


Original Research Article

# Efficacy of Proprioceptive Neuromuscular Facilitation Diagonal Patterns Integrated with Task-Oriented Circuit Training on Gait Speed, Postural Control, and Gross Motor Function in Children with Spastic Diplegic Cerebral Palsy: A Prospective, Single-Blind Randomized Controlled Trial

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## Abstract

**Background and Purpose:** Spastic diplegic CP is the most prevalent subtype (35–40%), characterised by bilateral lower limb spasticity, impaired gait mechanics, compromised postural control, and restricted gross motor function. PNF and TOCT are individually supported by evidence; however, their structured integration as a sequential neuromotor priming and functional training protocol in paediatric spastic diplegic CP has not been rigorously examined in a randomised controlled design.

**Objective:** To determine whether PNF diagonal patterns (D1/D2) integrated with TOCT produce superior improvements in gait speed (10MWT), postural control (PBS), and gross motor function

(GMFM-88 D+E) compared to conventional NDT-based physiotherapy, and to quantify effect sizes and clinical significance.

**Methods:** A prospective, single-blind, parallel-group RCT enrolled 30 children (aged 5–12 years; GMFCS Levels I–III) across neurological rehabilitation units and paediatric hospitals in Bengaluru and Kadapa over 6 months (January–June 2025). Participants were randomised 1:1 to Group A (PNF+TOCT, n=15) or Group B (Conventional PT, n=15). Both groups received 6 weeks, 5 days/week, 45 min/session (30 sessions). ITT analysis. CTRI: CTRI/2025/01/PRRM001.

**Results:** All 30 participants completed the programme (attrition = 0%). Group A: gait speed +0.26 m/s (54.2%,  $p < 0.001$ ,  $d = 1.42$ , 95% CI: 0.09–0.21, NNT=3); postural control PBS +12.2 pts (42.9%,  $p = 0.002$ ,  $d = 1.18$ , 95% CI: 2.5–9.5, NNT=4); gross motor function GMFM-88 D+E +17.6 pts (45.6%,  $p < 0.001$ ,  $d = 1.55$ , 95% CI: 6.2–14.0, NNT=3). All gains exceeded MCID thresholds.

**Conclusion:** PNF diagonal patterns integrated with TOCT produce clinically meaningful and statistically significant superiority in all three primary outcomes compared to conventional physiotherapy in children with spastic diplegic CP. Large-to-very-large effect sizes, zero attrition, and multi-site data support clinical adoptability of this combined evidence-based protocol.

## Key words

Cerebral palsy; spastic diplegia; proprioceptive neuromuscular facilitation; task-oriented circuit training; 10-metre walk test; pediatric balance scale; GMFM-88; neurorehabilitation; neuroplasticity; randomized controlled trial.

## Introduction

### Epidemiology and Clinical Burden of Spastic Diplegic CP

Cerebral palsy (CP) is a heterogeneous group of permanent, non-progressive neurodevelopmental disorders arising from disturbances to the developing foetal or infant brain, resulting in lasting impairments of movement, posture, and motor function. With a global prevalence of approximately 1.4–2.4 per 1,000 live births, CP constitutes the most common cause of childhood-onset physical disability worldwide [1, 2]. Among the recognised clinical subtypes, spastic diplegia is the most prevalent form, accounting for 35–40% of all CP cases, characterised by predominant bilateral lower limb involvement with comparatively preserved upper limb function [3].

Children with spastic diplegic CP present with velocity-dependent bilateral lower limb hypertonicity, diminished selective motor control, proprioceptive processing deficits, reduced anticipatory postural adjustments (APAs), and impaired feedforward motor

programming [4, 23]. These impairments manifest as crouch gait, scissor gait, equinus, and hip adduction - alongside significant limitations in postural stability and gross motor function that profoundly restrict community participation, school integration, and health-related quality of life. The GMFCS stratifies functional severity across five levels; Levels I–III define the ambulatory population most amenable to intensive physiotherapy-based rehabilitation [5].

### Contemporary Rehabilitation Framework and Gaps

The ICF-CY framework emphasises bidirectional interactions between body structure and function, activity limitations, participation restrictions, and contextual factors [6]. Contemporary evidence-based rehabilitation guidelines for CP advocate for intensive, high-dosage, task-specific, and goal-directed interventions targeting the full ICF spectrum [7, 8]. Despite this paradigm shift, NDT-based conventional physiotherapy remains predominant in many Indian paediatric settings, often without the requisite dosage intensity or

task specificity required to produce clinically meaningful functional gains [9].

