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Review Article

Effectiveness of hand-arm bimanual intensive therapy in neurological training: a comprehensive scientific literature review

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ABSTRACT

Hand-arm bimanual intensive therapy (HABIT) is an intensive rehabilitation approach designed to improve bimanual coordination and functional hand use in individuals with neurological impairments. Unlike constraint-induced movement therapy, HABIT emphasizes simultaneous bilateral practice of meaningful tasks, leveraging neuroplasticity principles to drive functional recovery. This scoping review synthesizes evidence from eight randomized controlled trials and high-quality protocols to evaluate the effectiveness, feasibility and innovations in HABIT and HABIT including lower extremities (HABIT-ILE) across cerebral palsy and stroke populations. A multi-phase search strategy was conducted across PubMed, Google Scholar and SciSpace, yielding 177 unique records. After screening and eligibility assessment, eight studies were included. Methodological quality and risk of bias was appraised and summarised. In unilateral cerebral palsy, HABIT consistently improved assisting hand assessment (AHA) scores, dexterity and caregiver-reported outcomes, with stronger effects observed in early interventions. HABIT-ILE demonstrated additional benefits for lower extremity function without compromising upper limb gains. In bilateral cerebral palsy, HABIT improved dialy functioning and dominant-hand dexterity, while large multisite trials confirmed feasibility across a wide severity spectrum. In stroke populations, HABIT delivered in the acute phase produces superior motor recovery compared to conventional rehabilitation, supporting its adaptability beyond paediatric contexts. Home-based HABIT models showed promise for dexterity and goal attainment, though bimanual performance gains were less robust. HABIT demonstrate consistent efficacy in enhancing functional outcomes across cerebral palsy and stroke, with early intensive delivery yielding the most clinically meaningful improvements. Evidence supports HABIT as a scalable, neuroplasticity-driven intervention, though heterogeneity in dosage, delivery models and outcome measures underscores the need for standardized protocols and exploration of adjunctive innovations such as neuromodulation and virtual reality.

Keywords: Hand-arm bimanual intensive therapy, Cerebral palsy, Stroke rehabilitation, Bimanual coordination, Neuroplasticity, Intensive motor training

INTRODUCTION

Hand-arm bimanual intensive therapy (HABIT) is an evidence-based intervention designed to improve bimanual coordination and functional hand use in individuals with neurological impairments. Originally developed for children with hemiplegic cerebral palsy, HABIT has evolved into a comprehensive therapeutic approach applicable across diverse populations and age ranges.[1] The intervention distinguishes itself from traditional rehabilitation approaches through its emphasis on intensive, massed practice of bimanual functional tasks rather than isolated unimanual exercises or constraint-based paradigms.[1]

The fundamental premise of HABIT is that coordinated use of both hands in meaningful, goal-directed activities drives neuroplastic reorganization and functional improvement more effectively than unilateral training alone.[1] Unlike constraint-induced movement therapy (CIMT), which restricts the less-affected limb to force use of the impaired hand, HABIT promotes simultaneous bilateral engagement in tasks that require interlimb coordination, such as stabilizing objects while manipulating them, opening containers, or playing games requiring two-handed interaction.[1,2]

HABIT interventions typically involve structured play and functional activities delivered in intensive formats, with dosages ranging from 50 to 90 hours over compressed timeframes of 1-2 weeks.[1-3] This high-dose, short-duration model contrasts sharply with conventional rehabilitation, which typically provides lower-intensity therapy distributed over extended periods.[1,2] The intensive delivery model is hypothesized to maximize neuroplastic potential by providing sufficient repetition and practice density to drive cortical reorganization and motor learning consolidation.[1,2]

Theoretical foundations

HABIT is grounded in contemporary motor learning theory and principles of skill acquisition. The intervention operationalizes key motor learning principles including task specificity, progressive challenge, active problem-solving, and distributed practice within massed training blocks.[5] Task specificity dictates that practice should involve functional, goal-directed activities that closely resemble real-world demands rather than abstract exercises.[1] Progressive challenge ensures that task difficulty is systematically increased as performance improves, maintaining an optimal level of difficulty that promotes learning without inducing frustration or failure.[5]

Active problem-solving is embedded within HABIT activities, requiring participants to plan, execute, and adapt bimanual strategies to accomplish task goals.[1] This cognitive engagement is theorized to enhance motor learning by recruiting executive function networks and promoting generalization beyond practiced tasks.[2] The intervention also incorporates principles of distributed practice, with multiple short practice sessions interspersed with brief rest periods throughout each training day.[6]

The bimanual focus of HABIT is theoretically motivated by evidence that coordinated bilateral movements engage interhemispheric neural networks and may facilitate recruitment of ipsilateral motor pathways in individuals with unilateral brain lesions.[7] For children with hemiplegic CP, bimanual practice may promote functional reorganization of motor control networks, potentially recruiting contralesional cortical regions to support affected-limb function.[7] In stroke populations, bilateral training is hypothesized to reduce interhemispheric inhibition and promote balanced activation of motor cortices.[8]

