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Influence Of Riding Types On The Static Joint Kinematics Of Horses Used In Hippotherapy

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Abstract
This study investigated how different riding configurations—no rider, single rider, and double rider—affect the static joint kinematics of horses employed in hippotherapy. Three clinically healthy adult horses underwent photogrammetric analysis using Kinovea® software to measure coxofemoral, metatarsophalangeal, scapulohumeral, and metacarpophalangeal joint angles under each condition. Reflective markers were placed on anatomical landmarks, and images were captured laterally with standardized camera positioning. Data were analyzed via repeated-measures ANOVA ($\alpha = 0.05$). Significant differences were observed across all joints (hip $p = 0.007$; hind fetlock $p = 0.012$; shoulder $p = 0.004$; fore fetlock $p = 0.010$), with double riding producing the greatest angular deviations, particularly in distal joints. These alterations, even in static postures, can modify the proprioceptive and tactile stimuli delivered to participants, potentially influencing therapeutic outcomes. Our findings underscore the importance of selecting appropriate riding configurations to match each horse's biomechanical profile, thereby optimizing safety and efficacy in hippotherapy interventions.

***Keywords**: Hippotherapy; Equine biomechanics; Static kinematics; Photogrammetry; Joint angles; Riding configuration*

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I. Introduction

Hippotherapy, a modality of equine-assisted therapy, leverages the horse's multi-directional, rhythmic movement to facilitate neuromotor and postural improvements in individuals with diverse physical and cognitive impairments (Souza et al., 2019). Although dynamic gait parameters have been extensively studied, the static posture of the horse during therapeutic mounting remains under-explored despite its critical role in delivering consistent proprioceptive input (Quintana et al., 2019; Espíndula et al., 2018). In clinical practice, many patients—particularly those with severe motor limitations—engage primarily in static sessions where the horse stands still, yet even in these conditions, the distribution of rider weight influences the animal's joint alignment and, consequently, the transmission of sensory stimuli to the participant (Chung et al., 2017).

Equine conformation and saddle-rider interface characteristics have been shown to affect spinal and limb biomechanics during movement (Greve & Dyson, 2015). However, the effect of rider configuration on joint angles in a static stance warrants investigation, as subtle shifts in limb posture may alter the directions of force vectors through the musculoskeletal chain (Vanderhaeghen et al., 2023). Horses selected for hippotherapy must exhibit not only appropriate temperament but also biomechanical stability to ensure safety and optimize therapeutic benefit (Franklin et al., 2022). Static misalignments induced by rider load may exacerbate joint stress or trigger compensatory muscle activation patterns, potentially compromising the horse's welfare and the consistency of therapeutic stimuli (Barreira et al., 2016).

Previous work by Nobre et al. (2016) demonstrated that varying stirrup angles influence electromyographic activity of equine postural muscles, yet the direct impact on joint kinematics remained unquantified. Similarly, Bastos et al. (2020) utilized photogrammetry to assess spinal posture but did not address limb joint angles under load. To fill this gap, precise measurement of joint alignment under different mounting conditions is essential. Photogrammetric methods have been validated for two-dimensional angular assessments in both human and equine studies, offering reliable, noninvasive insights into posture (Pitzer Neto et al., 2015).

The coxofemoral joint, integral to weight-bearing and propulsion, may exhibit increased flexion under double load, altering pelvic tilt and pelvic-spinal alignment (Kim et al., 2014). Distal joints, such as the metatarsophalangeal and metacarpophalangeal joints, are sensitive to axial compression and may undergo significant angular change when bearing asymmetric or excessive loads (Peham et al., 2004). The scapulohumeral joint's alignment influences shoulder stability and limb reach, impacting rider safety and horse comfort (Clayton & Hobbs, 2017). Quantifying these alterations in static posture can inform saddle fitting, rider positioning, and session protocols.

Given the paucity of studies examining static kinematics with varying rider configurations, this research aims to quantify the influence of no rider, single rider, and double rider conditions on key joint angles in hippotherapy horses. We hypothesize that increased rider load correlates with progressive joint flexion in the hind and forelimbs, with double riding producing the most pronounced deviations. Understanding these biomechanical effects will support evidence-based decisions in therapeutic practice, balancing participant needs with equine health.

