Original article

Impact of sensory perceptual motor core stability exercise program on trunk control in achieving independent sitting in children with cerebral palsy – a randomized controlled trial

Impacto do programa de exercícios sensório-perceptivo-motor para estabilidade do core no controle de tronco para alcançar o sentar independente em crianças com paralisia cerebral – um ensaio clínico randomizado

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ABSTRACT | AIM: Independent sitting, essential for children's crucial functional activities and motor development, is often impaired in Bilateral Spastic Cerebral Palsy (BSCP) due to neuromuscular control deficits. This double-blinded, randomized controlled trial evaluated the effectiveness of a Sensory Perceptual Motor Core Stability Exercise Program (SPMCSEP) to improve independent sitting control in this population, addressing the need for novel interventions beyond conventional therapy to specifically improve independent sitting control. **METHODS:** Seventy-two children aged 3-7 years with BSCP were randomly assigned to either SPMCSEP plus conventional therapy (n=36) or conventional therapy alone (n=36). Both groups received 1-hour sessions, 3 times weekly for 8 weeks. Sitting control was assessed using the Trunk Control Measurement Scale (TCMS) at baseline, 6, and 8 weeks. **RESULTS:** The SPMCSEP group showed statistically significant improvements in TCMS scores compared to the control group at 6 and 8 weeks ($p<0.05$). The intervention yielded a moderate effect size (0.52) and a substantial minimum detectable change (MDC), indicating a clinically meaningful enhancement in independent sitting control attributable to the SPMCSEP intervention. **CONCLUSION:** Incorporating SPMCSEP into rehabilitation programs as an adjunct to conventional therapy can significantly improve sitting control in children with BSCP, potentially supporting their continued motor development. Future studies is warranted to investigate the long-term impact of SPMCSEP on functional abilities and participation.

KEYWORDS: Cerebral Palsy. Sitting Position. Posture. Core Stability. Psychomotor Performance.

RESUMO | OBJETIVO: A capacidade de sentar-se de forma independente, essencial para atividades funcionais cruciais e para o desenvolvimento motor de crianças, é frequentemente prejudicada na Paralisia Cerebral Espástica Bilateral (PCEB) devido a déficits no controle neuromuscular. Este ensaio clínico randomizado e duplo-cego avaliou a eficácia de um Programa de Exercícios de Estabilidade do Core Sensório-Perceptivo-Motor (PEECSM) para melhorar o controle da postura sentada nesta população, abordando a necessidade de novas intervenções além da terapia convencional para melhorar especificamente o controle da postura sentada. **MÉTODOS:** Setenta e duas crianças com PCEB, com idade entre 3 e 7 anos, foram aleatoriamente designadas para o PEECSM mais terapia convencional (n=36) ou apenas terapia convencional (n=36). Ambos os grupos receberam sessões de 1 hora, 3 vezes por semana, durante 8 semanas. O controle da postura sentada foi avaliado utilizando a Escala de Medida de Controle de Tronco (EMCT) na linha de base, 6 e 8 semanas. **RESULTADOS:** O grupo PEECSM mostrou melhorias estatisticamente significativas nos escores da EMCT em comparação ao grupo controle em 6 e 8 semanas ($p<0,05$). A intervenção produziu um tamanho de efeito moderado (0,52) e uma mudança mínima detectável (CMD) substancial, indicando uma melhora clinicamente significativa no controle da postura sentada atribuível à intervenção PEECSM. **CONCLUSÃO:** A incorporação do PEECSM em programas de reabilitação como um complemento à terapia convencional pode melhorar significativamente o controle da postura sentada em crianças com PCEB, potencialmente apoiando seu desenvolvimento motor contínuo. Estudos futuros são necessários para investigar o impacto a longo prazo do PEECSM nas habilidades funcionais e na participação.

PALAVRAS-CHAVE: Paralisia Cerebral. Postura Sentada. Postura. Estabilidade Central. Desempenho Psicomotor.

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1. Background

Cerebral palsy (CP) is an umbrella term for permanent movement and posture development problems[1]. Chauhan et al., in a systematic review, reported a global prevalence of cerebral palsy ranging from 1.5 to 4 per 1000 live births, with India's prevalence falling between 2.08 and 3.88 per 1000 live births and Spastic CP been observed the most prevalent type[2,3].

