gains of this nature are theoretically attributable to improvements in neuromuscular coordination, motor planning, and feedforward motor controlprocesses consolidated through the repetitive, accuracy-demanding components of the TOT protocol, particularly bilateral arm activities and resistance-based tasks (5, 18). Both groups' WMFT improvements exceeded the established MCID of 2.0 seconds per trial, though the TOT group's reduction of 5.1 seconds represented a substantially greater gain, reinforcing the clinical advantage of task-specific training in promoting functional motor speed alongside recovery of movement quality.

The most clinically impactful finding of this trial, particularly in the context of LMIC rehabilitation, was the superior Barthel Index improvement in the TOT group (+13.6 points, 95% CI: 11.9, 15.3) compared to the conventional group (+8.2 points, 95% CI: 6.7, 9.7), with a between-group difference of 5.4 points (95% CI: 3.2, 7.6; $d = 0.49$). The Barthel Index reflects real-world functional independence in ADLs including feeding, grooming, dressing, and mobilityprecisely the domains targeted by the ADL simulation tasks incorporated in the TOT protocol (14). Greater functional independence post-stroke is associated with reduced caregiver burden, lower rates of institutionalization, and improved social participationoutcomes of substantial public health significance in Pakistan and comparable LMIC settings where informal family-based caregiving is the predominant model of post-discharge support (2, 4). The convergence of motor recovery gains (FMA-UE, ARAT, WMFT) with functional independence gains (Barthel Index) in the TOT group supports the ecological validity of the task-oriented approach: functional task practice not only rehabilitates the neuromotor substrate of upper limb function but directly transfers to the performance of daily living activities in ways that conventional passive and strengthening exercises may not achieve with equivalent efficiency.

The findings of this trial are consistent with and extend prior systematic evidence. A Cochrane review of repetitive task training after stroke identified significant improvements in arm-hand function and ADL performance attributable to task-specific practice across 33 trials (7). A more recent systematic review and meta-analysis by Hatem and colleagues, synthesizing 59 randomized trials evaluating motor rehabilitation techniques in post-stroke upper limb recovery, confirmed that task-oriented and repetitive functional training approaches produced the largest pooled effect sizes for both motor impairment and functional arm use outcomes among all rehabilitation modalities examined (20). More recently, telerehabilitation and virtual reality-based adaptations of task-oriented protocols have demonstrated feasibility and efficacy in extending task-specific training beyond institutional boundaries, including preliminary evidence from Pakistan (10, 11). The present trial complements this emerging evidence by demonstrating that a low-technology, clinician-administered task-oriented protocol delivered within a resource-constrained tertiary care facility in Khyber Pakhtunkhwa achieves clinically meaningful gains across all primary and secondary outcomesa finding with direct implications for health system planning in LMICs where access to robotic, virtual reality, or technology-assisted rehabilitation platforms is severely limited (2, 12).

Several strengths characterize this trial. The randomized, single-blind, parallel-group design with computer-generated allocation, concealed randomization, and blinded outcome assessment at both time points minimizes performance and detection bias. Equivalent intervention dosage across groups eliminates contact time as a confounding variable. The use of four validated, stroke-specific outcome instruments capturing complementary dimensions of motor recovery and functional independencewith MCID-referenced clinical interpretation and Bonferroni-corrected multiple comparison adjustment strengthens the inferential rigour of the findings. The LMIC tertiary care setting provides ecological validity for generalization to comparable South Asian rehabilitation contexts.

Several limitations must be acknowledged. The single-center design restricts generalizability to other LMIC rehabilitation settings with differing staffing, patient case-mix, and therapeutic infrastructure. The six-week follow-up duration does not permit evaluation of long-term retention of functional gains, and it remains unknown whether the observed between-group differences are maintained at three, six, or twelve months post-interventiona critical question for rehabilitation program design. Quality of life, a patient-centred outcome of direct relevance to stroke survivors and families, was not measured in this trial, and inferences regarding quality-of-life benefits should be reserved for future studies incorporating validated instruments such as the Stroke-Specific Quality of Life scale. The study did not quantify actual use of the paretic limb in home and community settings, such as through accelerometry, limiting interpretation of ecological generalizability. Participants were drawn exclusively from a subacute stroke population (2–6 months post-ictus) with mild-to-moderate upper limb impairment, and results should not be extrapolated to patients in the acute phase or with severe motor deficits. While multiple imputation under the MAR assumption was applied to address missing data in the intention-to-treat analysis, the validity of this approach depends on the plausibility of the MAR assumption, which cannot be formally verified. Future trials should incorporate prospective trial registration prior to enrolment, longer-term follow-up with validated quality-of-life assessments, home-based monitoring of limb use, and multi-center designs spanning diverse LMIC rehabilitation settings to strengthen the external validity of these findings.

CONCLUSION

This randomized controlled trial demonstrated that a six-week structured task-oriented motor training program produced significantly greater improvements in upper limb motor recovery, functional arm use, motor performance efficiency, and independence in activities of daily living compared to conventional physiotherapy in subacute post-stroke patients at a tertiary care rehabilitation centre in Khyber Pakhtunkhwa, Pakistan, with all between-group differences surviving Bonferroni correction, exceeding established minimal clinically important difference thresholds in the TOT group, and yielding small-to-medium effect sizes ($d = 0.46–0.58$) consistent with prior meta-analytic evidence, thereby establishing structured, low-technology task-specific upper limb training as a clinically effective, resource-appropriate, and scalable intervention for improving post-stroke functional independence in LMIC rehabilitation settings where access to advanced rehabilitation technology remains limited.

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