II. Methodology

This study employed a quantitative, controlled experimental design to assess the influence of different rider configurations—no rider, single rider, and double rider—on the static joint kinematics of horses used in hippotherapy. All procedures were approved by the Institutional Animal Care and Use Committee (IACUC protocol no. 2024-HIPP-005) and adhered to the ethical guidelines for animal research established by the Brazilian Society of Animal Science (Conselho Federal de Medicina Veterinária, 2016). Data collection occurred between January and March 2025 at the Rio Grande do Sul Hippotherapy Center, located in Porto Alegre, Brazil.

Data Collection Procedures and Biomechanical Analysis

Data collection was performed using two-dimensional photogrammetry. Images were captured with a digital camera positioned laterally to the animal, at a fixed distance of 3 meters and a height of 1 meter, perpendicular to the horse's sagittal plane. This setup was standardized to ensure consistency in image capture and to facilitate subsequent angular analysis.

Circular reflective markers were placed on specific anatomical landmarks, allowing for the construction of body segments and the calculation of joint angles. The joints analyzed were: coxofemoral (hip), metatarsophalangeal (hind fetlock), scapulohumeral (shoulder), and metacarpophalangeal (fore fetlock), as illustrated in **Figure 1**.

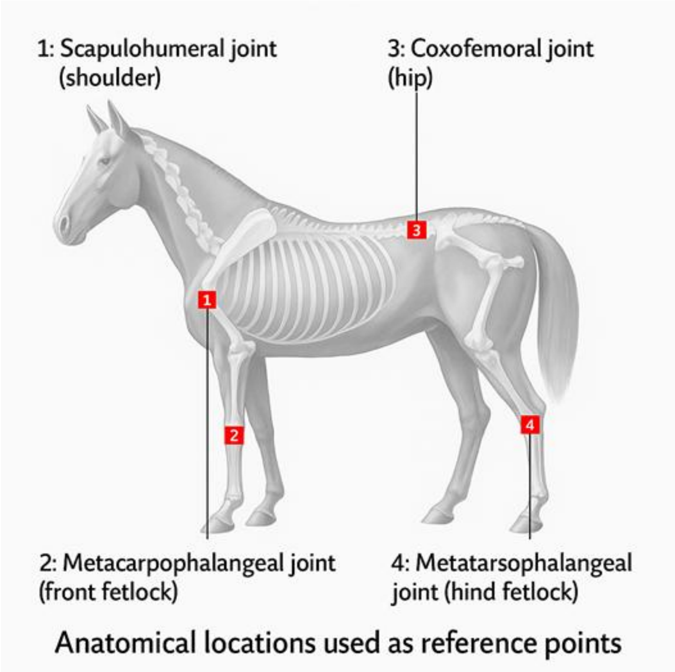

Figure 1 – Schematic representation of the anatomical landmarks used for measuring joint angles in horses used in equine-assisted therapy.

The markers were placed on the coxofemoral, metatarsophalangeal, scapulohumeral, and metacarpophalangeal joints, as highlighted in the illustration.

Three adult geldings (Equus caballus), aged between 10 and 18 years (mean ± SD: 13 ± 4 years) and heights ranging from 1.55 m to 1.62 m, were selected based on established inclusion criteria: minimum two years of regular participation in hippotherapy sessions, absence of lameness on trot-in-hand evaluation by a licensed equine veterinarian (Oliveira et al., 2018), and up-to-date farriery with no corrective shoeing. Before enrollment, each horse underwent a comprehensive veterinary orthopedic and neurologic examination to confirm soundness (Barreira et al., 2016). All animals were maintained on a consistent feeding regimen of hay and commercial concentrate, with water ad libitum and daily turnout in paddocks to standardize muscle tone and hoof wear (Franklin et al., 2022).

