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Comparison of PNF Stretching vs. Sustained Stretching for Hamstring Spasticity in Diplegic CP

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ABSTRACT: Background: Hamstring spasticity and the associated loss of muscle extensibility restrict knee extension, promote crouched postures, and limit gross motor function in children with spastic diplegic cerebral palsy (CP). Stretching is a routine component of physiotherapy, yet the choice between sustained (static) stretching and proprioceptive neuromuscular facilitation (PNF) stretching is largely guided by clinical preference rather than comparative evidence.

Objective: To synthesise the neurophysiological and clinical literature relevant to both techniques and to present a fully specified protocol for a randomised, assessor-blinded, parallel-group comparison of PNF (hold-relax) stretching and sustained stretching for hamstring spasticity and extensibility in children with spastic diplegic CP.

Methods: The proposed trial will recruit 62 children aged 6–15 years (GMFCS levels I–III), allocate them equally to either technique in addition to conventional physiotherapy, and deliver the intervention five days per week for eight weeks with follow-up at week twelve. The primary outcome is the active knee extension angle; secondary outcomes are the modified Tardieu angles, the Modified Ashworth Scale, the Gross Motor Function Measure-66, and gait speed.

Anticipated Findings: Both techniques are expected to improve hamstring extensibility, with PNF hypothesised to yield a larger gain in active knee extension and

sustained stretching a more feasible home-based profile. This paper reports no trial data; the hypotheses are stated explicitly so that they can be confirmed or refuted.

Conclusion: The protocol provides a transparent framework for generating comparative evidence to guide stretching prescription in diplegic CP

1. INTRODUCTION

1.1 Background

Cerebral palsy is an umbrella term for a group of permanent disorders of movement and posture that are attributed to non-progressive disturbances occurring in the developing fetal or infant brain and that are frequently accompanied by disturbances of sensation, cognition, communication, perception, and behaviour [1]. A systematic review and meta-analysis of population-based studies estimated the overall prevalence at approximately 2.1 per 1000 live births [2]. Spastic CP is the most common clinical type, and bilateral spastic involvement that affects the legs more than the arms, termed spastic diplegia, forms a large share of ambulatory cases [3]. Functional severity is conventionally graded with the Gross Motor Function Classification System (GMFCS), in which levels I–III describe children who walk with or without aids [4].

Spasticity is commonly described as a velocity-dependent increase in resistance to passive stretch that arises from hyperexcitable stretch reflexes [5]. In spastic paresis, however, the neural component does not act alone. Paresis, reduced selective motor control, and secondary changes in muscle and connective tissue contribute to the clinical picture, and these soft-tissue adaptations are increasingly regarded as a major source of the fixed resistance encountered during passive movement [6], [7]. The hamstrings are particularly vulnerable because they are biarticular muscles that cross both the hip and the knee. Restricted hamstring extensibility limits terminal knee extension, increases posterior pelvic pull in standing, and is closely associated with crouched gait, a pattern that raises the energy cost and mechanical load of walking [8].

1.2 Rationale and Problem Statement

Stretching is among the oldest and most widely used physiotherapy interventions for children with CP, and it is prescribed with the aim of reducing muscle stiffness, preserving joint range of motion, and delaying contracture. Systematic evidence for its effect is, however, modest. A review of passive stretching in children with CP concluded that stretching may produce small immediate gains in range of motion, but that evidence for sustained benefit, reduced spasticity, or improved function was insufficient [9]. A Cochrane review of stretch for the treatment and prevention of contractures across several clinical populations similarly found little or no clinically important effect on joint mobility for single sessions or for longer programmes [10]. These conclusions do not demonstrate that stretching is useless; they reflect heterogeneity in dose, technique, populations, and outcome measures, and the paucity of well-designed trials in children.

Two techniques dominate day-to-day practice. Sustained (static) stretching places the muscle in a lengthened position and maintains low-load tension for a defined time. PNF stretching combines a passive stretch with a voluntary isometric contraction, commonly of the muscle being stretched, followed by a further stretch into the new range; it is promoted on the basis of reflex-mediated relaxation and has been reported to produce large range-of-motion gains in non-disabled adults [11]. Whether the apparent advantage of PNF carries over to children with spastic diplegia, in whom the stretch reflex is hyperexcitable, motor control is impaired, and cooperation with multi-step instructions varies, remains uncertain. A direct, dose-matched comparison focused on the hamstrings of children with diplegic CP is therefore a clinically meaningful gap.