Neuroplasticity principles

HABIT leverages fundamental principles of experience-dependent neuroplasticity to drive functional recovery. Neuroplasticity is the brain's capacity to reorganize structure and function in response to experience is maximally engaged when practice is intensive, repetitive, task-specific, and behaviourally relevant. Animal models and human neuroimaging studies demonstrate that high-dose motor training induces expansion of cortical motor representations, strengthening of corticospinal projections, and reorganization of interhemispheric connectivity.[7]

The intensive dosage characteristic of HABIT (50-90 hours over 1-2 weeks) is designed to exceed critical thresholds for neuroplastic change. Evidence from constraint-induced therapy research suggests that approximately 60 hours of intensive practice may be necessary to induce measurable cortical reorganization and functional gains that persist beyond the training period.[1] HABIT protocols typically meet or exceed this threshold, providing sufficient practice density to drive neuroplastic adaptation. Task specificity is another critical neuroplasticity principle operationalized in HABIT. Neuroplastic changes are highly specific to the practiced movements and task contexts. By embedding practice within functional, goal-directed bimanual activities, HABIT promotes neuroplastic adaptations that directly support real-world hand use rather than isolated motor components. This task-specific approach is hypothesized to enhance transfer of training effects to daily life activities.[8]

The developmental timing of HABIT interventions is also informed by neuroplasticity principles. Early intervention during critical periods of brain development may capitalize on heightened neuroplastic potential in young children.[2,9] Recent trials have extended HABIT to infants as young as 6 months, targeting early developmental windows when neural circuits are maximally responsive to experience. The Araneda et al early HABIT-ILE trial demonstrated significant functional improvements in children aged 12–59 months, supporting the feasibility and efficacy of intensive training during early childhood.[9]

Clinical significance

The clinical significance of HABIT lies in its potential to address persistent functional limitations in bimanual coordination that are inadequately remediated by conventional rehabilitation approaches. For children with cerebral palsy, impaired bimanual hand use profoundly impacts independence in activities of daily living, including self-care, play, and academic tasks. Traditional therapy approaches often emphasize unimanual skill development or constraint-based paradigms that may not adequately address the coordinated bilateral control

required for most functional activities. HABIT offers a theoretically motivated, evidence-based alternative that directly targets bimanual coordination deficits. The intervention has demonstrated clinically meaningful improvements in standardized assessments of bimanual performance, including the AHA, which measures spontaneous use of the affected hand in bimanual tasks. Effect sizes for AHA improvements following HABIT interventions are typically moderate to large, with mean differences ranging from 5 to 7 AHA units exceeding the minimal clinically important difference of five units.[10]

Beyond standardized assessments, HABIT has demonstrated improvements in parent-reported functional goals and participation in daily activities.[9] The Canadian occupational performance measure (COPM), which captures individualized, family-centered goals, consistently shows significant improvements following HABIT interventions.[9] These goal-attainment outcomes are particularly clinically relevant, as they reflect meaningful changes in activities that families prioritize.[9]

For stroke populations, HABIT represents a promising approach to upper extremity rehabilitation that may complement or serve as an alternative to constraint-induced therapy.[3,8] The Meng et al trial demonstrated that HABIT delivered in the acute stroke phase produced superior motor recovery compared to conventional rehabilitation, with significant improvements in Fugl-Meyer assessment (FMA) and action research arm test (ARAT) scores.[3] These findings suggest that intensive bimanual training may be feasible and effective even in the early post-stroke period, potentially capitalizing on heightened neuroplastic potential during acute recovery phases.[3]

Over the last decade, multiple randomized controlled trials, feasibility studies, and study protocols have investigated the efficacy, feasibility, and mechanisms of HABIT across different populations and contexts. However, the evidence is heterogeneous in terms of population characteristics, intervention dosage, outcome measures, and delivery models. A scoping review is therefore appropriate to map the existing literature, summarize key findings, identify trends and gaps, and guide future research and clinical practice.

The aim of this scoping review is to systematically map and synthesize evidence from eight key studies examining HABIT and related bimanual intensive training approaches in children with cerebral palsy and adults after stroke.

The review focuses on intervention characteristics, outcome measures, effectiveness, feasibility, and emerging innovations such as neuromodulation and virtual reality. Additionally, this review provides comparative insights to highlight significant points relevant for dissertation discussion and future research planning.

LITERATURE REVIEW

Search strategy

This comprehensive literature review synthesized evidence from multiple systematic searches conducted across major scientific databases. The search strategy employed a multi-phase approach to ensure comprehensive coverage of HABIT effectiveness literature while specifically targeting eight key articles identified (Figure 1).

Phase 1: Comprehensive deep search

Initial searches were conducted in Google Scholar (60 papers across 3 targeted queries on HABIT in CP, stroke, and combined interventions), SciSpace Paper Search (300 papers across 3 queries on HABIT effectiveness, HABIT-ILE, and RCTs), SciSpace Full-Text Search (200 papers across 2 queries on HABIT in CP and stroke), and PubMed (20 papers on HABIT interventions). These searches yielded 177 unique papers after deduplication and relevance ranking.