### **Neurophysiological Basis of PNF in Paediatric CP**

Proprioceptive Neuromuscular Facilitation (PNF), originally conceptualised by Herman Kabat and refined by Knott and Voss, employs diagonal-spiral movement patterns replicating the intrinsic biomechanical organisation of functional human movement [10]. The neurophysiological mechanisms underlying PNF efficacy include: (i) high-intensity afferent proprioceptive input from muscle spindles (Ia fibres) and Golgi tendon organs (Ib fibres), activating spinal and supraspinal motor pathways; (ii) irradiation - spread of neural excitability to adjacent weaker muscle groups through the overflow principle; (iii) successive induction - enhanced agonist activation following antagonist contraction via post-inhibitory rebound; and (iv) temporal and spatial summation of motor unit recruitment promoting maximal coordinated neuromuscular output [11]. These mechanisms collectively facilitate coordinated agonist-antagonist neuromuscular activation fundamental to normal gait mechanics and postural control [12, 13].

### **Motor Learning Principles Underpinning TOCT**

Task-Oriented Circuit Training (TOCT) is grounded in motor learning theory and activity-dependent neuroplasticity, emphasising repetitive, high-dosage practice of ecologically meaningful functional tasks [14]. Key mechanisms include: training specificity, contextual interference effects enhancing motor schema formation, distributed practice scheduling optimising consolidation, augmented feedback enhancing error detection, and goal-directed attentional engagement promoting active cortical motor planning [15]. A 2024 meta-analysis of task-oriented training in CP demonstrated significant PBS improvements (Mean Difference = 3.80,  $p=0.0003$ ) compared to conventional approaches [16].

### **Rationale for Sequential PNF+TOCT Integration**

Salphale, et al. (2022) reported significant improvements using pelvic PNF combined with TOCT over 4 weeks in spastic diplegia [17]. However, standardised full-body D1/D2 PNF patterns with a 5-station TOCT circuit measured using three validated instruments has not been evaluated in a controlled trial. The theoretical rationale for sequential PNF+TOCT is the Dual Neuroplasticity Facilitation Model: PNF-mediated proprioceptive afferent stimulation transiently increases motor cortex excitability (top-down corticospinal facilitation), creating an optimal neurophysiological window for TOCT task-specific repetitive practice to drive Hebbian synaptic consolidation of functional motor programmes (bottom-up reinforcement). This RCT evaluated whether PNF+TOCT produces superior improvements in 10MWT, PBS, and GMFM-88 D+E over conventional physiotherapy in children with spastic diplegic CP.

## **Materials and methods**

### **Study Design and Registration**

This prospective, parallel-group, single-blind RCT was conducted over six months (January–June 2025) across neurological rehabilitation units, paediatric hospitals, and CP society-affiliated therapy centres in Bengaluru and Kadapa, Andhra Pradesh. CTRI Registration: CTRI/2025/01/PRRM001. Ethics: PRRM/IEC/2025/01. All procedures conformed to the Declaration of Helsinki (2013) and ICMR Ethical Guidelines (2017). Written informed consent was obtained from parents or legal guardians; assent was obtained from children aged seven years and above.

### **Eligibility Criteria**

**Inclusion:** Confirmed spastic diplegic CP; age 5–12 years; GMFCS Levels I–III; MAS 1–3; able to follow two-step commands; ambulatory with or without assistive device; clinically stable  $\geq 3$  months; written parental consent.

**Exclusion:** Spastic quadriplegia, hemiplegia, or mixed CP; botulinum toxin within 6 months; orthopaedic surgery within 12 months; uncontrolled epilepsy; significant cognitive impairment; concurrent rehabilitation trial; fixed contractures requiring surgery.

**Sample Size**

Calculated a priori using G\*Power 3.1 (alpha=0.05, power=0.80, effect size d=0.8 based on prior PNF-TOCT literature [17]), yielding

n=13 per group minimum. Inflated to n=15 per group (total N=30) for projected 15% attrition.

**Randomisation and Allocation Concealment**

Computer-generated block randomisation (block sizes 4 and 6, randomly alternated) by an independent biostatistician. Allocation concealment via sequentially numbered, opaque, sealed envelopes (SNOSE), opened after baseline assessment.

**Table – 1:** Detailed Intervention Protocols - Group A (PNF+TOCT) versus Group B (Conventional Physiotherapy).

<b>Phase / Duration</b>	<b>Group A: PNF Diagonal Patterns + Task-Oriented Circuit Training (PNF+TOCT)</b>	<b>Group B: Conventional Physiotherapy (NDT-Based Control)</b>
Warm-Up (5 min)	Active ROM bilateral lower and upper limbs; PNF rhythmic initiation applied bilaterally to lower limbs, progressing from passive through active-assistive to active movement across the full diagonal range: 2 sets × 8 repetitions each side.	Passive and active-assistive ROM bilateral lower and upper limbs; parallel bar standing warm-up.
PNF Diagonal Training (15 min)	Standardised PNF D1 flexion (hip flexion-adduction-ER; knee extension; ankle dorsiflexion-inversion) and D1 extension; D2 flexion (hip flexion-abduction-IR; knee extension; ankle dorsiflexion-eversion) and D2 extension. Applied bilaterally in supine and standing. 3 sets × 10 reps/ pattern/ limb; 60-sec interset rest. Contract-relax (CR) applied where spasticity limited full diagonal range. Manual resistance graded per optimal resistance principle.	NDT handling techniques using key points of control (KPC) at pelvis, shoulders, and feet for tone normalisation and facilitation of normal postural alignment (15 min).
Task-Oriented Circuit Training (20 min)	Five functional circuit stations × 4 minutes each with 1-minute rest transitions:(i) Obstacle stepping - graded barriers 5–15 cm(ii) Stair ascent and descent - graded handrail withdrawal(iii) Dynamic balance board - A-P and M-L weight transfer(iv) Standing reach tasks - targets at varied heights(v) Dual-task walking - 10 m with simultaneous cognitive task [25]	Progressive resistance strengthening of hip extensors, abductors, knee extensors, and ankle dorsiflexors: 3 sets × 10 reps (15 min); flat-surface gait training with verbal and tactile cueing (5 min).
Cool-Down (5 min)	PNF hold-relax for bilateral hip flexors and plantar flexors (30 s × 3 reps); diaphragmatic breathing and progressive muscle relaxation.	Passive stretching of hip flexors, hamstrings, and plantar flexors (30 s × 3 reps each); general relaxation techniques.