1.3 Objectives and Hypotheses

The objectives of this paper are (a) to critically synthesise the mechanistic and clinical evidence that bears on the two techniques, and (b) to present a rigorous protocol for a head-to-head trial. The trial is designed to test the following:

- (1) **H1:** PNF (hold-relax) stretching produces a greater improvement in active knee extension angle than sustained stretching after eight weeks of intervention.
- (2) **H2:** Both techniques reduce hamstring spasticity measured by the modified Tardieu scale and the Modified Ashworth Scale, with PNF showing the larger reduction in the dynamic component ($R2 - R1$).

- (3) **H3:** Improvements in hamstring extensibility are accompanied by improvements in gross motor function and gait speed, and these gains are partly retained at four weeks after cessation of treatment.

1.4 Organisation of the Paper

Section 2 reviews the pathophysiology of hamstring limitation and the mechanisms and evidence for each stretching technique. Section 3 describes the proposed methodology in a form that follows the SPIRIT recommendations for trial protocols [12] and the CONSORT framework for reporting parallel-group trials [13]. Section 4 presents the anticipated findings and a discussion of their interpretation, limitations, and clinical implications. Section 5 concludes the paper.

2. LITERATURE REVIEW

2.1 Why the Hamstrings Lose Extensibility in Spastic Diplegia

The limitation observed clinically as “tight hamstrings” is a composite of neural and mechanical factors (Fig. 1). On the neural side, damage to descending motor pathways reduces supraspinal inhibition and leaves stretch-reflex circuits hyperexcitable, so that hamstring activity is recruited during rapid lengthening [5]. On the mechanical side, muscle from children with spastic CP differs from typically developing muscle. Smith et al. reported that hamstring contractures in children with spastic CP were associated with a stiffer extracellular matrix and with sarcomeres that were longer in vivo than expected [14]. A subsequent review of the passive mechanics of CP muscle supports the view that contracture reflects altered tissue composition and stiffness as well as altered length [15]. For stretching, this has an important implication: a manoeuvre that only transiently modifies reflex excitability or sensation may improve range without changing the stiffness of the muscle itself.

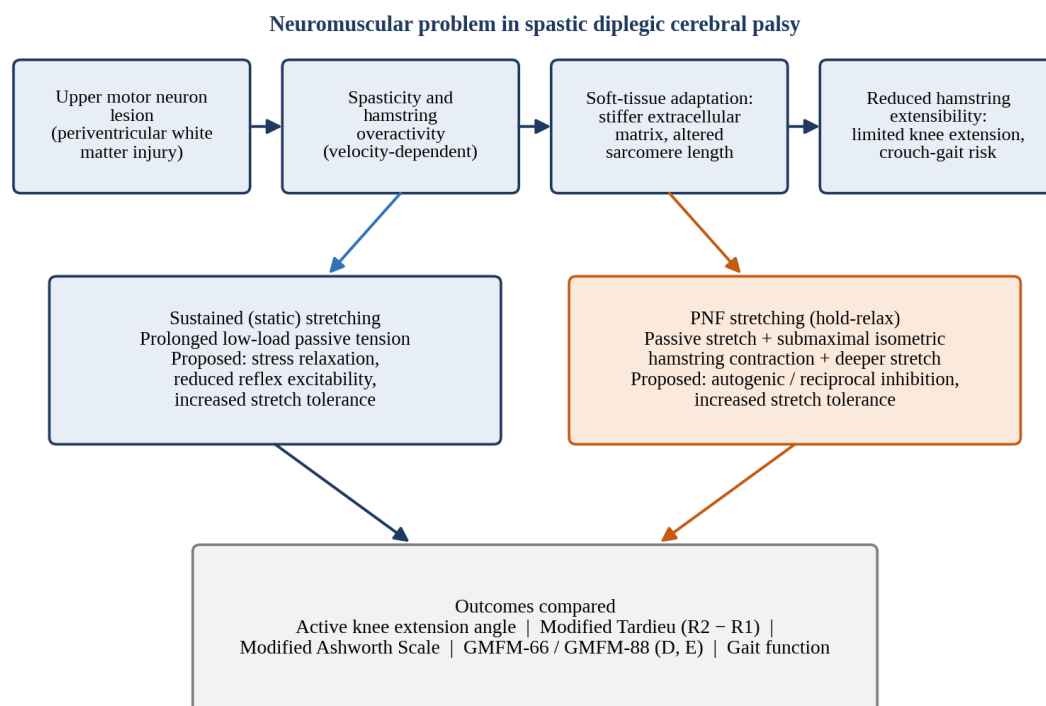


Fig. 1. Conceptual framework: pathway from upper motor neuron lesion to reduced hamstring extensibility, and the proposed targets of the two stretching techniques compared in this study.