Phase 2: Title-specific searches

Final targeted searches using exact article titles were conducted in Google Scholar (60 papers across 9 queries), SciSpace (23 papers across 6 queries), and PubMed (7 papers across 5 queries), resulting in 90 unique papers.

Search terms

Primary search terms included: hand-arm bimanual intensive therapy, HABIT, HABIT-ILE, bimanual training, cerebral palsy, stroke rehabilitation, intensive motor training, upper extremity rehabilitation, combined with population-specific terms (unilateral cerebral palsy, hemiplegic CP, bilateral cerebral palsy, acute stroke, chronic stroke) and intervention modifiers (tDCS, transcranial direct current stimulation, virtual reality, VR, home-based, telerehabilitation).

Selection criteria

This scoping review included randomized controlled trials, controlled clinical trials, and high-quality study protocols that investigated HABIT or HABIT-ILE. Eligible studies involved participants with neurological conditions, specifically cerebral palsy (unilateral or bilateral) or stroke (acute, subacute, or chronic), and implemented intensive bimanual training protocols defined as either a total dosage of at least 50 hours or a minimum of 2 hours per day for at least 5 consecutive days. Studies were required to report quantitative functional outcomes related to upper extremity performance, bimanual coordination, or activities of daily living. Only peer-reviewed full-text articles or preprints published in English were considered. Studies were excluded if they examined exclusively unimanual training approaches, such as constraint-induced

movement therapy without a bimanual component; were case reports or small case series involving fewer than 10 participants (unless specifically justified); failed to report quantitative outcome data; were limited to conference abstracts without accessible full texts; or investigated populations other than cerebral palsy or stroke (e.g., traumatic brain injury or multiple sclerosis) unless the intervention was directly relevant to HABIT mechanisms.