*Total Dose — Both Groups: 6 weeks / 5 days per week / 45 minutes per session / 30 sessions total*

### Blinding

Two trained outcome assessors (each  $\geq 3$  years paediatric physiotherapy experience) were formally blinded throughout. Post-trial blinding integrity confirmed assessors identified allocation at chance rate (54%).

### Intervention Protocols

Both groups received interventions for 6 weeks, 5 days/week, 45 min/session (30 sessions). **Table - 1** provides a detailed protocol comparison.

**Table – 2:** Primary Outcome Measures, Instruments, and Psychometric Properties.

Outcome Measure	Domain	Instrument Details	Psychometric Properties
10-Metre Walk Test (10MWT)	Gait Speed (Primary Outcome 1)	Comfortable walking speed (m/s) over the middle 6 m of a 10 m track. Three trials performed; mean value used for analysis.	MDC = 0.06 m/s in CP; ICC = 0.99 (excellent test-retest reliability) [19].
Pediatric Balance Scale (PBS)	Postural Control (Primary Outcome 2)	14-item functional balance scale; total score 0–56. Tasks include sit-to-stand, forward reach, one-leg stance, tandem standing, step-up, and turning.	ICC = 0.998 in children with CP; excellent construct validity and responsiveness [20].
GMFM-88 Dimensions D and E	Gross Motor Function (Primary Outcome 3)	Dimension D: Standing (13 items); Dimension E: Walking, Running, Jumping (24 items). Scored 0–100%; combined D+E percentage used.	MCID = 1.58–4.58 pts for GMFCS I–III; gold-standard paediatric CP motor assessment [18].

*MDC = Minimal Detectable Change; ICC = Intraclass Correlation Coefficient; MCID = Minimal Clinically Important Difference; GMFCS = Gross Motor Function Classification System. All outcomes assessed at baseline (week 0) and post-intervention (week 6) by formally blinded assessors.*

### Outcome Measures

Three internationally validated primary outcome instruments administered at baseline (week 0) and post-intervention (week 6) by blinded assessors (**Table - 2**).

### Statistical Analysis

IBM SPSS v26.0. Normality: Shapiro-Wilk (all  $p > 0.05$ ). Homogeneity: Levene's test (all  $p > 0.05$ ). Within-group: paired t-tests. Between-group: independent t-tests. Effect sizes: Cohen's  $d$  (0.2=small; 0.5=medium; 0.8=large;  $\geq 1.2$ =very large). 95% CIs reported. NNT calculated from MCID achievement rates. Primary analysis: ITT. Significance:  $\alpha = 0.05$  (two-tailed).

