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Genetic parameters of biokinematic variables of the trot in Spanish Purebred horses under experimental treadmill conditions

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Abstract

The purpose of this study was to estimate the genetic parameters of biokinematic variables in Spanish Purebred (SPB) horses in order to select those of sufficient interest to be measured in the pre-selection of the animals for possible inclusion in the breeding programme. Kinematic analysis of 130 SPB horses 4.6 ± 1.5 years old were recorded at the trot (4 m/s) on a treadmill. Genetic parameters were estimated using VCE software and a bivariate mixed animal model including age and stud as fixed effects and animal additive genetic effect and residual error as random effects.

In general, heritabilities were high (0.33–0.88). The angular variables presented the lowest heritabilities, whereas the maximum height of the fore-hoof and the duration of swing phase in the hindlimb gave the highest scores. Genetic correlations were also very high, so it was possible to reduce the number of breeding programme characteristics to stride duration, hindlimb swing phase duration, range of stifle and elbow angles, minimal angle of carpus, and minimal retraction-protraction angle of the hindlimb.

Keywords: Heritability; Genetic correlation; Equine locomotion; Biokinematic

Introduction

Traits based on competition and performance test scores represent the main selection criteria in most breeding schemes of sport horses. Additionally, it has been suggested that a gait and conformation test could be applied to detect young horses with good dressage ability more accurately (Barrey et al., 2002b). For equine performance it is possible to select by movement results because there is a favourable genetic correlation (Saastamoinen et al., 1998). From a biological point of view, locomotion can be defined as the ultimate mechanical expression of exercise activity and, in order to sustain an exercise activity, the organism requires a synergy between several systems (Barrey, 1999). Estimations of cardiovascular, metabolic, muscular and locomotor traits are used in breeding programmes, since a significant relationship with competition results has been reported (Rivero and Barrey, 2001).

The Spanish Purebred (SPB) horse, the Andalusian, is the most important breed in Spain and is employed in leisure and sports activities, mainly in classical dressage where it can compete to the highest standards in international dressage events. A Breeding Scheme for SPB horses was developed recently with the aim of improving dressage performance and a number of studies have already been carried out to assess aerobic capacity and fitness (Castejón et al., 1994). Variations in blood parameters (Rubio et al., 1995) have been studied using a treadmill under experimental conditions (Valette et al., 1991), and other studies carried out in this laboratory include an examination of muscle fibre type characteristics (López-Rivero

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et al., 1989, 1993) and an assessment of the normal kinematic pattern at hand-led walk (Galisteo et al., 2001), hand-led trot and mounted trot (Morales et al., 1998a,b; Cano et al., 1999, 2000, 2001a,b).

A study of genetic parameters (heritability and genetic correlations) for kinematic variables of the trot has not been reported although locomotion analysis has considerable potential in the selection of performance horses (Holmström, 1994) and knowledge of genetic parameters is essential (Ducro et al., 2005).

Gait analysis could provide early criteria for breeding in dressage and jumping breeding programmes (Barrey et al., 2002a), since trot characteristics in young horses can be used objectively to predict locomotor performance in future adult horses (Back et al., 1994b). The aim of the present study was to determine genetic parameters for the biokinematic variables of the trot in SPB horses on a treadmill. The range of variables was used to establish an efficient methodology for the pre-selection of animals.

Materials and methods

A total of 130 SPB males, registered in the Stud-book, were evaluated at the Laboratory of Equine Performance Control (Veterinary Faculty of Cordoba, Spain). The animals, which came from 24 stud farms, were aged between 4 and 7 years (mean 4.6 ± 1.5 years).

Biokinematic analysis at the trot on a treadmill

A clinical examination was performed on each horse on arrival. Only completely healthy animals were included in the study. In order to achieve a gait without stress (Buchner et al., 1994), at least four pre-experimental training sessions were undertaken. Each horse was given a 5 min warm-up, then 15 adhesive markers were attached to the right side of the standing horse at pre-defined skeletal reference points (Cano et al., 1999). These markers were 32 mm in diameter with contrasting colour (yellow), and were chosen so as to be easily identifiable and representative of the joints and radii under investigation (Fig. 1).

The recordings were done using a camcorder (Hi8 Sony 5000-E, Sony Electronics) with the shutter speed set at 1:4000. The camera was aligned in a perpendicular plane to the treadmill, with a field of view including all of the treadmill length. The speed of the flat treadmill was selected at 4 m/s. Two references measuring 1.2 m in height and graduated at 0.1 m were placed at a distance of 2 m in the middle of the treadmill belt and were used as a calibration system.

