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Article

Kinematic Analysis of the *Esbarrada* and *Volta Sobre Patas* Manoeuvres of Criollo Breed Horses Competing in *Freio de Ouro*

Gino Luigi Bonilla Lemos Pizzi ¹, Karina Holz ¹, Éverton Augusto Kowalski ¹, Priscila Fonseca Ribeiro ¹, Roberta Blake ^{2,*} and Charles Ferreira Martins ¹

¹ Universidade Federal de Pelotas; gino_lemos@hotmail.com (G.L.B.L.P.); karinaholz06@gmail.com (K.H.); evertonequinocultura@gmail.com (É.A.K.); priscilafri@hotmail.com (P.F.R.); martinscf68@yahoo.com.br (C.F.M.)

² Anglia Ruskin University

* Correspondence: roberta.blake@aru.ac.uk; Tel.: +44-(0)-1245 424200

Simple Summary: Equestrian sports have evolved beyond traditional disciplines, embracing specialized events that showcase breed-specific abilities. The Criollo horse breed, a product of centuries of genetic refinement, stands out in South America and internationally, particularly in events like the *Freio de Ouro*. This competition highlights the breed's versatility and skills, emphasizing manoeuvres like *esbarrada* and *volta sobre patas*, which demonstrate agility, coordination, and balance. Despite the breed's success, there's a lack of quantitative kinematic studies on these manoeuvres and their relation to horse morphology. Our study aims to fill this gap by using kinematics to analyze *esbarrada* and *volta sobre patas*, exploring any connections between static goniometry and maneuver dynamics. Understanding these movements not only enhances our appreciation of equine biomechanics but also informs breeding and training practices, ultimately benefiting both horses and riders in various equestrian disciplines.

Abstract: Background: Manoeuvres *esbarrada* and *volta sobre patas* are fundamental movements in equestrian activities, yet their kinematics remain largely unexplored. Objectives: This observational study aimed to kinematically describe the movements of *esbarrada* and *volta sobre patas* in Criollo breed horses. Methods: Kinematic analysis was conducted on 31 Criollo horses executing *esbarrada* and *volta sobre patas* manoeuvres. Results: The *esbarrada* maneuver covered a distance of 4.28 ± 0.99 m in 1.15 ± 0.11 s at a velocity of 3.77 ± 0.55 m/s. Angular kinematic variables revealed specific joint angles during the maneuver. In *volta sobre patas*, significant differences were found in spin duration and thoracic limb suspension between the first and second spins. Conclusions: *Volta sobre patas* demonstrated prolonged spinning duration and increased thoracic limb suspension in the second spin. Additionally, static conformation did not correlate with limb protraction angles during *esbarrada*.

Keywords: biomechanics; kinesiology; performance assessment

1. Introduction

Equestrian sports, traditionally centered on classic disciplines such as show jumping, dressage and cross-country, have been expanding their scope to more specialized disciplines with high cultural appeal at an international level, focusing on breeds with specific abilities around the world, since the Industrial Revolution in the mid-19th century [1]. Adelman & Thompson [2] described that equestrian culture accompanies important social transformations introduced by post-modernity, equally affecting global and local scenarios in the cultural and economic spheres related to the species. In South America, the Criollo breed gets prominence for comprising animals that have been genetically selected and modified over the decades, establishing a racial standard. Inserted in the continental equestrian context, the animals of this breed participate in 14 competitive events, with the *Freio de Ouro* being the highlighted modality, having great relevance in the genetic selection

process of the Criollo breed horses and impacting on the selection of animals with high zootechnical characteristics [3]. It is a competition that highlights the versatility and skills of horses, with special emphasis on gaits and manoeuvres that express aptitude for working with cattle [4]. Among these manoeuvres are the *esbarrada*, which highlights the horse's dexterity and agility when braking abruptly to change direction, and the *volta sobre patas*, composed of latero-flexions of the spine that require coordination and balance of the horse-rider system, being functional characteristics of great impact on the assessment of the animal's performance, temperament, and individual ability [5].

Animals of this breed also compete at an international level, such as in reining and dressage. Although there are homologous manoeuvres to these (e.g. sliding stop and spin) in different disciplines, there are no descriptive quantitative kinematic studies and the influence of morphology on movements of these types in the literature on equine biomechanics. Pimentel et al. [6] observed that linear and angular morphometric measurements of Criollo breed horses explained 83% of the variation in the morphological score in the context of *Freio de Ouro*, demonstrating the significant association between these characteristics and the judges' subjective assessment in the morphological analysis. However, there are no studies that associate this goniometric measurement with the dynamics of manoeuvres. Within this context, the objective of the present study is to present, through kinematics, the movements of *esbarrada* and *volta sobre patas* and determine whether there is an association between static goniometry and the dynamics of the manoeuvres.

2. Materials and Methods

Study Design

All procedures performed were approved by the Ethics Committee on the Use of Animals (CEUA) of the Federal University of Pelotas (UFPEL), under registration number of 51839-2019.

