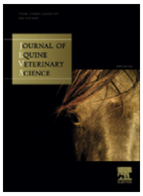
Journal of Equine Veterinary Science xxx (2013) 1-7

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com



Original Research

Kinematic Characterization of the Menorca Horse at the Walk and the Trot: Influence of Hind Limb Pastern Angle

Marina Solé PhD [a], Maria D. Gómez DVM [a], Alfonso Martínez Galisteo DVM [b], Rute Santos DVM [c], Mercedes Valera DVM [a]

[a] Department of Agro-Forestry Sciences, ETSIA, University of Sevilla, Sevilla, Spain
[b] Department of Comparative Anatomy and Pathology, University of Córdoba, Córdoba, Spain
[c] Department of Animal Science, Polytechnic Institute of Portalegre, Elvas, Portugal

A R T I C L E I N F O

Article history:
Received 6 October 2012
Received in revised form
13 November 2012
Accepted 13 December 2012
Available online xxx

Keywords:
Dressage
Equine
Gait quality
Locomotion
Morphology

A B S T R A C T

This paper describes the handled walking and trotting kinematics (linear, temporal, and angular traits) of 35 Menorca Purebred (MEN) stallions, and the relationships among these variables is presented for the first time, along with a discussion of the influence of the hind limb pastern angle on kinematic variables at both gaits. For data collection, all animals, aged between 3 and 10 years old and belonging to 28 different studs, were recorded under the same experimental and environmental conditions, using a three-dimensional (3D) semiautomatic movement analysis system. A total of 24 kinematic variables (temporal, linear, and angular) at the walk and the trot and a morphometric variable measured at the mid stance position of walking (hind pastern angle) were included in this analysis. Angle-time diagrams of the hind pastern angle while walking and trotting normalized to stride duration were also obtained. Generally the MEN stallions' forelimb movements closely resembled the movement characteristics of other European dressage performance breeds, while the hind limb locomotion showed a greater likeness to Iberian dressage Purebreds. Despite this, their ability in collection and propulsion at the walk and the trot was relatively low. The hind limb pastern conformation was partially connected to the hind limb movements for both gaits, with an apparently negative effect of excessively upright pasterns on the amplitude at the trot, which indirectly reduced collection ability.

1. Introduction

The Menorca Purebred (MEN) horse is an endangered local breed from the island of Menorca in Spain (surface area of 700 km^2), with a census of 3,500 animals included in its stud book. The census of the MEN horse population has increased, given the ideal features of these animals for dressage performance [24].

As a breed, the MEN horse is popularly known for its role in the regional festivities called *Jaleo Menorquín*. In these festivities, the horses carry out traditional movements among crowds of people with ease. The cadence is slightly modified by the speed of the movements. For example, the horse stands or walks on its hind limbs (called *el bot*). These horses are excellent for riding, and they are also used in classic dressage and Menorca dressage competitions, mainly at a regional level. Menorca dressage is a special type of dressage where the animals perform certain exercises and movements based on those performed during the traditional festivities.

Since 2007, the Spanish Ministry of Agriculture, Food, and Environment has overseen the breeding program for the MEN breed. (BOE-A-2010-5478) of this official breeding program include “the functional conformation of the animals and the ability to perform in Classic and

Corresponding author at: Marina Solé, Department of Agro-Forestry Sciences, ETSIA, University of Sevilla, Ctra. Utrera km 1, 41013 Sevilla, Spain.
E-mail address: ge2sobem@uco.es (M. Solé).

0737-0806/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.jevs.2012.12.002

Menorca dressage." In these types of populations, it is essential to evaluate the animals' performance aptitude early [5] in order to encourage both riders and breeders to improve the standards of training and increase participation in official dressage competitions. Here, the study of natural gait characteristics at the walk and the trot by image analysis could assist the selection of those animals which show correct conformation and kinematic functional traits.

The accuracy of the measurements obtained by using 3D motion capture systems compared to those using 2D methods has been discussed previously [17,33]. 3D motion capture systems have proved to be very reliable compared to other commercial systems, fulfilling the necessary requirements of a low-cost analysis system of 3D movement for a wide range of applications, including outdoor use [16]. For some of the kinematic traits studied, such as stride length, 3D methodology seems to give more accurate results. Projection of the 2D image on the calibration plan causes errors in 2D data when the animal moves out of the calibration plane [26].

In this work, a characterization of 24 kinematic variables obtained at the walk (12 variables) and the trot (12 variables) in MEN horses, during experimental tests using 3D image analysis, is presented for the first time. The main aim of this study was to describe linear, temporal, and angular kinematic characteristics of the limbs at the walk and the trot and their relationships in MEN horses, highlighting the influence of hind limb pastern angle, as injuries involving the pastern region are a common source of lameness in many types of performance horses such as dressage horses [9,28].