The relationship between hamstring length and gait is also less straightforward than often assumed. Musculoskeletal modelling of children with crouch gait showed that hamstring muscle-tendon lengths were not necessarily short and that lengthening velocities were reduced, indicating that muscle length and velocity estimates are useful for treatment decisions and that “tightness” should not be inferred from posture alone [8]. Likewise, in spastic diplegia the magnitude of spasticity

has been found to be a weaker correlate of gross motor function than muscle strength [16]. Together, these findings argue that a stretching trial should measure extensibility, spasticity, and function concurrently rather than relying on a single index.

2.2 Sustained (Static) Stretching

2.2.1 Principle and proposed mechanisms

In sustained stretching the therapist or caregiver moves the limb to the point of firm resistance and holds the position for a defined duration. The classic explanation is viscoelastic: when a muscle-tendon unit is held at constant length, the tension it generates gradually declines (stress relaxation), and repeated or prolonged loading can produce a creep response and a short-lived increase in passive extensibility [17]. A competing, and increasingly accepted, explanation is that regular stretching mainly alters the sensation of stretch, thereby allowing a person to tolerate greater tension and to reach a greater end-range angle without a measurable change in the intrinsic stiffness of the tissue [18]. Both mechanisms are plausible in CP, and the second may be especially relevant when pain or discomfort limits the range achieved.

2.2.2 Dose-response evidence

The most informative dose-response data come from studies of hamstring flexibility in adults. Bandy and Irion found that a single 30-second hold produced a greater gain in hamstring flexibility than a 15-second hold, and that 60 seconds provided no additional benefit over 30 seconds [19]. A follow-up study of adults with limited hamstring flexibility showed that a single 30-second stretch performed once per day was as effective over six weeks as longer or more frequent protocols [20]. A systematic review of acute stretching effects in healthy active individuals confirmed that static stretching reliably increases range of motion, while noting that very long holds may transiently impair force production [21]. These findings were obtained in neurologically intact people and cannot be transposed directly to children with CP, but they establish 30 seconds as a reasonable unit of hold time for the hamstrings.

2.2.3 Evidence in cerebral palsy

In children with CP, evidence for passive stretching is sparse and of variable quality, with small samples and heterogeneous protocols [9]. The Cochrane synthesis found that stretch had little or no clinically important effect on joint mobility, while acknowledging that the included trials were frequently low in dose and did not focus on children with spastic diplegia [10]. The practical advantages of sustained stretching are, nevertheless, clear: it is simple to teach, can be delivered by trained caregivers, requires no cooperation beyond tolerance of positioning, and does not require voluntary muscle activation.

2.3 Proprioceptive Neuromuscular Facilitation Stretching

2.3.1 Principle and variants

PNF stretching incorporates a voluntary muscle contraction into the stretching sequence. In the hold-relax technique the target muscle is first stretched passively, the person then performs an isometric contraction against resistance of the therapist, and, after relaxation, the muscle is moved passively into a greater range. In contract-relax, a concentric contraction accompanies the movement, while in agonist-contrast the antagonist is activated actively to assist the stretch. The traditional neurophysiological rationale invokes autogenic inhibition mediated by Golgi tendon organs after the contraction and reciprocal inhibition mediated by antagonist activation, both leading to a transient reduction of motoneuron excitability in the stretched muscle [11].

2.3.2 Evidence and critical appraisal

A review of PNF stretching mechanisms concluded that PNF stretching is effective for increasing range of motion and is often reported to give larger acute gains than static stretching in non-disabled participants, but also that the evidence supporting the proposed inhibitory reflex pathways is limited and that gains may be due in large part to increased stretch tolerance [11]. This is consistent with the sensory interpretation of flexibility change in general [18]. The distinction is important for CP. If PNF acts chiefly by changing tolerance and by transiently reducing reflex excitability, it may offer an immediate benefit in spastic muscle; if the gains depend on forceful contraction, there is a theoretical risk that effort and associated reactions will raise tone in a child with impaired selective motor control. A submaximal contraction intensity is therefore adopted in the protocol described in Section 3.

