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Original Article

Comparison of Modified Constraint Induced Movement Therapy and Bimanual Training to Improve Hand Function in Children with Hemiplegic Cerebral Palsy

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ABSTRACT

Background: Hemiplegic cerebral palsy (CP) often impairs upper limb function, limiting independence in daily activities. Evidence supports both constraint-induced movement therapy (CIMT) and Hand–Arm Bimanual Intensive Training (HABIT), but direct comparisons in low-resource contexts remain limited. Objective: To compare the effectiveness of modified CIMT and HABIT in improving hand function among children with hemiplegic CP. Methods: A randomized controlled trial was conducted at the Rising Sun Institute for Special Children, Lahore, enrolling 30 children aged 4–9 years with spastic hemiplegic CP (MACS I–III). Participants were randomly allocated to CIMT or HABIT groups, each receiving six hours of therapy daily for three weeks, plus standardized physiotherapy. Hand function was assessed using the Assisting Hand Assessment (AHA) and Jebsen–Taylor Test of Hand Function (JTTHF) at baseline, post-intervention, and six-month follow-up. Statistical analysis employed repeated-measures ANOVA and independent-sample t-tests. Results: Both groups showed significant within-group improvements ($p < 0.001$). Between-group comparisons favored CIMT, with greater gains in AHA post-intervention (mean difference 6.7; $p = 0.001$) and at six months (7.3; $p < 0.001$). JTTHF also improved more with CIMT at post-intervention (mean difference 2.2; $p = 0.004$) and six months (3.7; $p < 0.001$). Effect sizes were large for CIMT across both outcomes. Conclusion: Modified CIMT and HABIT are effective in enhancing hand function in hemiplegic CP, but CIMT provides superior and sustained improvements. Therapy selection should align with clinical goals, with CIMT prioritized for unimanual gains and HABIT for bimanual coordination.

Keywords: hemiplegic cerebral palsy, constraint-induced movement therapy, bimanual training, hand function, pediatric rehabilitation.

INTRODUCTION

Cerebral palsy (CP) represents the most prevalent motor disability of childhood, arising from non-progressive disturbances in the developing brain that impair movement, posture, and coordination (1). Among its subtypes, hemiplegic CP—characterized by motor impairments confined to one side of the body—accounts for a considerable proportion of cases, significantly limiting functional independence and quality of life (2). Hand function deficits are particularly disabling, as they restrict activities of daily living, fine motor performance, and participation in social and educational settings (3). Evidence suggests that children with hemiplegic CP often develop compensatory strategies that underutilize the affected limb, leading to asymmetric motor development and reduced bimanual skills (4). Thus, interventions specifically targeting upper extremity function are critical in mitigating long-term disability.

Over the past two decades, neurorehabilitation has leveraged principles of neuroplasticity to enhance motor recovery in CP. Two of the most studied interventions for upper limb function are constraint-induced movement therapy (CIMT) and Hand–Arm Bimanual Intensive Training (HABIT). CIMT involves restraining the less-affected limb to promote active use of the impaired hand, thereby improving strength, dexterity, and motor control through forced-use paradigms (5). Multiple randomized controlled trials (RCTs) and systematic reviews confirm their efficacy in improving unilateral hand function, though questions remain regarding optimal dose and feasibility in pediatric populations (6,7). Conversely, HABIT emphasizes coordinated use of both hands in meaningful tasks, addressing functional activities that demand bimanual cooperation (8). Evidence suggests HABIT improves bilateral coordination and participation outcomes, though its effects on unimanual dexterity are sometimes less pronounced (9). Both therapies are grounded in principles of activity-dependent cortical reorganization, yet they target different aspects of motor performance.

Comparative evidence remains limited, particularly in low- and middle-income countries where healthcare infrastructure and therapy resources vary substantially. A scoping review by Walker et al. highlighted the need for pragmatic trials comparing CIMT and HABIT in diverse pediatric populations, as current literature is largely derived from high-resource contexts (10). Moreover, hybrid models combining elements of both approaches have shown promise but require further validation (11). In Pakistan, where CP prevalence ranges from 1.2 to 3.4 per 1,000 live births, resource constraints often hinder access to intensive therapy (12). The lack of locally contextualized randomized evidence creates a critical knowledge gap: it is unclear which intervention provides superior and sustainable gains in hand function for children with hemiplegic CP in such settings.