2. Material and Methods

2.1. Horses

A total of 35 MEN stallions, between 3 and 10 years old, were analyzed. The animals had an average mean ± SEM height at withers of 162.52 ± 0.05 cm (stick measured) and were born in 28 different studs. Approximately half of the horses competed in classic or Menorcan dressage (16 animals) and were sometimes used in the *Jaleo Menorquin*, while the remaining horses were used only for leisure activities.

2.2. Methodology

All the animals were recorded under the same experimental and environmental conditions on the island of Menorca (Spain), as kinematic qualities are greatly influenced by the characteristics of the track [4]. Only stallions were included in the dataset analyzed because of the influence of the sex on these kinds of traits [19]. For recording purposes, 16 marks (32 mm in diameter) were placed on each horse's right side, in a readily identifiable anatomical position, as shown in Figure 1.

Each animal was presented by the same experienced handler at a comfortable speed on a track 16 m long and 2 m wide, with as little influence from the handler as possible. Four strides per horse were analyzed (the average was used for the statistical analysis). Every stride was recorded both walking and trotting, using two 50-Hz video cameras positioned diagonally, using the methodology described in a report by Miró et al [26]. Video records were processed using a 3D semiautomatic movement analysis system, UCOTrack (former SOMCAM3D, University of Cordoba, Spain) [16]. In total, one morphometric variable (hind pastern inclination) measured at the mid-stance position of walking (when the line that joins markers 11 and 15 forms a 90° angle with the horizontal) and 24 kinematic variables (temporal, linear, and angular), while walking and trotting were included in this study (Table 1). Angle-time diagrams of the hind pastern inclination at the walk and the trot normalized to stride duration were obtained.

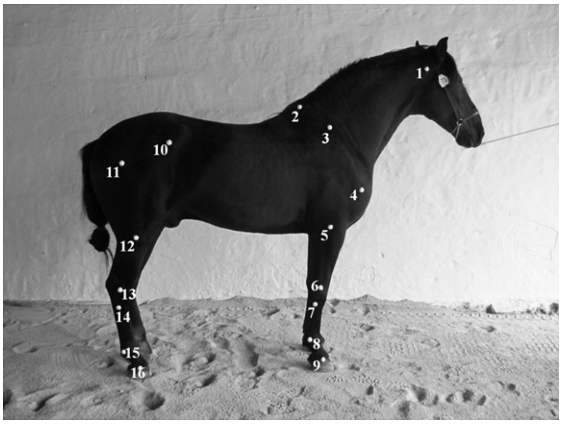


Fig. 1. Position of the 16 markers for the anatomical references of the Menorca Purebred horse: 1. atlas; 2. withers; 3. tuber spinae scapulae; 4. tuberculum majus humeri (pars caudalis); 5. lig. collaterale cubiti laterale; 6. processus styloideus lateralis radii; 7. basis os IV metacarpale; 8. lig. collaterale metacarpophalangeae laterale; 9. margo coronalis (forelimb) at the foot axis; 10. tuber coxae; 11. trochanter major femoris (pars caudalis); 12. lig. collaterale geni laterale; 13. malleolus lateralis tibiae; 14. basis os iv metatarsale; 15. lig. collaterale metatarsophalangeae laterale; 16. margo coronalis (hind limb) at the foot axis.

2.3. Statistical Analysis

Mean values, standard error of the means (SEM), and coefficient of variation (CV) for the kinematic variables analyzed at the walk and the trot are described. To assess the effect of the hind limb pastern angle, the 35 MEN horses analyzed were divided into two groups and were compared with a means comparison test at each point of the stride duration (group 1 with sloping pasterns of <60° and group 2 with upright pasterns of ≥60°, according to the frequency distributions of these animals).

Bearing in mind that most kinematic variables are dependent on speed [14,31], to determine the influence of hind pastern inclination on the kinematic traits, an analysis of covariance (ANCOVA) test was performed in which speed was treated as a covariable. Adjusted means were calculated excluding this effect and were compared with a means comparison test.

Pearson's correlations were computed between walking and trotting for the 24 kinematic variables studied. All statistical analyses were carried out using different procedures of Statistica for Windows (Microsoft, Redmond, WA) version 8.0 software [30].