PNF also imposes demands that sustained stretching does not. The child must understand and follow a multi-step instruction (relax, push gently, stop, relax), the therapist must grade resistance accurately, and the hamstring contraction must be isolated from trunk and hip compensation. These requirements are generally achievable in ambulatory children with diplegic CP who have adequate comprehension, but they limit the technique's transferability to the home.

2.4 Comparative Synthesis and Research Gap

Table 1 summarises the contrasts that frame the comparison. Most direct evidence for the superiority of PNF over static stretching derives from healthy adults and athletes, where outcomes are typically acute changes in range of motion [11], [21]. The evidence for sustained stretching in CP is limited and inconclusive [9], [10]. Consequently, there is no firm basis for choosing between the two techniques for the hamstrings of children with spastic diplegia, and a prospective trial with matched exposure time, blinded assessment, and multi-domain outcomes is warranted.

Table 1. Conceptual comparison of sustained stretching and PNF (hold-relax) stretching.

Feature	Sustained (static) stretching	PNF (hold-relax) stretching
Basic action	Passive hold of the muscle at end range for a set duration	Passive stretch, submaximal isometric contraction, relaxation, then deeper passive stretch
Proposed mechanisms	Stress relaxation and creep; increased stretch tolerance [17], [18]	Autogenic and reciprocal inhibition (proposed); increased stretch tolerance [11]
Active participation	Not required	Required; child must follow multi-step commands
Therapist skill	Low to moderate	Moderate to high (grading of resistance, isolation of hamstring contraction)
Carry-over to home	High; caregiver-delivered	Lower; requires trained handling
Theoretical risk in spasticity	Reflex activation if stretch is too fast	Tone increase or associated reactions if contraction is too strong
Evidence base	Hamstring dose studies in adults; limited, inconclusive in CP [9], [19]	Mostly non-disabled adults; very limited in CP [11]

3. PROPOSED METHODOLOGY

3.1 Study Design

The proposed study is a single-centre, two-arm, parallel-group, randomised controlled trial with blinded outcome assessment and a 1:1 allocation ratio. Participants receive the allocated stretching technique five days per week for eight weeks, in addition to a standardised conventional physiotherapy programme, and are reassessed at the end of weeks 4 and 8 and at a four-week follow-up (week 12). The protocol is organised according to SPIRIT [12] and the planned participant flow follows CONSORT [13] (Fig. 2). The trial will be prospectively registered in a public trial registry before enrolment.

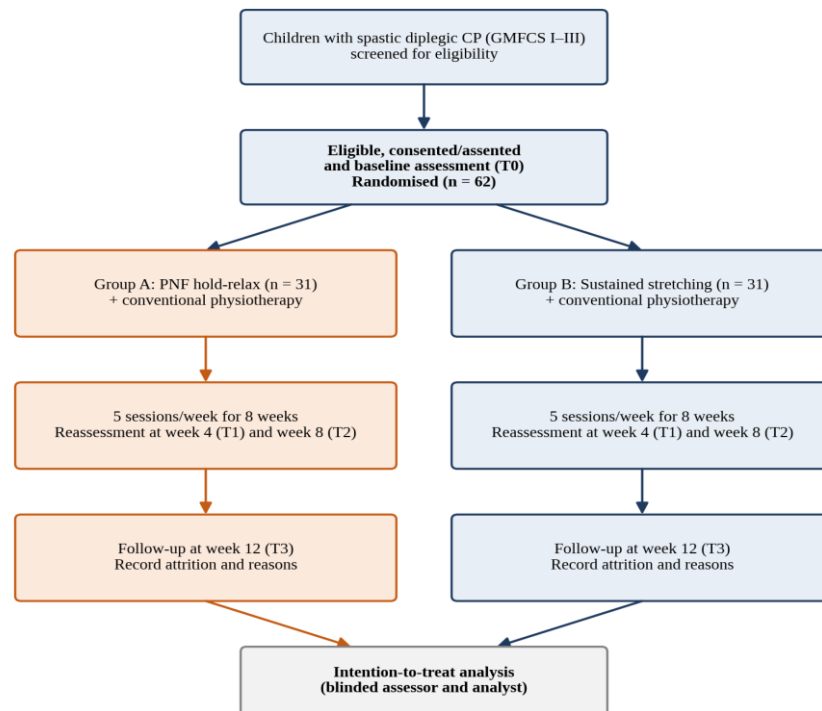


Fig. 2. Planned CONSORT-style participant flow for the randomised comparison of PNF and sustained stretching (T0 = baseline, T1 = week 4, T2 = week 8, T3 = week 12).