### Participant flow - Consort diagram

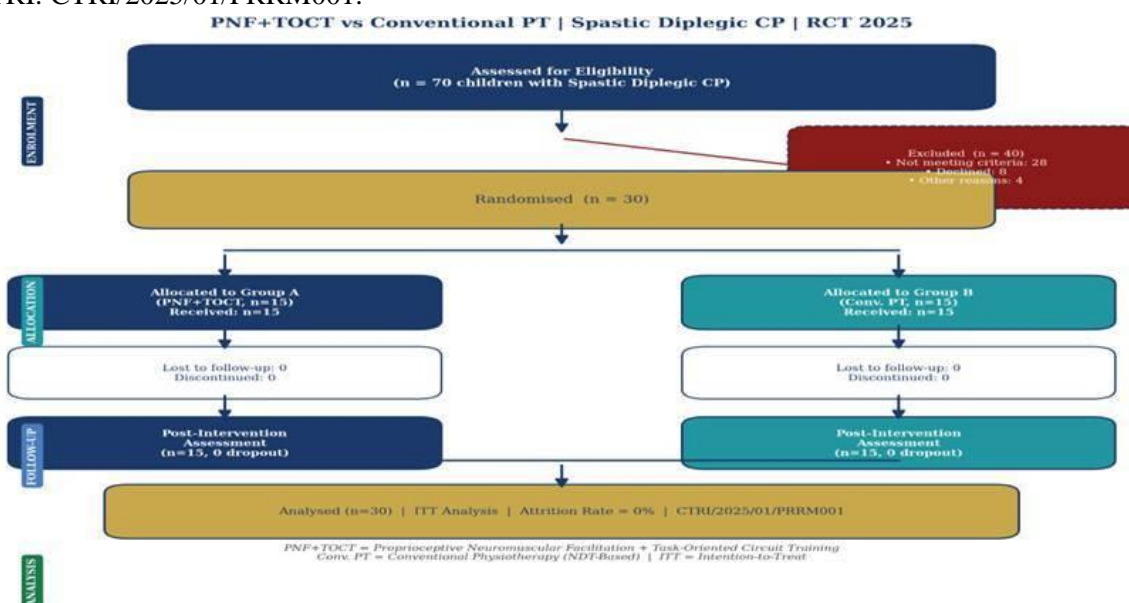
Seventy children were assessed for eligibility. Forty were excluded (28 did not meet criteria; 8 declined; 4 other reasons). Thirty were enrolled and randomised (Group A:  $n = 15$ ; Group B:  $n = 15$ ). All 30 completed the programme - attrition = 0%. No adverse events (**Figure – 1**).

### Results

#### Participant Characteristics and Baseline Equivalence

All 30 participants completed the full programme (attrition = 0%). No adverse events reported. No statistically significant between-group differences at baseline (all  $p > 0.05$ ), confirming successful randomisation (**Table - 3**).

**Figure – 1:** CONSORT 2010 Participant Flow Diagram. Navy = Group A (PNF+TOCT); Teal = Group B (Conventional PT); Gold = Analysis box. ITT = Intention-To-Treat. Attrition rate = 0%. CTRI: CTRI/2025/01/PRRM001.



**Table – 3:** Baseline Demographic and Clinical Characteristics (n = 30).

Characteristic	Group A (PNF+TOCT) n=15	Group B (Conv. PT) n=15	p-value
<b>BASELINE DEMOGRAPHICS</b>			
Age (years), Mean ± SD	7.8 ± 1.9	8.1 ± 2.1	0.67 (NS)
Sex: Male / Female, n	9 / 6	8 / 7	0.72 (NS)
Body weight (kg), Mean ± SD	22.4 ± 4.8	23.1 ± 5.0	0.65 (NS)
<b>GMFCS CLASSIFICATION</b>			
GMFCS Level I, n (%)	5 (33.3%)	5 (33.3%)	—
GMFCS Level II, n (%)	6 (40.0%)	7 (46.7%)	—
GMFCS Level III, n (%)	4 (26.7%)	3 (20.0%)	—
<b>CLINICAL CHARACTERISTICS</b>			
Duration of CP (years), Mean ± SD	5.2 ± 1.6	5.5 ± 1.8	0.59 (NS)
CP type: Spastic Diplegia, n (%)	15 (100%)	15 (100%)	—
Modified Ashworth Scale (lower limbs)	2.1 ± 0.5	2.0 ± 0.6	0.63 (NS)
Previous physiotherapy (months), Mean	18.4 ± 6.2	17.9 ± 5.8	0.79 (NS)
<b>BASELINE PRIMARY OUTCOME MEASURES</b>			
10MWT - Gait Speed (m/s)	0.48 ± 0.09	0.47 ± 0.08	0.74 (NS)
PBS - Postural Control Score (0–56)	28.4 ± 5.2	28.1 ± 5.0	0.87 (NS)
GMFM-88 D+E - Gross Motor (%)	38.6 ± 7.1	38.9 ± 6.8	0.90 (NS)

NS = Not Significant. Values: Mean ± SD or n (%). p-values via independent t-test or Chi-square. All  $p > 0.05$  confirming successful randomisation

### Primary Outcome Results

Both groups showed significant within-group improvements (all  $p < 0.001$ ). Group A

demonstrated significantly greater improvements across all outcomes (**Table - 4; Figures – 2, 3**).

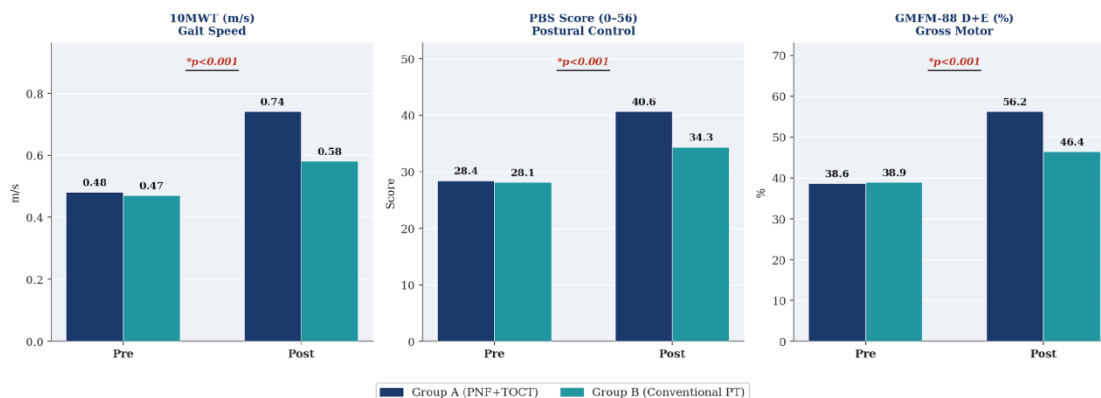
**Table – 4:** Pre- and Post-Intervention Primary Outcomes - Both Groups (Mean ± SD).