Table 1
Description of hind pastern angle and kinematic variables (temporal, linear, and angular) Menorca Purebred stallions at the walk and trot

Variable	Abbreviation	Type[a]	Description[b]
Morphometrics (cm)			
Hind pastern angle	Hpi	M	Angle between the horizontal line and the line that joins markers 15 and 16 at mid stance position in the walk
Kinematics			Measured at Walk & Trot
Speed (m/s)[c]	Sp	T	Number of frames taken to travel a known distance
Propulsion (%)[d]	P	T	% of propulsion duration, from mid stance position to lift-off
Stride length (cm)[c]	Stl	L	Mean distance covered between successive contacts of the four limbs
Overtracking (cm)[c]	Over	L	Distance between footfalls of the ipsilateral limbs (positive if the hind footfall is ahead of the front footfall)
Standing under hind limb capacity (cm)[d]	Suh	L	Distance between the projections on the horizontal line of markers 11 and 14, at the maximal flexion of the tarsus joint
Range of elbow joint (°)	Er	A	Difference between the maximum and the minimum angle of the elbow joint (angle that joins markers 4, 5 and 6)
Maximal retraction forelimb angle (°)	MaxRf	A	Maximal caudal angle that joins markers 2 and 9, and the horizontal line that crosses marker 2
Minimal protraction forelimb angle (°)	MinPf	A	Minimal caudal angle that joins markers 2 and 9, and the horizontal line that crosses marker 2
Range of hip (°)	Hr	A	Difference between the maximum and the minimum angle of the hip joint (angle that joins markers 10, 11 and 12)
Range of tarsus (°)	Tr	A	Difference between the maximum and the minimum angle of the tarsus joint
Maximal retraction hind limb angle (°)	MaxRh	A	Maximal caudal angle that joins markers 11 and 16, and the horizontal line that crosses marker 11
Minimal protraction hind limb angle (°)	MinPh	A	Minimal caudal angle that joins markers 11 and 16, and the horizontal line that crosses marker 11

[a]M is a morphometric variable, T is a temporal variable, L is a linear variable, and A is an angular variable.
[b]Markers are as shown in Figure 1.
[c]Data from ref. [13].
[d]Data from ref. [29].

3. Results

Because age and training level could influence movement characteristics [11,32], these effects were previously tested by ANOVA (results not shown). However, no differences were observed in the animals included in this analysis. Therefore, none of these effects were included in this work.

3.1. Description of Walking Parameters in MEN Horses

Descriptive statistics of the 12 kinematic variables obtained at the walk by image analysis for the MEN stallions are shown in Table 2. Angular variables presented a medium CV, which was, however, lower than those for the linear and temporal variables. The length of overtracking obtained the highest CV (406.51%), whereas the maximal hind limb retraction angle and minimal hind limb protraction angle had the lowest CVs (1.99% and 2.79%, respectively). The hind limb pastern inclination was analyzed (Table 3) using ANCOVA. The hind pastern conformation significantly influenced only three of the variables (propulsion, range of tarsal joint, and maximal retraction hind limb angle). The angle-time diagram of the hind pastern angle studied in the MEN stallions at the walk was different between the two types of inclinations studied (group 1 had sloping pasterns $<60^\circ$, and group 2 had upright pasterns $\geq 60^\circ$) (Fig. 2).

3.2. Description of Trot Parameters in MEN Horses

Descriptive statistics of the 12 kinematic variables analyzed at the trot in MEN stallions are also shown in Table 2. Angular variables also presented a medium CV, which was, however, lower than those for the linear and temporal variables. The length of overtracking obtained the highest CV (102.51%), whereas maximal forelimb and hind limb retraction angles had the lowest ones (3.02% and 1.75%, respectively). The influence of the hind limb pastern angle was also significant for three variables (stride length, standing under hind limb capacity, and minimal protraction hind limb angle). Differences were observed in the angle-time diagram of the hind pastern angle between the two groups studied in the MEN stallions at the trot (Fig. 2).

Table 2
Mean ± SEM values and CVs (%) of the 24 kinematic variables studied in 35 Menorca Purebred stallions at the walk and the trot

Kinematic Measurements	WALK			TROT		
	Mean	±SEM	CV	Mean	±SEM	CV
Sp (m/s)	1.68	0.02	8.49	3.74	0.08	12.76
P (%)	22.95	0.01	20.81	11.74	0.01	31.67
Stl (cm)	184.29	2.40	7.72	263.25	3.96	8.91
Over (cm)	−3.17	2.18	406.51	−11.75	2.04	102.51
Suh (cm)	10.07	0.59	34.80	12.36	0.57	27.27
Er (°)	52.29	0.60	6.79	61.81	1.10	10.55
MaxRf (°)	102.36	0.52	2.99	99.69	0.51	3.02
MinPf (°)	64.58	0.36	3.25	60.00	0.69	6.77
Hr (°)	25.42	0.63	14.68	25.73	0.43	9.79
Tr (°)	43.72	0.99	13.24	63.17	1.13	10.62
MaxRh (°)	110.75	0.37	1.99	111.69	0.33	1.75
MinPh (°)	67.41	0.32	2.79	68.79	0.48	4.14

CV, coefficient of variation.
All other abbreviations are as in Table 1.