3.2 Participants

Children will be recruited consecutively from the paediatric neurorehabilitation outpatient clinic. Eligibility is summarised in Table 2. Both limbs are treated, but the limb with the more restricted active knee extension at baseline is designated the index limb for the primary analysis in order to avoid inflating the effective sample size with correlated observations.

Table 2. Eligibility criteria.

Domain	Inclusion criteria	Exclusion criteria
Diagnosis	Spastic diplegic CP confirmed by a paediatric neurologist or physiatrist	Dyskinetic, ataxic, or mixed CP; unilateral or quadriplegic involvement
Age	6 to 15 years	Younger than 6 years or older than 15 years
Function	GMFCS level I–III	GMFCS level IV–V
Spasticity	Modified Ashworth grade 1 to 3 in the hamstrings of at least one limb	Fixed contracture precluding passive knee extension beyond the hamstring-length test range
Cognition and cooperation	Able to follow simple two-step verbal commands	Unable to cooperate with testing or treatment
Medical history	Stable medication for at least 3 months	Botulinum toxin injection within 6 months; lower-limb surgery within 12 months; selective dorsal rhizotomy; unstable epilepsy
Concurrent care	Willing to attend all sessions	Any other new stretching, casting, or orthotic intervention during the trial

3.3 Sample Size

The sample size was derived for a two-sided independent-samples comparison of the primary outcome between groups [22]. We assumed a between-group difference of 8° in active knee extension angle with a pooled standard deviation of 10° (a standardised effect, Cohen's d , of 0.8), a significance level of 0.05, and 80% power. These planning values are assumptions that represent the smallest difference the investigators consider clinically worthwhile; they are not estimates taken from a previous trial. Under these assumptions 26 children per group are required (Fig. 3). Allowing for 15% attrition, 31 children will be enrolled in each group, giving a total of 62. If the true standardised difference were smaller, the study would be underpowered for that effect (for $d = 0.5$, 64 children per group would be needed), a point addressed in the limitations.

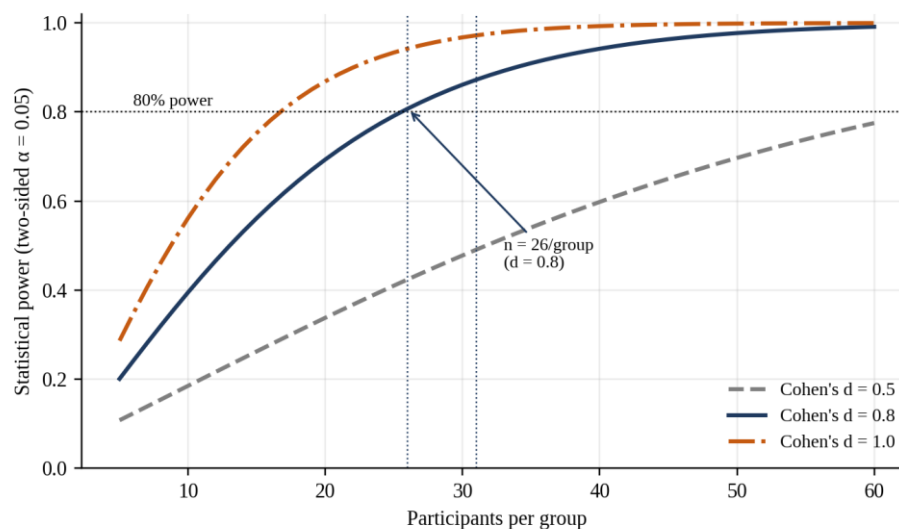


Fig. 3. Statistical power as a function of group size for three assumed standardised effects (two-sided $\alpha = 0.05$, independent-samples t-test). The planned analysis assumes $d = 0.8$.

