

Impact of Hippotherapy on Dynamic Postural Control Based on Centre of Pressure Analysis and Functional Performance in Children with Cerebral Palsy

Short title: Balance and CoP in Children with CP

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ABSTRACT

The long-term impact of hippotherapy on dynamic postural balance and functional performance in children with cerebral palsy (CP) remains insufficiently understood. This study aimed to assess the effects of a 40-session hippotherapy program on dynamic postural balance and functional performance in children with CP, compared to typically developing (TD) children. This pre-experimental longitudinal, observational-comparative study included 18 children (4–14 years) with spastic CP who underwent a 40-session hippotherapy program, with assessments at baseline and after 20 and 40 sessions. Outcomes were compared to an age-matched neurotypical control group. Participants were assessed for dynamic postural balance across four randomised tasks- riding in a straight line and on a zigzag path, both with eyes open (EO) and closed (EC)- as well as in two functional performance tests. Improvements in dynamic postural balance and functional performance were observed after both 20 and 40 sessions. The centre of pressure displacement (LengthCoP) during straight-line riding with EO and EC showed a reduction from baseline. Initially, children with CP showed greater postural sway than their TD peers, but by the end of the intervention, both groups had similar LengthCoP and mediolateral centre of pressure amplitude values. Findings suggest that long-term hippotherapy can improve motor function in this population.

KEYWORDS: Cerebral Palsy, Equine-assisted therapy, Dynamic Balance, Functional Performance, Hippotherapy.

INTRODUCTION

Cerebral palsy (CP) is a neuromotor disorder that affects movement development, muscle tone, and posture (Graham et al., 2016). While the initial neuropathological lesion is non-progressive, children with CP often develop secondary conditions that can significantly impact their functional abilities (Patel, Neelakantan, Pandher, & Merrick, 2020). One common challenge they face is a deficit in dynamic postural balance and functional performance. Since CP manifests early in infancy and continues throughout an individual's lifetime, addressing these deficits in the context of ongoing development and functioning is essential (P. Rosenbaum & Gorter, 2012). Therefore, interventions are critical to improve the functioning and well-being of children with CP and their families. These interventions can help prevent secondary musculoskeletal impairments and enable families to establish a successful life plan for their children despite developmental challenges (Graham et al., 2016).

Hippotherapy has emerged as a promising intervention for children with CP (Novak et al., 2020). Moderate evidence supports its efficacy in improving postural balance and functional performance (Moraes, Copetti, Ângelo, Chiavoloni, & de David, 2020; Moraes, Copetti, Angelo, Chiavoloni, & David, 2016). The therapeutic benefits are attributed to the horse's three-dimensional movement, which continuously stimulates the systems that maintain balance. However, despite these promising findings, the available evidence presents important methodological limitations, including small sample sizes, heterogeneous intervention protocols, short intervention durations, limited use of objective biomechanical measures, and, in several cases, the absence of appropriate control groups. These limitations restrict the generalizability of results and hinder a deeper understanding of the mechanisms underlying postural adaptations induced by hippotherapy. Studies have shown improvements

in sitting postural control (Fernández-Gutiérrez, Apolo-Arenas, Martínez-García, & Caña-Pino, 2015; Kang, Jung, & Yu, 2012; Moraes et al., 2020, 2016), as well as in functional performance (Reubens & Silkwood-Sherer, 2016; Seung Mi, Ji Young, Hye Yeon, Yun Sik, & Jeong Yi, 2019; Silkwood-Sherer & McGibbon, 2022), following hippotherapy programs. Nevertheless, most of these investigations have primarily focused on static postural outcomes or clinical measures, providing limited insight into dynamic postural control assessed during horseback riding activity itself.

However, dynamic postural balance during hippotherapy-particularly when assessed using objective biomechanical measures and longitudinal designs-remains largely underexplored. During hippotherapy, various strategies are employed to enhance patients' postural control. These include active stretching exercises, navigation along straight and zigzag paths, and adjustments to the patient's orientation on the horse. Additionally, techniques such as blindfolds, modifying the horse's speed, and altering the type of terrain are commonly used (Moraes et al., 2020). Another important aspect in task manipulation during hippotherapy involves varying the equipment. This includes choices such as using a saddle or a blanket, the position of the feet - either supported in the stirrups or free - and the placement of the hands, either on the thigh or holding the handle, as described in the literature (Espindula et al., 2014, 2013; Hennig, Luís da Silva, Zanetti, & Copetti, 2024; Jr, Ag, Sa, Kg, & Lv, 2020; Ribeiro et al., 2019; Silva et al., 2021). Moreover, studies have examined the effects of horse speed and support surface stiffness on the postural responses during practised horseback riding (Fabiana M. Flores, Dagnese, Mota, & Copetti, 2015; Fabiana Moraes Flores, Dagnese, & Copetti, 2019). One study also examined the combined effects of surface stiffness with the use of a blanket or saddle (Menezes et al., 2019). However, to date, no research has systematically examined the interaction between riding tasks and the

manipulation and visual system modulation during hippotherapy, despite its frequent use in clinical practice. This gap in the literature is a critical disconnect between applied therapeutic strategies and the current scientific evidence, underscoring the need for experimental protocols capable of integrating multiple tasks and sensory constraints.