Independent sitting is a fundamental capability crucial for reaching, performing daily activities, and acquiring functional skills, relying on effective postural and trunk control[4,5]. In children with spastic cerebral palsy, a primary dysfunction is the inability to coordinate postural muscle activation due to neuromuscular control abnormalities, hindering independent upright sitting[6]. Studies show that children with Bilateral Spastic Cerebral Palsy (BSCP) classified as Gross Motor Function Classification System–Extended Revised (GMFC–ER) levels III and IV face significant challenges in achieving this milestone[7,8]. These challenges arise from the complex interplay of impairments, including disrupted postural control, altered proprioception and sensorimotor processing, and weakened trunk muscles[5,9]. The inability to sit independently can adversely affect developmental milestones and functional skill acquisition, thus increasing demands on caregivers[10].

Conventional therapies have primarily focused on addressing abnormal muscle tone, core stability, muscle weakness, and motor control individually, often neglecting the integration of sensory and perceptual inputs with motor outputs[11]. While these approaches provide benefits, they may not fully capture the complexities of postural control deficits. There is a growing recognition of the multifaceted nature of BSCP, prompting the need for innovative, integrated strategies[12]. Although sensory-perceptual motor interventions and core stabilization training have been separately explored to improve movement and postural control in BSCP[5,12,13], a notable gap exists in the literature regarding the effectiveness of a comprehensive intervention that synthesizes these elements, such as the Sensory Perceptual Motor Core Stability Exercise Program (SPMCSEP). The potential synergistic advantages of this combined approach for enhancing sitting control in children with BSCP remain uncertain.

The rationale for a multimodal approach, such as the Sensory-Perceptual Motor Control and Stability Exercise Program (SPMCSEP), is based on the understanding that effective motor development requires the integration of various sensory systems and motor functions, as supported by motor control theories. Postural control, particularly trunk control, is essential for achieving independent sitting[5,9]. A stable trunk is fundamental for maintaining balance and facilitating controlled movements[14]. Trunk control significantly impacts mobility, balance, and daily activity participation, which can reduce caregiver burden[9,14,15]. The SPMCSEP focuses on trunk control through core stabilization exercises combined with sensory and perceptual feedback techniques, aiming to enhance postural control and improve independent sitting in children with bilateral spastic cerebral palsy (BSCP). This program enhances sensory awareness and integration, thereby improving body schema accuracy and postural control. It emphasizes feed-forward control through exercises that challenge anticipatory postural adjustments, while targeting sensory processing, perceptual skills, and core muscle strengthening[13,15-19]. Research by Iona Novak's group supports the importance of early intervention and neuroplasticity in managing cerebral palsy[20]; however, the effectiveness of combined sensory-perceptual and core stability interventions requires further exploration. The SPMCSEP distinguishes itself from traditional methods by its simultaneous focus on these interconnected systems, reinforcing principles of motor learning and neuroplasticity in children with BSCP through innovative therapeutic strategies.

The purpose of this study was to examine the effects of the novel SPMCSEP on enhancing independent sitting control in children diagnosed with BSCP. The hypothesis posited that children with BSCP who receive SPMCSEP in conjunction with conventional therapy would exhibit significantly greater improvements in independent sitting control compared to those who receive only conventional therapy.

2. Method

2.1 Study design

We conducted a prospective, randomized, double-blinded, parallel-group clinical trial with an equal allocation of participants from February 2022 to December 2023 at Puducherry state, India. The study was approved by the Institutional Ethics Committee (ECR/677/Inst/PY/2014/RR-17), adhered to the Declaration of Helsinki, and followed guidelines for research involving human subjects and good clinical practice. We prospectively registered the study in the Clinical Trial Registry of India (CTRI/2022/10/046279).

2.2 Participants

We screened and assessed 187 children with CP for eligibility from the District Intervention Centre, National Health Mission, and local special schools. Seventy-two children with BSCP were selected and enrolled in the study. An informed consent form, with a detailed explanation of the study's purpose, effects and procedures, was collected from parents or legal guardians before the study.

2.3 Inclusion criteria

- Children with spastic BSCP aged 3 to 7 years with the ability to follow verbal instructions without cognitive impairment and classified by GMFCS–ER as III-IV Level.

2.4 Exclusion criteria

- Visual, hearing impairments, and cardiac abnormalities or any impairments that would hinder the implementation of the study intervention.
- History of orthopedic surgery or botulinum toxin injections within the past six months.
- Other forms of cerebral palsy and spastic hemiplegic type of Cerebral Palsy.