3.4 Randomisation, Allocation Concealment, and Blinding

An independent researcher not involved in recruitment or assessment will generate a computer-based random allocation sequence with permuted blocks of variable size (4 and 6), stratified by GMFCS level (I–II vs. III). Allocation will be concealed in sequentially numbered, opaque, sealed envelopes opened by the treating therapist only after baseline assessment is completed. The participants and treating therapists cannot be blinded to a manual stretching technique. The outcome assessor and the statistician will remain blinded to group allocation; children and caregivers will be asked not to disclose the treatment performed to the assessor. Blinding integrity will be checked by asking the assessor to guess the allocation at the end of the study.

3.5 Interventions

3.5.1 Common elements

All participants receive a 30-minute conventional physiotherapy session five days per week, comprising lower-limb strengthening, balance training, and gait practice. The stretching intervention is delivered immediately after a standardised five-minute warm-up of cycling or walking, with the child in supine lying and the hip flexed to 90° for the hamstring position. Stretching is performed bilaterally, each limb in turn, by one of two physiotherapists with at least five years of paediatric experience who have been trained and calibrated in both techniques. Stretching is taken to the first point of firm resistance, and the child is asked to report discomfort; discomfort is not allowed to exceed a mild level (rated 3 or lower on the Wong-Baker FACES scale). Sessions will be logged to monitor attendance and adverse events.

3.5.2 Group B: sustained stretching

Each limb receives five repetitions of a passive hamstring stretch held for 30 seconds at the end of the available pain-free range, with 30 seconds of rest between repetitions. The 30-second hold was selected because it was found in healthy adults to be the shortest duration that yielded a clear flexibility gain with no further advantage at 60 seconds [19], [20].

3.5.3 Group A: PNF (hold-relax) stretching

Each repetition proceeds through four phases (Fig. 4). The limb is first moved passively to the first point of firm resistance and held for 10 seconds. The child then performs a six-second isometric hamstring contraction against the therapist's hand at a submaximal intensity of approximately 20–25% of perceived maximal effort, with verbal cues to “push your heel gently into my hand”. After a two-second relaxation, the limb is moved passively into the newly available range and held for 20 seconds. Five repetitions are performed per limb with 30 seconds of rest between them. The low contraction intensity was deliberately chosen to reduce the risk of overflow and tone increase in spastic muscle; this is a design decision based on clinical reasoning rather than on trial evidence.

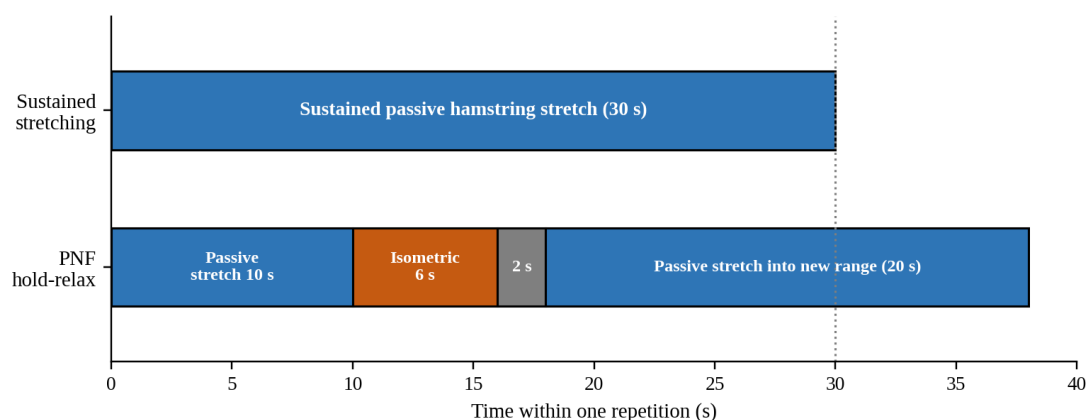


Fig. 4. Timing of one repetition in each stretching technique. Total loaded time per repetition is approximately 30 s for sustained stretching and 38 s for PNF, with comparable rest intervals and an identical number of repetitions.

Because the PNF repetition includes the contraction and relaxation phases, per-repetition exposure time differs slightly between groups (38 s vs. 30 s). This difference is considered inherent to the techniques; the number of repetitions, rest periods, session frequency, and total programme length are otherwise identical. Adverse events, including pain, muscle soreness, or increased spasm, will be recorded and a stop rule applied if pain persists beyond 24 hours.