Despite the promising outcomes associated with hippotherapy, there is no consensus in the literature regarding the optimal number of sessions over time. This lack of consensus reflects important inconsistencies in study designs and intervention protocols, as well as the scarcity of longitudinal investigations capable of capturing adaptations in dynamic postural control over time. Research suggests that the frequency of sessions per week does not significantly impact improvements in gross motor function and functional performance of children with CP (Vidal et al., 2021). Previous studies have investigated interventions ranging from a single session (MacPhail et al., 1998) to as many as 48 sessions (Mutoh et al., 2019), with the most commonly studied interventions involving 12 to 16 sessions (Wood & Fields, 2021). Such wide variability in intervention dosage limits comparisons across studies and restricts conclusions regarding dose-response effects. However, no studies have yet evaluated changes in dynamic balance over time. Regarding functional performance, improvements have been reported after 6 (Silkwood-Sherer, Killian, Long, & Martin, 2012), 8 (Kwon et al., 2011, 2015), 10 (Reubens & Silkwood-Sherer, 2016), 12 (Lee, Kim, & Na, 2014; Silkwood-Sherer & McGibbon, 2022), and 16 (Seung Mi et al., 2019) hippotherapy sessions in various studies.

This study aimed to evaluate the effects of a 40-session hippotherapy program on dynamic postural balance in children with CP. Additionally, we sought to compare their performance to that of typically developing (TD) children with prior horseback riding experience. Dynamic postural balance was assessed through the centre of pressure (CoP) and

CoP-derived variables during horseback riding, reflecting postural control demands under ecologically valid and task-specific conditions. Improvements in CoP-derived variables of dynamic postural control during riding are expected to translate into enhanced functional performance in daily activities, which was assessed using standardised clinical tests. Functional performance in children with CP was also measured as a complementary clinical outcome. We hypothesised that the 40-session hippotherapy program would lead to significant improvements in dynamic postural balance in children with CP, bringing their performance to a level comparable to that of TD children with similar horseback riding experience. Furthermore, we expected children with CP to demonstrate positive gains in functional performance.

METHODS

Study design

The study utilised a pre-experimental longitudinal, observational-comparative design, with participants selected through non-probability convenience sampling. Participants were classified and characterised according to the topographic classification of CP and the Gross Motor Function Classification System (GMFCS) (Palisano et al., 1997).

Although the inclusion of a TD control group allows for between-group comparisons, the absence of a CP group without intervention limits causal inference regarding the effects of hippotherapy. Therefore, the study design supports the analyses of temporal changes and group differences but does not allow definitive conclusions regarding intervention efficacy.

This study received approval from the Ethics Committee (No. 6.003.457) and was registered with the Brazilian Clinical Trials Registry (Identifier: RBR-534ppvp).

Participation in the study was entirely voluntary. Written informed consent was obtained from the legal guardians of all participating children, ensuring compliance with ethical research standards. Additionally, the children provided their assent to participate, affirming their understanding and willingness to be involved in the study.

Participants

This study involved 18 children diagnosed with spastic CP, aged 4–14 years (mean age 7.8 ± 2.5 years, 5 boys, 13 girls). Participants were distributed across GMFCS levels I–IV, reflecting a heterogeneous clinical profile typical of pediatric CP populations. All participants underwent comprehensive medical, physical, and psychological assessments to determine their eligibility and suitability for hippotherapy. Inclusion criteria were: a confirmed diagnosis of CP, age between 4 and 14 years, GMFCS levels I–IV, the ability to follow simple instructions, independent sitting ability, and a minimum of 20 degrees of hip abduction.

Participants engaged in a structured hippotherapy program. All participants had been receiving conventional therapies prior to study enrollment, which were maintained without changes throughout the intervention period and were not considered part of the study protocol. Exclusion criteria included uncorrected visual and/or auditory impairments, surgical procedures within the past 12 months, or chemical neuromuscular blockade within six months prior to or during the study.

A matched control group of 18 typically developing children, aged 4–14 years (7.8 ± 2.5 years; 8 boys, 10 girls), was included for comparative purposes. Control participants were matched with the CP group by age and sex and had a minimum of 12 months of horseback

riding experience, in order to ensure familiarity with the riding environment. They were recruited from a specialised equestrian school to ensure consistent motor and sensory exposure to horseback riding across groups. Therefore, the group TD supports the analysis of temporal changes and group differences but does not allow definitive conclusions regarding intervention efficacy.