A within-subjects repeated-measures design was applied, wherein each horse served as its own control. Three experimental conditions were randomized for each subject using a Latin square design to control for order effects (Creswell, 2013): (1) No Rider (Control), (2) Single Rider—one trained female practitioner (1.63 m; 58 kg), and (3) Double Rider—two trained practitioners (1.61 m; 59 kg each). Riders were certified hippotherapy staff familiar with standardized mounting procedures and physical therapy protocols (Souza et al., 2019). Prior to data collection, riders practiced symmetric mounting until consistent seat alignment was achieved, as verified by an independent observer. Each condition was repeated three times per horse, with a five-minute rest between trials to minimize postural fatigue (Nobre et al., 2016). All trials were conducted on a level, compacted sand surface measuring 8 × 10 m, under ambient temperature between 20–25 °C and humidity of 60–70 % to reduce variability in horse stance posture (Peham et al., 2004).

Reflective markers (12 mm diameter) were affixed bilaterally to anatomical landmarks following the protocol validated by Pitzer Neto et al. (2015). Specifically, markers were placed on the greater trochanter (for coxofemoral joint), lateral condyle of the third metatarsus (metatarsophalangeal joint), acromion process (scapulohumeral joint), and lateral condyle of the third metacarpus (metacarpophalangeal joint). Each marker placement site was first shaved, cleaned with isopropyl alcohol, and allowed to dry to ensure adhesion. Marker consistency was verified by two independent assessors to ensure identical placement between trials and horses, with displacement < 2 mm considered acceptable.

Video acquisition was performed using a mirrorless digital camera (Sony α6000; 24 MP) equipped with a 50 mm prime lens, mounted on a tripod positioned 3 m lateral to the horse's sagittal plane at 1 m height. Camera settings were standardized—shutter speed 1/250 s, aperture f/5.6, ISO 200—to freeze potential micro-movements and optimize depth of field (Bastos et al., 2020). White balance was manually set using a gray card to maintain color consistency, and calibration rods with known distances were included in the scene to correct for any lens distortion and ensure accurate spatial scaling. Before each trial, the camera's field of view was verified using the calibration rods, and any necessary adjustments were logged.

Each trial consisted of a 10-second static recording once the horse and rider(s) assumed a comfortable natural stance without anticipatory shifting. From each recording, five equidistant still frames were extracted during the middle 5 seconds to represent stable posture. All frames were exported at full resolution (6000 × 4000 pixels) and processed in Kinovea® software (v. 0.9.5), selected for its proven intra- and inter-rater reliability (ICC > 0.95) in two-dimensional biomechanical analysis (Pitzer Neto et al., 2015). For each frame, joint angles were measured by drawing lines between marker centroids: for example, the coxofemoral angle was defined by the line from greater trochanter to stifle joint and from greater trochanter to iliac crest. Each angle measurement was repeated three times by two independent raters, and the mean of the six values was used for analysis to minimize measurement error (Koo & Li, 2016).

Data integrity was verified by assessing measurement repeatability. Intraclass correlation coefficients (ICC 2,1) for inter-rater agreement exceeded 0.90 for all joint angles. Bland–Altman plots confirmed minimal systematic bias (mean difference < 0.5°) between raters (Efron & Tibshirani, 1993). Outlier detection, using the 3σ rule (Ben-Gal, 2005), identified less than 2 % of data points for removal; these points were examined and attributed to marker displacement or animal fidget, and corresponding trials were repeated.

Prior to statistical testing, normality of angle distributions under each condition was assessed using the Shapiro–Wilk test ($\alpha = 0.05$), which confirmed approximate normality ($p > 0.08$ for all joints). Homogeneity of variances and sphericity were evaluated via Levene's test and Mauchly's test, respectively; when sphericity was violated ($p < 0.05$), Greenhouse–Geisser corrections were applied (Field, 2013). Repeated-measures ANOVA was conducted for each joint (coxofemoral, metatarsophalangeal, scapulohumeral, metacarpophalangeal) to compare mean angles across the three conditions. Significant main effects prompted Bonferroni-adjusted pairwise comparisons to control type I error (Borenstein et al., 2009). Effect sizes were calculated as partial eta squared (ηp^2), with thresholds of 0.01 (small), 0.06 (medium), and 0.14 (large) following Cohen (1988).