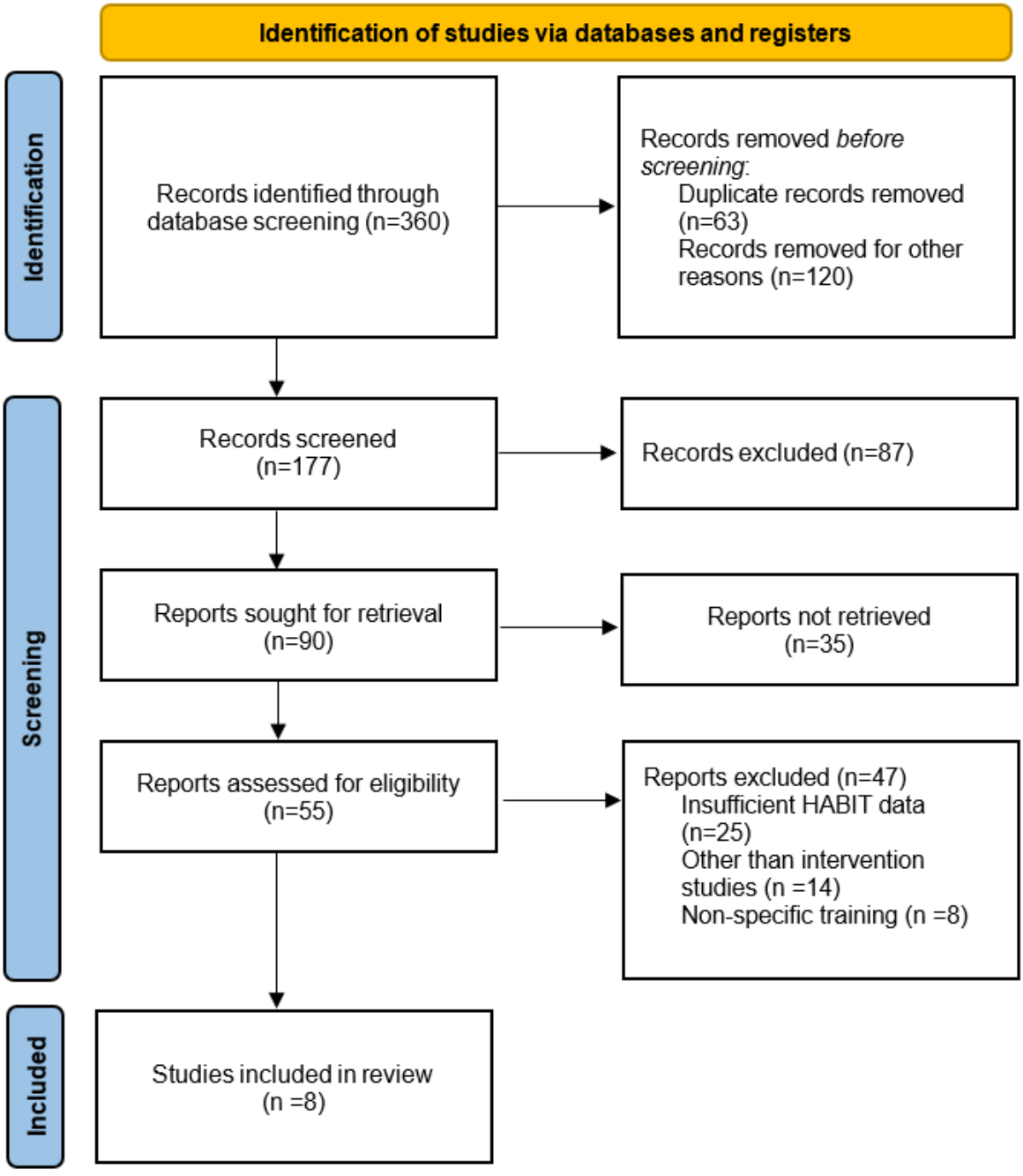

Figure 1: PRISMA 2020 flow diagram.

Quality assessment

Study quality was evaluated based on randomization procedures, blinding of assessors, sample size adequacy, intervention fidelity reporting, outcome measure validity, and completeness of statistical reporting. The top relevance-ranked papers from the combined search results formed primary evidence base for this review, supplemented by specific articles identified in user request. Risk of bias for each study is categorized as low, high/unclear based on Cochrane risk of bias tool for randomized controlled trials and Newcastle-Ottawa scale for cohort studies. Levels of evidence and modified McMaster results of methodology quality (Table 1).

Table 1: Risk of bias and quality assessment of included studies.

Study (author, year)	Randomization	Blinding	Sample size adequacy	Missing data	Overall risk of bias	Methodological quality
Gordon et al, 2007[1]	Adequate randomization; delayed treatment control	Single-blinded (assessor)	Small (n=20)	Minimal attrition	Some concerns (small sample, no participant blinding)	Moderate
Bleyenheuft et al, 2015[11]	Randomized; concealed allocation reported	Assessor-blinded	Small-moderate (n=24)	Low attrition	Some concerns (performance bias unavoidable)	Moderate
Araneda et al, 2024[2]	Matched-pairs RCT; strong allocation	Assessor-blinded; multisite	Adequate (n=49)	Low; ITT used	Low risk	High
Tournai et al, 2024[9]	Proper RCT design	Assessor-blinded	Moderate (n=46)	Minimal attrition	Low risk	High
Ferre et al, 2017[13]	Randomized	Assessor-blinded	Small (n=24)	Low attrition	Some concerns (home-based variability)	Moderate
Figueiredo et al, 2020[10]	Randomized controlled	Assessor-blinded	Moderate (n=41)	Low	Some concerns (no participant blinding; dosage imbalance)	Moderate-High
Meng et al, 2018[3]	Proper RCT; early allocation	Single-blinded	Large (n=128)	Minimal	Low risk	High
Manjunatha et al, 2024[16]	Randomized	Single-blinded	Small (n=30)	Not clearly reported	Some concerns (small sample; short duration)	Moderate

HABIT IN UNILATERAL CEREBRAL PALSY

Original HABIT randomized controlled trial

The seminal Gordon et al trial established proof-of-concept for HABIT in children with hemiplegic cerebral palsy.[1] This single-blinded randomized controlled trial enrolled 20 children (10 intervention, 10 delayed-treatment control) aged 3 years 6 months to 15 years 6 months with mild to moderate hand involvement. The intervention consisted of structured bimanual practice delivered 6 hours per day for 10 consecutive days, totalling 60 hours. Activities included play and functional tasks requiring coordinated bilateral hand use, such as stabilizing objects while manipulating them, opening containers, and playing board games.[1]

Primary outcomes included the AHA, accelerometry measuring involved extremity use, and caregiver surveys of hand use. Secondary measures assessed bimanual items from the Bruininks-Oseretsky test of motor proficiency and timing/simultaneity of a draw-opening task. Results demonstrated significant improvements in the intervention group across all outcome measures ($p<0.05$). AHA scores increased significantly, indicating improved spontaneous use of affected hand in bimanual activities. Accelerometry data confirmed increased involved extremity use during daily activities, corroborated by caregiver reports. Bimanual coordination items and simultaneity of bilateral movements also improved significantly.[1]

Gains were maintained at 1-month follow-up, suggesting short-term retention of training effects. The study established that intensive bimanual training could improve functional hand use in carefully selected children with hemiplegic CP, providing foundational evidence for subsequent HABIT research. However, limitations included small sample size, narrow eligibility criteria (excluding children with severe impairment), and short follow-up duration.[1]

HABIT-ILE: integration of lower extremities

Building on the original HABIT model, Bleyenheuft et al introduced HABIT-ILE (Hand and Arm bimanual intensive therapy including lower extremity), which simultaneously engages upper and lower extremities during intensive training. This randomized trial enrolled 24 children with unilateral spastic cerebral palsy, randomized to immediate HABIT-ILE or delayed treatment. The intervention delivered 90 hours over 10 days, incorporating activities requiring coordinated upper and lower extremity engagement.[11]