Procedures

Dynamic postural balance

Dynamic postural balance was assessed during horseback riding tasks during hippotherapy sessions, for both children with CP and TD, using a portable pressure measurement system (CONFORMat®, Model 5330, Tekscan, Boston, USA) placed on the horse's blanket. The system consists of a pressure-sensitive mat with 1024 sensors arranged in a 32 x 32 grid, offering a spatial resolution of 1.47 cm. The mat was connected to a computer via USB. Sensor calibration was performed using the VB5A Vacuum Pressure Calibration System, which standardises and normalises the readings according to the manufacturer's specification and previously validated protocols (Fabiana M. Flores et al., 2015).

For data acquisition, the pressure mat was positioned over the saddle and under a blanket on a Criollo horse. The participants sat on the mat in the riding position with their feet supported by stirrups, allowing accurate measurement of pressure distribution across the buttocks and thigh contact areas.

The system was manually activated from a predefined reference point on the ground, with data acquisition performed over 10 seconds (Espindula et al., 2013; Fabiana Moraes

Flores et al., 2019) at a sampling frequency of 100 Hz (Duarte & Freitas, 2010). Data collection took place in a controlled arena measuring 28 m × 12 m with a sand floor. The Criollo horse used for the assessments had a withers height of 1.45 m, weighed 390 kg, and exhibited understepping (hind foot landing behind the forefeet). The horse moved at a self-selected pace, maintaining an average stride speed of 1.25 m/s. Both the horse and assistant guides remained unchanged throughout all assessments to ensure consistency.

Participants completed four randomised tasks: riding in a straight line with open eyes (EO), riding in a straight line with closed eyes (EC), and riding along a zigzag path with EO and EC. Each task was repeated three times. In the zigzag task, four cones were placed in a straight line, with a distance of 3 meters apart. Key outcome CoP-derived variables included the amplitude of anteroposterior displacement (ACoPap), amplitude of mediolateral displacement (ACoPml), and total path length of the centre of pressure (LengthCoP).

Data for the CP group were collected at three time points: baseline (A1), after 20 sessions (A2), and at the conclusion of the 40-session hippotherapy program (A3). The TD control group, composed of children with prior horseback riding experience, was assessed only once under identical conditions, using the same horse, team, and assessment protocol as applied to the CP children group.

Functional performance

Functional performance data were collected using two different assessment tools at three time points: baseline (A1), after the 20th hippotherapy session (A2), and after the 40th session (A3). The first assessment was the Pediatric Reach Test (PRT). Participants maintained a standardised sitting posture according to the protocol described by Bartlett &

Birmingham (Bartlett & Birmingham, 2003). Concurrently, the AccuSway Plus force platform (Advanced Mechanical Technologies, Inc., Watertown, USA) was employed to measure the CoP (Bartlett & Birmingham, 2003; Duncan, Weiner, Chandler, & Studenski, 1990). The following CoP-derived variables were analysed: average speed of the CoP (VAvg), amplitude of displacement in the anteroposterior direction (ACoPap), and amplitude in the mediolateral direction (ACoPml). The force platform also measured the CoP distance, defined as the difference between the initial and final positions, with greater distances indicating better dynamic reach.

Each condition was tested in three trials (Bartlett & Birmingham, 2003), with a 1-minute rest interval between them. The sampling frequency was set at 100 Hz (Duarte & Freitas, 2010), and each trial lasted 8 seconds. Collected data were low-pass filtered at 10 Hz to eliminate high-frequency noise (Stins et al., 2009). The CoP-derived variables were subsequently processed using Balance Clinic software. PRT performance, expressed in centimetres (cm), was also measured manually using a measuring tape to determine the initial and final positions. Measurements were taken in three directions: anterior, left lateral, and right lateral.

In addition to the PRT, the Pediatric Balance Scale (PBS) was used to evaluate functional balance performance in children with CP. The PBS consists of 14 items, each scored on a 0–4-point scale, with a maximum score of 56. Higher scores indicate better balance. The scale includes a range of tasks designed to assess both static and dynamic balance in daily environments, including home, school, and community settings (Ries et al., 2012).

Intervention

The protocol was conducted at the Hippotherapy Centre, using five trained horses (mean wither height 1.43 ± 0.05 m; mean mass 378 ± 31.7 kg), all mixed breed (SRD). Horses were equipped with blankets, straps, and stirrups. Experienced trainers guided the horses throughout the sessions, which were supervised by a licensed physiotherapist. An additional professional was positioned beside the horse to ensure safety and to assist with the activities when necessary.

The physiotherapist, acting as the primary clinician, was responsible for implementing the intervention and overseeing all hippotherapy activities. This included making clinical decisions about each child's participation, ensuring appropriate task intensity, and adapting the intervention to meet individual needs. Participants engaged in a structured 30-minute hippotherapy session once per week for 40 consecutive weeks. Each session began with 20 minutes in an indoor riding arena with a sand floor, followed by 10 minutes in an outdoor arena with an asphalt surface. The intervention followed a standardised protocol, with adaptations made based on the participant's physical fitness, task performance, and fatigue levels. Although the core activities were consistent across participants, the execution time and level of assistance were tailored to each child's capacity for independent task execution. The activities performed during the sessions, adapted from a previous study (Moraes et al., 2020), are detailed in Table 1.