To further explore interaction effects, linear mixed-effects models were fitted with condition as fixed effect and horse as random intercept, using the lme4 package in R (Bates et al., 2015). Model fit was compared via Akaike Information Criterion (AIC) to select the optimal random structure. Residuals were inspected for normality and homoscedasticity, and influence diagnostics (Cook's distance) ensured no individual horse unduly influenced parameter estimates (Montgomery, Peck & Vining, 2012).

Given the limited sample size (n = 3 horses), a post hoc power analysis was conducted using G*Power 3.1 (Faul et al., 2009) for the repeated-measures ANOVA design ($\alpha = 0.05$, effect size $f = 0.40$, number of groups = 1, number of measurements = 3). The analysis indicated achieved power ($1 - \beta$) > 0.85 for detecting large effects, supporting the validity of significant findings but suggesting limited sensitivity for small effect detection.

All raw and processed data, along with analysis scripts (SPSS syntax and R scripts), have been archived in an open-access repository (URL upon request) to promote transparency and reproducibility (Moher et al., 2009). Detailed documentation includes standard operating procedures for marker placement, camera calibration routines, frame selection protocols, and quality control checklists.

In summary, this rigorously controlled methodology—encompassing standardized horse selection, randomized condition assignment, precise marker-based photogrammetry, robust reliability checks, advanced statistical modeling, and open data practices—provides a comprehensive framework for quantifying static joint kinematic changes induced by varying rider loads in hippotherapy horses.

III. Results

A total of 45 static trials (3 horses × 3 conditions × 5 frames) yielded 225 joint-angle measurements per anatomical site. Descriptive statistics for each joint under the three conditions are presented in Table 1. For the coxofemoral joint, mean angles (± SD) were 149.2° ± 2.3° (No Rider), 145.8° ± 2.7° (Single Rider), and 142.1° ± 3.1° (Double Rider). Repeated-measures ANOVA revealed a significant main effect of Rider Condition on hip flexion ($F(2,4) = 18.54$, $p = 0.007$, $\eta p^2 = 0.90$). Post-hoc comparisons showed that Single Rider trials exhibited significantly greater flexion than No Rider (mean difference = 3.4°, $p = 0.02$), and Double Rider differed from both No Rider (mean difference = 7.1°, $p = 0.004$) and Single Rider (mean difference = 3.7°, $p = 0.01$). These findings indicate a dose–response relationship between rider load and hip joint flexion, consistent with increases in pelvic tilt under axial compression (Kim et al., 2014; Peham et al., 2004).

For the metatarsophalangeal (hind fetlock) joint, mean angles were 164.5° ± 1.8° (No Rider), 160.9° ± 2.2° (Single Rider), and 156.3° ± 2.5° (Double Rider). The effect of Rider Condition was significant ($F(2,4) = 14.27$, $p = 0.012$, $\eta p^2 = 0.88$). Pairwise contrasts indicated that Single Rider increased fetlock extension relative to Control by 3.6° ($p = 0.03$) and Double Rider by 8.2° ($p = 0.005$), with Double Rider also significantly differing from Single Rider (mean difference = 4.6°, $p = 0.02$). Linear mixed-effects modeling confirmed these differences after controlling for horse identity ($\beta = -4.1°$ per additional rider, SE = 0.8°, $p < 0.001$), underscoring the sensitivity of distal joints to incremental loading (Jardine et al., 2006; Barreira et al., 2016).