Table 3
Mean ± SEM values for kinematic measurements in 35 Menorca Purebred stallions at the walk and the trot: results of ANCOVA test with speed as a covariable and adjusted means comparison test after ANCOVA

Kinematic Measurements[a]	WALK			TROT		
	Group 1 (Hpi = 53.33°)	Group 2 (Hpi = 66.30°)	*P* value[b]	Group 1 (Hpi = 53.33°)	Group 2 (Hpi = 66.30°)	*P* value[b]
P (%)	24.25 ± 0.01	20.75 ± 0.01	*	12.29 ± 0.00	10.81 ± 0.01	
Stl (cm)	183.70 ± 3.17	185.29 ± 3.75		267.0 ± 5.02	256.0 ± 6.25	*
Over (cm)	−3.74 ± 2.62	−2.20 ± 3.95		−11.0 ± 2.87	−12.0 ± 2.67	
Suh (cm)	9.43 ± 0.78	11.16 ± 0.84		11.0 ± 0.65	14.5 ± 0.73	**
Er (°)	52.82 ± 0.68	51.39 ± 1.11		60.5 ± 1.31	63.9 ± 1.86	
MaxRf (°)	102.07 ± 0.66	102.86 ± 0.82		99.8 ± 0.71	99.4 ± 0.68	
MinPf (°)	64.37 ± 0.45	64.93 ± 0.58		59.7 ± 0.90	60.4 ± 1.05	
Hr (°)	25.06 ± 0.86	26.02 ± 0.88		26.1 ± 0.57	24.9 ± 0.56	
Tr (°)	41.83 ± 1.11	46.56 ± 1.54	*	62.2 ± 1.45	64.7 ± 1.78	
MaxRh (°)	110.00 ± 0.41	112.02 ± 0.57	**	111.1 ± 0.37	111.3 ± 0.63	
MinPh (°)	67.32 ± 0.39	67.57 ± 0.56		67.9 ± 0.65	70.2 ± 0.45	**

Abbreviations are as in Table 1.
[a]Group 1 had sloping pasterns at <60°, and group 2 had upright pasterns, i.e., ≥60° according to the distribution frequencies of these animals.
[b]Asterisks indicate mean statistical significance within groups: $^{*}P < .05$ and $^{**}P < .01$.

3.3. *Correlations between Walking and Trotting Parameters*

The significant phenotypic correlations between the kinematic measurements analyzed at the walk and the trot in MEN stallions are given in Table 4, with only 14 statistically significant correlations of a possible 144. The maximal retraction forelimb angle (MaxRf) at the walk was the trait most correlated with trot variables, both from forelimbs and hind limbs, and some of these correlations had negative values (−0.38 to −0.45). The forelimb variables at the walk showed moderate positive correlations with the same forelimb variables measured at the trot, such as the maximal retraction forelimb angle (MaxRf: 0.65) and the minimal protraction forelimb angle (MinPf: 0.55). Moreover, the hind limb variables at the walk showed moderate positive correlations with the same hind limb variables measured at the trot, such as the range of hip (Hr: 0.47), the range of tarsus (Tr: 0.52) and the maximal retraction hind limb angle (MaxRh: 0.44). As for the temporal and linear variables, only propulsion (P) was phenotypically correlated between walking and trotting (0.49), and hip range (Hr) at the walk also showed moderately negative correlation with the standing under hind limb capacity at the trot (Suh: −0.38).

4. Discussion

4.1. *Description of Walking and Trotting Parameters in MEN Horses*

Walk involves a natural gait which has rarely been analyzed in equine locomotion studies when horses are handled [15]. Modification of the magnitudes leading to greater amplitude of movement (mainly for angular and linear traits) could result in increased locomotive efficiency and sports aptitude [27]. The trot is the most commonly analyzed gait in equine locomotion, as it can reflect the scores obtained in dressage tests [6] and is increasingly used to assess gait in the training of equine athletes [22].

In the present work, the description of 24 kinematic variables at the walk and the trot are shown for the first time in MEN stallions, using 3D methodology. Moreover, the influence of a particular conformation trait (hind