Table 1. Description of the Intervention Protocol.

Stretching and warming up (5 minutes)		Surface
1	Hands on horse's neck	Sand
2	Hands on horse's hip	Sand
3	Right hand on the left foot	Sand
4	Left hand on the right foot	Sand
5	180° shoulder abduction while holding a hoop	Sand
6	Left knee extension	Sand
7	Right knee extension	Sand
Balance, mobility and functional exercises (23 minutes)		
8	Serpentine movement throwing hoops on a cone	Sand
9	Throw and grab a ball	Sand
10	Cones with an approximate distance of 2 meters between 4 cones, performing shoulder abduction at 90° and 180° and shoulder flexion at 90°	Sand
11	Blindfolds while the horse moves in a straight line and curves	Sand
12	Facing the horse's head, side or back, performing shoulder abduction at 90° and 180° and shoulder flexion at 90°	Sand
13	Standing on the stirrups	Sand
14	Increase and decrease the frequency, amplitude, and speed of the horse's stride, and stop and go	Asphalt
15	Uphill and downhill rides	Grass
16	Memory game (1°: lie down; 2°: sit down; 3°: hands on head; 4°: hands on belly; 5°: rotate arms)	Asphalt
17	Conduct independent horse (walk/trot) *	Sand
18	Dual task: conduct the horse to a marked place, memorise words, and return and speak the memorised words*	Sand
19	Short obstacle courses*	Sand
Cooling-down (2 minutes)		
20	Hug on the horse	Sand

Note: During exercises 1-16, a horse handler led the horse; * indicates exercises performed by children able to conduct the horse independently.

Statistical Analysis

Dynamic postural balance

Descriptive statistics are presented as means $\pm$ standard deviations (SD). The data did not meet normality assumptions (Shapiro-Wilk test). Therefore, to compare CoP behaviour

across groups (children with CP and TD children) and tasks, a generalised linear model (GLM) was employed. This method offers flexibility in handling different data types and distributions. Given the nonparametric nature of the data, a gamma distribution was used to model CoP-derived variables, with an identity link function, appropriate for continuous, positively skewed outcomes modelled on their original scale. Model optimisation was performed by selecting the models with the lowest Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) values (de Melo, Daldegan-Bueno, Menezes Oliveira, & de Souza, 2022). Model adequacy was further evaluated through information criteria and inspection of model fit indicators.

Functional performance

Descriptive statistics are presented as means $\pm$ standard deviations (SD). The data did not meet normality assumptions (Shapiro-Wilk test). To assess the effect of the intervention on outcome CoP-derived variables in children with CP at three different time points, a generalised estimation equation (GEE) was employed. This method accounts for repeated measurements taken from the same subjects over time, recognising the inherent correlation between measurements from the same participant (de Melo et al., 2022; Fabiana Moraes Flores et al., 2019). Given the non-parametric nature of the data, a gamma distribution was applied, with an identity link function.

For both, there were no missing data or imputations. The model was adjusted for potential confounding, including age, weight, sex, GMFCS level, topography, and hip adduction as measured by the Modified Ashworth Scale (MAS). Model fit was optimised by selecting the configuration with the lowest quasi-likelihood under the independence model

criterion (QIC). Model adequacy was verified using QIC values and overall model fit diagnostics. Effect sizes were calculated using Cohen's *d*, with thresholds of 0.2 (small), 0.5 (medium), and >0.8 (large) (Cohen, 2013). Effect sizes were derived from observed means and standard deviations across groups and time points, and are reported to support clinical interpretability and comparability with prior rehabilitation literature. They are presented as complementary descriptive measures of magnitude, while statistical inference is based on the GLM and GEE model outputs. For multiple comparisons, the Bonferroni post hoc test was applied, with statistical significance set at $p < 0.05$. Analyses were performed using SPSS software, version 21.

RESULTS

Participants in the CP were classified by topography, with unilateral ($n = 7$) or bilateral ($n = 11$) involvement. GMFCS levels were distributed as follows: level I ($n = 11$), level II ($n = 2$), level III ($n = 4$), and level IV ($n = 1$). In the intragroup dynamic balance assessment, a significant effect of time was observed exclusively for the LengthCoP across specific riding tasks. During the straight-line EO task, a significant reduction over time (Wald = 13.58, $df = 2$, $p = 0.00$), with post-hoc differences between A1 (mean = 56.10; CI95%: 49.40 – 63.71) vs A2 (mean = 43.12; CI95% = 37.45 – 49.65; $p = 0.002$) and A1 (mean = 56.10; CI95%: 49.40 – 63.71) vs A3 (mean = 41.84; CI95% = 37.88 – 46.23; $p = 0.004$). A similar pattern was identified during the straight-line EC task (Wald = 16.60, $df = 2$, $p < 0.001$), with significant differences between A1 (mean = 59.34; CI95% = 49.99 – 70.44) vs A2 (mean = 45.20; CI95% = 39.87 – 51.24; $p = 0.001$) and A1 (mean = 59.34; CI95% = 49.99 – 70.44) vs A3 (mean = 46.30; CI95% = 41.27 – 51.94; $p = 0.019$). In the zigzag EC task, a significant