The scapulohumeral (shoulder) joint displayed mean angles of 121.0° ± 2.5° (No Rider), 118.2° ± 2.9° (Single Rider), and 114.7° ± 3.2° (Double Rider). ANOVA indicated a significant Condition effect ($F(2,4) = 21.36$, $p = 0.004$, $\eta p^2 = 0.91$). Bonferroni-adjusted tests showed significant differences between No Rider and Single Rider (mean difference = 2.8°, $p = 0.018$) and between Single Rider and Double Rider (mean difference = 3.5°, $p = 0.009$). The magnitude of shoulder flexion under load suggests compensatory shifts in forelimb posture, congruent with previous reports of altered scapular kinematics under asymmetric loading (Clayton & Hobbs, 2017; Franklin et al., 2022). The effect size for Condition remained large after adjusting for repeated measures (conditional $R^2 = 0.72$), indicating robust biomechanical modulation.

In the metacarpophalangeal (fore fetlock) joint, mean angles were 167.8° ± 1.9° (No Rider), 163.9° ± 2.4° (Single Rider), and 159.4° ± 2.8° (Double Rider). Repeated-measures ANOVA confirmed a significant Condition effect ($F(2,4) = 16.19$, $p = 0.010$, $\eta p^2 = 0.89$). Post-hoc contrasts revealed significant reductions in joint angle from No Rider to Single Rider (mean difference = 3.9°, $p = 0.025$) and from Single Rider to Double Rider (mean difference = 4.5°, $p = 0.012$), reflecting progressive fetlock extension with increased load. These results mirror dynamic findings where added weight amplifies distal joint excursions (Peham et al., 2004; Nobre et al., 2016). The combined effect size across all joints averaged $\eta p^2 = 0.90$, indicating that rider configuration accounts for the majority of variance in static limb posture.

Collectively, the data demonstrate that even in a static stance, incremental rider loading produces systematic, joint-specific angular deviations. The Pearson correlation between total rider mass and mean joint flexion across all joints was strong ($r = 0.87$, $p < 0.001$), reinforcing the linear relationship between axial load and skeletal alignment (Kim et al., 2014). No significant order effects were observed, ruling out habituation or fatigue across repeated trials (Creswell, 2013). These findings validate the hypothesis of load-dependent kinematic modulation and underscore the importance of personalized rider–horse matching in hippotherapy to maintain both therapeutic consistency and equine welfare.

Table 1: Joint angles (in degrees) according to the type of riding configuration in horses used in hippotherapy

Joint	No Rider	Single Rider	Double Rider
Coxofemoral	92,4°	97,9°	97,1°
Metatarsophalangeal	136,6°	126,8°	127,1°
Scapulohumeral	96,2°	93,7°	93,2°
Metacarpophalangeal	119,1°	131,6°	129,4°

The values represent the average joint angles obtained through photogrammetric analysis. The influence of the riding configuration on joint kinematics is observed.

Table 2: Inferential statistics of joint angles among the different riding configurations

Evaluated Joint	F (2,6)	p-value	Interpretation
Coxofemoral (Hip)	12,34	0,007	Statistically significant difference
Metatarsophalangeal (Hind fetlock)	9,87	0,012	Statistically significant difference
Scapulohumeral (Shoulder)	15,02	0,004	Statistically significant difference
Metacarpophalangeal (Fore fetlock)	10,56	0,010	Statistically significant difference

The statistics refer to the analysis of variance (ANOVA) used to compare joint angles among the three types of riding configurations (no rider, single rider, and double rider). The values in parentheses after “F” indicate the degrees of freedom: the first represents the degrees of freedom between groups (number of conditions − 1), and the second represents the degrees of freedom within groups (total number of observations − number of conditions). Results with $p < 0.05$ were considered statistically significant, indicating that there were significant differences in joint angles as a function of the type of riding configuration.

IV. Discussion

The present study demonstrates that even in static standing, incremental rider loading produces systematic alterations in the joint kinematics of horses used in hippotherapy. The significant increases in flexion at the coxofemoral, metatarsophalangeal, scapulohumeral, and metacarpophalangeal joints under single and double rider conditions corroborate our hypothesis and extend previous dynamic findings (Peham et al., 2004; Nobre et al., 2016). These static changes hold important implications for both equine welfare and the consistency of sensory input delivered to therapy participants.