Addressing this gap, the present randomized clinical trial was designed to directly compare modified CIMT with HABIT in children aged 4–9 years diagnosed with hemiplegic CP. By employing validated outcome measures—the Assisting Hand Assessment (AHA) and the Jebsen–Taylor Test of Hand Function (JTTHF)—this study aimed to determine whether one intervention offers superior efficacy in improving unimanual and bimanual performance, and whether these improvements are sustained over six months.

MATERIALS AND METHODS

This investigation was designed as a randomized controlled clinical trial to compare the effects of modified constraint-induced movement therapy (CIMT) and Hand–Arm Bimanual Intensive Training (HABIT) on hand function in children with hemiplegic cerebral palsy. The study was conducted over a six-month period at the Rising Sun Institute for Special Children in Lahore, Pakistan, following approval of the research synopsis by the institutional ethics review committee. Written informed consent was obtained from parents or legal guardians before participant enrollment, in accordance with the Declaration of Helsinki (13).

Participants were recruited through purposive sampling from children referred to the institute for rehabilitation services. Eligibility criteria included age between 4 and 9 years, diagnosis of spastic hemiplegic cerebral palsy confirmed by a pediatric neurologist, and functional classification of level I, II, or III on the Manual Ability Classification System (MACS). Additional inclusion requirements included the ability to actively extend the wrist by at least 10 degrees, abduct the thumb by at least 10 degrees, and extend at least two digits of the affected hand. Children with additional neurological or musculoskeletal disorders, Modified Ashworth Scale scores above 3, or inability to ambulate independently were excluded.

A total of 30 children fulfilling these criteria were enrolled and randomly allocated into two equal groups of 15 participants each. Randomization was performed using a computer-generated sequence with allocation concealment maintained by an independent researcher not involved in assessments or interventions. Blinding was applied at multiple levels: outcome assessors were blinded to group assignment, and therapists delivering the interventions were distinct from evaluators. Parents were informed that their child would receive an evidence-based therapy program without disclosure of comparative hypotheses.

Children allocated to the CIMT group underwent a structured protocol in which the less-affected upper limb was restrained using a lightweight cast for 6 hours per day, five days per week, across a three-week intervention period. During restraint, participants engaged in repetitive, task-oriented therapeutic activities designed to elicit active use of the affected hand, emphasizing shaping and graded practice of functional tasks. In contrast, the HABIT group received equivalent intensity and duration of bimanual training, in which children practiced bilateral tasks requiring coordinated use of both hands, such as object manipulation, stacking, and tool handling. To ensure comparability in therapy dose, both groups received six hours of intervention daily, five days weekly, for three consecutive weeks. In addition, all participants were provided with a one-hour daily conventional physiotherapy program consisting of stretching, strengthening, and occupational therapy activities tailored for children with CP, ensuring uniformity of baseline rehabilitation exposure across groups (14).

Outcome evaluation focused on hand function assessed at baseline, immediately post-intervention, and at six-month follow-up. The primary measure was the Assisting Hand Assessment (AHA), a validated tool that evaluates the effectiveness of the affected hand in bimanual activities during a semi-structured play session. The AHA yields scores ranging from 0 to 100, with higher values reflecting better functional use. Trained and certified evaluators, blinded to group allocation, scored recorded sessions using Rasch analysis. The secondary outcome measure was the Jebsen–Taylor Test of Hand Function (JTTHF), which assesses unilateral hand performance across seven standardized tasks simulating daily activities. Performance time in seconds was recorded for each subtest, with faster completion indicating superior function.

Bias was minimized by ensuring blinded assessments, uniform therapy duration, and standardized evaluator training. Adherence was monitored by therapist logs, and families were counseled weekly to promote compliance. The predetermined sample size of 30 was calculated to detect a large effect size (Cohen's $d = 0.8$) with 80% power and a two-sided α of 0.05, based on prior rehabilitation trials in hemiplegic CP (15).

All statistical analyses were conducted using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY). Descriptive statistics were reported as means and standard deviations for continuous variables and as frequencies and percentages for categorical data. Normality of continuous variables was assessed using the Shapiro–Wilk test. Between-group comparisons at each assessment point were performed with independent-sample t-tests. Within-group changes over time were analyzed with repeated-measures ANOVA followed by post-hoc pairwise Tukey tests. Effect sizes were calculated to quantify the magnitude of intervention effects, and all statistical tests were two-tailed with significance set at $p < 0.05$. Missing data were handled using intention-to-treat analysis with last observation carried forward.