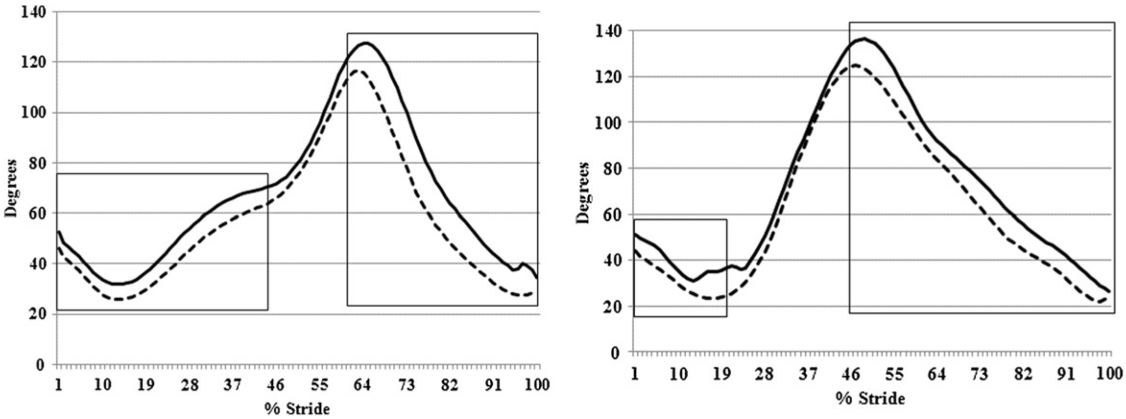


Fig. 2. Angle-time diagrams for the hind pastern angle joint at the walk (left) and at the trot (right) for the 35 Menorca Purebred stallions (group 1, <60° [broken line]; group 2, ≥60° [solid line]). Rectangle represents statistical significance within groups at $P < .05$.

Table 4
Significant Pearson's correlations between the 24 kinematic variables studied at the walk (vertical) and the trot (horizontal) for 35 Menorca Purebred stallions

Walk Variable	Trot Variable[a]						
	P	Er	MaxRf	MinPf	Hr	Tr	MaxRh
P	0.49 ± 0.026**						
Suh					−0.38 ± 0.028*		
Er			−0.38 ± 0.028*			0.38 ± 0.028*	
MaxRf		0.39 ± 0.028*	0.65 ± 0.023***				
MinPf			0.64 ± 0.023***	0.55 ± 0.025***			
Hr			−0.41 ± 0.028*		0.47 ± 0.027**		
Tr			−0.45 ± 0.027**			0.52 ± 0.026**	
MaxRh							0.44 ± 0.027**
MinPh			0.34 ± 0.028*				

Abbreviations are as in Table 1.
[a]Asterisks indicate statistical significance: *$P < .05$; **$P < .01$; ***$P < .001$.

pastern angle) on MEN horses' locomotion also was studied.

The average speed obtained at the walk (1.68 m/s) (Table 2) was the same found for Spanish Purebred horses (SPB) or German horses (GE) with 2D videography [5,12]. It was also similar to the SPB recorded on a treadmill (1.70 m/s, without inclination [27]) with Arab (AR) and Anglo-Arab (AA) horses at a handled walk (1.63 and 1.64 m/s, respectively [15]) and European Warmblood (EW) ridden horses with a high degree of training in classic dressage at a medium walk (1.73 m/s [10]), although these studies used 2D methodology and any comparisons will therefore serve only for reference.

The average speed obtained at the trot (3.74 m/s) (Table 2) was similar to those found in hand for AA and SPB horses (3.70 and 3.9 m/s, respectively [8]) and EW (3.88 m/s [21]) and GE horses (3.97 m/s [5]). Nevertheless, most of the mean values obtained for the variables analyzed in the MEN stallions did not differ greatly from those obtained for the breeds shown in the reviewed references.

Although the stride length studied with 2D might produce values 3% to 4% higher than when using the 3D methods at the trot [26], the results obtained in this work should really be compared with the 2D analysis, because there is no published information about 3D studies in other breeds.

In this case, the stride length of the MEN horses appeared to be within the range of the values obtained for the other Spanish horse breeds but still lower than Warmbloods. This variable at the walk (184.29 cm) was closer to that of AA (187.0 cm) and EW horses at a medium walk (187 cm) but lower than GE (201 cm) horses. Height at withers has a positive major effect on linear parameters [14], and the values obtained with the 3D method are lower than those with the 2D method [26]. However, although MEN horses were among the smallest horses (162.52 cm vs. 161, 173, and 168 cm, respectively), they had a remarkably high walk amplitude. The stride length at the trot (263.25 cm) was also similar to the AA (263.64 cm) and SPB (268.26 cm) strides but lower than that of EW (above 290 cm) horses. Greater stride length is one of the most highly valued features and one which is prized in dressage performance. Warmblood breeds have been selected for sport performance for many years, which would explain the differences observed between best performers (Warmbloods [5]) and the Spanish equine breeds.

The CVs obtained for the length of overtracking at the walk and trot (406.51% and 102.51%, respectively) were very high and, therefore, unsuitable for breed characterization. However, the averages (−3.17 cm at the walk and −11.75 cm at the trot) were less than zero, values which are undesirable for the future sport performance of the MEN horses. Thus, it would certainly be of interest to introduce this trait into the breeding program of this breed, in order to avoid any locomotion pattern deficiencies in the future.