Video sequences were digitised in a computer using a real-time video recording card, Matrox Marvel G-400-TV, (Matrox Graphics), including six complete strides of both fore and hind-limbs, per horse. The beginning of the stride was determined visually from the video sequence when the hoof touched the ground (Clayton, 1995). Stride variables were obtained from digitised videos in a semiautomatic analysis system (SMVD 2.0) which enabled calculations to be made of two-dimensional coordinates in each frame of the markers on the skin (Galisteo et al., 1998), at a rate of 50 frames/s.

Twenty variables were studied: 5 linear, 5 temporal and 10 angular variables. The linear traits were: stride length (StL), forelimb length (FL), hindlimb length (HL) and fore and hindlimb maximum height of hoof (FMHL and HMHL). The temporal variables were: stride duration (StD), forelimb stance and swing phase duration (FStD and FSwD), hindlimb stance and swing phase duration (HStD and HSwD). The angular variables were: range of elbow, stifle and tarsus angles (ERA, SRA and TRA), retraction-protraction range of fore and hindlimb (FRPRA and HRPRA), minimal angle of carpus, stifle and tarsus (CmA, SmA and TmA), minimal retraction–protraction angle of the hindlimb (HMRPA) and maximal retraction–protraction angle of the forelimb (FMRPA).

Linear and angular variables were obtained from digitalised images using graduated references placed on the middle of the treadmill, with the exception of the forelimb and hindlimb length (FL and HL), since the speed was constant in this study and could therefore be estimated indirectly from the fore and hindlimb duration (FL = forelimb duration ∗ velocity and HL = hindlimb duration ∗ velocity). Temporal variables were calculated directly from videotape. The detailed methodology of measurement for each variable can be found in Cano et al. (1999). Maximum heights reached by the marker placed on the coronet were measured (CmA) in each right fore and hindlimb, and stride frequency was estimated as 1/stride duration.

Genetic and statistic analysis

A preliminary descriptive statistical analysis and ANOVA for the analysis of the influence of age and stud-farm over biokinematic variables

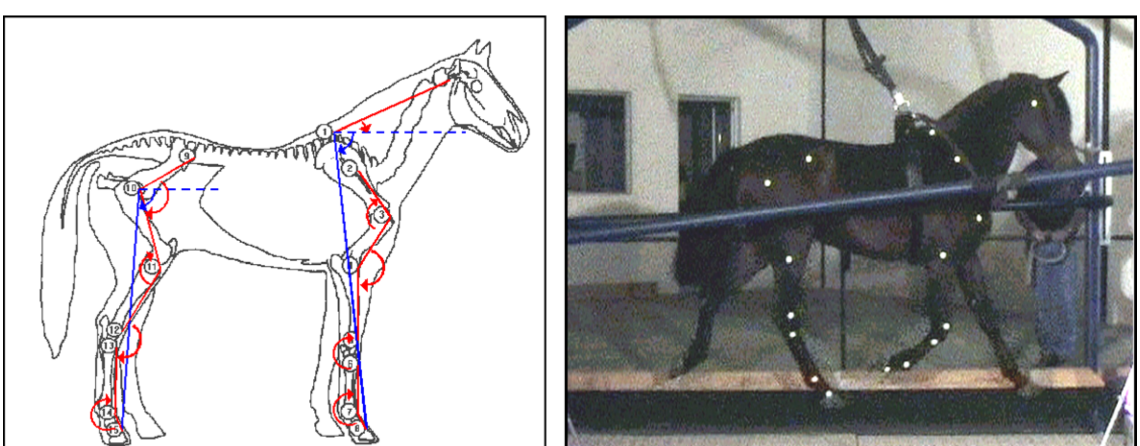


Fig. 1. Position of the markers placed on the horse for the study of biokinematic variables at the trot on a treadmill. 1, withers; 2, tuber of the spine of the scapula; 3, greater tubercle of the humerus (caudal part); 4, lateral collateral ligament of the elbow joint; 5, lateral styloid process of the radius; 6, base of the 4th metacarpal bone; 7, lateral collateral ligament of the fore fetlock joint; 8, coronet of the fore hoof (over the pastern axis); 9, tuber coxae; 10, greater trochanter of the femur (caudal part); 11, lateral collateral ligament of the stifle joint; 12, lateral malleolus of the tibia; 13, base of the 4th metatarsal bone; 14, lateral collateral ligament of the hind fetlock joint; 15, coronet of the hind hoof (over the pastern axis).