Experimental Design

Thirty-one (31) Criollo breed horses (*Equus caballus*) were evaluated, aged between 5 and 10 years, 22 males and 9 females, with an average weight of 428.41 ± 24.47 kg and withers height of 1.42 ± 0.01 m. These individuals belonged to training centres in the southern microregion of the state of Rio Grande do Sul, Brazil. All selected horses were trained and competitors in the *Freio de Ouro* discipline. The training regimen of these individuals comprised a minimum period of two years of weekly exercise routines. Each training centre has its rider responsible for training and performs similar routines at least five times a week. The competition regulations allow animals of any age group and gender, classifying the same number of males and females for the final stage.

Collections were carried out in equestrian training centres in June 2022. All animals were subjected to the same previously defined experimental and environmental conditions. Furthermore, all equestrian surfaces comprised a sand-based soft floor, mimicking the competition arenas in the discipline. Before the kinematic analysis, the horses were subjected to a specific clinical examination of the locomotor system to determine the health status of the population sample. The evaluation was carried out by an experienced clinician, who found a grade 0 on the AAEP scale (American Association of Equine Practitioners) regarding the presence of lameness in the animals included in the study. All individuals were considered healthy, without lameness or other musculoskeletal illnesses and, therefore, able to be included in the investigation.

Kinematic Data Collection

The kinematic analysis was carried out using the 2D videography technique according to Robin [7]. Thirty retroreflective markers (30 mm in diameter) were positioned and fixed with double-sided tape by the same operator on the right and left sides of the animals, in the anatomical region referring to the bony protuberances of the middle third of the facial crest, lateral apex of the atlas wing (C1), dorsal to the spinous process of the first sacral vertebra (S1) and on the anatomical eminences of each limb: Thoracic Limbs - Tuberosity of the spine (scapula), cranial aspect of the greater tubercle (humerus), lateral tuberosity at the insertion of the lateral collateral ligament of the joint of the elbow

(radius), styloid process (ulna), lateral collateral ligament of the fetlock (III metacarpal bone), coronary line on the podophalangeal axis (middle phalanx); Hind limbs - Coxal tuberosity, greater trochanter (femur), lateral condyle (tibia), lateral malleolus (fibula), lateral collateral ligament of the fetlock (III metatarsal), coronary line on the podophalangeal axis (middle phalanx).

The study field was 10 meters long and 3 meters wide, demarcated by cones for easy identification. By the sides, there was an area to allow the animals to slow down and reposition themselves. A high-speed camera with 240fps and 1280x550 resolution was used, levelled horizontally by a fixed tripod 1 meter high and positioned between 7 and 10 meters from the centre of the platform. A 72W LED light was also positioned above the camera to activate the reflectivity of markers placed on subjects. Exactly in the centre of the field, a 1-meter ruler was placed in horizontal and vertical positions to calibrate the software system. This configuration was standard for all training centres, being reproduced equally in each location.

Before data collection, a walk and trot warm-up was performed for a period of 10 minutes. Then, the riders led the animals in a straight line exactly to the centre of the study field, starting from a point located 20m away. Two slow-motion videos were obtained, bilaterally, of each horse, during the *esbarrada* and *volta sobre patas* movements. After collection, the videos were processed and analysed using the Quintic Biomechanics® v33 2D motion analysis system, where the variables obtained were tested and quantified.

Kinematic Variables

Esbarrada

The variables analyzed during the *esbarrada* movement comprised temporal, linear and angular values, being measured individually for the fore and hind limbs on both sides, as well as in the vertebral segments. Initially, measurements were taken of the length (m) and duration of the *esbarrada*(s), based on the first frame of contact of the pelvic limb(s) on the ground until the sliding completely stopped. Soon after, the length/time ratio was performed to determine the speed of the manoeuvre.

Moreover, the angular variables investigated consisted of the protraction angle ($^{\circ}$) of the thoracic and pelvic limbs at the time of engagement of these segments for the manoeuvre (Figure 1). In addition to this, at the same moment, the angle of the head was also measured, between the central point of the atlas wing, with vertices between the facial crest and the scapular marker, as well as each joint of the thoracic limbs (scapulohumeral, humeroradioulnar, antebrachiocarpal and metacarpophalangeal) and pelvic (lumbosacral, coxofemoral, femurotibiopatellar and tarsocrural). The angular measurement referring to the metatarsophalangeal joint was not included in the study due to the impossibility caused by artefacts in the images arising from the presence of sand during the animals' execution of the manoeuvre.

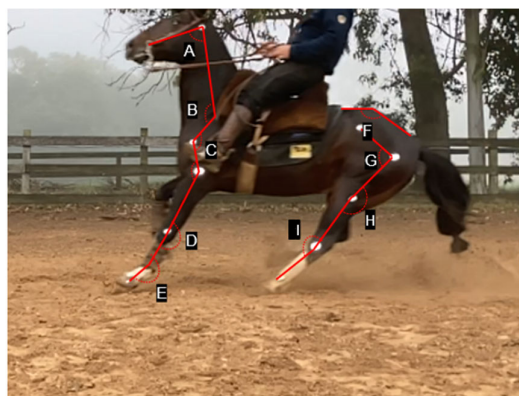


Figure 1. Moment of engagement of pelvic limbs before hoof-ground contact during the execution of the *esbarrada* manoeuvre on Criollo breed horses competing in the Freio de Ouro, with the

representation of the kinematic angles analyzed: head angle (A), scapulohumeral (B), humeroradioulnar (C), antebrachiocarpal (D), metacarpophalangeal (E), lumbosacral (F), coxofemoral (G), femurotibioapatellar (H) and tarsocrural (I).