Good propulsion and longitudinal activity at both the walk and the trot are advantageous for gait collection [5]. Therefore, it will be desirable that these traits (amplitude and propulsion) were taken into account for the progress of the MEN breed in dressage performance as selection criteria within the official breeding program. MEN horses showed lower propulsion activity at the trot (12%) than at the walk (23%), and this is not advantageous for gait collection. These values were lower than those reported for other breeds with both gaits [5,15]. The low collection ability at the walk and the trot was also shown by the average values of standing under hind limb (10.07 cm at the walk and 12.36 cm at the trot). In both cases, the values were different from zero. The highest degree of gait collection is produced under the rider, although no references for this variable have been published, so comparison with other breeds is not possible.

Regarding angulation traits, no differences were found by Miró et al [26] between 2D and 3D image analysis methods at the trot, and thus, direct comparisons between breeds are possible. MEN horses showed a lower range of elbow joint at the walk (52.29°) than SPB horses (64.2° and 59.3°[12,15]) and was closer to that of the AA (55.9°[15]), whereas this trait at the trot (61.81°) was close to the values obtained for the AA (60.1°[8]) or EW (63°[21]) breeds and lower than the value obtained for the SPB (67.1°[8]) horses. Thus, the elevated movement, which is also desirable in dressage horses, was not found to be characteristic of MEN horses, although this could be improved by selection.

Generally, the forelimb locomotion pattern of the MEN horses at the walk appeared to be more similar to the locomotion pattern of the AA breed than to that of the SPB (characterized by its elevations). However, the maximal retraction forelimb angle (99.69°) and minimal protraction forelimb angle (60°) of the MEN horses were found to be closer to those of the SPB breed (100.1° and 64.5°, respectively [15]). The forelimb locomotion pattern of the MEN horses at the trot did not have the same elevations as those of the SPB, but the natural ease of protraction can be highlighted, which was superior to that of the EW (65° [10]) horse.

However, the similarity between the movement of the hind limbs in the MEN and those in the SPB breeds at the walk was greater. The range of hip (25.42°) and range of tarsus (43.72°) of the MEN horses were similar to those of the SPB breed (31.8° and 44.5°, respectively [12]), and the same was shown for the minimal protraction hind limb angle (67.41° in the MEN and 70.23° in the SPB breed [27]). At the trot, the hind limb joint movements of MEN horses were close to those of the AA, as with the range of hip (25.75° vs. 24.8°, respectively [8]) and the range of tarsus (63.17° vs. 61.3°, respectively [8]).

According to Back et al [2], the range of movement of tarsal joints is positively correlated with good gait punctuations. In the present study, MEN horses at the trot showed a wider range of tarsus movement (63.17°) than GE (52° [5]) horses. They also showed comparatively less retraction (111.69°) and more protraction (68.79°) in the hind limbs than other Spanish breeds (maximal retraction hind limb angle 115.7° and 114.9° and minimal protraction hind limb angle 74.8° and 71.8° for the AA and SPB horses, respectively; [8]).

In addition, the hind limb retraction angle is also involved in the act of propulsion, as it generates the impulse of displacement [20]. Therefore, this could account for the low propulsion observed in MEN horses, although it can be assumed that an excessive delay of the hind limbs adversely affects protraction, as previously described by Santos [29] in Lusitano horses. Moreover, different muscle composition within the breeds could also influence the locomotion pattern, as can be seen in the histochemical differences in the skeletal muscle reported by López-Rivero et al [23].

Finally, the influence of hind pastern angle on the locomotion of MEN horses at the walk and the trot was also analyzed (Table 3), because of the established relationship between an unsuitable conformation of the pastern region and injury [25]. Only 3 of the 12 variables studied at the walk were significantly different in both groups. The propulsion was higher for the horses with sloping hind pasterns, and upright hind pasterns were apparently associated with an excessive retraction of the hind limb and a larger range of motion in the tarsus joint (no differences were found in the minimal protraction hind limb angle). In the present study, it was observed that the angle-time diagram of the hind pastern angle at the walk (Fig. 2) changed according to the inclination of this joint. The differences observed suggest that, at the walk, the hind limb pastern conformation affected the hind limb movements. This may be due to the fact that breeders do not have sufficient knowledge about the influence of conformation on locomotion, which could result in inaccurate selection of horses for breeding.

At the trot, 3 of the 12 variables studied were also significantly different between the groups for the hind pastern angle. The stride length was longer in those horses with sloping hind pasterns, whereas upright hind pasterns seemed to cause a smaller protraction of hind limbs and poor standing under hind limb capacity. Similarly to what was observed in the angle-time diagram of the hind pastern angle at the walk (Fig. 2), the hind limb movement pattern at the trot changed according to the inclination of this joint. Therefore, at the trot, an excessively upright hind pastern conformation apparently had a negative effect on the amplitude and indirectly reduced the ability to collect.

In addition, excessively upright or sloping hind pastern angles may predispose the horse to major risk of injury [25]. It is therefore recommended to reach the optimum hind pastern conformation, which may be beneficial for the performance results of the MEN horses, since pastern injuries are often breed or use-specific (Fig. 2) [9].