3.6 Outcome Measures

The primary outcome is the active knee extension (AKE) angle, measured with a universal goniometer in supine lying with the hip held at 90° flexion; the angle between the shank and the vertical is recorded, and larger values indicate greater tightness. The AKE test has demonstrated good test–retest reliability for hamstring tightness [23]. The secondary outcomes include the modified Tardieu angles of catch (R1) and full passive range (R2) at a fast velocity, with the difference $R2 - R1$ used as an index of the dynamic spasticity component [24]; the Modified Ashworth Scale (MAS) for resistance to passive movement [25]; the Gross Motor Function Measure-66 (GMFM-66) for gross motor function [26]; and the 10-metre walk test at self-selected speed. The MAS has been examined in children with spastic CP, with reliability that depends on the muscle group tested [27], and is therefore interpreted alongside the Tardieu measures. Outcome definitions are listed in Table 3 and the assessment timetable in Table 4.

Table 3. Outcome measures.

Outcome	Instrument	Procedure and interpretation	Level
Primary: hamstring	Active knee extension	Goniometric angle at end of active knee extension, hip at 90°; lower angle indicates	Impairment

extensibility	(AKE) angle	improved extensibility	
Passive hamstring length	Popliteal angle	Passive knee extension at hip 90° flexion to the first firm resistance	Impairment
Spasticity (dynamic)	Modified Tardieu: R1, R2, R2 – R1	R1 at fast stretch (angle of catch), R2 at slow stretch (full passive range)	Impairment
Spasticity (tone)	Modified Ashworth Scale (0–4)	Grade of resistance to passive hamstring stretch	Impairment
Gross motor function	GMFM-66	Interval-scale score from 66 items; higher is better	Activity
Gait speed	10-metre walk test	Self-selected speed over the central 10 m of a 14 m walkway; mean of three trials	Activity

To limit measurement error, the assessor will complete a reliability exercise before the trial, and the intra-rater intraclass correlation coefficient (ICC) will be interpreted with the guidelines for selecting and reporting ICCs [28]; an ICC (two-way mixed, absolute agreement) of 0.75 or higher will be required before enrolment begins. All measurements follow a fixed order (AKE, popliteal angle, Tardieu, MAS, walk test, GMFM-66), with the same device and examiner, in the same room and at the same time of day, to reduce variance.

Table 4. Schedule of enrolment, interventions, and assessments (SPIRIT format).

Activity	T0 baseline	T1 week 4	T2 week 8	T3 week 12
Eligibility screening and consent	✓			
Randomisation	✓			
Stretching intervention (5 sessions/week)		✓	✓	
AKE, popliteal angle	✓	✓	✓	✓
Modified Tardieu, MAS	✓	✓	✓	✓
GMFM-66	✓		✓	✓
10-metre walk test	✓	✓	✓	✓
Adverse events and adherence		✓	✓	✓

3.7 Statistical Analysis

Analysis will follow the intention-to-treat principle. Normality will be examined with the Shapiro–Wilk test and graphical methods. The primary hypothesis (H1) will be tested using analysis of covariance of the week-8 AKE angle with the baseline value and GMFCS stratum as covariates. Repeated outcomes over T0 to T3 will be analysed with a linear mixed-effects model including group, time, and the group $\times$ time interaction, with a random intercept for each participant; both limbs may be used in a sensitivity analysis. Between-group differences will be reported as adjusted mean differences with 95% confidence intervals and as standardised effect sizes. Ordinal outcomes (MAS) will be compared with the Mann–Whitney U test on change scores or with ordinal regression. Missing data will be handled with multiple imputation under a missing-at-random assumption, and a complete-case analysis will be reported as a sensitivity check. Because there are three secondary

hypotheses, secondary outcomes will be interpreted as exploratory and the Holm procedure used to adjust p-values. The two-sided significance level is 0.05.

3.8 Ethical Considerations

The study will be conducted in accordance with the Declaration of Helsinki after approval from the institutional ethics committee. Written informed consent will be obtained from parents or legal guardians, and age-appropriate assent will be obtained from the children. Participation will not alter access to standard care, and families will be free to withdraw at any time. Data will be de-identified and stored securely, and any serious adverse event will be reported to the committee within 24 hours.

4. ANTICIPATED FINDINGS AND DISCUSSION

4.1 Hypothesised Outcome Profile

As this paper presents a protocol and a literature synthesis, no efficacy data are reported. Table 5 states the pattern of results that the hypotheses in Section 1.3 predict. These predictions are explicit so that the eventual trial can be judged against them, and a pattern in which sustained stretching performs as well as or better than PNF would be an equally informative result.