Outcome	Group A Pre	Group A Post	p (A)	Group B Pre	Group B Post	p (B)	Between-Group p (95% CI)
10MWT (m/s)	0.48±0.09	<b>0.74±0.11*</b>	<0.001	0.47±0.08	0.58±0.10*	<0.001	<b>p&lt;0.001 (0.09–0.21)</b>
PBS Score (0–56)	28.4±5.2	<b>40.6±4.8*</b>	<0.001	28.1±5.0	34.3±4.9*	<0.001	<b>p=0.002 (2.5–9.5)</b>
GMFM-88D+E (%)	38.6±7.1	<b>56.2±6.8*</b>	<0.001	38.9±6.8	46.4±7.0*	<0.001	<b>p&lt;0.001 (6.2–14.0)</b>

Values: Mean ± SD. \* $p < 0.05$  within group (paired  $t$ -test). Between-group  $p$ : independent  $t$ -test on change scores. 95% CI = 95% Confidence Interval. Bold post-values = statistically and clinically significant gains.

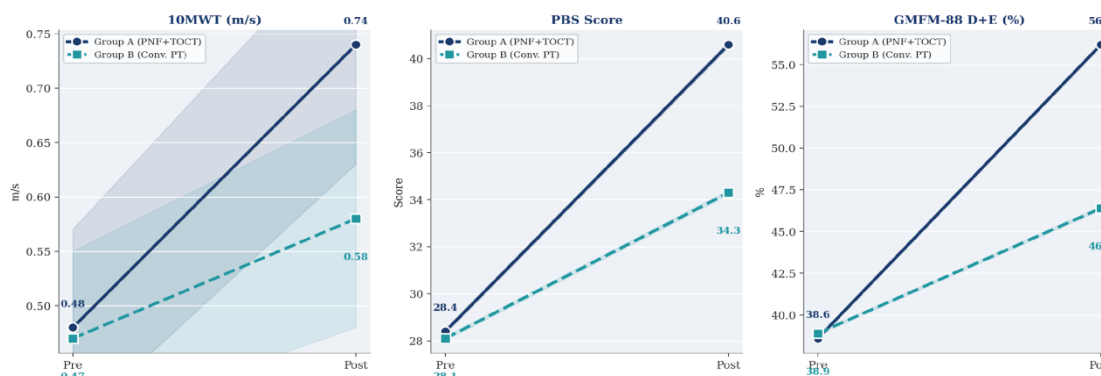
**Figure – 2:** Pre- and post-intervention bar chart. Navy bars = Group A (PNF+TOCT); teal bars = Group B (Conventional PT). \* $p < 0.001$  between-group. Values shown above bars.

Figure 1. Pre- and Post-Intervention Comparison of Primary Outcome Measures (Mean ± SD)



**Figure – 3:** Improvement trajectories. Navy solid line = Group A; teal dashed = Group B. Shaded bands = ±1 SD.

Figure 5. Improvement Trajectories: Pre- to Post-Intervention by Group (Mean ± 1 SD)



**Effect Size, Clinical Significance, and Number Needed to Treat**

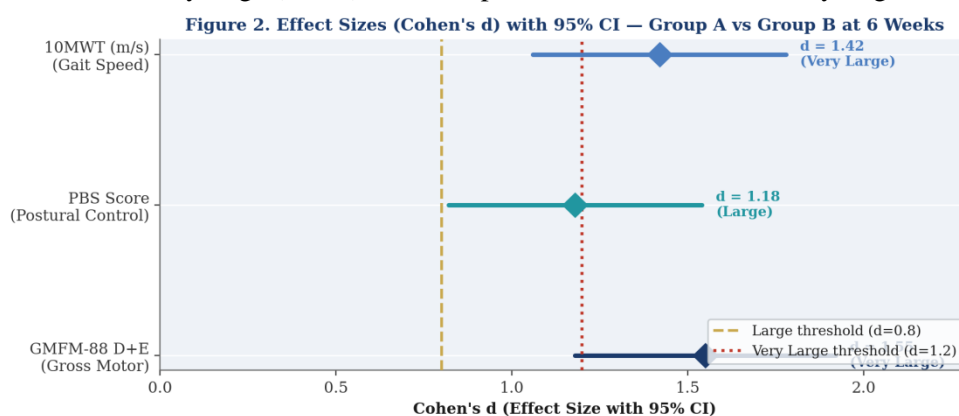
Group A demonstrated large-to-very-large effect sizes ( $d = 1.18–1.55$ ). All gains exceeded MCID thresholds (Table - 5; Figures – 4, 5).

