Livestock Science 253 (2021) 104701

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Prediction of adult conformation traits from shape characteristics of Pura Raza Español foals

MD Gómez [a], A Molina [b], MJ Sánchez-Guerrero [a], M Valera [a,*]

[a] Departamento de Agronomía, ETSIA, Universidad de Sevilla, Sevilla, Spain
[b] Departamento de Genética, Universidad de Córdoba, Córdoba, Spain

A R T I C L E   I N F O

Keywords:
Biometrics
Body
Genetic parameters
Horse
Morphological traits

A B S T R A C T

Horse conformation has been proposed as an indirect indicator of performance, since their genetic correlations are often positive and high. In Pura Raza Español (PRE) horses, the selection of conformation traits more related to functionality and performance allows a pre-selection of animals and contributes towards saving costs and increasing the genetic progress. The aim of this paper is to evaluate the predictability of 16 conformation traits (14 body measurements and 2 linear conformation traits) in adult PRE horses, focusing on the conformation traits of foals. The dataset included 155,716 records (82,408 young and 73,308 adult horses) with conformation traits from 142,244 different horses, aged between 1-36 years old. Animals between 1-3 years old were included in the 'young' group and older animals in the 'adult' group. A univariate General Linear Model procedure followed by a Tukey-post-hoc test were used to assess the statistical significance of non-genetic effects. Heritability values were estimated univariately. The fitted models included breeder, age and inbreeding (F) as covariates, and sex and coat colour as fixed effects. Coat colour and F were significant for 75% and 87.5% of the traits analysed, respectively; and the other effects analysed were significant for all the conformation traits. Heritability values ranged between 0.178±0.0063 and 0.795±0.0098 in young horses, and between 0.273±0.0038 and 0.894±0.0007 in adult horses. The genetic correlations of the conformation traits between young and adult horses were above 0.75 for 93.75% of the conformation traits analysed, which confirms the efficiency of pre-selection in young horses based on conformation features to predict their adult performance.

1. Introduction

Conformation is a crucially important trait in nearly all horse breeds (Staiger et al., 2016). It is the result of natural and artificial selection for various purposes (Folla et al., 2020). Besides, conformation is considered a reliable indicator of horse performance, which plays an important role in modern sport horse purchase and breeding decisions (Sánchez-Guerrero et al., 2016). It has long been a driving force in horse selection and breed identification, particularly as a predictor for performance and susceptibility to injury. However, it is also important for the aesthetics, wellness, durability and functionality of horses (Forest, 1996), because conformation defines the limits of the range of movement and function of the horse and its ability to perform (Mawdsley et al., 1996). Besides, in any equine discipline, there are certain conformations and body dimensions that are considered desirable and believed to be advantageous for performance and riding ability (Kristjansson et al., 2016; Staiger et al., 2016), and which have therefore been proposed as indirect indicators of performance capacity, since the heritability coefficients of conformation traits are often higher than those found for performance traits (Saastamoinen and Barrey, 2000).

The Pura Raza Español (PRE) is a multi-purpose breed with ancestors dating back thousands of years in the Iberian Peninsula and recognised as an individual breed since the 15th century (Sánchez-Guerrero et al., 2014), whose studbook was founded in 1912. They are the most important breed in Spain in terms of census and impact on international trade (Sánchez-Guerrero et al., 2017).

Historically, PRE horses have been selected mostly based on aesthetical criteria, but their continuous use in different field work activities and their age-old tradition as a saddle breed has maintained their functional characteristics and versatility. In this context, their official

* Corresponding author at: Departamento de Agronomía. Escuela Técnica Superior de Ingeniería Agronómica. Universidad de Sevilla. Ctra. Utrera km 1. 41013, Sevilla Spain.

E-mail address: mvalera@us.es (M. Valera).

https://doi.org/10.1016/j.livsci.2021.104701
Received 3 July 2021; Received in revised form 4 September 2021; Accepted 6 September 2021
Available online 8 September 2021
1871-1413/

breeding program includes conformational (Gómez et al., 2009; Sánchez-Guerrero et al., 2016), functional (Sánchez-Guerrero et al., 2017) and reproductive traits (Gómez et al., 2020; Valera et al., 2006) with interest for breeders, as the main selection criteria. The inclusion of conformation traits in the selection program of PRE horse is justified by the history of the breed, where beauty and elegance have always played a key role. But also performance ability has always been very important. The estimated heritability values make selection for conformation traits feasible (Molina et al., 1999). On the other hand, the selection of the conformation traits more related to functionality and of traits related with functional performance for dressage ability offers us an increased reliability of the genetic evaluations and a pre-selection of animals which will be trained for dressage, and contributes towards saving costs and increasing the genetic progress of the breed (Sánchez-Guerrero et al., 2017).

According to Sánchez-Guerrero et al. (2017), the breeding programs should look ahead to the future, and it would be a positive breakthrough if breeders could carry out breed improvements in the near future with other variables which are currently collected in most foals. In order to carry out an early indirect selection of performance ability of the animals by morphological traits, given the favourable genetic relationships existing between conformation and performance traits in PRE horses (Sánchez et al., 2014), the genetic relationships between conformation traits in young and adult horses must be evaluated. These conclusions agree with the proposal of the International Working group on Linear Profiling in Warmblood Horse, held under the Interstallion working group direction, which evaluated the feasible application of early evaluation of conformation traits in foals and the correlations between different age groups during the workshop of the year 2020 (IWLPWH, 2020).

Therefore, with the aim of evaluating the predictability of these conformation traits in adult PRE horses based on the conformation traits registered in foals, the analyses have been carried out based on body measurements and linear conformation traits for the first time in this species.