4.2. Correlations between Walking and Trotting Parameters

The relationship between walking and trotting locomotion traits is rarely discussed, and there is little in the literature on this subject. Hobbs et al [18] showed differences in kinematics between walking, trotting, and cantering in a circle; Baban et al [1] reported some phenotypic correlations between walking and trotting in Lipizzaner horses; and Back et al [3] concluded that kinematics records at the walk were similar to, and thus predictive for, locomotion at the trot.

The present study revealed few significant phenotypic correlations (9.7) between walking and trotting (Table 4). Nevertheless, propulsion, maximal and minimal retraction forelimb angles, and range of hip, range of tarsus, and maximal retraction hind limb angle recorded at the walk could be considered predictive of locomotion at the trot for the same traits, as moderate-to-high positive correlations were found between them (ranging between 0.44 and 0.65). These values showed the high relevance of hind limb movements in the prediction of equine locomotion. It can be noted that the range of the hip at the walk obtained a negative correlation with standing under hind limb capacity at the trot (−0.38), which suggests that a greater flexion of the hip while walking is associated with a better collection at the trot. This is consistent, as a more flexed hip joint leads to greater pelvis rotation [3], which corresponds with greater motion in the lumbosacral joint and suppleness in the loins. These characteristics are essential for collection and contribute to the transmission of the impulse generated by the hind limbs to the forelimbs [7].

Furthermore, it was shown that the maximal retraction forelimb angle at the walk obtained the maximum number of significant phenotypic correlations with trotting variables. For instance, the range of joint movements at the trot (range of elbow, hip and tarsus) had negative values with the maximal retraction forelimb angle at the walk (−0.38, −0.41, and −0.45, respectively). Therefore, apparently, MEN horses with a greater retraction of forelimbs at the walk had poorer flexion of the joints at the trot.

5. Conclusions

Walking in MEN stallions can be characterized by its amplitude and by the forelimb traits being defined by its extension rather than its elevated movements. At the trot, the kinematic traits of the MEN stallions are distinguished from other dressage Iberian breeds by the natural ease of the forelimb protraction. Generally the MEN stallion's forelimb movements closely resemble the movement characteristics of other European dressage performance breeds, while the hind limb locomotion shows a greater likeness to the Iberian dressage Purebreds.

In spite of this, their ability for collection and propulsion, both at the walk and the trot, is relatively low. The hind limb pastern conformation is partially connected to the hind limb movements at the walk and the trot. The hind limb pastern conformation apparently has a negative effect of excessively upright angles on the amplitude at the trot, which indirectly reduces the collection ability. The relevance of hind limb movements in equine locomotion has once again been highlighted, as most of the hind limbs traits between walking and trotting were phenotypically correlated.

Acknowledgments

This work was funded by the Breeders Association of Menorca Horses (http://www.cavalls-menorca.com) and the research project Conservación y Gestión sostenible de la raza equina menorquina mediante la caracterización genética y morfológica: Estrategias para el mantenimiento de la diversidad genética RZ2008-00011-00-00, financed by the National Program of Resources and Agrifood Technologies (Spanish Ministry of Education and Science national subprogram of genetic resources for agrifood interests).