2.5 Sample size

Sample size was estimated using a power analysis to compare two independent means. The planned study sample size was calculated based on previous literature by Elanchezhian and SwarnaKumari[21]. A minimum clinically significant difference of 10 points in the Trunk Control Measurement Scale (TCMS) score between the groups was assumed, with a standard deviation of 15. A significant level of 0.05 and a power of 0.80 were selected. Accounting for a 10% dropout rate, a total sample size of 72 (36 in each group) was estimated.

2.6 Randomization and allocation

Demographic information was gathered from children diagnosed with cerebral palsy and their mothers. Following the acquisition of informed consent, participants were randomly assigned to either the SPMCSEP group or the conventional therapy group. This assignment was conducted using a block randomization method via a computer-generated sequence, which was blinded to both the primary investigator and the allocator by an independent research staff member. The group allocations were recorded on paper, folded, and inserted into opaque sealed envelopes by a neutral staff member who was not involved in the study. Subsequently, participants were assigned to their respective intervention groups by the act of opening the sealed envelopes.

2.7 Outcome measure

We assessed independent sitting control using the Trunk Control Measurement Scale (TCMS)[22], and no other secondary outcome were used for this construct. TCMS is composed of 15 items evaluating both static and dynamic aspects of trunk control. The scale comprises two sections: static sitting balance (5 items) and dynamic sitting balance (10 items). The section on dynamic sitting balance is divided into two subscales: selective movement control (7 items) and dynamic reaching (3 items). Heyrman et al., (2011) reported the following psychometric properties for the TCMS: Minimum Detectable Change (MDC): 4.6 points, Intra-rater reliability: ICC = 0.985, Inter-rater reliability: ICC = 0.997, Internal consistency: $\alpha = 0.94522$.

2.8 Baseline measures

Demographic information regarding participants, including age, gender, height, weight, and gestational age of mothers, was obtained through interviews and case records. Each item in the Trunk Control Measurement Scale (TCMS) was assessed using a standardized adjustable chair, where children were positioned without back, arm, or foot support, maintaining upright posture. The best performance from three attempts for each item was recorded for scoring. Each item was rated on a scale from 0 to 3, with higher total scores (0–58) indicating improved trunk control. Assessments were conducted by a trained pediatric physiotherapist who was blinded to group allocation, ensuring consistency through a standardized training protocol. Intra-rater reliability was established with intraclass correlation coefficients (ICCs) exceeding 0.90. The mothers of children with cerebral palsy were also blinded to group allocation. Outcome measures were assessed at baseline, after six weeks to minimize attrition bias, and again at eight weeks into the intervention.

2.9 Procedure

All participants in this study were evaluated prior to the intervention to assess their impairments and GMFC-ER scaling, adhering to the SPIRIT guidelines. The SPMCSEP group received conventional therapy along with SPMCSEP, while the conventional therapy group engaged in strength training, passive stretching, functional training, and coordination training within the established treatment framework.

2.10 Intervention

The Specialized Program for Motor Control and Sensory Enhancement for Pediatric Populations (SPMCSEP) involves a series of tailored exercises developed with the understanding that cerebral palsy (CP) is a complex condition affecting multiple developmental domains. This program integrates sensory, perceptual, and motor training[23,24] based on principles of motor learning theories[25,26] to address the interrelated challenges faced by children with Bilateral Spastic Cerebral Palsy (BSCP).

2.10.1 Therapeutic tools used for SPMCSEP

2.10.1.1 Sensory tools

- Heavy blankets. To offer deep pressure input and improve the body awareness.
- Sensory brushes for tactile stimulation and sensory integration.

2.10.1.2 Therapeutic exercise balls

- Peanut balls.
- Bolsters.
- Foam mats.

2.10.1.3 Motor, and core stability tools

- Balance boards to improve coordination and balance.
- Small equipment includes cones, markers, and bean bags for dynamic exercises and games.
- Small soft Balls.

2.10.1.4 Perceptual equipment

• Mirrors to improve body awareness and visual feedback.
• Soft toys.

2.10.2 Components of the intervention

Each SPMCSEP session begins with a 10-minute segment of conventional therapy, including range-of-motion exercises, strength training, and passive stretching. This precedes core stability exercises, perceptual skills activities, and sensory integration tasks, each lasting approximately 15 minutes.