Primary outcomes were the AHA and six-minute walk test. Results showed significant improvements in both primary outcomes (AHA: $p<0.001$; 6MWT: $p=0.002$) and most secondary assessments following HABIT-ILE, but not during the conventional therapy control period. Notably, improvements were observed for both upper and lower extremity function, suggesting that simultaneous engagement of multiple limbs does not attenuate upper extremity gains.[11] This finding was further supported by

Saussez et al who retrospectively compared 86 children receiving either HABIT (n=42) or HABIT-ILE (n=44) and found similar upper extremity improvements in both groups, with HABIT-ILE showing additional benefits for activities of daily living involving lower extremities.[12]

Early HABIT-ILE in young children

The Araneda et al trial extended HABIT-ILE to young children aged 12-59 months, testing whether early intensive intervention could capitalize on heightened neuroplastic potential during critical developmental periods. This prospective, matched-pairs randomized clinical trial enrolled 50 children (49 analyzed) with spastic or dyskinetic unilateral CP across multiple European centers. The intervention delivered 50 hours of HABIT-ILE over 2 weeks, compared to usual motor activity in the control group.[2]

The primary outcome was the AHA, with secondary outcomes including gross motor function measure-66 (GMFM-66), pediatric evaluation of disability inventory-computer adaptive test (PEDI-CAT) daily activities domain, and COPM performance and satisfaction scores. Results demonstrated significant superiority of early HABIT-ILE across all outcomes from baseline to 3-month follow-up: AHA: adjusted mean difference 5.19 units (95% CI, 2.84-7.55; $p<0.001$), GMFM-66: mean difference 4.72 units (95% CI, 2.66-6.78), PEDI-CAT daily activities: mean difference 1.40 units (95% CI, 0.29-2.51), COPM performance: mean difference 3.62 units (95% CI, 2.91-4.32) and COPM satisfaction: mean difference 3.53 units (95% CI, 2.70-4.36).

These effect sizes exceeded minimal clinically important differences for the AHA (5 units) and COPM (2 points), indicating clinically meaningful improvements. The trial demonstrated feasibility and efficacy of intensive training in very young children, supporting early intervention approaches.[2]

Infant HABIT-ILE

Extending HABIT to even younger populations, Tournai et al conducted a randomized clinical trial of baby HABIT-ILE in infants aged 6-18 months with unilateral CP. This trial enrolled 48 infants (46 analyzed; 24 treatment, 22 control) and delivered 50 hours of baby HABIT-ILE over 2 weeks, compared to usual motor activities.[9]

The primary outcome was the mini-AHA with secondary outcomes including COPM, GMFM-66, and other motor/functional measures. Results showed significant improvement in mini-AHA favoring the treatment group ($p=0.008$; $\eta p^2=0.11$), with a mean difference of 7.4 units in the treatment group versus 1.9 units in controls. COPM performance and satisfaction scores also significantly favored treatment ($p<0.001$; $\eta p^2=0.35$ and 0.33, respectively). However, GMFM-66 improved in both groups with no significant interaction ($p=0.43$), suggesting that gross motor improvements may occur with usual care in this age group.

The trial demonstrated feasibility of delivering intensive training to infants and showed quantitative improvements in affected-hand use during bimanual tasks and parent-reported functional goals.

These findings support the potential for very early intervention to influence developmental trajectories of hand function.[9]

Home-based HABIT models

Recognizing barriers to intensive day-camp delivery, Ferre et al tested a caregiver-directed home-based intensive bimanual training model. This randomized trial enrolled 24 children (aged 2 years 6 months to 10 years 1 month) with unilateral spastic CP, randomized to home-based HABIT (H-HABIT) or lower-limb functional intensive training control (LIFT-control). Both groups performed activities 2 hours per day, 5 days per week, for 9 weeks, totalling 90 hours. The intervention was delivered at home, directed by caregivers, and supervised remotely via telerehabilitation.[13]

H-HABIT showed greater improvement on the box and blocks test compared to LIFT-control, indicating improved dexterity. H-HABIT also demonstrated significant improvement in COPM-Performance compared to control. However, no improvement was observed on the Assisting Hand Assessment, suggesting that home-based delivery may not replicate the bimanual performance gains observed in intensive day-camp models. Both groups showed equal improvement in COPM-Satisfaction. The study concluded that home-based HABIT improved dexterity and functional goal attainment but may require refinement to enhance bimanual coordination outcomes.[13]

HABIT IN BILATERAL CEREBRAL PALSY

HABIT for daily functioning

Figueiredo et al conducted a randomized controlled trial specifically examining HABIT effectiveness in children with bilateral cerebral palsy. This trial enrolled 41 children aged 4-16 years classified as manual ability classification system (MACS) levels I-III, randomized to HABIT (n=21) or customary care (n=20). The HABIT group received 90 hours delivered in a day-camp model, while the control group received approximately 4.5 hours of customary care.[10]

Primary outcomes focused on daily functioning, assessed via the PEDI and COPM. Secondary outcomes included unimanual dexterity (Jebsen-Taylor test, box and blocks test) and bimanual performance (Both hands assessment).