2. Material and methods

2.1. Description of traits and database

The original dataset with morphological traits included 155,716 records (94,935 females and 60,781 males; 82,408 young and 73,308 adult horses) with conformation traits from a total of 142,244 horses (55,182 males and 87,062 females), aged from 1 to 36 years old (with an average of 5.44±1.766 years old). Animals between 1-3 years old were included in the 'young' group and animals 4 years old or more were considered adult horses in the analysis. The names of the traits analysed and the distribution of the records available for each trait by sex and age group are shown in Supplementary Table 1. The number of records ranged between 10,153 and 78,399 for young horses and between 15,553 and 70,765 for 'adults' horses, for leg length and chest width, respectively. The data were collected in the period of 1985 – 2018, in the studs, sportive competitions and morphological events. Repeated measurements of 7.57% of the animals were available in the dataset.

A total of 16 conformation traits were evaluated in PRE horses. There were 14 body measurements (figure 1): 4 of body dimensions of the trunk (body length -BL-, chest width -CW-, thorax depth -TD- and thorax perimeter -TP-), 3 of the head and neck (head length -HL-, head width -HW- and neck length -NL-), 4 of the forelimb (leg length -LL-, shoulder length -SL-, knee perimeter -KP- and cannon bone perimeter -CP-) and 3 of the hind-limb (croup length -CL-, point of hip-stifle distance -HSD- and femur bone length -FL-)) and 2 linear conformation traits related with forelimb conformation (knee frontal angle -KFA- and knee lateral angle -KLA), previously described by Sánchez et al. (2013). They have been selected because of the influence of limb deviation on health status in warmblood riding horses shown by Johsson et al. (2014). To collect the information about the two linear conformation traits previously indicated, the appraisals used a structured score sheet with a scale of nine categories in which the extremes represented the biological extremes for the population for the linear traits. Data were collected in the studs, sportive competitions and morphological events.

The conformation traits were collected by 10 different vets, previously trained according to the standard procedures and using easily palpable landmarks, following Sánchez-Guerrero et al. (2016). A non-elastic measuring tape was used for the perimeters and a hippo

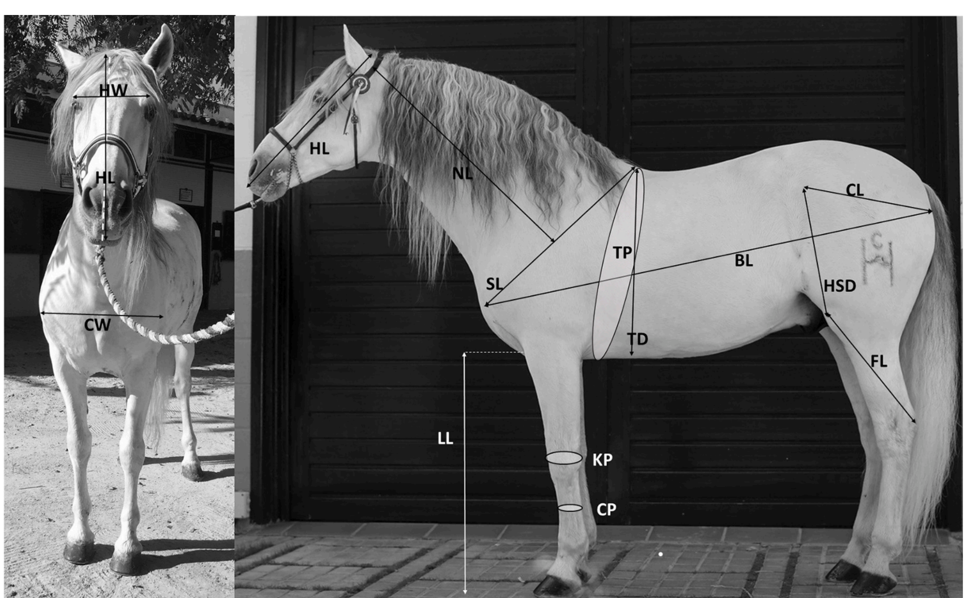

Figure 1. Graphical representation of the 14 body measurements in Pura Raza Español horses included in the analysis.
Where: LL is Leg length; BL is Body length; HL is Head length; HW is Head width; NL is Neck length; CW is Chest width; SL is Shoulder length; TD is Thorax depth; CL is Croup length; HSD is Point of hip-stifle distance; FL is Femur bone length; TP is Thorax perimeter; KP is Knee perimeter and CP is Cannon bone perimeter.

meter (measuring stick with a second extendable branch) was used for linear measurements. All the measurements were taken from the left side of the animal, while it was standing on a hard surface and flat ground, assuming a natural position. The horse was positioned for measurements with the front and rear legs parallel and perpendicular to the ground. The toes were in line. No sedatives were used.

2.2. Descriptive statistic

A univariate General Linear Model (GLM) procedure was previously used to assess the statistical significance of the non-genetic effects which could influence the conformation traits to include in the REML model used in further analyses. This was followed by a Tukey-post-hoc test to study the categorical effects. Statistical analyses were performed using SAS software (SAS, 2011).

The breeder (11,761 classes) was included due to its relation to differences in horse management. The sex (2 classes: male and female) was included to evidence sexual dimorphism in the breed. The coat colour (5 classes: bay, black, chestnut, grey and other minority colours) was included to analyse its pleiotropic role on conformation traits. In addition, the combination of sex-age (4 classes: 2 age classes: young horses between 1 and 3 years and adult horses over 3 years old, for each sex group) was included due to its relation to growth differences. The continuous effect of inbreeding (estimated using the complete pedigree information registered in the official Studbook of PRE horses with the software ENDOG 4.8 (Gutierrez et al., 2010)) was also included as co-variate to evidence possible inbreeding depression effects.