were performed. The distribution of the measured traits was checked for normality and for outliers, using quantile–quantile plots (Johnson and Wichern, 1992). A preliminary study of the relationship between the traits was made by a factor analysis that enabled a reduction of the number of variables and the detection of the structure in the relationship between them (Statsoft Inc., 2001). For the statistical analysis of the different variables we employed Statistica for Window (Statsoft, 2001). The genetic parameters (heritabilities and genetic correlations) of these traits were estimated using the VCE4 programme (Groeneveld, 1998), a bivariate mixed animal model including age and stud of animal as fixed effects, and animal additive genetic effect and residual error as random effects. The levels of heritability were estimated as the average value weighted by their standard errors, because of the bivariate model.

To complete the pedigree for the calculation of the inverse of the relationship matrix, the SPB Horse Studbook was used, and we added all of the recorded ancestors of the animals evaluated up to the fourth generation giving a total of 1503 animals. The average relatedness between the analysed animals was 0.073.

The additive genetic variance and covariance of the traits were estimated according to a restricted maximum likelihood procedure (REML) using a Quasi-Newton algorithm with exact derivatives to maximise the log likelihood. An approximate standard error (SE) of the genetic parameters was estimated from the inverse of the approximation of the Hessian matrix when convergence was reached (Groeneveld, 1996).

Results[1]

Table 1 shows descriptive statistics for the 20 variables. All were adjusted to a normal distribution ($P<0.05$) without any mathematical transformations. Their coefficients of variation (CV) are in the medium-high range, between 4% and 10% for 60% of the variables. Maximal retraction-protraction angle of forelimb and minimal retraction-protraction angle of hindlimb presented the lowest CV (1.9% and 2.1%, respectively) and fore and hindlimb maximum height of hoof the highest CV (23.1% and 20.7%, respectively). The influence of age was evaluated using ANOVA (data not shown). Only two angular variables were statistically significant in relation to age (range of elbow angle and minimal stifle angle). Three variables showed significant changes related to the stud-farm (forelimb stance phase duration, minimal stifle angle and minimal retraction-protraction angle of hindlimb). There was no interaction between age and stud-farm.

Fig. 2 gives a graphical representation of the factor analysis (principal component analysis) for trot variables and the correlations between the main factors and analysed variables can be observed. The first factor (32.39% of total variance) was related to most of the linear and temporal variables. The second factor (21.42%) was related to most of the angular (minimal angle of carpus, stifle and tarsus, elbow and stifle angles) and elevation variables (hindlimb maximum height of hoof). The third (10.30%) was related to the oscillation variables (retraction-protraction range of fore and hindlimb), and the fourth (9.13%) to variables that condition forelimb elevation (forelimb maximum height of hoof, range of elbow angle and maximal retraction-protraction angle of forelimb).

[1] Supplementary data are available on line: see 10.1016/j.tvjl.2007. 07.031

Table 1
Descriptive statistics and heritability (h^2) of 20 biokinematic variables measured in Spanish Purebred horses ($n = 130$) on a treadmill

Variables[a]	Mean ± SE	Minimum	Maximum	CV (%)	$h^2 \pm$ SE
StD	0.66 ± 0.003	0.58	0.73	4.8	0.87 ± 0.189
StL	2.63 ± 0.012	2.31	3.05	5.0	0.83 ± 0.218
FL	2.63 ± 0.012	2.16	3.05	5.2	0.66 ± 0.258
FStD	0.27 ± 0.002	0.15	0.33	8.8	0.63 ± 0.317
FSwD	0.39 ± 0.002	0.31	0.48	6.9	0.87 ± 0.154
FMHL	25.10 ± 0.520	13.69	41.98	23.1	0.88 ± 0.141
HL	2.64 ± 0.011	2.31	3.04	4.9	0.87 ± 0.154
HStD	0.28 ± 0.001	0.24	0.31	5.3	0.86 ± 0.197
HSwD	0.38 ± 0.002	0.32	0.45	7.2	0.88 ± 0.141
HMHL	16.40 ± 0.305	9.55	25.14	20.7	0.45 ± 0.272
ERA	67.06 ± 0.686	47.25	83.21	11.40	0.86 ± 0.179
SRA	48.98 ± 0.487	38.51	64.45	11.1	0.74 ± 0.283
TRA	68.65 ± 0.679	52.35	87.56	11.0	0.57 ± 0.260
FRPRA	38.68 ± 0.180	34.42	44.00	5.2	0.83 ± 0.169
HRPRA	44.96 ± 0.233	38.93	51.42	5.8	0.63 ± 0.309
CmA	84.13 ± 0.767	58.73	106.08	10.2	0.86 ± 0.139
SmA	112.94 ± 0.795	91.25	139.18	7.8	0.36 ± 0.273
TmA	93.85 ± 0.818	68.55	115.35	9.7	0.56 ± 0.298
HMRPA	69.82 ± 0.133	66.53	73.29	2.1	0.33 ± 0.187
FMRPA	102.62 ± 0.179	96.87	106.90	1.9	0.38 ± 0.243