To define the influences of joint goniometry during the *esbarrada* maneuver, measurements were taken while standing position of the aforementioned joints, where the averages found were: scapulohumeral $112.35 \pm 11.37^\circ$; humeroradioulnar $139.65 \pm 13.14^\circ$; antebrachiocarpal $183.26 \pm 4.72^\circ$; metacarpophalangeal $214.33 \pm 13.68^\circ$; head $107.47 \pm 9.88^\circ$; lumbosacral $128.40 \pm 13.06^\circ$; coxofemoral $99.40 \pm 8.95^\circ$; femurotibioapatellar $154.68 \pm 11.96^\circ$ tarsocrural $154.73 \pm 7.86^\circ$.

Volta Sobre Patas

For the *volta sobre patas* manoeuvre, angular and temporal variables were measured, due to the impossibility of obtaining linear measurements given the three-dimensional characteristic of the movement. In the present study, the *volta sobre patas* manoeuvre consisted of Set 1, relating to a pair of complete and subsequent spins to the same side, followed by another Set 2, consisting of two contralateral spins, both being performed at different Moments (M1 and M2), thus totalling four repetitions with eight turns (Figure 2). The time (s) for each set of *voltas* was obtained at both moments. At the same time, the average suspension time of both forelimbs simultaneously was evaluated in each set of spins.

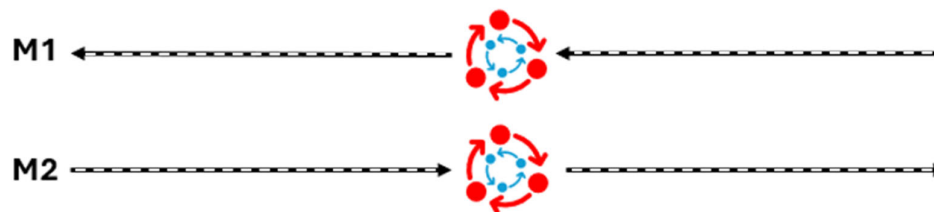


Figure 2. Scheme representing the two Moments (M1 and M2) where *volta sobre patas* was analysed, with Set 1 (red) being the first pair of spins to the same side and Set 2 (blue) being the pair of contralateral spins (the sizes of the circles and arrows are only illustrative and do not reflect the circumference made by the animals).

Also, the support and suspension times of each fore and hind limb were obtained during an entire spin. Finally, the adduction and abduction angles of the thoracic and pelvic limbs were measured when perpendicular to the camera. To determine the quantitative parameters of these variables, both Sets were observed at the same moment (M1) and the average values of the fore and hind limbs on the outer side of the spin (OFL and OHL, respectively) and of the contralateral limbs, on the internal side of the spin were taken, where they were called inner fore limb (IFL) and pivot hind limb (PHL) – the latter, due to its characteristic of serving as a support axis during the manoeuvre. In the forelimbs, the angles were measured at the vertex between a vertical line and another straight line from the scapular marker to the one at the fetlock level; In the hindlimbs, a similar measurement was performed, and the straight line in the segment was between the marker referring to the thigh tuberosity and the pelvic fetlock (Figure 3). All analyses included frames chosen where the animal was closest to the centre of the study field, to avoid perspective and parallax errors.