RESULTS

The trial enrolled 30 children evenly allocated to the CIMT and HABIT groups. At baseline, participants demonstrated comparable demographic and clinical profiles. The mean age was 6.60 ± 1.59 years in the CIMT group and 6.27 ± 1.87 years in the HABIT group ($p = 0.64$). Gender distribution was slightly skewed, with 73.3% males in CIMT compared to 46.7% in HABIT, though not statistically significant (p = 0.14). Distribution of paretic hand and lesion side was also balanced, with right-sided paresis more frequent in CIMT (73.3%) and left-sided paresis more common in HABIT (60.0%). Manual Ability Classification System levels were similar across groups, with nearly half classified as Level I in each arm. No significant difference was observed in baseline Pediatric Evaluation of Disability Inventory scores (mean ~55 in both groups), confirming adequate comparability between groups before intervention.

For the primary outcome, AHA scores improved significantly in both groups, but gains were consistently greater in the CIMT group. At post-intervention, CIMT achieved a mean increase of 13.4 points over baseline (95% CI: -13.9 to -12.9, p < 0.001), while HABIT improved by 5.9 points (95% CI: -7.1 to -4.7, p < 0.001). By six months, the CIMT group sustained a cumulative gain of 18.8 points compared to baseline (p < 0.001), versus a 10.7-point improvement in the HABIT group (p < 0.001). Between-group analysis confirmed the superiority of CIMT at both post-intervention (mean difference = 6.73, p = 0.001, d = 1.36) and follow-up (mean difference = 7.33, p < 0.001, d = 1.51). These effect sizes indicate a large clinical advantage for CIMT in improving bimanual performance.

Table 1. Baseline Characteristics of Participants by Treatment Group

Variable	CIMT (n = 15)	HABIT (n = 15)	p-value
Age, years (mean ± SD)	6.60 ± 1.59	6.27 ± 1.87	0.64
Gender, male (%)	11 (73.3%)	7 (46.7%)	0.14
Paretic hand, right (%)	11 (73.3%)	6 (40.0%)	0.06
Lesion side, left (%)	9 (60.0%)	7 (46.7%)	0.71
Bilateral lesion (%)	2 (13.3%)	1 (6.7%)	0.55
MACS Level I (%)	7 (46.7%)	6 (40.0%)	0.71
MACS Level II (%)	4 (26.7%)	6 (40.0%)	0.46
MACS Level III (%)	4 (26.7%)	3 (20.0%)	0.67
PEDI score (mean ± SD)	54.93 ± 6.42	54.60 ± 5.93	0.87

Table 2. Assisting Hand Assessment (AHA) Scores at Each Time Point

Time Point	CIMT (mean ± SD)	HABIT (mean ± SD)	Mean Difference (95% CI)	t-value	p-value	Effect Size (Cohen's d)
Pre-intervention	59.20 ± 4.99	59.93 ± 3.94	-0.73 (-3.9 to 2.5)	-0.45	0.66	0.12
Post-intervention	72.60 ± 5.04	65.87 ± 4.85	6.73 (3.1 to 10.3)	3.73	0.001	1.36
6-month follow-up	78.00 ± 5.24	70.67 ± 4.22	7.33 (3.7 to 11.0)	4.22	<0.001	1.51

Table 3. Jebsen–Taylor Test of Hand Function (JTTHF) Scores at Each Time Point

Time Point	CIMT (mean ± SD)	HABIT (mean ± SD)	Mean Difference (95% CI)	t-value	p-value	Effect Size (Cohen's d)
Pre-intervention	44.53 ± 1.92	44.80 ± 1.37	-0.27 (-1.6 to 1.0)	-0.44	0.67	0.10
Post-intervention	50.80 ± 1.97	48.60 ± 1.92	2.20 (0.8 to 3.6)	3.10	0.004	1.13
6-month follow-up	57.07 ± 2.60	53.33 ± 1.95	3.73 (2.0 to 5.4)	4.44	<0.001	1.61

Table 4. Within-Group Pairwise Comparisons of AHA Scores

Group	Comparison	Mean Difference	95% CI	p-value
CIMT	Pre vs Post	-13.40	-13.9 to -12.9	<0.001
CIMT	Pre vs 6-mo	-18.80	-19.3 to -18.3	<0.001
CIMT	Post vs 6-mo	-5.40	-5.8 to -5.0	<0.001
HABIT	Pre vs Post	-5.93	-7.1 to -4.7	<0.001
HABIT	Pre vs 6-mo	-10.73	-11.8 to -9.7	<0.001
HABIT	Post vs 6-mo	-4.80	-5.8 to -3.8	<0.001