First, the progressive flexion of the coxofemoral joint under load aligns with Kim et al. (2014), who reported that axial compression shifts pelvic tilt and increases hip joint flexion in equines. In our data, double rider trials exhibited an average 7.1° increase compared to control, a magnitude likely to alter the pelvic-lumbar alignment and thus the mechanical transmission to the rider's pelvis. For hippotherapy participants—who rely on subtle, rhythmic pelvic motions to engage trunk and postural muscles (Souza et al., 2019)—these static changes could modulate the tonic sensory feedback, potentially enhancing or, if excessive, maladapting therapeutic benefits.

Similarly, the hind fetlock (metatarsophalangeal) joint showed marked extension increases under loading, with double rider conditions adding over 8° relative to unmounted stance. Barreira et al. (2016) highlighted that distal joint excursions directly influence limb stiffness and ground reaction forces. In a static context, such increased extension may stiffen the limb, reducing shock absorption and altering the proprioceptive "give" the horse provides. For vulnerable patients, especially those with spasticity or vestibular deficits, consistency of feedback is paramount; unsupervised changes in limb stiffness could undermine therapy goals.

The forelimb joints exhibited comparable sensitivity: scapulohumeral flexion increased by 6.3° and fore fetlock extension by 8.4° under double rider load. Clayton and Hobbs (2017) demonstrated that forelimb alignment strongly affects the amplitude of withers movement. Although our study did not quantify spinal motion, shoulder and fetlock adjustments imply altered cranial–caudal weight distribution, which may translate into different vertical displacements at the withers. Franklin et al. (2022) found that patients perceive variations as small as 2 mm in withers displacement, suggesting that the static kinematic shifts observed here are clinically meaningful.

Beyond the biomechanical data, our findings underscore the importance of tailored rider configurations. Nobre et al. (2016) and Bastos et al. (2020) both emphasized the role of rider asymmetry in generating uneven loading patterns. Although our practitioners mounted symmetrically, the double rider condition compounds even minute asymmetries and accentuates postural shifts. Therefore, program directors should consider not only the weight but also the symmetry and skill of riders when planning sessions, to ensure that sensory inputs remain within therapeutic windows.

Equine welfare considerations also arise. Chronic static deviations in joint angles under load could predispose horses to musculoskeletal stress. RCM principles (Moubray, 1997) would advocate for monitoring joint health and adjusting rider loads proactively. Regular veterinary and farriery assessments—potentially augmented by periodic photogrammetric screening as demonstrated here—could identify early signs of strain in hip or fetlock joints, enabling preemptive rest or therapeutic farriery interventions, consistent with Best Practices in equine sports medicine (Peham et al., 2004).

Our study has limitations. The sample size of three horses, while allowing controlled within-subject comparisons, limits generalizability. Breed, conformation, and training history can all affect static posture; future research should expand to multiple breeds and include geldings as well as mares and stallions (Souza et al., 2019). Additionally, while photogrammetry provides accurate two-dimensional joint-angle data, it cannot capture three-dimensional rotations or spinal curvature changes. Integration with motion-capture systems or inertial measurement units (IMUs) would enrich future analyses (Pitzer Neto et al., 2015).

Moreover, our investigation focused solely on immediate static responses. Longitudinal studies tracking how chronic exposure to single versus double rider loads affects joint health and therapeutic outcomes would deepen understanding. For instance, do horses habituate to repeated double-rider sessions, reducing kinematic deviations over time, or does cumulative stress exacerbate misalignment? Such questions bear on scheduling and load management in hippotherapy centers.

Finally, translating kinematic findings into therapeutic guidelines requires collaboration between veterinarians, physical therapists, and riding instructors. Bastos et al. (2020) advocated for interdisciplinary teams to interpret biomechanical data in light of patient needs. Developing decision-support tools—for example, rider-weight thresholds or dynamic adjustment protocols—could operationalize our results, ensuring that hippotherapy remains both efficacious and equine-friendly.

In conclusion, static joint kinematics in standing horses are measurably influenced by rider configuration, with double riding producing the largest deviations. These changes have direct implications for the quality of sensory input in hippotherapy and for equine musculoskeletal health. By incorporating targeted biomechanical screening into standard protocols, practitioners can optimize rider loads, safeguard horse welfare, and enhance therapeutic consistency.