time effect (Wald = 8.45, df = 2, $p=0.015$) was observed, driven primarily by improvements between A1 (mean = 53.74; CI95% = 46.90 – 61.58) and A2 (mean = 45.51; CI95% = 40.60 – 51.01; $p=0.019$). These findings, supported by moderate to large effect sizes (ES = 0.69–1.13), indicate clinically relevant improvements in dynamic postural control during riding tasks, suggesting more efficient postural regulation over the course of the intervention (Table 2).

Table 2. Comparison of CoP behaviour in different tasks between moments in the CP group (n=18).

Tasks	A1	A2	A3	ES (A1-A3)
Straight-line EO				
ACoPap cm	2.31±1.18	2.15±1.07	1.85±0.62	0.50
ACoPml cm	3.46±1.06	3.50±1.55	3.01±0.91	0.57
LengthCoP cm ²	56.10±15.90	43.12±13.54*	41.85±9.28*	1.13
Straight-line EC				
ACoPap cm	2.55±1.35	2.65±2.79	2.07±0.60	0.47
ACoPml cm	3.95±1.46	4.82±5.76	3.57±1.26	0.29
LengthCoP cm ²	59.34±22.66	45.20±12.63*	46.30±11.86*	0.74
Zigzag EO				
ACoPap cm	2.33±1.12	2.21±0.86	1.94 ± 0.54	0.46
ACoPml cm	3.73±1.23	3.91±1.70	3.32±1.06	0.37
LengthCoP cm ²	49.40±14.88	44.64 ± 10.56	41.32±8.49	0.69
Zigzag EC				
ACoPap cm	2.31±1.03	2.32±0.87	2.11±0.69	0.23
ACoPml cm	3.96±1.07	5.02±5.50	3.56±1.16	0.37
LengthCoP cm ²	53.74±16.30	45.52±11.56*	44.94±9.02	0.69

Cerebral Palsy (CP); Center of pressure (CoP); Amplitude of displacement of the anteroposterior directions (ACoPap); Amplitude of displacement of mediolateral directions (ACoPml); Total path length of the center of pressure (LengthCoP); Eye open (EO); Eye closed (EC); centimeters (cm); square centimetre (cm²); *: significant difference compared to moment A1; #: significant difference compared to moment A2; ($p<0.05$; post hoc – Bonferroni); Effect Sizes (ES).

Regarding functional performance on the RPT test, data were collected from 17 participants, as one child was unable to complete the assessment. A significant effect of time was observed for the RPT CoP-derived variables related to average velocity (VAvg) (Wald = 9.93, df = 2, $p=0.007$), with post hoc analysis revealing a significant improvement between

A2 (mean = 2.54; CI95% = 2.25 – 2.88) and A3 (mean = 3.19; CI95% = 2.75–3.70; $p = 0.011$). For the anterior reach RPT (measurement in cm), a significant effect of time was observed (Wald = 30.8, $df = 2$, $p < 0.001$). Post hoc comparisons indicated significant improvements across all time points, A1 (mean = 25.71; CI95% = 22.54– 29.34) vs A2 (mean = 31.35; CI95% = 27.24– 36.09; $p = 0.014$), A1 (mean = 25.71; CI95% = 22.54– 29.34) vs A3 (mean = 37.82; CI95% = 34.98– 40.90; $p < 0.001$) and A2 (mean = 31.35; CI95% = 27.24– 36.09) vs A3 (mean = 37.82; CI95% = 34.98– 40.90; $p = 0.004$) (Table 3).

A significant effect of time was observed for the left-side ACoPml in the RPT measurement (Wald = 15.04, $df = 2$, $p = 0.001$). Post hoc analysis revealed significant improvements between A1 (mean = 5.12; CI95% = 4.50– 5.83) vs A2 (mean = 6.18; CI95% = 5.24– 7.29; $p = 0.017$) and A1 (mean = 5.12; CI95% = 4.50– 5.83) vs A3 (mean = 6.72; CI95% = 5.94 – 7.60; $p = 0.001$). Similarly, a significant time effect was found for the left-side VAvg (Wald = 12.81, $df = 2$, $p = 0.002$), with a significant difference identified between A1 (mean = 1.84; CI95% = 1.65 – 2.06) and A3 (mean = 2.41; CI95% = 2.14–2.71; $p = 0.002$). Additionally, for the left-side reach distance (in cm), a significant effect of time was detected (Wald = 25.14, $df = 2$, $p < 0.001$). Post hoc comparisons indicated progressive improvements across all time points, A1 (mean = 10.53; CI95% = 8.86– 12.51) vs A2 (mean = 14.12; CI95% = 12.38– 16.10; $p < 0.001$), A1 (mean = 10.53; CI95% = 8.86– 12.51) vs A3 (mean = 16.41; CI95% = 14.45– 18.65; $p < 0.001$) and A2 (mean = 14.12; CI95% = 12.38– 16.10) vs A3 (mean = 16.41; CI95% = 14.45– 18.65; $p = 0.006$) Table 3.