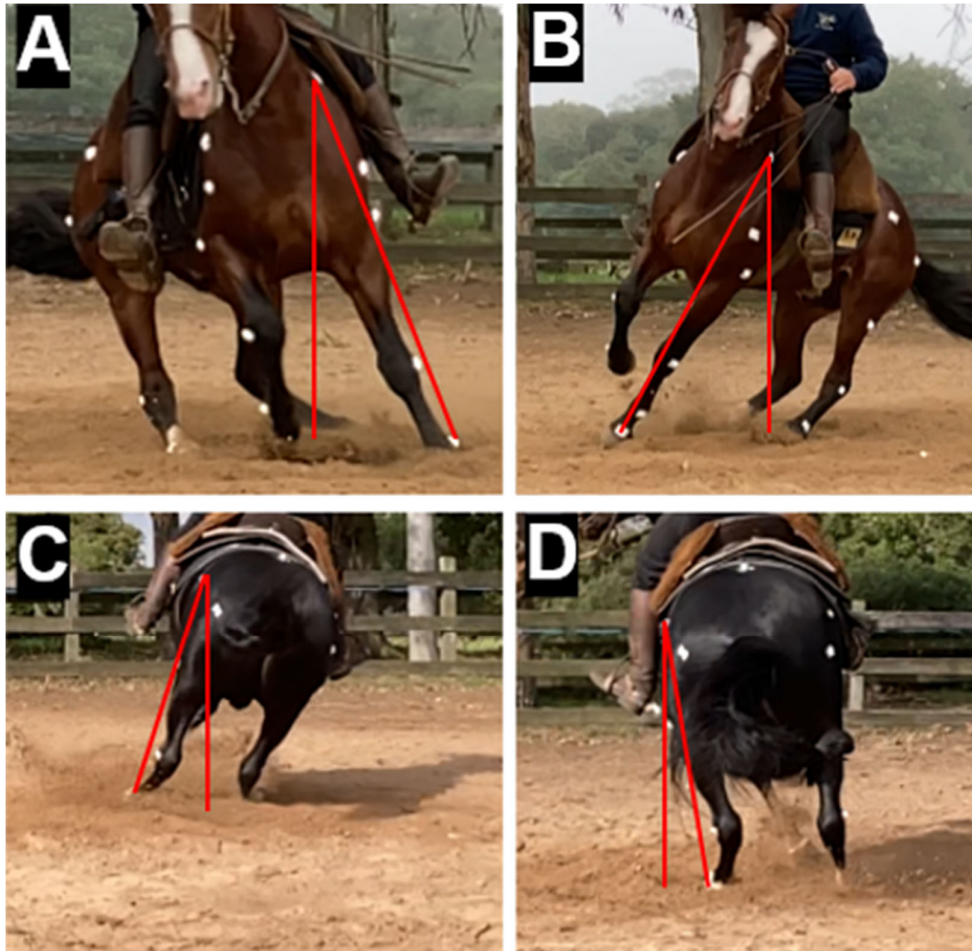


Figure 3. Angular measurement of forelimbs abduction and adduction movements (A and B, respectively) and hindlimbs (C and D, respectively) in Criollo breed horses competing in Freio de Ouro during the *volta sobre patas* manoeuvre.

Statistical Analysis

For each kinematic variable, the average values and standard deviation between the videos collected from each side during the manoeuvres were considered and, subsequently, the average value between the right and left sides was adopted for descriptive statistics. Aiming to compare the static and dynamic angular variables during the *esbarrada*, these were subjected to multiple linear regression analysis with the static goniometric data and the fore and hindlimbs protraction angles. In the temporal variables of the *volta sobre patas*, the total times of the first and second sets of spins were compared to describe the change over time in both Moments, as well as the time of simultaneous suspension of the thoracic limbs. Initially, the data were tested for normality using the Shapiro-Wilk test. For parametric data, means were compared using the paired T-test, while non-parametric data were analysed using the Wilcoxon test. For all hypotheses, a value of $p \leq 0.05$ was assumed. Statistical analyses were performed using SPSS® IBM v20 software. Descriptive values of the final means and standard deviation (SD) of all variables, except for the total and simultaneous thoracic suspension times of the *volta sobre patas* sets, were obtained for each thoracic and pelvic limb.

3. Results

The descriptive statistics of the kinematic variables of *esbarrada* and *volta sobre patas* of the 31 animals included in the study are shown below.

3.1. Esbarrada

The sliding length was 4.28 ± 0.99 m long, with a duration of 1.15 ± 0.11 s and a speed of 3.77 ± 0.55 m/s. In the angular kinematic variables, the head angle was $81.47 \pm 6.91^\circ$, and protraction angles of $27.06 \pm 2.81^\circ$ and $32.99 \pm 4.22^\circ$ for the thoracic and pelvic limbs respectively. No significant relation was determined between static goniometry and the protraction angles of the fore and hindlimbs during the moment of limb engagement ($p > 0.05$). The descriptive angular values of the joints for each thoracic and pelvic limb, as well as the total average value, are described in Tables 1 and 2.

Table 1. Angles of the joints of the right and left thoracic limbs of Criollo breed horses competing in the Freio de Ouro during engagement in the esbarrada manoeuvre.

Joint	Limb		Two-sided average
	RFL	LFL	
Scapulohumeral	$116,04 \pm 10,78$	$119,20 \pm 13,43$	$117,68 \pm 6,44$
Humeroradioulnar	$129,85 \pm 9,94$	$130,42 \pm 14,71$	$130,19 \pm 6,52$
Antebrachioacarpal	$179,70 \pm 4,87$	$182,00 \pm 5,32$	$180,87 \pm 3,40$
Metacarpophalangeal	$220,14 \pm 10,96$	$220,43 \pm 10,93$	$220,29 \pm 6,42$

The results are expressed as mean \pm standard deviation of the mean (SD). RFL: Right forelimb ($^\circ$); LFL: left forelimb ($^\circ$). N = 31.

Table 2. Angles of the joints of the right and left pelvic limbs of Criollo breed horses competing in the Freio de Ouro during engagement in the esbarrada manoeuvre.