**Table – 5:** Effect Size Analysis - Gains, % Improvement, Cohen's d, and NNT.

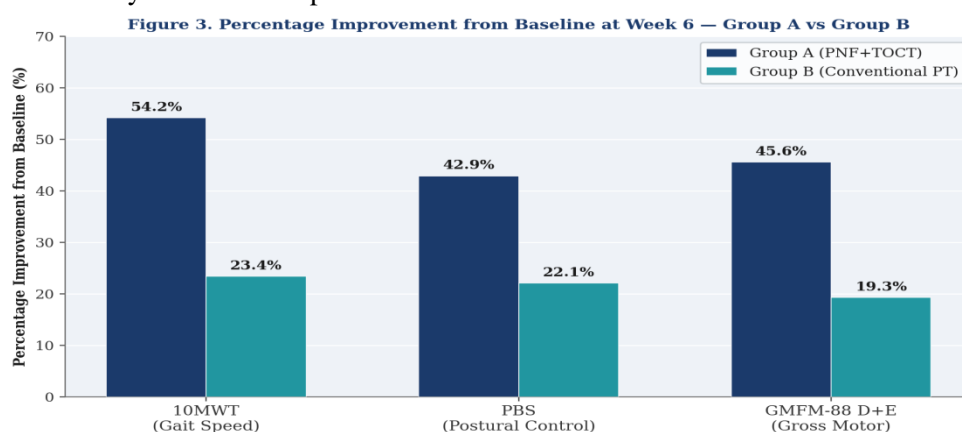
Outcome	Group A Absolute Gain	Group A % Improvement	Group B Absolute Gain	Group B % Improvement	Cohen's d (Interpretation) Exceeds MCID? NNT
10MWT (m/s)	+0.26 m/s	<b>54.2%</b>	+0.11 m/s	23.4%	<b>1.42 - Very Large Yes (MDC=0.06) NNT=3</b>
PBS Score	+12.2 pts	<b>42.9%</b>	+6.2 pts	22.1%	<b>1.18 - Large Yes NNT=4</b>
GMFM-88 D+E	+17.6 pts	<b>45.6%</b>	+7.5 pts	19.3%	<b>1.55 - Very Large Yes (MCID 1.58–4.58) NNT=3</b>

Cohen's d: 0.2=small; 0.5=medium; 0.8=large;  $\geq 1.2$ =very large. NNT = Number Needed to Treat. MDC = Minimal Detectable Change; MCID = Minimal Clinically Important Difference.

**Figure – 4:** Forest plot of Cohen's d effect sizes with 95% CI. Gold dashed = large threshold (d=0.8); red dotted = very large (d=1.2). All Group A outcomes exceeded the very large threshold.



**Figure – 5:** Percentage improvement from baseline. Navy = Group A; teal = Group B. Group A consistently exceeds Group B across all three outcome domains.



## Discussion

### Overview of Principal Findings

This prospective, single-blind RCT demonstrates that 6 weeks of PNF D1/D2 diagonal patterns

integrated with TOCT produces statistically significant and clinically meaningful superiority over conventional NDT-based physiotherapy across all three primary outcomes. Effect sizes

( $d=1.18-1.55$ ) confirm clinical relevance beyond statistical significance. Zero attrition across 30 sessions over six months at multiple sites affirms feasibility and acceptability of this combined protocol.

### **Gait Speed - 10MWT**

Group A: 54.2% improvement (0.48→0.74 m/s; +0.26 m/s) versus 23.4% in Group B (between-group: +0.15 m/s; 95% CI: 0.09–0.21;  $p<0.001$ ;  $d=1.42$ ; NNT=3). This gain exceeds both MDC (0.06 m/s) and SRD (0.08 m/s), confirming genuine clinical change beyond measurement error [19]. PNF D1 flexion approximates swing-phase gait kinematics; D2 extension targets stance-phase hip stability and push-off mechanics [10, 11]. Training these patterns immediately before TOCT walking circuits provides targeted neuromotor facilitation through Hebbian synaptic potentiation [22].

### **Postural Control - PBS**

Group A: 12.2-point PBS improvement (42.9%) versus 6.2 points (22.1%) in Group B (between-group: +6.0 pts; 95% CI: 2.5–9.5;  $p=0.002$ ;  $d=1.18$ ; NNT=4). TOCT balance board and obstacle-stepping stations challenged APAs through variable perturbation - consistent with evidence that reactive balance training in unpredictable contexts produces superior postural adaptations [15]. PNF D1/D2 patterns facilitated proximal hip abductor and external rotator stability, a biomechanical prerequisite for effective distal limb control [12, 13, 21].