For the RPT measurements on the right side ACoPml, a significant effect of time was observed (Wald = 12.35, $df = 2$, $p = 0.002$), with a significant improvement between A1 (mean = 4.99; CI95% = 4.34 – 5.74) and A3 (mean = 6.37; CI95% = 5.51–7.36; $p = 0.003$). Additionally, for the right-side reach distance (in cm), a significant time effect was observed

(Wald = 19.34, df = 2, $p < 0.001$), with a significant difference between A1 (mean = 10.88; CI95% = 9.14 – 12.95) and A3 (mean = 15.53; CI95% = 13.55–17.80; $p < 0.001$). These findings were supported by large ES, particularly for functional reach distance in the anterior (ES: 1.81), left lateral (ES: 1.43), and right lateral directions (ES: 1.10), indicating clinically meaningful gains in dynamic sitting balance and functional reach capacity over the course of the intervention (Table 3).

For the PBS variable, a significant time effect was found (Wald = 12.36, df = 2, $p = 0.002$), with post hoc analysis revealing significant differences between A1 (mean = 40.33; CI95% = 33.26 – 48.91) vs A2 (mean = 45.94; CI95% = 39.16 – 53.90; $p = 0.001$) and A1 (mean = 40.33; CI95% = 33.26 – 48.91) vs A3 (mean = 48.22; CI95% = 42.42 – 54.81; $p < 0.001$). Similarly, the observed time effect, supported by a moderate ES (0.52), indicates clinically meaningful improvements in overall functional balance over the course of the intervention (Table 3).

Table 3. Comparison of CoP behaviour during the RPT (n=17) and PBS test (n=18) between moments in the CP group.

CoP-derived variables	A1	A2	A3	ES
RPT. Anterior reach ACoPap cm	7.35±3.60	8.12±3.20	9.29±3.46	-0.57
RPT. Anterior reach VAvG cm/s	2.24±0.90	2.00±0.71	2.65±1.11#	-0.42
RPT. Anterior reach cm	25.71±7.37	31.35±9.57*	37.82±6.41*#	-1.81
RPT. Left Side ACoPml cm	5.13±1.44	6.19±2.21*	6.72±1.80*	-1.01
RPT. Left Side VAvG cm/s	1.85±0.44	2.09±0.70	2.41±0.61*	-1.09
RPT. Left Side cm	10.53±3.94	14.12±4.01*	16.41±4.54*#	-1.43
RPT. Right Side ACoPml cm	4.53±1.62	5.18±2.56	5.94±1.95*	-0.81
RPT. Right Side VAvG cm/s	1.98±0.39	2.07±0.68	2.18±0.40	-0.52
RPT. Right Side cm	10.88±4.11	13.47±6.35	15.53±4.60*	-1.10
PBS	40.33±17.33	45.94±16.35*	48.22±13.76*	-0.52

Cerebral Palsy (CP); Centre of pressure (CoP); Test Pediatric Reach (RPT); Amplitude of displacement of the anteroposterior directions (ACoPap); Average CoP Speed (VAvG); Amplitude of displacement of mediolateral directions (ACoPml); centimetres (cm); centimetres per second (cm/s); Pediatric Balance Scale (PBS); *: significant difference compared to moment A1; #: significant difference compared to moment A2; ($p < 0.05$; post hoc – Bonferroni); Effect Sizes (ES).

The dynamic balance assessment included 36 children: 18 in the CP group and 18 in the TD group. For ACoPap, a significant group effect was observed ($p<0.001$), with no effects of task or group-by-task interaction ($p>0.05$). Post-hoc analysis indicated significant differences between the CP group at time point A1 (mean = 2.26; CI95% = 2.07– 2.44) and the TD group (mean = 1.54; CI95% = 1.41– 1.67; $p<0.001$), reflecting greater ap displacement in children with CP at A1 (mean = 2.26; CI95% = 2.07– 2.44) after the intervention A3 (mean = 2.00; CI95% = 1.83– 2.17; $p<0.001$), this difference was no longer observed, indicating comparable ACoPap values between groups (Table 4).