Joint	Limb		Two-sided average
	RHL	LHL	
Lumbosacral	$121,34 \pm 9,51$	$126,12 \pm 9,37$	$123,73 \pm 5,73$
Coxofemoral	$86,38 \pm 8,95$	$86,87 \pm 8,22$	$86,63 \pm 4,95$
Femurotibipatellar	$143,51 \pm 9,32$	$142,98 \pm 8,99$	$143,25 \pm 9,16$
Tarsocrural	$131,93 \pm 13,81$	$131,69 \pm 13,53$	$131,81 \pm 9,99$

The results are expressed as mean \pm standard deviation of the mean (SD). RHL: Right hindlimb ($^\circ$); LHL: left hindlimb ($^\circ$). N = 31.

3.2. Volta Sobre Patas

In this section, we present the average data of the temporal and angular kinematic variables of the volta sobre patas manoeuvre (Table 3). The times of the Sets of spins differed in both Moments (M1, $p = 0.023$; M2, $p < 0.001$), as well as the time of simultaneous suspension of the thoracic limbs ($p = 0.013$ and 0.023 , respectively). The kinematic values of the support and suspension times, along with adduction and abduction angles of the thoracic and pelvic limbs measured for each side of the manoeuvre are shown in Table 4.

Table 3. Temporal kinematic variables of volta sobre patas of Criollo breed horses in training for Freio de Ouro.

Variable	Volta sobre patas					
	Set 1 (M1)	Set 2 (M1)	Total M1	Set 1 (M2)	Set 2 (M2)	Total M2
Total duration	$4,47 \pm 0,62^A$	$4,73 \pm 0,81^B$	$9,20 \pm 1,43$	$4,52 \pm 0,89^a$	$4,71 \pm 0,99^b$	$9,23 \pm 1,88$
Thoracic suspension	$0,39 \pm 0,17^A$	$0,42 \pm 0,16^B$	$0,81 \pm 0,33$	$0,41 \pm 0,18^a$	$0,42 \pm 0,16^b$	$0,83 \pm 0,34$

The results are expressed as mean \pm standard deviation of the mean (SD). Set 1 (M1): Set 1 of *volta sobre patas* in Moment 1 (s). Set 2 (M1): Set 2 of *volta sobre patas* in Moment 1 (s). Set 1 (M2): Set 1 of *volta sobre patas* in Moment 2 (s). Set 2 (M2): Set 2 of *volta sobre patas* in Moment 2 (s). Thoracic suspension: total time (s) of both thoracic limbs in the suspension phase. Different letters (A, B & a, b) on the same line within each Moment indicate significant differences ($p \leq 0.05$). N = 31.

Table 4. Times of the support and suspension phases and abduction and adduction angles of each limb of Criollo breed horses in training for Freio de Ouro during the volta sobre patas manoeuvre.

Phase	Limb			
	IFL	OFL	PHL	OHL
Support	2,56 ± 0,27	2,62 ± 0,32	2,89 ± 0,58	2,71 ± 0,40
Suspension	1,91 ± 0,59	1,97 ± 0,63	1,68 ± 0,67	1,84 ± 0,57
Movement				
Abduction	12,33 ± 4,25	15,40 ± 4,66	9,42 ± 3,11	9,85 ± 4,41
Adduction	16,65 ± 4,94	12,86 ± 4,39	11,37 ± 8,16	8,65 ± 2,98

The results are expressed as mean ± standard deviation of the mean (SD). IFL: inner forelimb in the circle; OFL: outer forelimb in the circle; PHL: pivot hindlimb; OHL: outer hindlimb in the circle. Support: total support time of the limb during a Set of *volta sobre patas* (s). Suspension: total suspension time of the limb during a set of *volta sobre patas* (s). Abduction: maximum abduction angle of the limb perpendicular to the camera (°). Adduction: maximum angle of adduction of the limb perpendicular to the camera (°). N= 31.

4. Discussion

4.1. Esbarrada

The *esbarrada* manoeuvre is complex and consists of an abrupt stop of the horse at high speed, symbolizing the instantaneous response to the rider's direction [8]. The animal approaches through a gallop, in a physical space that comprises around 20 meters. The results demonstrate that the animal slides a distance of $4.28 \pm 0.99\text{m}$ with a time of $1.15 \pm 0.11\text{s}$ at the first moment of contact with the surface. The speed decreases due to the deceleration that the movement promotes and may vary depending on the intrinsic factors of different equestrian surfaces, such as shear force, depth and composition material [9,10].