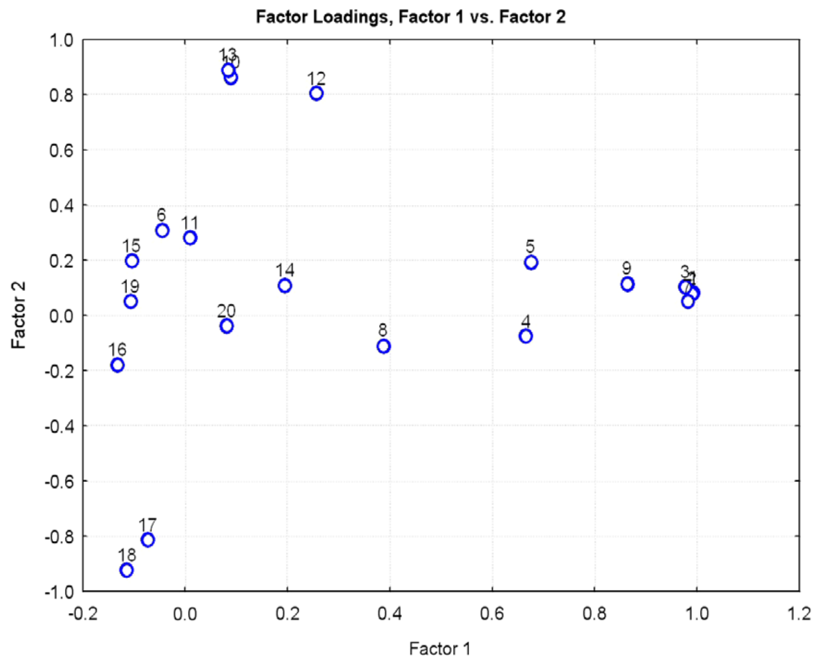
[a] Linear variables: StL, stride length; FL, forelimb length; HL, hindlimb length; FMHL and HMHL, fore and hindlimb maximum height of hoof. Temporal variables: StD, stride duration; FStD and FSwD, forelimb stance and swing phase duration; HStD and HSwD, hindlimb stance and swing phase duration. Angular variables: ERA, SRA and TRA, range of elbow, stifle and tarsus angles; FRPRA and HRPRA, retraction-protraction range of fore and hindlimb; CmA, SmA and TmA, minimal angle of carpus, stifle and tarsus; HMRPA, minimal retraction-protraction angle of the hindlimb; FMRPA, maximal retraction-protraction angle of the forelimb. SE, standard error of the mean; CV, coefficient of variation.

The heritabilities (Table 1) were high, ranging between 0.33 (minimal retraction-protraction angle of hindlimb) and 0.88 (forelimb maximum height of hoof and duration of swing phase of hindlimb). The temporal variables had the highest heritabilities (0.63–0.88), with values >0.5. The heritabilities for linear variables ranged between 0.45–0.88, with 80% being >0.5. Regarding the angular variables, these had the lowest heritabilities (0.33–0.86) with maximal retraction-protraction angle of forelimb and minimal retraction-protraction angle of hindlimb lowest of all.

The genetic correlations are shown in Table 2. In general, they had a high magnitude, and 38% of them had a negative sign and ranged, in absolute values, between 0.11 (FSwD–CmA and FMHL–FRPRA) and 0.99 (StD–TmA, FStD–FMRPA, HSwD–HMHL, HSwD–FMRPA). Only 26% were <0.50. Forelimb swing phase duration, hindlimb swing phase duration and range of stifle angle (with 16, 13 and 11 variables, respectively) were the most correlated with an absolute value. On the other hand, minimal angle of carpus, stifle and tarsus were always negatively correlated with the rest of variables analysed (8, 7 and 9, respectively).