References

[1] Baban M, Curik I, Antunovic B, Cacic M, Karabi N, Mijic P. Phenotypic correlations of stride traits and body measurements in Lipizzaner stallions and mares. J Equine Vet Sci 2009;29:513-8.
[2] Back W, Barneveld A, Bruin G, Schamhardt HC, Hartman W. Kinematic detection of superior gait quality in young trotting Warmbloods. Vet Quarterly 1994;16:91-6.
[3] Back W, Schamhardt HC, Barneveld A. Are kinematics at walk related to the locomotion of a warmblood horse at the trot? Vet Quarterly 1996;18:79S-84S.
[4] Barrey E, Landjerit B, Wolter R. Shock and vibration during the hoof impact on different track surfaces. Equine Exe Phys 1991;3:97-106.
[5] Barrey E, Desliñes F, Poirel D, Biau S, Rivero JL, Langlois B. Early evaluation of dressage ability in different breeds. Equine Vet J 2002;34:319-24.
[6] Barrey E, Biau S. Relationships between stride characteristics and scores in dressage tests. Pferdeheilkunde 2004;20:140-4.
[7] Bennet D. Principles of conformation analysis, vols. I—III. Gaithersburg, MD: Fleet Street Publishing Co; 1992.
[8] Cano MR, Vivo J, Miró F, Morales JL, Galisteo AM. Kinematic characteristics of Andalusian, Arabian and Anglo-Arabian horses: a comparative study. Res Vet Sci 2001;71:147-53.
[9] Carpenter R, Baxter G. The equine pastern. Compend Contin Educ Vet 2011;33(4):E1-7.
[10] Clayton HM. Comparison of the stride kinematics of the collected, medium and extended walks in horses. Am J Vet Res 1995;56:849-52.
[11] Denham S, Staniar W, Dascanio J, Phillips A, Splan R. Linear and temporal kinematics of the walk in Warmblood foals. J Equine Vet Sci 2012;32:112-5.
[12] Galisteo AM, Cano MR, Miró F, Vivo J, Morales JL, Agüera E. Angular joints parameters in the Andalusian horses at the walk obtained by normal videography. J Equine Vet Sci 1996;16:73-7.
[13] Galisteo AM, Vivo J, Cano MR, Morales JL, Miró F, Agüera E. Differences between breeds (Dutch Warmblood vs Andalusian Purebred) in forelimb kinematics. J Equine Sci 1997;8:43-7.
[14] Galisteo AM, Cano MR, Morales JL, Vivo J, Miró F. The influence of speed and height at the withers on the kinematics of sound horses at the hand-led-trot. Vet Res Commun 1998;22:415-23.
[15] Galisteo AM, Morales JL, Cano MR, Miró F, Agüera E, Vivo J. Interbreed differences in equine forelimb kinematics at the walk. J Vet Med A 2001;48:277-85.
[16] Garrido-Castro JL, Medina-Carnicer R, Galisteo AM. Design and evaluation of a new three-dimensional motion capture system based on video. Gait Posture 2006;24:126-9.
[17] Hobbs SJ, Levine D, Richards J, Clayton H, Tate J, Walker R. Motion analysis and its use in equine practice and research. Vet Med Austria 2010;97:55-64.
[18] Hobbs SJ, Licka T, Polman R. The difference in kinematics of horses walking, trotting and cantering on a flat and banked 10 m circle. Equine Vet J 2011;43:686-94.
[19] Holmström M, Magunsson LE, Philipsson J. Variation in conformation of Swedish Warmblood horses on conformational characteristics if elite sport horses. Equine Vet J 1990;22:186-93.
[20] Holmström M. Quantitative studies on conformation and gait analyses in the riding horse. PhD thesis. Uppsala, Sweden:Saint Louis University; 1994.
[21] Holmström M, Fredricson I, Drevemo S. Biokinematic effect of collection on the trotting gaits in the elite dressage horse. Equine Vet J 1995;27:281-7.
[22] Leleu C, Cotrel C, Barrey E. Effect of age on locomotion of Standardbred trotters in training. Equine Comp Exerc Physiol 2004;1:107-17.
[23] López-Rivero JL, Agüera E, Monterde JG, Rodríguez-Barbudo MV, Miró F. Comparative study of muscle fiber type composition in the middle gluteal muscle of Andalusian, Thoroughbred and Arabian horses. J Equine Vet Sci 1989;9:337-40.
[24] Magrama. Ministry of agriculture, food and ambient. http://www.magrama.gob.es/es/ganaderia/temas/zootecnia/razas-ganaderas/; 2012.
[25] Marks D. Conformation and soundness, In: Proceedings of the 46th Annual Convention of the American Association of Equine Practitioners. San Antonio, Texas, USA; 2000. p.39–45.
[26] Miró F, Santos R, Garrido-Castro JL, Galisteo AM, Medina-Carnicer R. 2D versus 3D in the kinematic analysis of the horse at the trot. Vet Res Commun 2009;33:507-13.
[27] Molina A, Valera M, Galisteo AM, Vivo J, Gómez MD, Rodero A, et al. Genetic parameters of biokinematic variables at walk in the Spanish Purebred (Andalusian) horse using experimental treadmill records. Livest Sci 2008;116:137-45.
[28] Murray RC, Walters JM, Snart H, Dyson SJ, Parkin TDH. Identification of risk factors for lameness in dressage horses. Vet J 2010;184:27-36.
[29] Santos R. Genetic characterization of the Lusitano Purebred horse sport aptitude by kinematic traits at the trot. PhD thesis. Córdoba, Spain:University of Córdoba; 2008.
[30] Statsoft Inc. STATISTICA (data analysis software system), version 8. www.statsoft.com; 2007[accessed 01.03.2013].
[31] Weishaupt MA, Hogg HP, Auer JA, Wiestner T. Velocity-dependent changes of time, force and spatial parameters in Warmblood horses walking and trotting on a treadmill. Equine Vet J 2010;42(suppl 38):S530-7.
[32] Wejer J, Lendo I, Lewczuk D. The effect of training on the jumping parameters of inexperienced Warmblood horses in free jumping. J Equine Vet Sci, doi:10.1016/j.jevs.2012.07.009.
[33] Weller R, Pfau T, Babbage D, Brittin E, May SA, Wilson AM. Reliability of conformational measurements in the horse using a three-dimensional motion analysis system. Equine Vet J 2006;38(7):610-5.