The starting point of the manoeuvre begins with ventroflexion of the lumbosacral joint, reaching average angular values of $123.73 \pm 5.73^\circ$, allowing engagement of the pelvic limbs ventrally to the trunk, which protracts $32.99 \pm 4.22^\circ$ due to the flexor action on the joints of this segment [11]. The kinematic data in the present study quantitatively characterize the patterning of the *esbarrada* manoeuvre. In the animals evaluated, this movement was performed with different dynamic biometric aspects, with particularly dissimilar characteristics when compared to genetic groups in similar sports (e.g. Quarter Horse), such as erect neck and flexion in the atlantooccipital region, reaching average indices of $81.47 \pm 6.91^\circ$, allowing dorsiflexion of the spine to engage the pelvic limbs. It is notorious that the protraction of the thoracic limbs is facilitated by the extensor action in the joints of these segments, with a bilateral average of scapulohumeral of $117.68 \pm 6.44^\circ$, $130.19 \pm 6.52^\circ$ for humeroradioulnar and values of $180.87 \pm 3.40^\circ$ for antebrachiocarpal and $220.29 \pm 6.42^\circ$ in metacarpophalangeal joint. These quantitative objective values indicate extensor activity in the limb, allowing protraction of $27.06 \pm 2.81^\circ$ for stabilization of the thoracic limbs during the slide. Numerically, the pelvic limbs showed protraction of $32.99 \pm 4.22^\circ$, compared to the angular values observed in the thoracic limbs when executing the *esbarrada* manoeuvre. These dynamic values characterize that the degree of pelvic protraction is directly related to flexion actions mainly of the more proximal joints, facilitating the engagement of the limb in the region ventral to the abdomen.

Despite the variability in the morphometry of the animals used in this study recorded at the station, no significant relations ($p > 0.05$) were observed with the kinematic values of protraction of the fore and hind limbs, indicating that extrinsic factors such as training, physical conditioning and experience of trainer/rider and characteristics of the equestrian surfaces determine the skill in the movement of this manoeuvre.

The sliding stop is a manoeuvre with similar features to the *esbarrada*, characteristic in the reining, a Western riding discipline. In this equestrian sport, the horse is subjected to abrupt deceleration from a fast gallop to a sliding stop, maintaining balance and sliding on the pelvic limbs [12,13], a manoeuvre like that performed by horses in the Criollo breed, despite having a striking visual characteristic of the head being kept in a lower position, with the neck being positioned

cranioventrally extended. Within this context, the descriptive data presented fills an existing scientific gap, serving as a basis for different equestrian disciplines where the execution of this movement is required. Although numerical variations occurred in the observations captured during the kinematics, these did not appear when comparisons were made on both the left and right sides, demonstrating coordination during the biomechanics of the *esbarrada*.

4.2. Volta Sobre Patas

This is a manoeuvre performed where the horse spins around its axis through lateroflexions of the spine to both sides, completing a pair of circles [14]. In the present study, although the total manoeuvre time was numerically similar, differences were observed at both Moments (M1: $p = 0.023$; M2: $p < 0.001$), when Sets 1 and 2 were considered. A plausible hypothesis lies in the complex interaction between biomechanical and neuromuscular factors during the execution of these movements. During the first set of spins, it is possible that the horses are initially adapting to the specific kinetic and kinematic demands associated with the manoeuvre. A plausible explanation for this divergence lies in the hypothesis of motor coordination since athletic performance in this manoeuvre is the result of coordinated muscular actions, influenced by the composition of muscle fibres and the precise integration between the nervous system and muscular contraction [15].

Initially, it is crucial to consider that performing repeated *voltas sobre patas* requires precise coordination between different muscle groups and neuromotor systems. During the execution of the first Set, the muscles responsible for stabilization and lateral propulsion of the axial segments are relatively less activated, resulting in an initially more optimized biomechanical efficiency. However, as the sequence of turns progresses to the second Set, there is a need to quickly change direction, activating muscle groups responsible for the contralateral movement, leading to a slight decrease in the effectiveness of the stabilization and propulsion mechanisms that can be observed as increasing time in the Set 2. Within the results observed, the thoracic suspension time can be translated as a synchronization of the movements of the thoracic limbs and greater stability for a new sequence of lateral propulsions of these segments, allowing the suspension time in the second set to be prolonged, thus elucidating the increase in this duration compared to the first Set in both M1 and M2 ($p = 0.013$ and 0.023 , respectively). It is necessary to remember that this manoeuvre is performed after other athletic demands throughout the *Freio de Ouro* event. This rapid neuromuscular activity can be influenced by the accumulation of metabolites, such as lactate, and the decreased availability of anaerobic energy, resulting in decreased muscle responsiveness and coordination [16]. This effect has already been observed in humans, where muscle fatigue led to a change in the organization of movement, and other researchers suggest a similar effect in horses, highlighting the temporal sequence of fatigue and changes in coordination [17,18]. Consequently, executing the turns in the second set, regardless of the moment (M1 or M2), may require prolonged and more intense muscular activity to maintain the necessary stability and boost, thus prolonging the total duration of the movement. Johnston et al. [19] concluded that both load and fatigue can alter locomotor patterns in horses, leading to an increase in kinematic variables, such as joint excursion and stride length, corroborating the changes observed in temporal variables observed in the present study. Therefore, it is important to consider that previous experience and motor learning also play a significant role in this temporal disparity. Horses from different equestrian disciplines can learn and adapt their movement strategies based on previous experiences, through the unique structure and coordination of the limbs, refining their biomechanical efficiency over time [20]. In short, the difference observed in the duration of subsequent spins in horses submitted to the *volta sobre patas* manoeuvre can be explained by the complex interaction between neuromuscular activity, biomechanical optimization, and motor learning. Future studies utilizing more detailed biomechanical analysis techniques and incorporating additional investigations, such as muscle activity and biomechanical load distribution, may benefit from more detailed analysis of muscle activation patterns, joint kinematics, and metabolic variables to further elucidate the underlying mechanisms. to this temporal discrepancy.