- Core stability exercises: Include supine and prone weight shifts, rolling, pelvic bridging, and trunk rotations.

- Perceptual skills exercises: Include peg board activities, puzzles, obstacle crossing, and mirror play.
- Sensory integration: Includes tactile stimulation, vestibular input through swings, and proprioceptive input through weighted blankets.
- Visual tracking activities.
- Bilateral motor coordination activities.
- Tactile stimulation and therapist handling guidance through subtle cues, light facilitation, and environmental manipulation to promote independent movement initiation.
- Each exercise is performed with appropriate rest intervals to prevent fatigue.
- Progression: The intensity, duration, and complexity of exercises are gradually increased based on the child's progress and tolerance.
- Feedback: The therapist provides verbal and tactile feedback to guide the child's movements and promote learning.

Each exercise is performed in sets of 8 to 10 repetitions, with adjustments made based on the child's progress. The main objective is to empower the child to initiate movements independently by engaging their core muscles. The sessions are conducted three times weekly for eight consecutive weeks. Throughout the intervention, we monitored for adverse effects, with no issues reported related to the SPMCSEP program.

2.10.2.1 Conventional therapy

Participants received conventional therapy, typical for children with Bilateral Spastic Cerebral Palsy (BSCP), including strength training, passive stretching, functional training, and coordination training, standardized as much as possible.

Key components were:

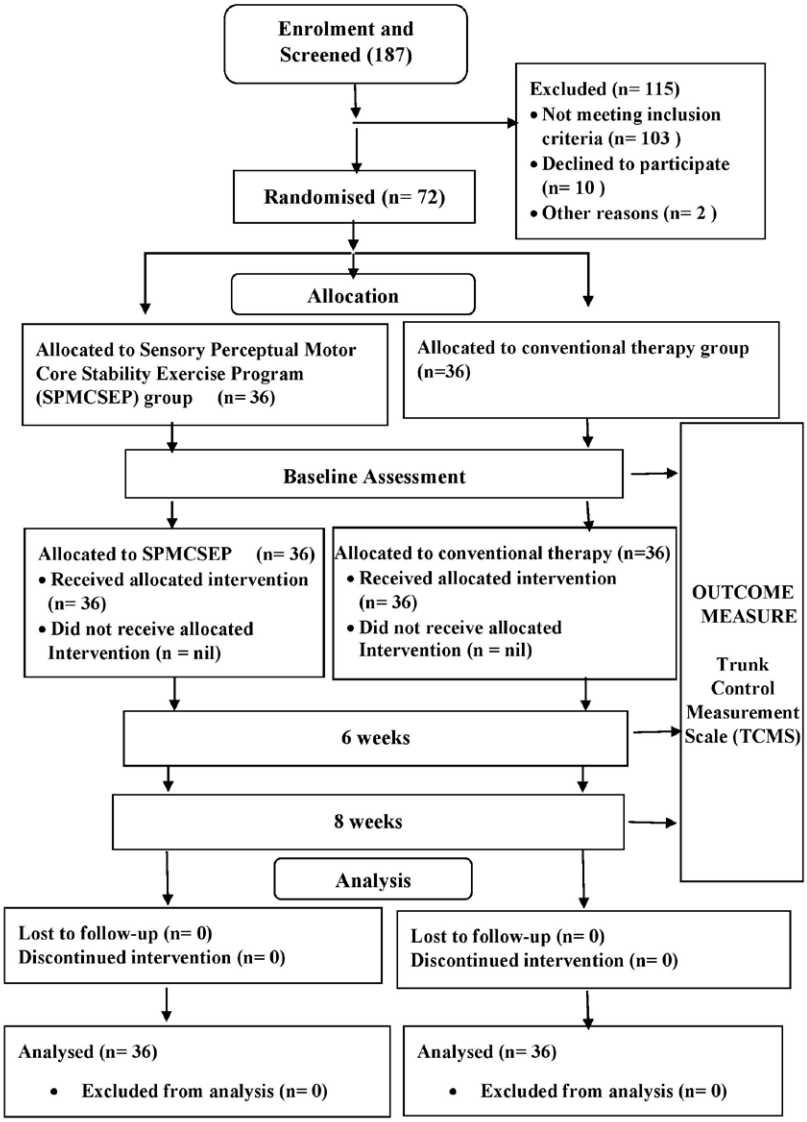
- Strength training (e.g., active assisted range of motion, Theraband exercises).
- Passive stretching.
- Functional training (e.g., supported sitting, transfers).
- Coordination training (e.g., balance exercises).