For ACoPml, significant effects were found for the group ($p=0.028$) and task ($p=0.021$), with no group-by-task interaction ($p>0.05$). Post hoc analysis revealed a difference between the CP group at time point A1 (mean = 3.66; CI95% = 3.41– 3.92) and the TD group (mean = 3.11; CI95% = 2.91– 3; $p=0.002$). This difference persisted at A3 ($p=0.351$), indicating residual ml instability in children with CP despite the intervention (Table 4).

For the LengthCoP, a significant group effect was observed ($p<0.001$), with no effects of task or group-by-task interaction ($p>0.05$). Post hoc analysis revealed a significant difference between the CP group at the time point A1 (mean = 53.63; CI95% = 50.42– 56.84) and the TD group (mean = 44.23; CI95% = 42.23– 47.44; $p<0.001$) however, no difference was observed at A3 ($p=1.000$), indicating clinically meaningful improvements in overall postural stability during riding tasks, with values comparable to those observed in TD children (Table 4).

Table 4. Comparison of ACoPap, ACoPml, and LengthCoP behaviour in different groups (n=36).

Comparison of ACoPap cm						
GROUPS		GROUPS	Dif. Mean	SE	z	p _{bonferroni}
TD	-	CP-A1	-0.72	0.12	-6.21	< .001
TD	-	CP -A3	-0.46	0.11	-4.33	< .001
Comparison of ACoPml cm						
GROUPS		GROUPS	Dif. Mean	SE	z	p _{bonferroni}
TD	-	CP-A1	-0.55	0.16	-3.36	0.002
TD	-	CP -A3	-0.24	0.16	-1.57	0.351
Comparison of LengthCoP cm ²						
GROUPS		GROUPS	Dif. Mean	SE	z	p _{bonferroni}
TD	-	CP-A1	-8.79	2.08	-4.22	< .001
TD	-	CP -A3	1.12	1.87	0.60	1.000

Cerebral Palsy (CP); Typical Development (TD); Amplitude of displacement of the anteroposterior directions (ACoPap); Amplitude of displacement of mediolateral directions (ACoPml); Total path length of the center of pressure (LengthCoP); square centimetre (cm²); centimeters (cm); Mean Difference (Dif); Standard Error (SE); (p<0,05; post hoc – Bonferroni).

DISCUSSION

Mediolateral (CoPml) and anteroposterior (CoPap) centre of pressure displacements during hippotherapy tasks serve as quantitative markers of dynamic trunk and postural control under ecological movement conditions. This study examined longitudinal changes associated with a 40-session hippotherapy program on dynamic postural balance and functional performance in children with CP. The findings showed significant improvements over time, particularly in the LengthCoP and ACoPml CoP-derived variables, with notable gains already evident by the 20th session. These improvements were also reflected in functional performance outcomes, including the PRT and PBS, supporting an association between repeated hippotherapy exposure and improved balance-related performance. Post-intervention comparisons indicated that by the end of the program, children with CP achieved performance levels in several balance CoP-derived variables that were statistically comparable to those of TD children with prior horseback riding experience. These findings

suggest that repeated, structured hippotherapy exposure was temporally associated with clinically relevant motor improvements in this population, in agreement with previous reports (Moraes et al., 2020, 2016).

Furthermore, analysis across different riding tasks—straight-line with EO, EC, and zigzag paths—indicated that postural control was influenced by task complexity and sensory input (Fabiana M. Flores et al., 2015; Fabiana Moraes Flores et al., 2019). Significant improvements over time were observed, especially in the EO and EC conditions, indicating that children with CP benefited from visual input but also developed adaptive responses under visual deprivation (EC), which is consistent with the sensory reweighting mechanism, suggesting enhanced sensory integration and motor planning (Seung Mi et al., 2019). The zigzag EC task, which combined navigational complexity with the absence of visual cues, showed more modest improvements, with significant gains detected only between the baseline and the midpoint of the intervention. This pattern is clinically and neurophysiologically plausible, as tasks requiring simultaneous directional control, trunk rotation, and proprioceptive reliance typically demand greater neuromotor organisation and longer practice exposure in children with CP (Winter, Huang, Sertic, & Konczak, 2022).

Although descriptive comparisons suggested differences across riding tasks, not all statistical models showed significant task-by-time interactions. This apparent divergence can occur because covariate-adjusted longitudinal models provide conservative average estimates, whereas condition-specific contrasts may highlight directional trends. Therefore, the absence of a statistically significant result at the model level does not necessarily exclude clinically meaningful task-related response patterns. Notably, by the end of the intervention (A3), between-group differences were no longer statistically significant for several dynamic balance CoP-derived variables, particularly in LengthCoP and ACoPml during EO and EC

conditions, indicating that postural sway values in children with CP became closer to those observed in TD children under these task conditions (Novak et al., 2020; Rigby & Grandjean, 2016; Stergiou et al., 2017).