2.3. Genetic analysis

The heritability values were estimated univariately with a linear animal model using REML (Reduced Maximum Likelihood), taking advantage of the ease of using Models with a disconnected residual covariance structure in the same analysis as VCE software (Groeneveld et al., 2010).

This model deals well with a situation common in animal breeding, having to make a joint analysis with two subpopulations, when there are many different animals or there is a different number of records per animal in both sub-populations. In our case, the number of adult animals available was much higher than the number of young animals. The advantage of analysing all the available information jointly in both databases is to increase the number of animals and therefore the reliability of the genetic and environmental estimates. To achieve this, it is necessary to have a long, reliable pedigree that allows us to connect both subpopulations via common ancestors. This requirement is perfectly fulfilled in the case of the PRE horse.

The fitted models included the following systematic effects: breeder, age and inbreeding as covariates, sex and coat colour as fixed effects.

$Y_{ijklmn} = \mu + coat_i + sex_j + Breeder_k + F_l\ (L,Q) + age_m\ (L,Q) + a_o + e_{ijklmno}$ where: Y_{ijklmn} is the observed value for the conformation traits of the nth animal; μ is the model constant; $coat_i$ is the fixed effect of coat colour i (i= 1-5); sex_j is the fixed effect of sex j (j= 1, 2), $Breeder_k$ is the fixed effect of breeder k (k=1-11,761); F_l is the linear and quadratic effect of inbreeding included as covariate in the model; age_m is the linear and quadratic effect of age included as covariate in the model; an is random effect of the nth animal; and e_{ijklmn} is the random residual effect. Given that it is acceptable for the residual variance of these types of variables to be much higher in the case of young growing animals than in the case of adults, we have assumed in the model heterogeneity of the variance (young/adult).

Pedigree information for the genetic evaluation was collected from the PRE horses' official stud-book. All the pedigree known (at t least four generations of the horses on record) was considered in the pedigree file for the genetic evaluation. The number of animals included in the pedigree file for the analysis of each conformation trait is included in Supplementary Table 1.

Given the length of the pedigree (16.58 average maximum known generations in the whole studbook and over 60% of known ancestors until the 9th generation (Gómez et al., 2020)) and the close genetic relationship existing in the breed, all the recorded animals had known parents and the studs were well-connected between each other.

3. Results

The influence of the different non-genetic effects which can contribute to the variance in the conformation traits was evaluated with a GLM procedure, and statistically significant differences were found for all of them ($p < 0.05$) (Table 1). Coat colour was significant for 75% of the conformation traits analysed (except HW, HSD and both linear traits), and F for 87.5% (except HSD and KLA), while the other effects analysed were significant for all the conformation traits included in the analysis.

Table 2 shows the results of the Tukey post-hoc least squared means test analysis of the significant environmental effect ($p < 0.05$) by age and sex on 16 conformation traits analysed in PRE horses. The 37.5% of the traits analysed show significant differences between the sexes and age groups: 5 body measurements (LL, CW, HSD, FL and KP) and 1 linear conformation trait (KLA). Significant differences ($p < 0.05$) were found in all the traits analysed between sexes within age groups, except for BL in adult animals. Significant differences were also evident between age groups within sexes for 75% of the traits analysed in males (except HW, SL, TD and CP) and 81.25% in females (except HW, NL and TP).

Most of the conformation traits analysed showed a medium-high level of variance according to the CV results, except BL in both sexes and age groups and TP in young animals, with values below 4%. The trait with the lowest variance (<4%) was BL, in all sexes and age groups. The CV for the linear traits in all ages and sex groups and CW in adult animals showed the highest CV (>10%), ranging from 10.98% (for CW in adult females) to 13.83% (for KLA in adult males).

The genetic parameters estimated for 16 conformation traits in PRE horses are shown in Table 3. The heritability values ranged between 0.178±0.0063 and 0.795±0.0098 in young horses, for CW and HSD, respectively; and between 0.273±0.0038 and 0.894±0.0007 in adult horses, for CW and BL, respectively. The genetic correlations between young and adult horses for each conformation trait analysed were also estimated, and were above 0.75 for 93.75% of the conformation traits

Table 1
Univariate General linear model analysis of the environmental effects on 16 conformation traits in Pura Raza Español horses.

Conformation traits	Significance level (p)				
	Breeder	Sex	Coat	Inbreeding	Age (sex)
LL	***	***	***	*	***
BL	***	***	***	***	***
HL	***	***	*	***	***
HW	***	***	n.s.	**	***
NL	***	***	***	***	**
CW	***	***	***	**	***
SL	***	***	***	***	***
TD	***	***	***	***	***
CL	***	***	***	***	***
HSD	***	***	n.s.	n.s.	***
FL	***	***	***	***	***
TP	***	***	***	***	***
KP	***	***	**	***	***
CP	***	***	**	***	***
KFA	***	***	n.s.	*	***
KLA	***	***	n.s.	n.s.	***

Where: LL is Leg length; BL is Body length; HL is Head length; HW is Head width; NL is Neck length; CW is Chest width; SL is Shoulder length; TD is Thorax depth; CL is Croup length; HSD is Point of hip-stifle distance; FL is Femur bone length; TP is Thorax perimeter; KP is Knee perimeter; CP is Cannon bone perimeter; KFA is Knee frontal angle; and KLA is Knee lateral angle. And for the significance level * is p≤0.05; ** is p≤0.01 and *** is p≤0.001.

Table 2
A Tukey post-hoc least squared means test analysis of the significant environmental effect by age and sex on 16 conformation traits analysed in Pura Raza Español horses.