Conventional and SPMCSEP therapy sessions were matched: 1-hour, 3 times/week for 8 weeks.

2.11 Statistical data analysis

Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS), version 27.0 (SPSS, Chicago, Illinois), and results were reported according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines (see Figure 1). The normality of all variables was assessed using the Kolmogorov-Smirnov test. Due to non-normal data distribution, descriptive statistics were presented as median and interquartile range (IQR). Categorical and dichotomous variables were analyzed with the Chi-square test of independence. Within-group comparisons utilized the Wilcoxon test, while between-group comparisons employed the Mann-Whitney U test, with statistical significance set at $p < 0.05$. The effect size index (d) for each TCMS domain was calculated from the Z score and classified as small ($0.1 < \text{Effect} \leq 0.3$), medium ($0.3 < \text{Effect} \leq 0.5$), or large (Effect > 0.5).

Figure 1. Study flow chart according to CONSORT – Guidelines for reporting of trial



Source: the authors (2025).

3. Results

We screened 187 children with spastic cerebral palsy for eligibility at the beginning of the study. Seventy-two children of both sexes, aged 3 to 7 years, with cerebral palsy participated in this study. Kolmogorov-Smirnov test indicated a significant deviation from normality for our continuous TCMS data, supporting the use of the Wilcoxon and Mann-Whitney U tests for within- and between-group comparisons, respectively.

Table 1. Age and gender distribution of study participants

AGE	GROUP				TOTAL (n = 72)		Chi–Square value	p - Value
	Conventional Group (n = 36)		SPMCSEP Group (n = 36)					
3	9	25.0%	4	11.1%	13	18.1%	2.599	0.458
4	16	44.4%	21	58.3%	37	51.4%		
5	7	19.4%	7	19.4%	14	19.4%		
6	4	11.1%	4	11.1%	8	11.1%		
Mean Age	4.16		4.30					
GENDER								
Female	16	44.4%	17	47.2%	33	45.8%	0.056	0.813
Male	20	55.6%	19	52.8%	39	54.2%		

Source: the authors (2025).

Table 1 presents the demographic characteristics of the study participants in terms of age and gender distribution. Both groups had a relatively balanced gender distribution, with a slight majority of males in the conventional group and a slight majority of females in the SPMCSEP group. No statistically significant differences were observed between the conventional and SPMCSEP groups for either age ($p = 0.458$) or gender ($p = 0.813$). This suggests that the two groups matched in terms of these demographic factors.

Table 2. Comparison of anthropometric measures between groups

Anthropometric measures	Conventional Group Median (IQR) (n = 36)	SPMCSEP Group Median (IQR) (n = 36)	Mann-Whitney U	P value
Height cm	98 (89,101)	99 (96,100)	542	0.232
Weight kg	12 (10,13)	12 (11,13)	592	0.528
Birthweight kg	2 (2,2)	2 (2,3)	511	0.120
Gestational age Months	37 (36,39)	37 (36,38)	539	0.210

Source: the authors (2025).

Table 2 presents a comparison of anthropometric measures between the conventional and SPMCSEP groups. We found no statistically significant differences ($p > 0.05$) for the variables examined. This suggests that the two groups were identical in terms of physical characteristics, further strengthening the internal validity of the study.

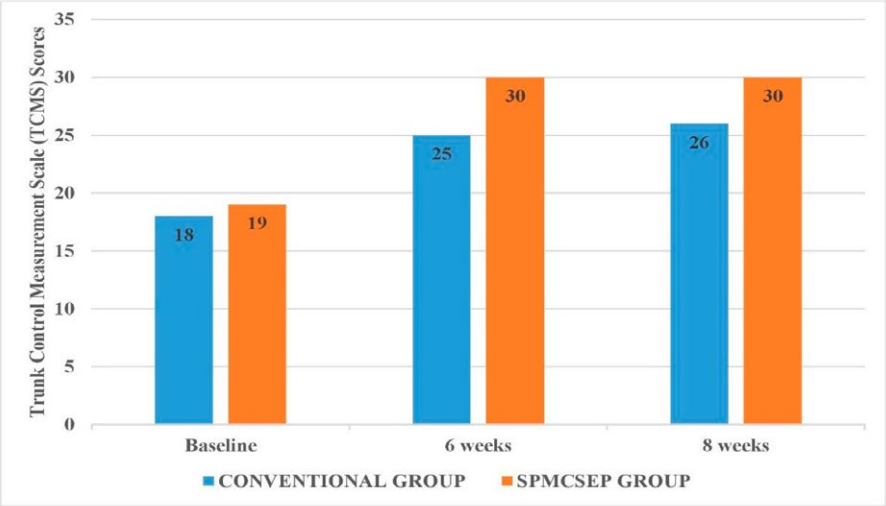
Table 3. Comparison of Trunk Control Measurement Scale (TCMS) scores between groups