Discussion

The trot is the horse's gait of preference, since a good balance is achieved between energy expenditure and



	Variable	Factor 1	Factor 2	Factor 3	Factor 4
1	**StD**	0,992*	0,082	0,036	0,000
2	**StL**	0,990*	0,080	0,041	0,015
3	**FL**	0,977*	0,103	0,028	0,022
4	**FStD**	0,665*	-0,075	-0,126	-0,323
5	**FSwD**	0,674*	0,196	0,144	0,304
6	**FMHL**	-0,046	0,311	-0,078	0,855*
7	**HL**	0,982*	0,053	0,053	0,008
8	**HStD**	0,387*	-0,107	0,371	0,024
9	**HSwD**	0,863*	0,117	-0,148	-0,039
10	**HMHL**	0,089	0,865*	-0,171	0,215
11	**ERA**	0,009	0,282	0,375	0,692*
12	**SRA**	0,255	0,805*	-0,011	0,125
13	**TRA**	0,083	0,890*	0,219	0,106
14	**FRPRA**	0,195	0,111	0,708*	-0,088
15	**HRPRA**	-0,105	0,198	0,827*	0,070
16	**CmA**	-0,133	-0,177*	-0,154	-0,755
17	**SmA**	-0,073	-0,813*	0,022	-0,096
18	**TmA**	-0,114	-0,921*	-0,180	-0,075
19	**HMRPA**	-0,107	0,051	-0,575*	-0,282
20	**FMRPA**	0,081	-0,036	0,430	-0,623*

Fig. 2. Results of a principal component analysis for the trot variables measured in Spanish Purebred horses ($n = 130$) on a treadmill. Factor coordinates are shown and significant variables are marked with ∗. Linear variables: StL, stride length; FL, forelimb length; HL, hindlimb length; FMHL and HMHL, fore and hindlimb maximum height of hoof. Temporal variables: StD, stride duration; FStD and FSwD, forelimb stance and swing phase duration; HStD and HSwD, hindlimb stance and swing phase duration. Angular variables: ERA, SRA and TRA, range of elbow, stifle and tarsus angles; FRPRA and HRPRA, retraction-protraction range of fore and hindlimb; CmA, SmA and TmA, minimal angle of carpus, stifle and tarsus; HMRPA, minimal retraction-protraction angle of hindlimb; FMRPA, maximal retraction-protraction angle of forelimb.

forward movement (Morales et al., 1998a). The characteristics of the trot and its variations are very important in dressage performance, because they are the basis of top level performed passage and piaffe (Barrey et al., 2002b). Furthermore, they are considered more heritable than those of the walk (Barrey et al., 2001). The gait is valued in clinical evaluation (Johnston et al., 2004; Weishaupt et al., 2004) and is increasingly used to assess gait in the training of equine athletes (Leleu et al., 2004).

According to estimates published by several authors, the heritability of dressage performance is rather low, because non-genetic effects, such as training, have a large influence (Langlois, 1980; Bruns, 1981; Huizinga and van der Meij, 1989). Additionally, dressage performance can only be measured later in life (Ducro et al., 2005) so indirect selection criteria for dressage performance are necessary. After the approval of the Breeding Scheme for the SPB horse, it was necessary to consider the genetic studies of kinematic variables.

Patterns of locomotion evolve and are modified with age (Cano et al., 2001b) and, as a result, an analysis was made of the influence of age. As shown by Cano et al. (1999), the variables that differ more by age in SPB horses are angular traits. Significant differences in linear and temporal variables are not observed. In the present work, the range of elbow angle and the minimal stifle angle showed greater influence of age, in accordance with the findings of Back et al. (1995). Hence, it is possible to make an early phenotypic pre-selection of the animals due to the slight influence of age in most of the variables. According to our results, variations among studs have been responsible for the different variables. Furthermore, studs can influence variations in training, horsemanship level and management, as well as the different morphological types in the breed. The treadmill allows a good standardisation of experimental conditions (for example the control of the speed), and limits the environmental factors that can condition the results, such as the type of racetrack (Barrey et al., 1993).

The limited variability detected previously in this breed (Cano, 1999) has been corroborated by the relatively low CV obtained in the majority of the variables in the present study (Table 1), and demonstrates quite homogenous results although the animals came from different studs. The considerable elevation of the limbs (fore and hindlimb maximum height of hoof) is a distinctive character of SPB horses (Galisteo et al., 1997), despite showing a great range of variation, and therefore susceptible to selection.

Maximal retraction-protraction angle of forelimb and minimal retraction-protraction angle of hindlimb showed the lowest CV, indicating a high uniformity. According to Cano et al. (2000), these are the variables influenced more by training and low levels of variation are therefore compatible with the minimum level of training required.