Table 5. Hypothesised direction of change after eight weeks (predictions, not observed data). ↑ = improvement, ↑↑ = larger improvement, ↔ = little or no change.

Outcome	Sustained	PNF	Basis for the prediction
AKE angle (primary)	↑	↑↑	PNF reported to give larger range gains in non-disabled adults [11]
Tardieu R2 – R1	↑	↑↑	Contraction followed by relaxation may reduce reflex-mediated resistance
Modified Ashworth Scale	↑	↑	Scale is coarse and expected to show limited sensitivity [27]
GMFM-66	↔ / ↑	↔ / ↑	Function depends on strength and motor control as well as range [16]
10-metre walk speed	↔	↔ / ↑	Conventional therapy is common to both arms
Retention at week 12	Partial	Partial	Stretch effects generally regress without continued stretching [10]

4.2 Mechanistic Interpretation

If PNF proves superior for AKE, there will be at least three non-exclusive explanations to consider. First, the voluntary contraction and subsequent relaxation may transiently lower reflex excitability, allowing a larger range to be reached before resistance rises [11]. Second, the contraction phase may increase the child's tolerance of the stretch sensation, in line with the view that flexibility gains are largely sensory [18]. Third, the greater exposure time and attention per repetition may contribute. The design cannot separate these explanations; however, the combination of AKE, Tardieu, and popliteal measures provides indirect discrimination. A gain in the AKE angle with a stable popliteal angle, for example, would be compatible with a change in active control or tolerance rather than in passive length.

Conversely, if sustained stretching is equivalent to PNF, the result would favour the simpler approach because it requires no active participation and can be taught to caregivers. A null difference together with small improvements in both arms would also be consistent with reviews that describe stretching effects as small and dependent on dose [9], [10], and would argue for testing higher-dose or longer-duration programmes rather than abandoning stretching.

4.3 Clinical Implications

Three practical consequences follow. First, if PNF yields clinically meaningful improvements that exceed those of sustained stretching, clinicians could reserve it for children with adequate comprehension and selective control and use caregiver-delivered sustained stretching for the home programme, so that the two techniques are complementary rather than competitive. Second, the inclusion of function and gait speed ensures that the clinical relevance of any change in range is evaluated; improvements in range that are not accompanied by functional benefit would be consistent with the weak association between impairment and function noted earlier [16]. Third, the explicit dose descriptions, adverse-event monitoring, and safety rules provide a template for reproducible stretching prescription in this population.

4.4 Strengths and Limitations

The strengths of the proposed design include randomised allocation with concealment, blinded outcome assessment, matched session frequency and repetition number, clear reporting of dose, and measurement across impairment and activity domains. Several limitations should be acknowledged. The trial is single-centre with a modest sample, and the assumed effect size is large; smaller true differences would be missed. The treating therapists and participants cannot be blinded, creating a risk of performance bias. The Modified Ashworth Scale and the Tardieu scale depend on examiner judgment, and the examiner may infer allocation from limb behaviour. The eight-week duration is short relative to the timescale of muscle remodelling, so the study addresses short-term change rather than the prevention of contracture. Finally, the dosage of both techniques draws on adult hamstring data and clinical reasoning, which may differ from the optimal dose for children with CP.

4.5 Directions for Future Research

If the trial supports a difference between techniques, subsequent work should examine dose-response by varying contraction intensity and hold time, include instrumented measures such as shear-wave elastography, dynamometry, and three-dimensional gait analysis to separate neural from mechanical effects, and compare therapist-delivered PNF with caregiver-delivered sustained stretching in the home setting. Multi-centre trials with longer follow-up will be required to determine whether improved extensibility alters the trajectory of crouch gait or the need for orthopaedic surgery.

5. CONCLUSION

Hamstring tightness in spastic diplegic CP reflects both hyperexcitable reflexes and altered muscle mechanics, and stretching techniques are likely to act, at least in part, through sensory and reflex pathways rather than through changes in tissue stiffness. The current evidence does not allow a confident choice between PNF and sustained stretching in this population. This paper synthesised the supporting literature and presented a trial-ready protocol that compares the two methods with matched frequency, blinded assessment, and measures of extensibility, spasticity, and function. The anticipated findings are stated as hypotheses rather than results. Completion of the proposed trial would give clinicians evidence to individualise stretching prescription and would indicate the doses and outcome measures that should be carried into larger multi-centre studies.

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