Conformation traits	Males				Females			
	Young		Adult		Young		Adult	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
LL	80.77[a]	5.95	79.57[b]	6.12	78.39[c]	6.22	77.09[d]	6.00
BL	159.72[a]	3.29	159.61[ab]	3.36	159.23[c]	3.337	159.60[b]	3.40
HL	62.25[a]	5.29	61.84[b]	5.26	61.83[b]	5.16	61.55[c]	5.037
HW	23.65[a]	7.77	23.63[a]	8.30	23.25[b]	7.63	23.26[b]	7.53
NL	75.71[a]	6.65	75.46[b]	6.01	74.20[c]	6.48	74.23[c]	6.27
CW	43.19[a]	8.77	41.83[b]	13.05	42.08[c]	8.88	40.78[d]	10.98
SL	66.95[a]	5.81	66.98[a]	5.40	66.28[b]	6.10	65.87[c]	6.07
TD	73.43[ab]	5.51	73.37[a]	5.39	73.52[b]	5.43	73.74[c]	5.30
CL	53.07[a]	5.89	53.35[b]	6.00	53.27[b]	6.21	52.87[c]	5.92
HSD	49.41[a]	9.44	48.48[b]	9.16	49.92[c]	9.32	49.63[d]	8.79
FL	53.28[a]	7.72	53.75[b]	7.59	52.45[c]	7.60	52.05[d]	7.62
TP	188.83[a]	3.94	188.42[b]	3.88	191.17[c]	4.78	191.14[c]	4.96
KP	33.73[a]	5.09	33.48[b]	5.05	31.56[c]	4.88	31.27[d]	5.10
CP	20.98[a]	6.00	20.98[a]	6.28	19.96[b]	6.11	19.92[c]	6.08
KFA	5.33[a]	12.71	5.30[b]	13.22	5.28[b]	12.89	5.26[c]	13.05
KLA	5.16[a]	13.41	5.09[b]	13.83	5.25[c]	13.16	5.21[d]	12.44

Where: LL is Leg length; BL is Body length; HL is Head length; HW is Head width; NL is Neck length; CW is Chest width; SL is Shoulder length; TD is Thorax depth; CL is Croup length; HSD is Point of hip-stifle distance; FL is Femur bone length; TP is Thorax perimeter; KP is Knee perimeter; CP is Cannon bone perimeter; KFA is Knee frontal angle; KLA is Knee lateral angle, and CV is Coefficient of variation.
Different letters indicate differences between sexes and age groups ($p < 0.05$).

Table 3
Genetic parameters estimated for the 16 conformation traits analysed in Pura Raza Español horses.

Conformation traits	Young			Adult			Young-adult	
	VarA	VarB	h^2±S.E.	VarA	VarB	h^2±S.E.	Cov (year-age)	r_g
LL	1.79	0.22	0.35±0.025	1.43	0.28	0.31±0.015	7.46	0.99±0.000
BL	16.99	1.77	0.57±0.006	33.38	1.67	0.89±0.001	21.32	0.90±0.008
HL	9.56	0.47	0.75±0.011	7.03	0.59	0.62±0.007	6.80	0.83±0.017
HW	1.79	0.22	0.53±0.014	1.43	0.28	0.41±0.007	1.25	0.78±0.023
NL	20.95	1.61	0.74±0.012	17.60	2.33	0.67±0.004	15.76	0.82±0.017
CW	0.18	0.14	0.18±0.006	0.80	0.20	0.27±0.004	1.79	0.52±0.024
SL	6.38	2.41	0.38±0.011	10.59	1.58	0.61±0.004	6.15	0.75±0.018
TD	5.96	1.24	0.35±0.007	14.04	0.98	0.72±0.006	7.32	0.80±0.014
CL	9.87	1.02	0.77±0.011	7.74	0.94	0.66±0.004	7.36	0.84±0.016
HSD	23.51	2.03	0.80±0.010	15.05	2.12	0.64±0.004	14.25	0.76±0.018
FL	11.85	2.20	0.63±0.014	11.67	1.89	0.64±0.007	9.80	0.83±0.019
TP	27.43	10.90	0.36±0.008	92.48	8.14	0.86±0.001	38.08	0.76±0.012
KP	1.51	0.17	0.54±0.007	2.905	0.14	0.85±0.001	1.86	0.89±0.008
CP	0.55	0.11	0.35±0.008	0.81	0.07	0.50±0.005	0.61	0.91±0.011
KFA	0.32	0.03	0.59±0.016	0.256	0.02	0.49±0.007	0.21	0.75±0.026
KLA	0.45	0.01	0.75±0.011	0.32	0.01	0.60±0.005	0.31	0.81±0.020

Where: LL is Leg length; BL is Body length; HL is Head length; HW is Head width; NL is Neck length; CW is Chest width; SL is Shoulder length; TD is Thorax depth; CL is Croup length; HSD is Point of hip-stifle distance; FL is Femur bone length; TP is Thorax perimeter; KP is Knee perimeter; CP is Cannon bone perimeter; KFA is Knee frontal angle; KLA is Knee lateral angle; h2= Heritability; S.E=Standard error; VarA= Variance Animal; VarB= Variance Breeder; rg= Genetic Correlation and Cov= Covariance.

analysed.

4. Discussion

Because of the wide range of functions required for horses, it is not easy to obtain versatile animals which are adaptable to all the activities included in the breeding programs, taking into consideration the different environments in which they are raised all around the world. Therefore, to economise on money and time, it is recommended that the first step in the selection of animals based on conformation traits should be the implementation of a two-stage selection system for functional ability. Horses are initially selected based on their morphological features (Ducro et al., 2007; Bussiman et al., 2018). After that, the second selection stage is applied, to determine the performance of horses in equestrian events. This system allows indirect selection to take place at an earlier age (reducing the generation interval), while direct selection for functionality can be based on multiple records of individual performance (thus increasing the accuracy of selection).