In the factor analysis (Fig. 2), it was observed that factor 1 could be named as a kinematic factor because it was related to most of the linear and temporal variables. Factor 2, which could be considered the joint factor, was related to most of the angular variables. The third factor was related

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Table 2
Genetic correlations (R) between trot variables in Spanish Purebred horses on a treadmill ($n = 130$)

StD[b]	$R \pm$ **SE**[a]	**FSwD**[b]	$R \pm$ **SE**[a]	**HStD**[b]	$R \pm$ **SE**[a]
FStD	0.51 ± 0.079	HL	0.72 ± 0.104	TmA	−0.86 ± 0.326
FSwD	0.71 ± 0.150	HStD	0.31 ± 0.214	**HSwD**[b]	$R \pm$ **SE**[a]
HStD	0.50 ± 0.191	HSwD	0.66 ± 0.118	HMHL	0.99 ± 0.151
HSwD	0.93 ± 0.050	HMHL	0.67 ± 0.268	SRA	0.78 ± 0.397
SRA	0.87 ± 0.366	ERA	0.25 ± 0.172	TRA	0.90 ± 0.525
SmA	−0.79 ± 0.536	SRA	0.53 ± 0.208	FRPRA	0.51 ± 0.220
TmA	−0.99 ± 0.270	TRA	0.70 ± 0.274	SmA	−0.69 ± 0.606
StL[b]	$R \pm$ **SE**[a]	FRPRA	0.51 ± 0.193	TmA	−0.57 ± 0.441
FStD	0.45 ± 0.251	CmA	−0.11 ± 0.075	FMRPA	0.99 ± 0.012
FSwD	0.73 ± 0.116	SmA	−0.63 ± 0.329	**HMHL**[b]	$R \pm$ **SE**[a]
HStD	0.55 ± 0.284	TmA	−0.86 ± 0.316	TmA	−0.74 ± 0.265
HSwD	0.98 ± 0.054	**FMHL**[b]	$R \pm$ **SE**[a]	**ERA**[b]	$R \pm$ **SE**[a]
SRA	0.81 ± 0.330	HStD	0.38 ± 0.317	FRPRA	0.54 ± 0.166
SmA	−0.75 ± 0.490	HSwD	−0.27 ± 0.236	CmA	−0.68 ± 0.155
FL[b]	$R \pm$ **SE**[a]	ERA	0.68 ± 0.040	**SRA**[b]	$R \pm$ **SE**[a]
FStD	0.35 ± 0.318	FRPRA	0.11 ± 0.074	TRA	0.93 ± 0.146
FSwD	0.75 ± 0.131	HRPRA	0.30 ± 0.246	CmA	−0.29 ± 0.209
HStD	0.64 ± 0.322	CmA	−0.98 ± 0.132	SmA	−0.77 ± 0.737
SRA	0.89 ± 0.291	**HL**[b]	$R \pm$ **SE**[a]	TmA	−0.57 ± 0.271
SmA	−0.81 ± 0.639	HStD	0.48 ± 0.233	**TRA**[b]	$R \pm$ **SE**[a]
FStD[b]	$R \pm$ **SE**[a]	HSwD	0.97 ± 0.057	FRPRA	0.60 ± 0.306
FSwD	−0.35 ± 0.255	SRA	0.74±0.344	TmA	−0.97 ± 0.081
FMHL	−0.28 ± 0.251	FRPRA	0.90 ± 0.612	**FRPRA**[b]	$R \pm$ **SE**[a]
HL	0.50 ± 0.352	HRPRA	0.95 ± 0.849	HRPRA	0.50 ± 0.290
HSwD	0.46 ± 0.218	CmA	−0.12 ± 0.084	CmA	−0.23 ± 0.135
SRA	0.85 ± 0.634	SmA	−0.66 ± 0.563	**HRPRA**[b]	$R \pm$ **SE**[a]
FMRPA	0.99 ± 0.105	TmA	−0.83 ± 0.500	CmA	−0.31 ± 0.282
FSwD[b]	$R \pm$ **SE**[a]	**HStD**[b]	$R \pm$ **SE**[a]	TmA	−0.54 ± 0.381
FMHL	0.16 ± 0.073	TRA	0.86 ± 0.778	FMRPA	−0.58 ± 0.576
		CmA	−0.19 ± 0.168		