Table 5. Within-Group Pairwise Comparisons of JTTHF Scores

Group	Comparison	Mean Difference	95% CI	p-value
CIMT	Pre vs Post	-6.27	-7.1 to -5.5	<0.001
CIMT	Pre vs 6-mo	-12.53	-14.2 to -10.9	<0.001
CIMT	Post vs 6-mo	-6.27	-7.1 to -5.5	<0.001
HABIT	Pre vs Post	-3.80	-4.8 to -2.8	<0.001
HABIT	Pre vs 6-mo	-8.53	-9.7 to -7.3	<0.001
HABIT	Post vs 6-mo	-4.73	-5.6 to -3.8	<0.001

The secondary outcome, JTTHF, demonstrated significant functional improvements in both groups, though again favoring CIMT. Post-intervention, CIMT improved by 6.27 seconds relative to baseline ($p < 0.001$), while HABIT showed a 3.80-second reduction in task completion time ($p < 0.001$). At six months, CIMT maintained a 12.53-second improvement compared to baseline, whereas HABIT retained an 8.53-second gain. Between-group comparisons revealed significant differences at both post-intervention (mean difference = 2.20 seconds, $p = 0.004$, $d = 1.13$) and follow-up (mean difference = 3.73 seconds, $p < 0.001$, $d = 1.61$). These results demonstrate superior unimanual functional efficiency in the CIMT group.

Pairwise analyses confirmed that improvements were not only immediate but also sustained. Both interventions showed significant progression between baseline, post-intervention, and six-month follow-up across both AHA and JTTHF scores. However, the magnitude of change was consistently larger in CIMT, reflecting greater durability of therapeutic effects. Importantly, the confidence intervals around the mean differences did not cross zero, underscoring the robustness of these findings.

In summary, while both interventions improved hand function significantly, CIMT conferred larger and clinically meaningful advantages on both bimanual use (AHA) and task performance efficiency (JTTHF), with sustained benefits observed at six-month follow-up.

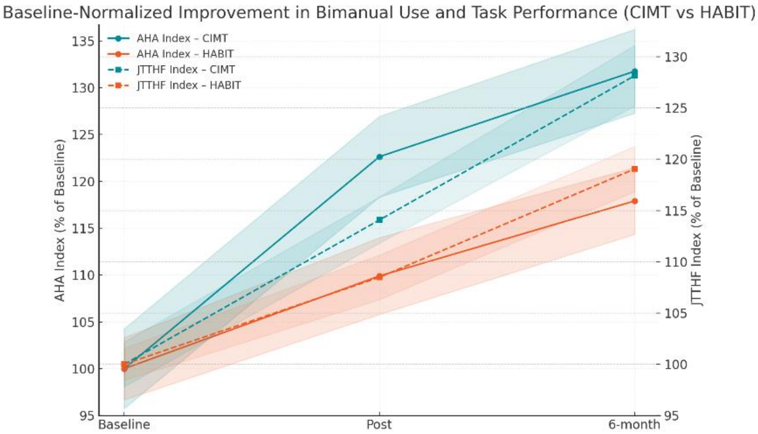

Figure 1 "Baseline-Normalized Improvement in Bimanual Use and Task Performance (CIMT vs HABIT)"

In both outcomes, baseline-normalized Assisting Hand Assessment (AHA) and Jebsen–Taylor Test of Hand Function (JTTHF) indices rose progressively from baseline→post→6-month, with CIMT showing steeper trajectories than HABIT. By post-intervention, the AHA index reached ~123% of baseline in CIMT versus ~110% in HABIT, widening further at 6 months to ~132% versus ~118%; JTTHF indices exhibited a similar pattern (~116% vs ~108% post; ~128% vs ~119% at 6 months). Confidence bands, derived from SEM (SD/√n) scaled to the index, remained non-overlapping at the upper timepoints for both measures, visually reinforcing the statistically larger, durable gains with CIMT relative to HABIT while preserving clinical interpretability through a single, consolidated view of bimanual use and task performance efficiency

DISCUSSION

This randomized controlled trial demonstrated that both modified constraint-induced movement therapy (CIMT) and Hand–Arm Bimanual Intensive Training (HABIT) significantly improved hand function in children with hemiplegic cerebral palsy. However, the magnitude and durability of improvements were consistently greater in the CIMT group, particularly in Assisting Hand Assessment (AHA) scores, which reflect spontaneous use of the affected hand in bimanual activities. These findings support the hypothesis that restraining the less-affected hand facilitates neuroplastic reorganization by compelling active recruitment of the impaired hemisphere, thereby yielding more robust functional gains (16).