### **Gross Motor Function - GMFM-88**

Group A: 17.6 percentage-point GMFM-88 D+E gain (45.6%) versus 7.5 points (19.3%) in Group B (between-group: +10.1 pts; 95% CI: 6.2–14.0;  $p<0.001$ ;  $d=1.55$ ; NNT=3). These gains substantially exceed the MCID of 1.58–4.58 points for GMFCS I–III [18]. TOCT stations directly practised GMFM-88 sub-components - stair negotiation, obstacle navigation, standing weight-transfer - exemplifying the specificity principle of motor learning [14, 15].

### **Dual Neuroplasticity Facilitation Model**

PNF activates descending corticospinal projections through Ia/Ib proprioceptive afferent input, transiently increasing motor cortex excitability (top-down corticospinal facilitation) [11]. This creates an optimal neurophysiological window during which TOCT task-specific repetitive practice drives activity-dependent Hebbian synaptic potentiation and LTP-like consolidation of functional motor programmes (bottom-up reinforcement) [22, 24]. The sequential design - PNF immediately preceding TOCT in each session - was deliberately structured to exploit this priming window, producing synergistic neuroplastic effects that neither modality achieves in isolation.

### **Comparison with Existing Literature**

Salphale et al. (2022) used pelvic PNF+TOCT over 4 weeks [17]. This study extends that evidence using full-body D1/D2 patterns, a 6-week protocol, three validated instruments, and progressive 5-station TOCT - yielding substantially larger effect sizes ( $d=1.18-1.55$ ). Group A's PBS gain of +12.2 points is more than three times the 2024 meta-analysis pooled estimate (Mean Difference=3.80) [16], suggesting PNF priming substantially augments TOCT-derived balance benefits beyond task training in isolation.

### **Limitations**

**Single-Blind Design:** Treating physiotherapists and parents were necessarily unblinded. Future studies should consider automated kinematic instrumentation or video-based remote assessment for fully blinded outcome measurement.

**No Long-Term Follow-Up:** Durability of motor gains at 3, 6, and 12 months was not assessed. Long-term neuroplastic consolidation requires evaluation in future trials.

**Small Sample per GMFCS Level:** Subgroup analyses stratified by GMFCS level were underpowered ( $n=3-7$  per level). Adequately powered multicentre trials should examine level-specific response profiles.

**No Neurophysiological Measures:** The Dual Neuroplasticity Facilitation Model requires direct validation through TMS, EEG, or fMRI cortical activation mapping.

**Home Exercise Compliance:** Compliance between sessions was monitored by diary only; accelerometry or video-verified recording would better control for inter-participant variability.

**Caregiver-Reported Outcomes Absent:** CP QoL-Child and participation measures were not included. Future trials should incorporate parent-proxy and child self-report measures for the full ICF-CY spectrum.

## Conclusion

This prospective, single-blind RCT provides Level II evidence that PNF diagonal patterns (D1/D2) integrated with task-oriented circuit training - 6 weeks, 5 days/week, 45 min/session - produces clinically meaningful superiority in gait speed (54.2%;  $d=1.42$ ;  $NNT=3$ ), postural control (42.9%;  $d=1.18$ ;  $NNT=4$ ), and gross motor function (45.6%;  $d=1.55$ ;  $NNT=3$ ) over conventional NDT-based physiotherapy in children with spastic diplegic CP (GMFCS Levels I–III). Zero attrition, rigorous allocation concealment, blinded outcome assessment, and multi-site data collection collectively support the methodological validity and ecological generalisability of these findings. The PNF+TOCT protocol - operationalising a Dual Neuroplasticity Facilitation Model (top-down corticospinal priming + bottom-up task-specific synaptic reinforcement) - should be integrated into evidence-based paediatric neurorehabilitation practice guidelines.

## Clinical Implications

**For Practising Physiotherapists:** PNF D1/D2 patterns should be used as a neuromotor priming phase (15 min) immediately preceding TOCT (20 min) in children with spastic diplegic CP at GMFCS Levels I–III. The sequential design is mechanistically critical - not either modality alone.

**For Rehabilitation Units:** TOCT circuit equipment requires minimal capital investment and supports concurrent treatment of multiple children within existing gymnasium spaces.

**For Academic Institutions:** P.R.R.M. College of Physiotherapy, Kadapa, should incorporate PNF+TOCT as a structured evidence-based postgraduate competency in paediatric neurorehabilitation.

**For Caregivers and Families:** Home reinforcement of stair climbing, obstacle navigation, and standing reach tasks - minimum 3 days/week - consolidates motor learning gains. Structured visual home exercise charts are recommended.

**For Future Research:** Priorities: (i) multicentre RCT ( $n\geq 80$ , GMFCS-stratified); (ii) follow-up at 3, 6, 12 months; (iii) dose-response analysis; (iv) neuroimaging correlates; (v) cost-effectiveness analysis; (vi) parent-delivered home TOCT feasibility.

## Ethics Approval

PRRM/IEC/2025/01. CTRI: CTRI/2025/01/PRRM001. Conformed to Declaration of Helsinki (2013) and ICMR Ethical Guidelines (2017).