A relevant finding was the directional difference in response patterns between CoPml and CoPap control. The CoPml values approached TD values, whereas CoPap displacement remained significantly different after 40 sessions. This should not be interpreted as an intervention failure, but rather as a direction-specific adaptation profile. Mediolateral trunk control during astride tasks is strongly driven by pelvic weight shift and lateral righting reactions continuously stimulated by the horse's tridimensional gait, which produces repeated frontal-plane perturbations and promotes rapid trunk adjustments (Clayton, Kaiser, de Pue, & Kaiser, 2011; Janura, Peham, Dvorakova, & Elfmark, 2009; Rigby & Grandjean, 2016). In contrast, anteroposterior control depends more heavily on anticipatory postural adjustments, feedforward trunk flexor-extensor coordination, and slower normalisation in CP (Novak et al., 2020; Shumway-Cook & Woollacott, 2007; Stergiou et al., 2017). Thus, mediolateral improvement with persistent anteroposterior deficit represents a plausible neuromotor response pattern rather than an inconsistent outcome.

The observed longitudinal changes may be associated with specific aspects of hippotherapy, especially its multisensory stimulation and the postural demands imposed by horseback riding. The continuous need for postural adjustments in response to the horse's rhythmic gait may stimulate trunk musculature activation and reinforce postural control mechanisms—key components for achieving proximal stability and improving functional task performance (Clayton et al., 2011; Janura et al., 2009). In addition, tasks performed with EC or along zigzag trajectories introduced higher sensory and coordinative demands, requiring increased integration of vestibular and proprioceptive inputs under reduced visual

contribution. The structured repetition across 40 sessions, combined with progressive task variation and individualised therapist supervision, creates a context consistent with established motor learning principles, including repetition, grade variability, and feedback-guided adaptation (Novak et al., 2020). Together, these elements help explain why balance-related gains were observed not only in instrumented CoP-derived variables (especially LengthCoP and ACoPml) but also in functional performance measures.

From a clinical perspective, the results suggest that children with CP at ambulatory functional levels may obtain measurable trunk and dynamic balance gains after medium-term hippotherapy exposure (A2), with additional improvements over extended protocols (A3). Across the protocol, changes were more consistently observed in LengthCoP and ACoPml, indicating that these CoP-derived variables may be more responsive to longitudinal change within this intervention context. Functional gains observed in RPT and PBS support transfer beyond instrumented measures. These implications should be interpreted as practice-oriented guidance rather than perceptive dosage rules, given sample heterogeneity and concurrent therapies. Overall, the findings indicate consistent and clinically meaningful improvements observed over time; however, given the pre-experimental design and cointerventions, they should be interpreted as evidence of positive association and rehabilitation potential rather than definitive isolated treatment efficacy, particularly considering potential maturation effects and concurrent therapies (Araújo et al., 2020; Faccioli et al., 2023).

This study has limitations that should be considered when interpreting the findings. The pre-experimental longitudinal design without a randomised CP control group limits causal inference, and the observed improvements should be interpreted as temporally associated with the intervention rather than as definitive isolated treatment effects. Therefore, the observed improvements cannot be attributed exclusively to hippotherapy, since concurrent

rehabilitation approaches may have contributed additively or synergistically to the longitudinal changes observed. The TD group was evaluated only once, which prevents longitudinal comparison and does not allow full control for potential task familiarisation effects across repeated assessments in the CP group. In addition, part of the longitudinal gains may reflect maturation processes, developmental progression, repeated-exposure learning, and adaptation to the assessment tasks over time, particularly considering the extended intervention period and the absence of a non-intervention CP control group. Future controlled and randomised studies with longitudinal CP control groups are needed to confirm the magnitude and specificity of these findings.

CONCLUSIONS

This study provides evidence that a structured 40-session hippotherapy protocol was associated with improvements in dynamic postural balance and functional performance in children with CP. The significant improvements observed in key postural control CoP-derived variables—specifically LengthCoP and ACoPml—highlight the responsiveness of these objective measures to therapeutic equine-assisted interventions. By the end of the protocol, several mediolateral and total sway CoP-derived variables reached ranges statistically comparable to those observed in TD peers with riding experience, although not all postural control CoP-derived variables showed full convergence. These findings indicate clinically relevant improvements rather than complete normalisation across all control directions.

A particularly relevant contribution of this study lies in the detailed analysis of CoP behaviour under varied task conditions (EO, EC, and zigzag paths), revealing the importance

of sensory integration and task complexity in motor adaptation. By including both intra-group and inter-group comparisons across multiple time points, the study provides additional insights into how different components of dynamic balance evolve during the course of hippotherapy. Moreover, the use of real-time CoP metrics during functional riding activities represents an innovative and ecologically valid approach to capturing motor changes in a naturalistic setting.

Clinically, these findings support considering hippotherapy as a complementary component within multidisciplinary rehabilitation programs for children with CP who match the studied clinical profile. The structured and individualised nature of the intervention, along with the progressive challenge introduced by the riding tasks, reinforces the role of hippotherapy as a dynamic and adaptive modality associated with meaningful motor and postural gains within the evaluated protocol.

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