[a] Only the correlations with convergence in the parametric space are shown.
[b] Linear variables: StL, Stride length; FL, forelimb length; HL, hindlimb length; FMHL and HMHL, fore and hindlimb maximum height of hoof. Temporal variables: StD, stride duration; FStD and FSwD, forelimb stance and swing phase duration; HStD and HSwD, hindlimb stance and swing phase duration. Angular variables: ERA, SRA and TRA, range of elbow, stifle and tarsus angles; FRPRA and HRPRA, retraction-protraction range of fore and hindlimb; CmA, SmA and TmA, minimal angle of carpus, stifle and tarsus; HMRPA, minimal retraction-protraction angle of the hindlimb; FMRPA, maximal retraction-protraction angle of the forelimb. SE, standard error of the mean.

to most of the limb oscillation variables, so it could be the limb oscillation factor. Likewise, factor 4 related to variables that condition the elevation of the forelimb and so could be named as the characteristic related to the breed, since the forelimb flexion characteristics of SPB horses are typical of the breed and are oriented to an attractive gait (Galisteo et al., 1997). This shows the complexity of the parameters related to the biokinematic aptitude of the horse.

Stride variables were influenced by different factors with speed as an underlying factor (Drevemo et al., 1980; Leach and Cymbaluk, 1986; Leach and Drevemo, 1991; Galisteo et al., 1998). Theoretically, locomotion on the treadmill and on the ground are no different, whereas speed is constant (van Ingen Schenau, 1980). Despite this, and due to the presence of other factors, there are documented changes in biokinematic (Buchner et al., 1994) and energetic variables (Sloet van Oldruitenborgh-Oosterbaan and Barnevelt, 1995) between treadmill and ground studies. We worked with a speed of 4 m/s, similar to that employed previously in other breeds (Back et al., 1994a, 1995, 1996). It therefore seemed most appropriate to evaluate traits at the trot (Cano et al., 2001b).

According to Back et al. (1994a), at the same velocity, stride length and stride duration were inversely proportionally related, and good gaits were related to longer strides and lower frequencies. In our study, stride length (2.63 m) was slightly lower than that indicated by the work of Weishaupt et al. (2004) in Warmblood riding horses on a treadmill (2.66 m). Our stride frequency ($1.51\ s^{-1}$) was slightly higher than the value ($1.36\ s^{-1}$) that Weishaupt et al. (2004) reported. A good score in movement is also conditioned by other factors, such as forelimb stance phase duration and the duration of swing phase in fore and hindlimb (Barrey et al., 2002b).

The values obtained in our study for forelimb stance phase duration (0.27 s), duration of swing phase in forelimb (0.39 s) and duration of swing phase in hindlimb (0.38 s), were closely related (0.27 s, 0.40 s and 0.40 s) with those found in Dutch Warmblood horses (Back et al., 1994a). The values were slightly lower (0.32 s, 0.44 s and 0.48 s) for the Warmblood riding horses (Weishaupt et al., 2004), but according to Bayer (1973) the best trotter horses show shorter duration of stance phase in the forelimbs and a longer duration of stance phase in the hindlimbs. In our results, as in those obtained by Back et al. (1994a), the values of these variables are practically equal.

According to Barrey et al. (1997), a good trotter must have great flexion of the elbow and carpus joints at the beginning of the swing phase, variables that are not modified with training in SPB horses (Cano et al., 2000). Our average value for the range of elbow angle (67.06°) was higher than that found by Back et al. (1994a, 1995, 1996). That the value of the oscillation range of this joint was higher in SPB horses was expected, because, according to Cano et al. (2001a), the greater forelimb elevation at the trot is a distinctive feature of their locomotion, compared with other breeds.

The range of movement of the tarsal and knee joints, and the angle of retraction of hindlimbs reflect the capacity of propulsion, implied in the generation of the impulse of displacement (Holmström et al., 1994). According to Back et al. (1994a), the range of movement in the stifle and tarsal joints is correlated with good gait punctuations and must be larger. In the present study, SPB horses showed a larger range of movement in these joints (48.98° movement in the stifle and 68.65° for the tarsal joint) than the Dutch Warmblood horses analysed by Back et al. (1994a). As a consequence they exhibited elevated movement (Barrey et al., 2002b), whereas the movements of Warmblood horses are more extended.

The duration of the oscillation, the total range of protraction-retraction and the maximum flexion of the tarsal joint can be considered indicative characteristics of the quality of the movement (Back et al., 1994b), since they allow objective predictions to be made of mature locomotion. In general, SPB horses flex their joints more than other breeds, due to the greater flexion of elbow and carpal joints (Cano et al., 2001b). Thus, for example, the *minimal tarsus angle* showed an average value (55.4°) higher than found in Dutch Warmblood horses (Back et al., 1995).