As already mentioned, in the present study the second set of *volta sobre patas* always lasts longer than the first. Although speed was not measured due to the two-dimensional limitations of the

technique, it can be inferred that there is a decrease in this variable between each spin. Still, within this context, the data confirm the active participation of the thoracic limbs in pushing the trunk laterally, with greater degrees of abduction and adduction when compared to the pelvic limbs which, in turn, serve as a pivot for the circular movement. The support and suspension times of the appendicular segments demonstrate this active biomechanics during the manoeuvre.

Therefore, in this study, for the first time in the literature on equine biomechanics, the abduction and adduction angles of the appendicular segments were quantitatively characterized, with variations between thoracic and pelvic limbs and the internal and external sides of the spin. In the forelimbs, abduction angles reached $12.33 \pm 4.25^\circ$ (inner side of the circumference) and $15.40 \pm 4.66^\circ$ (outer side), while adduction angles were 16.65 ± 4.94 (inner side of the circumference) and 12.86 ± 4.39 (outer side). In the hindlimbs, the abduction angles measured were 9.42 ± 3.11 (pivot limb) and 9.85 ± 4.41 (outer side of the circle), while the adduction angles were 11.37 ± 8.16 and 8.65 ± 2.98 , respectively. These objective quantitative records can be used in future studies, when focused on the coordination of equine limbs in the sagittal plane during closed circular movements, highlighting the importance of adequate physical preparation in competing animals. These attributes can be amplified by stretching and warming up to improve muscle and joint flexibility, crucial factors for superior athletic performance. Abduction and adduction capacity is closely linked to limb flexibility, directly influencing the effectiveness of circular movements during competitions, such as the *Freio de Ouro*, and can maximize range of movement and motor coordination, providing animals with a significant competitive advantage.

4.3. Relationship of Manoeuvres with Equestrian Discipline

According to the ABCCC regulations for the *Freio de Ouro* competition, updated in 2015, the horses of this breed are harmonious and balanced equines and derive from the Spanish Andalusian horses introduced in Latin America, which began to be domesticated, selected and transformed due to several crossbreeding [21,22]. Weighing between 400 and 450 kg, females must have a minimum height of 1.38 meters and a maximum of 1.48 meters, while males are between 1.40 and 1.50 meters. Its structure includes moderately prominent withers, muscular trunk and loin, and its moderately broad and long croup, slightly inclined to facilitate muscular descent during pelvic movements [14]. In the rural routine, this physical demand is requested, mainly, when a cattle escapes from a herd, where the horse needs to stop quickly and agilely change directions to bring the animal back to the group. The appreciation of these movements not only highlights the cultural tradition but contributes to the selection and preservation of the intrinsic characteristics of the Criollo breed, combined with the cultural preservation of the work function performed by the horse on livestock farms [23]. In 2022, the *Freio de Ouro* was recognized as a manifestation of national culture in Brazil, through Law No. 14,394. To reach the finals, horses and their riders need to go through qualifying tests in different geographic regions of southern Latin America, occurring mixing morphological and functional stages, including reining, cutting and handling cattle, demanding the maximum of their abilities and athletic capabilities, with high-intensity exercises since their training [24,25].

The *Freio de Ouro* is intrinsically characterized by its multifactorial nature, which requires the harmonious combination of several physical and behavioural elements of individuals of the Criollo breed, such as agility, obedience, balance and muscular resistance of the horse-rider system [26]. This comprehensive competition highlights the versatility of the equestrian discipline, while also evaluating the team's ability to face challenges ranging from executing precise manoeuvres to demonstrating physical and mental endurance [27]. Typically, the sequence includes the demonstration of specific gaits, such as the walk, trot and canter, followed by a smooth transition to manoeuvring and cutting.

This specific biomechanics of the movements of *esbarrada* and *volta sobre patas* depends on joint mobility of the appendicular skeleton with the axial axis. It is important to consider the fact that the first manoeuvre requires repositioning the spine in an extended position, with great participation from the shoulder and fetlock region, keeping the thoracic limbs in a considerable degree of protraction ($27.06 \pm 2.81^\circ$) and allowing a greater axial diagonalization, thus facilitating pelvic

engagement for sudden braking. Furthermore, the erect position of the neck and the reduced flexion of the head ($81.47 \pm 6.91^\circ$) allow greater stability and accuracy for the animal to bump and then return to the station after stopping. The position of a horse's head and neck significantly affects the characteristics of its back and stride [28,29]. When the neck is extended, there is an increase in extension in the thoracic region and flexion in the pelvic and lumbar region, while a lowered neck produces the opposite effect [28]. This is due to the influence of the neck muscles on head movement and posture maintenance [30]. In dressage, different head and neck positions can lead to changes in the horse's movements, with an extremely high neck position potentially increasing the risk of injury [31]. This information highlights the importance of considering the position of the horse's head and neck in training and rehabilitation programs, as well as being in line with the kinematic aspect that Criollo breed horses perform during the moment the limbs are engaged in the *esbarrada* manoeuvre, thus maximizing its biomechanical efficiency.