Results demonstrated that HABIT produced significantly greater improvements in daily functioning compared to

customary care: COPM performance: $\chi^2(1)=9.50$, $p<0.01$, COPM satisfaction: $\chi^2(1)=5.07$, $p<0.05$, PEDI functional skills: $\chi^2(1)=6.81$, $p<0.01$ and PEDI caregiver assistance: $\chi^2(1)=6.23$, $p<0.05$. HABIT also improved dominant-hand dexterity on the box and blocks test ($\chi^2(1)=3.99$, $p<0.05$). However, no group effect was observed for bimanual performance on the both hands assessment or nondominant-hand dexterity. The authors concluded that HABIT improved daily functioning and dominant-hand dexterity in children with bilateral CP, though bimanual performance measures did not show significant group differences.[10]

Multisite HABIT-ILE for bilateral CP

Sakzewski et al reported results from a large multisite randomized controlled trial of HABIT-ILE in children with bilateral cerebral palsy. This trial enrolled 90 participants (HABIT-ILE n=46, usual care n=44) with a mean age of 10.4 (SD 3.0) years and GMFCS levels II (n=32), III (n=31), and IV (n=27). The intervention delivered HABIT-ILE in an intensive format, compared to usual care.[14]

Results demonstrated that HABIT-ILE led to superior changes in goal performance and self-care compared to usual care. The study included children across a broad range of functional severity, demonstrating applicability of HABIT-ILE to children with more significant motor impairments (GMFCS IV). Specific effect sizes and detailed outcome data were not fully available in the extracted metadata, but the trial represents the largest HABIT-ILE study in bilateral CP to date.[14]

Preschool HABIT-ILE protocol

Recognizing the need for age-appropriate HABIT adaptations for younger children with bilateral CP, Sakzewski et al published a protocol for a randomized controlled trial of preschool HABIT-ILE. This protocol targets 60 children aged 2-5 years with bilateral CP classified as GMFCS II-IV.

The intervention delivers 3 hours per day for 10 days (30 hours) in a group-based format with 4-6 children per group, supplemented by a written home program for an additional 10 hours, targeting a total dose of 40 hours.[15]

The primary outcome was the Peabody developmental motor scales-second edition, with secondary outcomes including GMFM-66, both hands assessment, PEDI-CAT, COPM, ACTIVLIM-CP, executive function measures, accelerometry, and quality of life measures.

This protocol represents an important adaptation of HABIT-ILE for preschool-aged children with bilateral CP, addressing a gap in evidence for this population.[15]

HABIT IN STROKE POPULATIONS

Acute stroke HABIT

Meng et al conducted a ground-breaking randomized controlled trial repurposing HABIT for acute stroke rehabilitation. This single-blind RCT enrolled 128 patients with acute stroke (aged 45-75 years) who had stable vital signs, Glasgow coma scale score >8, and upper-limb muscle strength exceeding level 2 on the medical research council scale.

Patients were randomized to HABIT or conventional rehabilitation program (CRP) within 48 hours of stroke onset.[3]

The HABIT intervention was modified for the acute stroke context, delivering 1-hour sessions twice per day, 5 days per week, for 2 consecutive weeks, totalling 20 hours. This dosage was substantially lower than pediatric HABIT protocols (60-90 hours) but represented intensive training relative to conventional acute stroke rehabilitation. The modified HABIT approach reduced primary bimanual practice time from 6 hours/day to 2 hours/day by omitting video games, card games, and manipulative tasks, focusing on functional bimanual activities appropriate for acute stroke patients.

Primary outcomes were the FMA and ARAT. Secondary outcomes included neurophysiologic measures: motor-evoked potential amplitude (AMP), resting motor threshold (RMT), and central motor conduction time (CMCT).

After 2 weeks, the HABIT group demonstrated significantly superior outcomes compared to CRP: FMA: 51.7±6.44 vs. 43.5±5.6 ($p<0.001$), ARAT: 34.5±6.2 vs. 33.3±6.3 ($p=0.022$) and AMP: 1.1±0.1 vs. 1.0±0.1 ($p<0.001$).[3]

CMCT and RMT showed no significant differences between groups. The significant improvements in FMA and ARAT, coupled with increased motor-evoked potential amplitude, suggest that HABIT delivered in the acute stroke phase can enhance motor recovery and may facilitate corticospinal excitability.

This trial provided the first randomized evidence that intensive bimanual training is feasible and effective in acute stroke, potentially capitalizing on heightened neuroplastic potential during early recovery phases.[3]

Additional stroke HABIT evidence

Manjunatha et al conducted a smaller prospective randomized controlled trial examining HABIT effectiveness in acute stroke.[16] This single-blinded trial enrolled 30 acute stroke subjects allocated to HABIT (1 hour daily for 5 sessions with follow-up to 3 weeks) or conventional physiotherapy.