Due to the low heritability of dressage performance traits, the use of indirect breeding criteria is essential to improve this aptitude. According to Barrey et al. (2002b), indirect breeding selection using biokinematic variables could be more efficient than selection based on performance results. It has been assumed that some specific characteristics of the gaits could be selected genetically and contribute to dressage performance (Barrey et al., 2002b). The trot is the most important gait in the total score for dressage in competition (Biau and Barrey, 2004). The correlation between trot score and total dressage score is 0.73 (Wallin et al., 2003).

According to Barrey et al. (2002a), the characteristics of trot show a moderate to high heritability, and they should therefore be used for early dressage selection (2–3 years). Although in the literature we reviewed information is scarce about the genetic parameters of these variables, and the heritability values that were found oscillate between 0.10 (Meinardus et al., 1986) and 0.50 (Ducro et al., 2002). However, in general, the heritabilities obtained in the present work have been high. Some 80% of variables showed heritabilities >0.5, which can be due, in addition to the nature of the characters, to the lack of genetic selection (Falconer and MacKay, 1996) in this breed. On the other hand, it could be caused by the greater control of the environment in which the information was collected. The standard errors are quite high for the genetic parameters reflecting the limited number of animals included in the study because of the complexity and labour intensity of the test and variables estimation.

In general, the angular variables, maximal retraction–protraction angle of the forelimb (0.33), minimal retraction–protraction angle of the hindlimb (0.38) and minimal stifle angle (0.36), presented the lowest heritabilities, although these are medium level values. This finding could be due to the fact that the first two variables are more affected by differences in training levels (Cano et al., 2000) than the others. The highest heritability (0.88) obtained was for forelimb maximum height of hoof and duration of swing phase in the hindlimbs. The medium–high heritability of most of the analysed variables ensure a suitable genetic answer if used as selection criteria. On the other hand, the genetic correlations also resulted in very high values (about 75% were >0.50) and 37.8% were negative – the minimal angle of carpus, stifle and tarsus are always negatively correlated with the rest of the variables because the decrease in this parameter always produces an increase in the others. Fore and hindlimb swing phase duration and range of stifle angle had a higher number of significant correlations (16, 13 and 11, respectively). These genetic results, together with the phenotypic correlations showed in the factor analysis, can contribute to select the variables to control on the treadmill.

Taking our results at face value, we can consider that hindlimb swing phase duration and range of stifle angle must be included as pre-selection criteria for animals that are going to be included in the Breeding Scheme of the SPB horse because, in addition to being highly correlated, they have high heritabilities and influence the hindlimb function, which is clearly very important for dressage horses (Holmström, 1994). Although forelimb swing phase duration presented higher correlations with the rest of the variables compared to the hindlimb swing phase duration, it is very much influenced by the level of training (Cano et al., 2000), which mitigates against the inclusion of forelimb swing phase duration in an early selection programme.

The inclusion of the range of elbow angle and the minimal angle of the carpus are recommended both for their importance in dressage (Holmström et al., 1995) and also because they showed high heritabilities. The same applies to stride duration, which influences stride frequency, and this variable must be low for horses performing in dressage (Barrey et al., 2002a). Finally, instead of showing a lower heritability, minimal retraction–protraction angle of the hindlimb must be included because it is important in the collection of the limbs, essential for some exercises in dressage, and was not correlated with the other variables studied.

Conclusions

The biokinematic characteristics measured on the treadmill have high heritabilities in SPB horses, which imply that they could be used as an efficient tool for selecting breeding horses. However, in order to develop this selective process, it is essential to reduce the number of variables. It is necessary to verify the relationship between the variables and dressage performance in competition so as to select breeding criteria definitively, and this can be done using the competition scores obtained by young horses (4–6 years old) in specific tests held in Spain since 2004. Thus characteristics such as hindlimb swing phase duration and range of stifle angle must be maintained as they show higher genetic correlations with the rest of the biokinematic variables, and their heritabilities are sufficiently high. The range of elbow angle, minimal angle of carpus and stride duration could also be included in the breeding programme because, in addition to showing a suitable level of heritability, their importance in dressage performance has been emphasised by other authors. Given the importance of the minimal retraction-protraction angle of the hindlimb in the collection of the limbs, this factor could also be included in the Breeding Scheme of SPB horses despite its lower heritability.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tvjl.2007.07.031.

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