The range of movement during ventroflexion in movements such as *esbarrada* occurs through the lumbosacral joint ($123.73 \pm 5.73^\circ$), being the point of greatest intervertebral mobility among the thoracic, lumbar and sacral segments due to characteristics such as increased thickness and decreased height of the intervertebral disc, wide divergence of the dorsal spinous processes, poorly developed interspinous ligament, absence of supraspinous ligament and vertical orientation of the articular facets [32–35]. The biomechanics of this axial joint segment allows a greater range of motion in the hip, especially at the coxofemoral joint, promoting a consequent accentuated mobility of the distal joints in the pelvic limb [36]. Hodson et al. [37] had already described the relationship between range of hip movement and greater protraction angles of the pelvic limb in gaits such as walk, a fact that can be corroborated for manoeuvres like *esbarrada*, as observed in the present study. This kinematics allows the tarsal region to promote the main ventral engagement with the abdomen, directly influencing pelvic protraction.

4.4. Applicability of the 2D Kinematic Model for Manoeuvre Analysis

Despite the effectiveness of 2D kinematics as a viable method for the in-situ evaluation of movement patterns in horses [38], the presence of factors such as sand elevation during the execution of the *esbarrada* can override the markers, compromising the accuracy of digitisation for the thoracic and, mainly, pelvic joints during movement. This made it impossible to measure the kinematic values of the angular variables of the metatarsophalangeal joint in hindlimbs. Faced with these challenges, the integration of advanced technologies, such as accelerometers and 3D cinematography, emerges as a promising perspective to overcome the limitations of this technique [39]. These tools could provide a more comprehensive and detailed analysis of the key moments of *esbarrada* and sliding stop in horses, offering more accurate measurement of the quantitative variables related to these manoeuvres in future investigations.

Likewise, the 2D analysis of the *volta sobre patas*, which is essentially a lateralized movement, presents specific challenges that can be improved through the incorporation of 3D video capture technologies. The lateral nature of this movement demands a more comprehensive understanding of the three-dimensional dynamics involved. While two-dimensional videography made it possible to measure extremely important temporal variables, as well as adduction and abduction angles at specific moments that the video made possible, 3D cinematography and other technological tools can provide a more complete and detailed view, allowing for more precise measurements of the movement patterns for the axial and appendicular segments during *volta sobre patas* and homologous movements. Thus, the application of three-dimensional technologies enriches biomechanical analysis, contributing to a broader and more refined understanding of this complex behaviour not only of Criollo breed horses but also of other equestrian disciplines that frequently perform this kind of movement [40,41].

4.5. General Considerations

The Criollo breed has been expanding its participation in the South American economic and competitive scenarios over the decades, going beyond the boundaries of the breed's traditional

equestrian events, including reports of individuals participating in the FEI's World Equestrian Games. This phenomenon reflects not only the genetic excellence and athletic abilities inherent to the breed, but also the determination of breeders and trainers to promote the global recognition of the Criollo horse as a competitive force in various equestrian disciplines. Internationalization not only increases its cultural and economic appreciation, but also opens new market opportunities and collaborations, contributing to the expansion and strengthening of the sports business related to this equestrian discipline. Therefore, it is essential to contribute to the international scientific community with studies that present and introduce, in an unprecedented way, descriptive investigations into the biomechanics of these individuals.

The presentation of unrivalled kinematic data on manoeuvres performed by horses in non-conventional equestrian disciplines is extremely relevant, as the results provide a more in-depth understanding of the biomechanics of horses during specific movements, contributing to the advancement of scientific knowledge in the field of equestrian disciplines. This kinematic data can reveal crucial information about the efficiency, coordination, and movement patterns of horses in less explored disciplines at an international level, offering valuable insights for trainers, veterinarians and researchers. Gaining this more detailed understanding can influence training practices, and injury prevention methods, and even affect equipment and arena design. Nevertheless, the dissemination of unpublished kinematic data may in the future contribute to the development of more objective judging standards in equestrian competitions, providing scientifically based criteria to evaluate the quality of execution of manoeuvres. This scientific basis can help promote the safety and well-being of horses, ensuring that sporting practices are sustainable and respectful of the equine as an athlete.

5. Conclusions

As a conclusion, in the present study, a new methodological approach was presented for the kinematic analysis of the *esbarrada* and *volta sobre patas* manoeuvres of Criollo breed horses competing in *Freio de Ouro*, as well as homologous movements to these. The determination of values through videography was based on movement analysis models created from their real movement patterns and serve as an example of what is performed at the competition level of this equestrian discipline.

Static goniometry has no association with the protraction angles of the thoracic and pelvic limbs during the moment of engagement in the *esbarrada*. In the *volta sobre patas* manoeuvre, the second Set of spins lasts longer than the first, with a greater suspension of both thoracic limbs at both moments.

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