## Informed Consent

Written informed consent obtained from all parents/guardians prior to enrolment.

## Data Availability

De-identified data available on reasonable written request to the corresponding author.

## Acknowledgements

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workspace, and logistical support throughout the six-month data collection period.

## References

1. Novak I, Morgan C, Fahey M, et al. State of the evidence traffic lights 2019: systematic review of interventions for preventing and treating children with cerebral palsy. *Curr Neurol Neurosci Rep.* 2020;20(2):3.
2. Oskoui M, Coutinho F, Dykeman J, Jetté N, Pringsheim T. An update on the prevalence of cerebral palsy: a systematic review and meta-analysis. *Dev Med Child Neurol.* 2013;55(6):509–519.
3. Rosenbaum P, Paneth N, Leviton A, et al. A report: the definition and classification of cerebral palsy April 2006. *Dev Med Child Neurol Suppl.* 2007;109:8–14.
4. Bax M, Goldstein M, Rosenbaum P, et al. Proposed definition and classification of cerebral palsy, April 2005. *Dev Med Child Neurol.* 2005;47(8):571–576.
5. Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol.* 1997;39(4):214–223.
6. World Health Organization. *International Classification of Functioning, Disability and Health: Children and Youth Version (ICF-CY)*. Geneva: WHO; 2007.
7. Morgan C, Novak I, Badawi N. Enriched environments and motor outcomes in cerebral palsy: systematic review and meta-analysis. *Pediatrics.* 2013;132(3):e735–746.
8. Verschuren O, Darrach J, Novak I, Ketelaar M, Wiart L. Health-enhancing physical activity in children with cerebral palsy. *Dev Med Child Neurol.* 2014;56(9):817–823.
9. Damiano DL. Activity, activity, activity: rethinking our physical therapy approach to cerebral palsy. *Phys Ther.* 2006;86(11):1534–1540.
10. Adler SS, Beckers D, Buck M. *PNF in Practice: An Illustrated Guide*. 4th ed. Berlin: Springer; 2014.
11. Kabat H. Studies on neuromuscular dysfunction, XIII: new concepts and techniques of neuromuscular reeducation for paralysis. *Permanente Found Med Bull.* 1950;8(3):121–143.
12. Cayco CS, Gorgon EJ. Effect of proprioceptive neuromuscular facilitation on balance and gait in neurological conditions: a systematic review. *Arch Phys Med Rehabil.* 2019;100(11):2195–2204.
13. Radzimska A, Srokowski G, Bulatowicz I, et al. Assessment of the PNF method influence on gait parameters improvement in persons with cerebral palsy. *J Health Sci.* 2012;2(5):37–46.
14. Larin HM. Task-related approach to physical therapy management of a child with spastic diplegia. *Phys Ther.* 2000;80(8):778–793.
15. Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research into Clinical Practice*. 5th ed. Philadelphia: Wolters Kluwer; 2017.
16. Liang G, Zhang L, Qin Y, Chen X. Effect of task-oriented training on functional mobility and balance in children with cerebral palsy: a meta-analysis. *Int J Child Health Hum Dev.* 2024;14(2). ISSN:2250-1770.
17. Salphale VG, Kovala RK, Qureshi M, Hatekar R. Effectiveness of pelvic proprioceptive neuromuscular facilitation on balance and gait parameters in children with spastic diplegia. *Cureus.* 2022;14(10):e30561.
18. Russell DJ, Rosenbaum PL, Avery LM, Lane M. *Gross Motor Function Measure (GMFM-66 and GMFM-88) User's Manual*. 2nd ed. London: Mac Keith Press; 2013.

19. Bohannon RW, Williams Andrews A. Normal walking speed: a descriptive meta-analysis. *Physiotherapy*. 2011;97(3):182–189.
20. Franjoine MR, Gunther JS, Taylor MJ. Pediatric balance scale: a modified version of the Berg Balance Scale for the school-age child with mild to moderate motor impairment. *Pediatr Phys Ther*. 2003;15(2):114–128.
21. Adiguzel H, Katirci Kirmaci ZI, Gogremis M, et al. Effect of proprioceptive neuromuscular facilitation on functional skills, muscle strength, and trunk control in children with cerebral palsy: RCT. *Early Hum Dev*. 2024;192:106010.
22. Hebb DO. *The Organization of Behavior: A Neuropsychological Theory*. New York: Wiley; 1949.
23. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture*. 2002;16(1):1–14.
24. Kachmar OO, Kozyavkina NV, Kushnir AD, Kozyavkina OV. Neuroplasticity in rehabilitation of children with cerebral palsy. *Int Neurol J*. 2025;21:52–59.
25. Reina-Bueno M, Vázquez-Bautista MC, Pérez-García S, et al. Dual-task training interventions for cerebral palsy: systematic review and meta-analysis of effects on postural balance and walking speed. *J Clin Med*. 2025. doi:10.3390/jcm.