Due to the large number of traits, the process of selection can be performed by preparing indexes such as those suggested by Vicente et al. (2014) and Sánchez-Guerrero et al. (2017). However, it is also important to test the usefulness for selection and the predictability of the conformation traits measured in young horses in order to ensure that the indirect selection is carried out correctly. Cervantes et al. (2009) concluded that, although shape is extremely important for breed quality, size is a more important factor for the morpho-functional characteristics of Spanish Arab horses. We therefore carried out the analyses to evaluate the predictability of conformation traits in young and adult horses in PRE horses using conformation measurements and linear type traits.

In this study, the effect of horse management has been tested using information about the breeder for each animal. The influence of breeders' management on growth rates has been also reported by Brown-Douglas and Pagan (2009), who observed significant differences in body weight, height at withers and daily gain between populations of Thoroughbreds. These differences were caused by the management of the growing horses under different environmental conditions, such as nutrition, care or climatic conditions. All of the analysed traits show the significant influence of the breeder.

For several centuries, characteristics in behaviour, performance and suitability of horses have been attributed to coat colours. In addition, personal communication with breeders confirms that there is still a strong belief in differences between horses of different colours for those traits (Druml et al., 2008; Sánchez-Guerrero et al., 2018). In the PRE production system, coat colour is also a major attribute which determines breeding practices and has a demonstrated influence on morphological differentiation (Bartolomé et al., 2010; Sánchez-Guerrero et al., 2018). Furthermore, 75% of the traits analysed showed significant influence of coat colour, except HW, HSD, KFA and KLA.

The influence of inbreeding on body measurements in PRE horses has also been demonstrated by Gómez et al. (2009), with a depressive effect. Although real efforts have been made by the breeders to reduce the average F over the last few generations (Perdomo-González et al., 2020), 87.5% of the conformation traits analysed showed significant influence of inbreeding, except HSD and KLA.

Several authors affirm that the effect of sex plays an important role in determining body size and shape (Staiger et al., 2016) and indicate the existence of a marked sexual dimorphism (Bartolomé et al., 2019), which can be seen in physical differences in body size associated with gender. Although there are some authors who affirm that differences between sexes in foals are not significant for conformation measurements (Çilek, 2009; Purzyc et al., 2011), our results have shown the existence of sexual dimorphism in young PRE horses, coinciding with the analysis by Saastamoinen (1990a) in Finnhorse foals. The influence of age on body measurements has been also evidenced by several authors. This influence is conditioned mainly by growth and corporal development of the animals within their development conditions (e.g. climatic conditions or nutritional management). Significant differences have been shown by different authors, mainly in foals at different ages (Luiz et al., 2019; Saastamoinen, 1990a). In this analysis, all the traits analysed showed a significant influence of age.

In this context, the results of the Tukey post-hoc least squared means test shown in Table 2 illustrates the significant differences between sexes and age groups. In general, the average values of conformation traits obtained in PRE males were higher than those obtained in females in traits related with size (LL, BL, HL, HW, NL, CW, SL, FL, KP and CP). However, these values were higher in females for traits related with thorax (TD and TP) and croup development (HSD and CL), which are maternal regions related with pregnancy and birth capacity (Sánchez-Guerrero et al., 2016).

The coefficients of variation (CV) are the most important measure of variation. It generally assumed that the higher the phenotypic variation of traits, the greater the genetic variation, which guarantees a sufficient selection response (Jakubec et al., 2007). The CV ranged from 3.29% (BL in young males) to 13.83% (KLA in adult males). Most of the conformation traits analysed (90.63%) showed a medium-high level of variance in both sexes and age groups, which therefore guarantees the selection response, while only BL in both sexes and TP in males exhibited low variability (CV< 4%). This fact could be explained by the strong selection pressure for size and proportionality that breeders have exercised for years in the PRE population, as a criterion for the registration of breeding stocks in the official studbook, by fixing height and length traits and those related with them, like BL, in order to control body dimensions. The CV for the linear traits in all ages and sex groups and CW in adult animals showed the highest CV (>10%), exhibiting large phenotypic variation. These are the traits with a higher variation capacity and, in addition, those with more options for selection in this population.

Suontama et al. (2011) reported that high heritability for foal traits and high genetic correlations between the foal and studbook traits (collected in animals with 3-4 years-old) indicate that an early selection for conformation traits would be efficient in the breeding programs of Finnhorse and Standardbred trotters. As a result, early selection for body measurements can be efficient in the breeding programs for horses, an important necessity on horse breeding and selection by the Interstallion International working group for conformation traits analysed in horses (IWLPWH, 2020).

In general, the heritability values obtained for the analyzed traits were of medium-high level. And all of them were significant according to their low standard errors (ranging between 0.006 and 0.025 in young horses and between 0.001 and 0.015 in adult horses). In this sense, as the method used in this work ensures the analysis of all the available information, there is an increase of the reliability of the genetic estimates and an improvement of the estimation of the genetic parameters and the fixed effects. For example, if we compare the results obtained in this work with the estimates obtained with the classic models using a unique data set, in which only common animals were included, for two traits highly related with dressage, as CW and CP, the estimates of the errors for the heritability values were 1000 times lower (data not shown). Besides, the -Log Likelihood estimation shown a better fit with the models with heterozygosity compared to a classic model (-344462.7 vs -19935.2 for the CW and -323639.5 vs 19653.9 for the CP).