Hand dexterity was measured by the nine-hole peg test (NHPT) and arm motor function by the Fugl-Meyer upper extremity scale (FMUE).

Results showed that HABIT therapy was moderately effective for NHPT performance ($t=4.10$, $p<0.006$) and highly effective for FMUE performance ($t=3.96$, $p<0.011$) compared to conventional physiotherapy.

The study concluded that HABIT is an effective intervention to improve both hand dexterity and arm motor function in acute stroke patients. While this trial had a smaller sample and shorter intervention duration than Meng et al it corroborated the feasibility and effectiveness of HABIT in acute stroke rehabilitation.[3,16]

Table 2: Summary of results of HABIT across neurological conditions.

Study (author, year)	Study design	Population and age (in years)	Neurological condition	Habit type and dose	Outcome measures	Key results	Clinical implication
Gordon et al, 2007[1]	Single-blinded RCT	n=20; 3.5-15.5	Unilateral CP	HABIT; 60 h/10 days	AHA, accelerometry, BOTMP	Significant improvement in AHA, hand use, coordination	Proof of concept for unilateral CP
Bleyenheuft et al, 2015[11]	RCT	n=24; children	Unilateral CP	HABIT-ILE; 90 h/10 days	AHA, 6MWT	Significant UE and LE improvements	UE gains not diluted by LE training
Araneda et al, 2024[2]	Multisite RCT	n=49; 12-59 months	Unilateral CP	Early HABIT-ILE; 50 h/2 weeks	AHA, GMFM-66, PEDI-CAT, COPM	Clinically meaningful gains across all outcomes	Strong evidence for early intervention
Tournai et al, 2024[9]	RCT	n=46; 6-18 months	Unilateral CP (infants)	Baby HABIT-ILE; 50 h/2 weeks	Mini-AHA, COPM	Significant Mini-AHA and COPM gains	Feasible and effective in infancy
Ferre et al, 2017[13]	RCT	n=24; 2.5-10	Unilateral CP	Home HABIT; 90 h/9 weeks	Box and Blocks, COPM	Improved dexterity; no AHA change	Home model less effective for bimanual use
Figueiredo et al, 2020[10]	RCT	n=41; 4-16	Bilateral CP	HABIT; 90 h	PEDI, COPM, BBT	Improved daily functioning	Best for participation goals
Meng et al, 2018[3]	Single-blind RCT	n=128; adults	Acute stroke	Modified HABIT; 20 h	FMA, ARAT, MEP	Superior motor recovery vs control	Effective in early stroke
Manjunatha et al, 2024[16]	RCT	n=30; adults	Acute stroke	HABIT; 5 h	NHPT, FMUE	Moderate-high effectiveness	Supports acute stroke use

DISCUSSION

The present scoping review synthesized evidence on the effectiveness of HABIT across neurological populations, with particular emphasis on cerebral palsy and stroke. Overall, the literature demonstrates a clear progression in methodological rigor, population diversity, and intervention innovation. Early proof-of-concept trials established the feasibility and foundational efficacy of HABIT, while more recent multisite randomized controlled trials have strengthened the evidence base by employing larger samples, improved randomization procedures, and standardized outcome measures. Collectively, the findings support HABIT as an effective, task-specific, and neuroplasticity-driven intervention for improving upper limb function and participation in individuals with neurological impairments.

From a methodological perspective, HABIT research has evolved substantially over time. The initial trial by Gordon et al though limited by a small sample size and delayed-treatment control design, played a critical role in establishing proof of concept and informing subsequent trials.[1] Later studies, including the early HABIT-ILE trial by Araneda et al and large stroke trials such as Meng et al demonstrated improved internal validity through adequate sample sizes, matched-pairs randomization, and multisite recruitment.[2,3] Despite these advancements, blinding of participants and therapists remains a consistent challenge due to the behavioural nature of the intervention. Most studies mitigated this limitation through blinded outcome assessment and, in some cases, objective measures such as kinematics or neurophysiological outcomes. Nevertheless, future trials would benefit from greater use of active, dosage-matched control groups to isolate the specific effects of bimanual training from nonspecific intensive practice effects.[5]

Participant selection criteria across HABIT trials reveal a gradual expansion in age range, severity, and diagnostic

inclusion. Early trials primarily targeted school-aged children with mild-to-moderate unilateral cerebral palsy, thereby enhancing internal validity but limiting generalizability. More recent studies have extended HABIT to preschool children, infants, and children with bilateral cerebral palsy, reflecting growing recognition of early neuroplastic potential.[7,8] Trials in infants and very young children demonstrate feasibility and clinically meaningful improvements but also highlight challenges related to outcome measurement sensitivity and developmental variability. While inclusion criteria have broadened, many studies still exclude individuals with severe cognitive impairment, uncontrolled seizures, or recent medical interventions, which may limit applicability to real-world clinical populations. These findings underscore the need for future research examining moderators of treatment response, such as age, severity, lesion characteristics, and baseline function.[10,11]