	Conventional Group Median (IQR) (n = 36)	SPMCSEP Group Median (IQR) (n = 36)	Mann-Whitney U	P value	Z value	Effect size
Static Sitting Balance (SSB)						
Baseline	12 (10,13)	12 (11,14)	584	0.464	0.732	
6 weeks	14 (13,16)	15 (14,16)	478	0.053	1.939	0.23
8 weeks	15 (13,16)	16 (14,17)	500	0.090	1.696	0.20
Selective Movement Control (SMC)						
Baseline	5 (4,5)	5 (4,5)	630	0.831	0.213	
6 weeks	8 (7,9)	10 (9,11)	227	<0.001*	4.839	0.57
8 weeks	9 (7,9)	10 (9,11)	276	<0.001*	4.294	0.51
Dynamic Reaching (DR)						
Baseline	2 (2,3)	2 (2,4)	579	0.404	0.834	
6 weeks	3 (2,3)	5 (4,6)	111	<0.001*	6.325	0.75
8 weeks	3 (2,3)	5 (4,6)	97	<0.001*	6.392	0.75
Trunk Control Measurement Scale						
Baseline	18 (16,21)	19 (17,22)	578	0.428	0.793	
6 weeks	25 (22,27)	30 (26,33)	257	<0.001*	4.418	0.52
8 weeks	26 (23,28)	30 (27,33)	258	<0.001*	4.407	0.52

*Statistically significant at 5% level of significance
Source: the authors (2025).

Table 3 depicts the comparison of TCMS scores between the conventional and SPMCSEP groups, revealing significant differences in the Selective Movement Control (SMC) and Dynamic Reaching (DR) subscales at both 6 and 8 weeks of follow-up ($p < 0.001$). The SPMCSEP group consistently revealed higher median scores in these subscales, implying superior trunk control. Although there were no statistically significant differences in the Static Sitting Balance (SSB) subscale, both groups showed improved median scores after the intervention. However, the SPMCSEP group consistently outperformed the conventional group in terms of SSB scores. Overall, the TCMS scores established a significant difference between the groups at 6 and 8 weeks ($p < 0.001$). Participants in the SPMCSEP group exhibited higher median TCMS scores, attributing greater overall improvement in trunk control (Figure 2).

Figure 2. Clustered column chart: comparison of Trunk Control Measurement Scale (TCMS) between groups



Source: the authors (2025).

The analysis revealed a large effect size of 0.52 for the overall TCMS scale, suggesting a substantial difference between the groups. Large effect sizes were observed for the Selective Movement Control (0.57) and Dynamic Reaching (0.75) subscales, further emphasizing the effectiveness of the SPMCSEP in improving these specific aspects of trunk control.

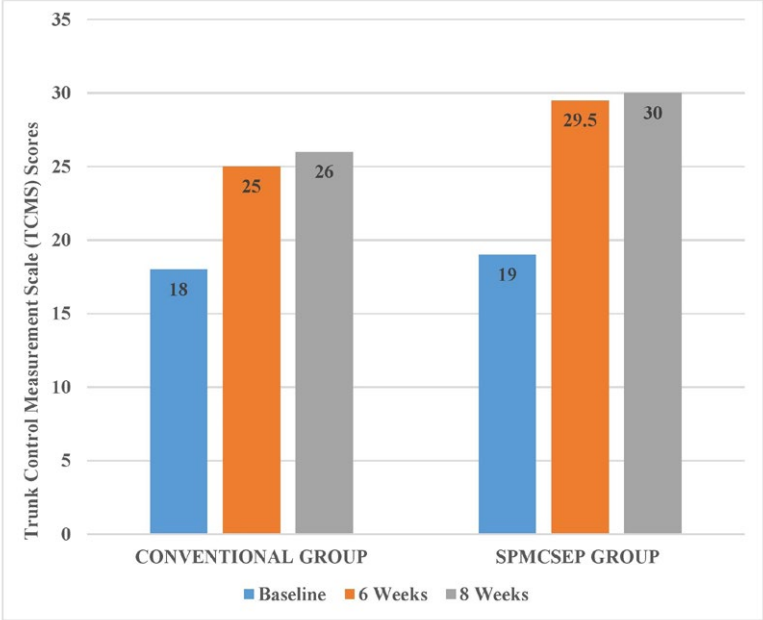
Table 4. Comparison of TCMS scores at each follow-up within groups