In the PRE population, the lowest heritability values were obtained for CW (0.18 in young-0.27 in adult), in line with the bibliography reviewed for this trait (0.16-0.42 (Bussiman et al., 2018; Dominguez-Viveros et al., 2019; Ghezelsoflou et al., 2018; Gómez et al., 2009)). This fact could be explained because the CW can be strongly influenced by the animals' body condition and the training, mainly in the lateral work which is very important in the training for higher levels of dressage competitions.

The highest heritability values were obtained for HSD in young horses (0.795) and BL in adult horses (0.894), and were higher than those reported for the reviewed authors for HSD (0.21 in the Iranian Turkoman horses (Ghezelsoflou et al., 2018) and for BL (0.12-0.75 in different populations (Bussiman et al., 2018; Çilek, 2012; Dominguez-Viveros et al., 2019; Druml et al., 2008; Gharahveysi et al., 2008; Ghezelsoflou, H. et al., 2018; Gómez et al., 2009; Molina et al., 1999; Pretorius et al., 2004; Solé et al., 2014; Suontama et al., 2009)).

In general, the heritability values obtained in PRE horses were of medium-high level for both age groups, and all of them were slightly higher than those obtained in the reviewed bibliography for the same traits in different horse populations (Bakhtiari and Heshmat, 2009; Bramante et al., 2016; Bussiman et al., 2018; Çilek, 2012; Dario et al., 2006; Dominguez-Viveros et al., 2019; Druml et al., 2008; Gharahveysi et al., 2008; Ghezelsoflou et al., 2018; Kapron et al., 2013; Müller et al., 2021; Pretorius et al., 2004; Solé et al., 2014; Suontama et al., 2009) in Friesian horses; Murgese horses; Noriker draught horses; Iranian Arab horses; Iranian Thoroughbred horses; PRE horses; Finnhorse trotters; Turkish Arabian foals; Wielkopolski horses; Menorca Horses; Murgese horses; Campolina horses; Iranian Turkoman horses; Mexican population of PRE horses; Sarinian Anglo Arab horses and Mangalarga horses, respectively.

Different authors (Çilek, 2012; Saastamoinen, 1990b) have reported an increasing trend with age for heritability of body measurements. In the PRE population, the heritability values were similar in both age groups for LL (0.35 and 0.31 in young and adult horses, respectively), NL (0.74 and 0.67) and FL (0.63 and 0.64), whereas the highest differences between age groups were observed for BL (0.57 and 0.89), SL (0.38 and 061), TD (0.35 and 0.72), CW (0.36 and 0.86) and KP (0.54 and 0.85). However, there was no clear trend of an increase with age.

Different studies have been published about the rates of body-weight gain and growth of specific skeletal segments in young horses, mainly in foals. However, there are no studies about the predictability of body measurements in adult horses based on those in young horses from a genetic point of view. In this study, the genetic correlations between young and adult PRE horses were estimated for 16 analysed conformation traits in order to evaluate the predictability of the traits in adult horses. As was expected, high and positive correlations were obtained for all the traits analysed, which ranged between 0.52 for CW and 0.99 for LL. The values were strong and above 0.75 for all traits, except for CW. Saastamoinen (1990b) also obtained adequate correlations for body measurements at different ages in Finnhorse foals aged between 6-48 months, which may permit early selection for fast growth, and other authors have analysed the correlation between functional traits between young and adult horses (Bugislaus et al., 2006; Gómez et al., 2010; Thorén-Hellsten et al., 2006). However, there are no previous studies about the genetic correlations of body conformation traits in horses comparing young and adult horses.

5. Conclusion

Body conformation traits analysed in the PRE population were highly heritable, as in other horse breeds, which allows us to predict a high genetic progress through the breeding programs when this kind of information is used for selection of breeding stock. The early selection of morphological traits allows us not only to increase the reliability of the genetic evaluations, but also to pre-select young animals to be trained for dressage based on conformation traits related with functional performance, resulting in savings in costs and increased genetic progress of the breed. In this study, the genetic correlations of conformation traits between young and adult PRE horses were high and positive, ensuring the efficiency of the pre-selection of young horses based on conformation features related with the functional ability to perform, an important necessity on horse breeding and selection by the Interstallion International working group for conformation traits analysed in horses.

Acknowledgements

The authors wish to thank the National Association of Pura Raza Español Horse Breeders (ANCCE) for providing the data used in this study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.livsci.2021.104701.

References

Bakhtiari, J., Heshmat, G., 2009. Estimation of genetic parameters of conformation traits in Iranian Thoroughbred horses. Livest. Sci. 123, 116–120. https://doi.org/10.1016/j.livsci.2008.10.014.

Bartolomé, E., Goyache, F., Molina, A., Cervantes, I., Valera, M., Gutiérrez, J.P., 2010. Pedigree estimation of the (sub) population contribution to the total gene diversity: the horse coat colour case. Animal 4, 867–875. https://doi.org/10.1017/S1751731110000182.

Bartolomé, E., Milho, S., Prazeres, J., 2019. Genealogical and morphological analysis of Lusitano Purebred horses participating at international Dressage competitions. Res. Vet. Sci. 122, 124–131. https://doi.org/10.1016/j.rvsc.2018.11.018.

Bramante, G., Cito, A.M., Ciani, E., Piragostini, E., 2016. Multi-trait animal model estimation of genetic parameters for morphometric measurements in the Murgese horse breed. Livest. Sci. 191, 139–142. https://doi.org/10.1016/j.livsci.2016.07.011.

Brown-Douglas, C.G., Pagan, J.D., 2009. Body weight, wither height and growth rates in Thoroughbreds raised in America, England, Australia, New Zealand and India. Kentucky Equine Res. Adv. Equine Nutr. IV 213–220.