Intervention protocols across studies demonstrate substantial variability in dosage, intensity, and duration, which complicates direct comparison and determination of optimal dosing. Paediatric HABIT protocols commonly deliver between 50 and 90 hours of training over one to two weeks, consistent with motor learning and neuroplasticity principles favouring high-intensity, massed practice. In contrast, stroke-related HABIT trials typically employ lower total dosages, reflecting differences in medical stability and rehabilitation contexts. Although intensive dosing appears effective, no studies to date have systematically examined dose–response relationships within the same population. As a result, the minimum effective dose and the added value of higher dosages remain unclear. Addressing this gap through dose-comparison trials is critical for improving efficiency and reducing burden on families and healthcare systems.[12,16]

Delivery models represent another important area of variation and innovation within HABIT research. Most efficacy studies have employed intensive day-camp formats, which ensure intervention fidelity and therapist supervision but require substantial organizational resources. Home-based and hybrid delivery models have emerged as potential solutions to accessibility barriers. While home-based HABIT has demonstrated feasibility and some functional benefits, it has not consistently replicated the magnitude of bimanual performance gains observed in supervised camp-based interventions.[15] Hybrid models combining supervised training with parent-coached home practice may represent a promising compromise, balancing efficacy with feasibility. However, these models rely heavily on caregiver capacity and require further validation through non-inferiority and cost-effectiveness analyses.

Outcome measurement in HABIT trials spans impairment, activity, and participation domains, consistent with the international classification of functioning, disability and health framework. The assisting hand assessment remains the most widely used and sensitive measure of bimanual performance in unilateral cerebral palsy, with consistent evidence of clinically meaningful improvements following HABIT.[12,10] In contrast, assessment of bimanual performance in bilateral cerebral palsy remains challenging, as measures such as the both hands assessment may lack sensitivity to change. Functional and participation-level measures, including the COPM and paediatric evaluation of disability inventory, consistently demonstrate significant improvements, highlighting HABIT's real-world relevance. However, the individualized nature of some measures complicates cross-study synthesis and underscores the need for standardized outcome sets.[11]

Across neurological conditions, HABIT demonstrates condition-specific patterns of effectiveness. In unilateral cerebral palsy, evidence consistently supports moderate to large improvements in bimanual hand use, functional goals, and daily activities, with effect sizes exceeding minimal clinically important differences. In bilateral cerebral palsy, evidence suggests meaningful improvements in daily functioning and dexterity, though bimanual coordination outcomes are less consistent. In stroke populations, HABIT has demonstrated significant improvements in upper extremity motor impairment and functional capacity, particularly when delivered in the acute phase. Neurophysiological findings from stroke trials further suggest that HABIT may enhance corticospinal excitability, providing mechanistic support for observed functional gains.[10]

Innovations such as HABIT-ILE, neuromodulation augmentation, and technology-enhanced delivery models represent important directions for future development. The integration of lower extremity training within HABIT-ILE has demonstrated that simultaneous engagement of upper and lower limbs does not dilute upper limb gains and may enhance overall functional relevance. Preliminary protocols exploring transcranial direct current stimulation and vagus nerve stimulation aim to potentiate training-induced neuroplasticity, though definitive efficacy data are not yet available. Virtual reality and device-mediated HABIT show promise for improving motivation, scalability, and therapist efficiency, but require validation in larger controlled trials to ensure transfer of gains to real-world activities.[11]

From a clinical perspective, the evidence supports HABIT as an effective intervention for individuals with neurological conditions who have goals related to bimanual coordination and functional hand use.[2] Children with unilateral cerebral palsy and mild-to-moderate impairment appear to derive the greatest benefit, though emerging evidence supports use in younger children, bilateral cerebral palsy, and acute stroke. Appropriate patient selection, family support, and organizational capacity are critical determinants of successful implementation. Intensive dosing over short durations appears central to efficacy, emphasizing the need for

healthcare systems to accommodate non-traditional rehabilitation models.[4]

Despite its strengths, the HABIT literature is characterized by several limitations. Sample sizes in many trials remain modest, control groups are often suboptimal, and long-term follow-up data are scarce. Heterogeneity in populations, interventions, and outcome measures complicates synthesis and limits definitive conclusions regarding optimal protocols. Additionally, socioeconomic, cultural, and healthcare system factors influencing access and adherence are rarely examined. Addressing these limitations through larger, multicentre trials with longer follow-up and standardized outcomes is essential for advancing the field.

CONCLUSION

This scoping review demonstrates that HABIT is a versatile and effective intervention for improving upper extremity function in children with cerebral palsy and adults after stroke. The adaptability of HABIT across age groups, severity levels, and delivery modes underscores its clinical relevance. Emerging innovations such as neuromodulation, early intervention models, and virtual reality-based delivery represent important future directions. Further high-quality trials with standardized outcomes and long-term follow-up are required to optimize clinical translation.

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