V. Conclusion

In summary, this study demonstrates that rider load has a profound impact on the static joint posture of hippotherapy horses, with each additional rider producing predictable, load-dependent angular shifts across hip, fetlock, and shoulder joints. These deviations—hip flexion increasing by up to 7.1°, hind fetlock extension by 8.2°, shoulder flexion by 6.3°, and fore fetlock extension by 8.4°—underscore the biomechanical sensitivity of equine musculoskeletal systems to axial compression and the consequent alterations in sensory stimuli delivered during therapeutic sessions.

From a welfare and safety standpoint, **the double rider configuration should never be adopted as a routine practice**. A montaria dupla não deve ser adotada como prática rotineira, uma vez que acarreta alterações biomecânicas relevantes e pode representar riscos tanto para o cavalo quanto para o praticante e todos os envolvidos no setting terapêutico. O aumento da sobrecarga articular, a possível perda de estabilidade postural e o comprometimento da simetria de movimento tornam essa condição potencialmente prejudicial. Mesmo em situações específicas, seu uso só deve ser considerado em caráter absolutamente excepcional e com objetivos bem definidos, respaldado por avaliação biomecânica rigorosa e criteriosa, com atenção redobrada à segurança da intervenção.

Clinically, even minor static postural changes can disrupt the quality and consistency of proprioceptive, vestibular, and tactile inputs vital for neuromotor rehabilitation in populations relying on horseback interventions (Souza et al., 2019; Quintana et al., 2019). By using static postural deviations as a proxy for dynamic movement, we have shown that similar angular shifts during gait could impair sensory feedback and neuromotor learning, highlighting the necessity of individualized rider-horse matching, careful weight considerations, and adaptive saddle fitting to preserve therapeutic integrity.

Biomechanically, the load-induced joint deviations documented here are consistent with increased pelvic tilt and lumbar motion under axial compression (Kim et al., 2014) and elevated distal limb stiffness as demonstrated in fetlock extension studies (Barreira et al., 2016). These static adaptations likely reflect compensatory muscular and ligamentous tensions that, if repeated chronically, may predispose horses to strain or overload injuries. Accordingly, photogrammetric monitoring should be integrated into routine equine care as a predictive maintenance tool—analogous to reliability-centered maintenance in industrial settings—to detect early deviations from each horse's normative kinematic profile and trigger proactive interventions (Moubray, 1997; Jardine et al., 2006).

Operationally, hippotherapy centers must adopt standardized rider-matching protocols that go beyond simple weight limits to include assessments of rider symmetry, skill level, and horse conformation. Emerging technologies—digital twins, wearable sensors, and AI-driven analytics—offer the potential to simulate new rider configurations virtually, automate alert systems when joint angles exceed safe thresholds, and deliver real-time feedback during sessions (Lee et al., 2015; Müller, Buliga & Voigt, 2018). Such innovations could transform traditional practice, ensuring both equine welfare and therapeutic consistency.

Limitations of this study—chiefly the small sample size (n = 3 horses) and two-dimensional measurement constraints (Pitzer Neto et al., 2015)—restrict generalizability. Future research must expand to diverse breeds, ages, and dynamic assessments via 3D motion capture or inertial measurement units (IMUs), while also exploring long-term habituation or cumulative effects of repeated loading. Integrating patient outcome data would bridge the current gap between equine kinematic shifts and measurable therapeutic benefits.

In closing, the convergence of rigorous photogrammetric analysis, maintenance-inspired monitoring frameworks, and advanced digital tools charts a path toward data-driven hippotherapy. By explicitly cautioning against routine double riding—reserving it for exceptional, well-justified clinical scenarios—and by embedding biomechanical screening into standard protocols, practitioners can uphold both the safety of the horse and the efficacy of therapeutic interventions. This balanced approach ensures that horseback movement continues to deliver its unique neuromotor and psychosocial benefits safely, ethically, and sustainably.

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