Bussiman, F.D.O., Perez, B.D.C., Ventura, R.V., Silva, F.F.E., Peixoto, M.G.C.D., Vizoná, R.G., Mattos, E.C., Ferraz, J.B.S., Eler, J.P., Curi, R.A., Balieiro, J.C.D.C., 2018. Genetic analysis of morphological and functional traits in Campolina horses using Bayesian multi-trait model. Livest. Sci. 216, 119–129. https://doi.org/10.1016/j.livsci.2018.08.002.

Cervantes, I., Baumung, R., Molina, A., Druml, T., Gutiérrez, J.P., Sölkner, J., Valera, M., 2009. Size and shape analysis of morphofunctional traits in the Spanish Arab horse. Livest. Sci. 125, 43–49. https://doi.org/10.1016/j.livsci.2009.03.006.

Çilek, S., 2012. Heritablity parameters for some body measurements in Turkish Arabian foals. Iran. J. Vet. Res. 13, 323–329. https://doi.org/10.22099/ijvr.2012.613.

Çilek, S., 2009. Environmental factors affecting growth characteristics in Purebreed Arabian foals reared at Anadolu State Farm in Turkey. J. Anim. Vet. Adv. 8, 148–154.

Dario, C., Carnicella, D., Dario, M., Bufano, G., 2006. Morphological evolution and heritability estimates for some biometric traits in the Murgese horse breed. Genet. Mol. Res. 5, 309–314.

Dominguez-Viveros, J., Rodríquez-Almeida, F.A., Callejas-Juárez, N., Aguilar-Palma, N., Ortea-Gutiérrez, J.A., 2019. Selection of models and estimation of genetic parameters for zoometric measures of Pura Raza Español horses in Mexico. Agrociencia 53, 833–840.

Druml, T., Baumung, R., Sölkner, J., 2008. Morphological analysis and effect of selection for conformation in the Noriker draught horse population. Livest. Sci. 115, 118–128. https://doi.org/10.1016/j.livsci.2007.06.015.

Ducro, B.J., Koenen, E.P.C., van Tartwijk, J.M.F.M., Bovenhuis, H., 2007. Genetic relations of movement and free-jumping traits with dressage and show-jumping performance in competition of Dutch Warmblood horses. Livest. Sci. 107, 227–234. https://doi.org/10.1016/j.livsci.2006.09.018.

Folla, F., Sartori, C., Mancin, E., Pigozzi, G., Mantovani, R., 2020. Genetic parameters of Linear Type Traits scored at 30 months in Italian Heavy Draught Horse. Animals 10. https://doi.org/10.3390/ani10061099, 1099.

Forest, A., 1996. La conformation d'un cheval. Son importance avant l'achat en fonction d'un service recherche´et pour le choix des reproducteurs., in: Proceeding of the 7th Symposium of Council Animal Production of Quebec. Saint-Hyacinthe 4–13.

Gharahveysi, S., Kashan, N.E.J., Gerami, A., Torshizi, R.V., 2008. Estimation of genetic parameters of Iranian Arab Horses population. Pak. J. Biol. Sci. 11, 280–284. https://doi.org/10.3923/pjbs.2008.280.284.

Ghezelsoflou, H., Hamidi, P., Gharahveysi, S., 2018. Study of factors affecting the body conformation traits of Iranian Turkoman horses. J. Equine Sci. 29, 91–96. https://doi.org/10.1294/jes.29.91.

Gómez, M.D., Sánchez, M.J., Bartolomé, E., Cervantes, I., Poyato-Bonilla, J., Demyda-Peyrás, S., Valera, M., 2020. Phenotypic and genetic analysis of reproductive traits in horse populations with different breeding purposes. Animal 14, 1351–1361. https://doi.org/10.1017/S1751731120000087.

Gómez, M.D., Valera, M., Molina, A., Gutiérrez, J.P., Goyache, F., 2009. Assessment of inbreeding depression for body measurements in Spanish Purebred (Andalusian) horses. Livest. Sci. 122, 149–155. https://doi.org/10.1016/j.livsci.2008.08.007.

Groeneveld, E., Kovac, M., Mielenz, N., 2010. VCE. Users's Guide and Reference Manual Version 6.0.

Gutierrez, J.P., Goyache, F., Cervantes, I., 2010. User ' s Guide ENDOG v4.8 A Computer Program for Monitoring Genetic Variability of Populations Using Pedigree Information 45.

Jakubec, V., Rejfkova, M., Volenec, J., Majzlík, I., Vostrý, L., 2007. Analysis of linear description of type traits in the varieties and studs of the Old Kladrub horse. Czech J. Anim. Sci. 52, 299–307.

Johsson, L., Nasholm, A., Roepstorff, L., Egenvall, A., Dalin, G., Philipsson, J., 2014. Conformation traits and their genetic and phenotypic associations with health status in young Swedish Warmblood riding horses. Livest. Sci. 163, 12–25. https://doi.org/10.1016/j.livsci.2014.02.010.

Kapron, M., Czerniak, E., Lukaszewicz, M., Danielewicz, A., 2013. Genetic parameters of body conformation and performance traits of Wielkopolski horses registered in the successive volumes of the Herdbook. Arch. Tierzucht 56, 127–136. https://doi.org/10.7482/0003-9438-56-012.

Kristjansson, T., Bjornsdottier, S., Albertsdottir, E., Sigurdsson, A., Pourcelot, P., Crevier-Denoix, N., Arnason, T., 2016. Association of conformation and riding ability in Icelandic Horses. Livest. Sci. 189, 91–101. https://doi.org/10.1016/j.livsci.2016.05.010.