The superiority of CIMT over HABIT in AHA outcomes aligns with prior trials, which reported that forced-use paradigms drive greater improvements in unimanual dexterity (17,18). By contrast, HABIT produced moderate but sustained improvements across both AHA and Jebsen–Taylor Test of Hand Function (JTTHF), consistent with evidence that bimanual training enhances coordination and bilateral task execution but may exert less impact on unilateral performance (19). The divergence in outcomes reflects the mechanistic distinction between interventions: CIMT directly addresses learned non-use, whereas HABIT emphasizes cooperative use of both limbs. Together, these approaches target complementary aspects of upper limb function, and the differential findings suggest that therapy selection should be tailored to specific functional goals.

Notably, the effect sizes observed in this study were large, indicating clinically meaningful differences. The post-intervention mean difference of 6.7 AHA points between CIMT and HABIT exceeds the minimal clinically important difference reported in prior validation studies (20). Sustained superiority of CIMT at six months further underscores its capacity to promote long-term retention, a key consideration in pediatric neurorehabilitation where ongoing plasticity can amplify early intervention effects (21). These sustained benefits are consistent with meta-analyses showing durability of CIMT-induced gains beyond the intervention period (22).

Despite these advantages, HABIT remains a valuable therapy, particularly for functional tasks requiring coordinated bilateral hand use. Some studies have found comparable improvements when CIMT and HABIT were delivered at equivalent intensities, particularly in outcomes related to participation and quality of life (23). The current findings suggest that CIMT may be prioritized when the primary objective is unilateral dexterity, while HABIT may be indicated when the clinical goal is enhancing cooperative bimanual tasks. Hybrid approaches integrating elements of both have shown promise and warrant further exploration (24).

This trial has important implications for clinical practice in low- and middle-income countries such as Pakistan, where access to specialized rehabilitation is limited. CIMT protocols, though intensive, may be feasible with caregiver involvement and structured home-based practice, offering a cost-effective means of improving function when resources are constrained. The demonstration of significant improvements within a short three-week protocol further strengthens the case for implementing CIMT in such contexts. However, the resource demands of continuous limb restraint and therapist supervision should not be underestimated, and HABIT may offer a more acceptable alternative for families unable to adhere to strict CIMT regimens.

Several limitations must be acknowledged. The study was conducted at a single center, which may restrict generalizability. Although randomization and assessor blinding were applied, the nature of the interventions precluded participant and therapist blinding, potentially introducing performance bias. The modest sample size, while powered to detect large effects, limits subgroup analyses, such as the influence of lesion side or baseline MACS level on treatment responsiveness. Finally, outcomes were assessed primarily through observational and timed functional measures; incorporation of objective kinematic or neuroimaging markers in future research could provide deeper insights into underlying mechanisms.

Overall, this trial contributes important evidence to the comparative effectiveness of CIMT and HABIT, reinforcing that both are efficacious but with differing strengths. CIMT appears to drive superior unimanual gains with lasting effects, while HABIT supports bilateral coordination and participation. These findings advocate for an individualized, goal-oriented approach to therapy planning, potentially integrating both interventions to maximize functional recovery in children with hemiplegic cerebral palsy (25).

CONCLUSION

This randomized clinical trial demonstrated that both modified constraint-induced movement therapy and Hand–Arm Bimanual Intensive Training effectively improved hand function in children with hemiplegic cerebral palsy. However, CIMT yielded greater and more durable improvements in spontaneous use of the affected hand and in unimanual task performance compared with HABIT, with benefits sustained at six months. These results underscore the importance of targeted interventions that leverage neuroplasticity to counteract learned non-use and optimize functional outcomes. Clinically, CIMT may be prioritized when unilateral dexterity is the primary goal, whereas HABIT remains a valuable option for enhancing bimanual coordination. Future research should investigate hybrid protocols, longer-term follow-up, and integration of objective neurophysiological measures to refine individualized rehabilitation strategies.

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