TCMS		Median (IQR)	Baseline vs 6th and 8th week P value	6th week vs 8th week
Control	Baseline	18 (16,21)	-	-
	6 weeks	25 (22,27)	<0.001*	<0.001*
	8 weeks	26 (23,28)	<0.001*	
Experimental	Baseline	19 (17,22)	-	-
	6 weeks	29.5 (26,33)	<0.001*	<0.001*
	8 weeks	30 (27,33)	<0.001*	

*Statistically significant at 5% level of significance
Source: the authors (2025).

Table 4 presents the within-group analysis of TCMS scores using the Friedman test revealed a statistically significant difference between time points for both the conventional and SPMCSEP groups. This suggests that improvements in trunk control occurred over time within each group. To identify specific time points at which significant changes occurred, we conducted Wilcoxon signed-rank test. The results revealed statistically significant improvements in TCMS scores from baseline to both 6 and 8 weeks of follow-up ($p < 0.001$*) in both the conventional and SPMCSEP groups. This suggests that the intervention had a positive impact on trunk control over time, even in the conventional group that received only conventional therapy. The within-group analysis shows that both groups experienced overall improvements in trunk control development, as illustrated in Figure 3. However, the SPMCSEP group achieved greater improvements compared to the control group, suggesting the added benefit of the SPMCSEP intervention.

Figure 3. Clustered column chart: comparison of TCMS scores at each follow-up within group



Source: the authors (2025).

4. Discussion

This study primarily aimed to evaluate the effectiveness of a novel Sensory Perceptual Motor Core Stability Exercise Program (SPMCSEP) in improving independent sitting control in children with Bilateral Spastic Cerebral Palsy (BSCP). The main quantitative findings revealed a statistically significant improvement in Trunk Control Measurement Scale (TCMS) scores in the SPMCSEP group compared to the conventional therapy group ($p < 0.05$) after the eight-week intervention. The reported moderate effect size ($d=0.52$) and Minimum Detectable Change (MDC) indicate a clinically meaningful improvement. An effect size of this magnitude suggests that the SPMCSEP intervention resulted in a noticeable and practical change in children's sitting ability. This improvement is likely to translate to real-world benefits, such as enhanced participation in daily activities, improved interaction with their environment, and reduced need for support from caregivers. While statistical significance indicates the reliability of the finding, the effect size provides a measure of the magnitude of the treatment effect. In this context, the moderate effect size supports the adoption of SPMCSEP as a clinically relevant intervention for improving sitting control in children with BSCP. These findings directly address the identified gap in the literature regarding the integrated application of sensory-perceptual and core stability training for this population, demonstrating the potential benefit of this multimodal approach beyond conventional therapy alone. The observed improvements in independent sitting control have significant functional and clinical implications, potentially leading to enhanced mobility, greater independence in activities of daily living, and a reduced burden on caregivers.

Our findings align with the growing recognition of the importance of addressing both motor and sensory-perceptual impairments in children with cerebral palsy. While previous studies have explored core stability and sensory-perceptual interventions separately, this study provides evidence for the effectiveness of their integration in the form of SPMCSEP. To further contextualize our results, we acknowledge the significant contributions of Iona Novak's research group, in prioritization of early intervention to capitalize on neuroplasticity and improve long-term outcomes[20]. SPMCSEP, focusing on a fundamental functional outcome (independent sitting control) and integrated approach, can be viewed as an intervention that aligns with these principles. Further research should explicitly compare SPMCSEP to interventions categorized as effective in Novak's reviews to solidify its place within the evidence-based practice framework[20]. Our findings contribute to this body of knowledge by demonstrating the potential of an early interventional integrated approach, based on the principles of neuroplasticity aiming to establish foundational motor skills may offer advantages over traditional methods by synergistically targeting multiple underlying deficits.