Luiz, M.A., Senna, D., Padilha, F.G.F., Nogueira, W.A., Fonseca, A.B., Vallin De Mello, M. F, Ferreira, A.M.R, 2019. Morphometric measurements and zootechnical indices of the Pantanal in race horses of different ages and gender. Trop. Anim. Health Prod. 51, 2145–2151. https://doi.org/10.1007/s11250-019-01910-5.

Mawdsley, A., Kelly, E.P., Smith, F.H., Brophy, P.O., 1996. Linear assessment of the Thoroughbred horse: An approach to conformation evaluation. Equine Vet. J. 28, 461–467. https://doi.org/10.1111/j.2042-3306.1996.tb01618.x.

Molina, A., Valera, M., Dos Santos, R., Rodero, A., 1999. Genetic parameters of morphofunctional traits in Andalusian horse. Livest. Prod. Sci. 60, 295–303. https://doi.org/10.1016/S0301-6226(99)00101-3.

Müller, V., Moraes, B., Carvalho, I., Wendt, C., Patten, R., Nogueira, C.E., 2021. Genetic parameters of morphometric measurements in Criollo horses. J. Anim. Breed. Genet. 138, 174–178. https://doi.org/10.1111/jbg.12503.

Perdomo-González, D., Sánchez-Guerrero, M.J., Molina, A., Valera, M., 2020. Genetic structure analysis of the Pura Raza Español horse population through partial inbreeding coefficient estimation. Animals 10. https://doi.org/10.3390/ani10081360, 1360.

Pretorius, S.M., van Marle-Koster, E., Mostert, B.E., 2004. Description of the Friesian horse population of South Africa and Namibia. South African J. Anim. Sci. 34, 149–157. https://doi.org/10.4314/sajas.v34i3.3958.

Purzyc, H., Kobryńczuk, F., Bojarski, J., 2011. Sexual dimorphism in Hucul horses using discriminant analysis. Animal 5, 506–511. https://doi.org/10.1017/S1751731110002223.

Saastamoinen, M., 1990a. Factors affecting growth and development of foals and young horses. Acta Agric. Scand. 40, 387–396.

Saastamoinen, M., 1990b. Heritabilities for body size and growth rate and phenotypic correlations among measurements in young horses. Acta Agric. Scand. 40, 377–386.

Saastamoinen, M.A., Barrey, E., 2000. Genetics of conformation, locomotion and physiological traits, Bowling, A.T., Ruvinsky, A.The Genetics of the Horse. London, 439–472.

Sánchez-Guerrero, M.J., Cervantes, I., Molina, A., Gutiérrez, J.P., Valera, M., 2017. Designing an early selection morphological linear traits index for dressage in the

Pura Raza Español horse. Animal 11. https://doi.org/10.1017/S1751731116002214.

Sánchez-Guerrero, M.J., Gómez, M.D., Molina, A., Valera, M., 2013. Genetic analyses for linear conformation traits in Pura Raza Español Horses. Livest. Sci. 157, 57–64. https://doi.org/10.1016/j.livsci.2013.07.010.

Sánchez-Guerrero, M.J., Molina, A., Gómez, M.D., Peña, F., Valera, M., 2016. Relationship between morphology and performance: Signature of mass-selection in Pura Raza Español horse. Livest. Sci. 185, 148–155. https://doi.org/10.1016/j.livsci.2016.01.003.

Sánchez-Guerrero, M.J., Negro-Rama, S., Demyda-Peyras, S., Solé-Berga, M., Azor-Ortiz, P.J., Valera-Córdoba, M., 2018. Morphological and genetic diversity of Pura Raza Español horse regarding to the coat colour. Anim. Sci. J. 90, 14–22. https://doi.org/10.1111/asj.13102.

Sánchez, M.J., Gómez, M.D., Peña, F., Monterde, J.G., Morales, J.L., Molina, A., Valera, M., 2014. Relationship between conformation traits and gait characteristics in Pura Raza Español horses. Arch. Tierzucht 56, 137–148. https://doi.org/10.7482/0003-9438-56-013.

SAS, 2011. Sas/Statistical Users Guide for Personal Computer.

Solé, M., Cervantes, I., Gutiérrez, J.P., Gómez, M.D., Valera, M., 2014. Estimation of genetic parameters for morphological and functional traits in a Menorca horse population. Spanish J. Agric. Res. 12 (125) https://doi.org/10.5424/sjar/2014121-4686.

Staiger, E.A., Bellone, R.R., Sutter, N.B., Brooks, S.A., 2016. Morphological variation in gaited horses breeds. J. Equine Vet. Sci. 43, 55–65. https://doi.org/10.1016/j.jevs.2016.04.096.

Suontama, M., Saastamoinen, M.T., Ojala, M., 2009. Estimates of non-genetic effects and genetic parameters for body measures and subjectively scored traits in Finnhorse trotters. Livest. Sci. 124, 205–209. https://doi.org/10.1016/j.livsci.2009.01.017.

Suontama, M., van der Werf, J.H.J., Juga, J., Ojala, M.T., 2011. The use of foal and studbook traits in the breeding programmes of Finnhorse and Standardbred trotters. J. Anim. Breed. Genet. 128, 114–123. https://doi.org/10.1111/j.1439-0388.2010.00886.x.

Valera, M., Blesa, F., Santos, R.Dos, Molina, A., 2006. Genetic study of gestation length in andalusian and arabian mares. Anim. Reprod. Sci. 95, 75–96. https://doi.org/10.1016/j.anireprosci.2005.09.008.

Vicente, A.A., Carolino, N., Ralao-Duarte, J., Gama, L.T., 2014. Selection for morphology, gaits and functional traits in Lusitano horses: II. Fixed effects, genetic trends and selection in retrospect. Livest. Sci. 164, 13–25. https://doi.org/10.1016/j.livsci.2014.03.017.