Research reveals that children with BSCP often struggle with poor trunk control because of various neurophysiological issues, weak trunk muscles, and inadequate core stability, hindering their ability to sit independently[5,9]. Children with cerebral palsy often face challenges in interpreting, integrating, and engaging sensory information from the body and environment, leading to difficulties in planning and executing organized motor behaviors like sitting control[15,27,28]. The SPMCSEP may have helped children with spastic cerebral palsy improve their ability to maintain an upright sitting position by enhancing sensory awareness, proprioception, weight symmetry, and maintenance of the body's center of mass (COM) within the base of support[4,9,29]. These improvements could have altered sensory input to the central nervous system, potentially affecting the child's perception and execution of movement control[5,10,15,18,20,27]. However, we acknowledge that this study did not directly measure these underlying mechanisms and it is important to note that our study primarily measured functional sitting control, and future research directly assessing these specific mechanisms is warranted to further elucidate the pathways of change.

Children with cerebral palsy often have impaired feed-forward control, contributing to postural instability[29]. SPMCSEP's focus on postural disturbances and directionally specific responses may enhance feed-forward control, leading to faster reaction times and improved sitting[27,29-31]. SPMCSEP's core stability exercises and symmetrical weight distribution may improve trunk stability, postural alignment, movement, and responses to postural disturbances. These findings align with core stability training research[28,30,32]. However, unlike conventional approaches, SPMCSEP integrates core stability exercises with sensory and perceptual training, potentially explaining our enhanced outcomes. While conventional therapies improve motor function in children with cerebral palsy[11,20,30], the uncertainty in efficacy evidence for many standard care interventions is a problem, warranting further research across cerebral palsy types and severities. This study addresses this gap by examining SPMCSEP's effectiveness for children with BSCP.

Children with cerebral palsy often exhibit atypical postural control patterns, a preference for top-down muscle recruitment, and a limited ability to adjust to postural activity[4,5]. The SPMCSEP may have contributed to improved postural control by providing targeted sensory input and training specific motor patterns to address these underlying deficits. However, further research is needed to confirm these potential mechanisms.

This study demonstrates the efficacy of SPMCSEP in improving sitting control in children with BSCP. However, several limitations should be considered when interpreting these findings. While the study's focus on Independent sitting control and restriction to children with BSCP at GMFCS levels III-IV were methodological design choices, other limitations include the single-center design, which may limit the external validity and generalizability of the results to broader clinical populations. The potential for unintentional bias, despite evaluator blinding, cannot be entirely excluded. Future research should include multi-center trials with more diverse populations, including children with different CP subtypes, severity levels, and age ranges, to determine the broader applicability of this intervention. Further investigation is also needed to explore the influence of factors such as healthcare infrastructure, therapist expertise, and adherence in real-world settings on the translation of these results.

5. Clinical implication

The findings of this study support the integration of SPMCSEP into the treatment of children with BSCP. By targeting specific sensory, perceptual, and motor components, SPMCSEP appears to be a valuable adjunct to traditional therapies. The improved trunk control achieved through this intervention can positively influence independent sitting, participation in play activities, various aspects of daily living, and lower caregiver workload.

6. Conclusion

This study demonstrates that an 8-week SPMCSEP, when added to conventional therapy, can improve sitting control, as measured by the TCMS, in children with BSCP at GMFCS levels III-IV. The improvements observed suggest that incorporating SPMCSEP into rehabilitation programs may offer an additional benefit beyond conventional therapy alone for this specific population. The results provide strong evidence for the efficacy of SPMCSEP in improving trunk control and facilitating the attainment of independent sitting control in children with BSCP. Improvements seen in the SPMCSEP group are encouraging, further research is needed to isolate the unique contribution of SPMCSEP and to determine its long-term effects in the development of other milestones. functional outcomes, and participation in activities of daily living.

Authors contributions

The authors declared that they have made substantial contributions to the work in terms of the conception or design of the research; the acquisition, analysis or interpretation of data for the work; and the writing or critical review for relevant intellectual content. All authors approved the final version to be published and agreed to take public responsibility for all aspects of the study.

Competing interests

No financial, legal, or political conflicts involving third parties (government, private companies, and foundations, etc.) were declared for any aspect of the submitted work (including but not limited to grants and funding, advisory board participation, study design, manuscript preparation, statistical analysis, etc.).

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