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Estimation of genetic parameters for morphological and functional traits in a Menorca horse population

Marina Sole[1]*, Isabel Cervantes[2], Juan Pablo Gutierrez[2], Maria Dolores Gomez[1] and Mercedes Valera[1]

[1] *Departamento de Ciencias Agro-Forestales. Universidad de Sevilla. 41013 Sevilla, Spain*
[2] *Departamento de Producción Animal. Facultad de Veterinaria. 28040 Madrid, Spain*

Abstract

Functional conformation and performance in Classic and Menorca Dressage are the main selection criteria in the Menorca Horse breeding program. Menorca Dressage is an alternative Classical Dressage discipline which is exclusive of the Menorca Island, but including a series of movements that the animals perform in the traditional festivities called "*Jaleo Menorquín*". One of these movements involves the horse raising its forelimbs and standing or walking on its hindlimbs, which is called "*el bot*". To make the Menorca horse breed more competitive in the equestrian market, it is necessary to understand the genetic background that characterizes the aptitude for Menorca Dressage and its relationship with conformation traits. The analysed data consisted of 15 conformation traits from 347 Menorca horses (200 males and 147 females), with 1,550 performance records in Menorca Dressage competitions. Genetic parameters were estimated using linear and threshold animal models. The heritabilities for heights and lengths were high (0.45-0.76), those for angulations and binary conformation traits were low to moderate (0.10-0.36) as were the scores for dressage performance (0.13-0.21). The results suggest that the analyzed traits could be used as an efficient tool for selecting breeding horses.

Additional key words: dressage; morphology; Bayesian; heritability; local breed.

Introduction

The Menorca horse is widely known for its role in the regional festivities called "*Jaleo Menorquín*". It is a low census breed with 3,186 animals registered in the official studbook younger than 20 years old, mainly located on the island of Menorca. From the morphological point of view, they are black-coated animals with a sleek silhouette, 1.60 m average wither height and suitable for riding. Stallions mainly participate in exhibitions, festivals and equestrian exercises, especially dressage, which is a tough test of their functional skills, especially in a type of dressage called "Menorca Dressage". The recovery of the traditional festivities where the horse is involved and its skills for Menorca Dressage have helped the Menorca horse population to gradually increase its census (Solé *et al*., 2013).

The Menorca Dressage is similar to Classical Dressage, where the animal has to carry out different exercises on a track at walk, trot and canter. However, it also includes some specific movements that animals perform guided by the rider during the traditional festivities "*Jaleo Menorquín*"; for example, the horse stands or walks on its hindlimbs that is called "*el bot*" (Fig. 1). This exercise is awarded with a high score if the performance is vertical and balanced, and the score is even higher if the horse walks or jumps in this position, thus reflecting the increased level of difficulty. Other specific Menorca exercises are the front limb spins (the forelimb circling around the haunches at trot) and hindlimb spins (the hindlimb circling around the shoulders at trot). In these exercises, the regularity of the movement changes with the speed and the imbalance of impulsion, unlike Classical Dressage where the regularity and impulsion must be well balanced and maintained during the exercise. Other rules include the costume of the rider, which is modelled on 18th and 19th century Menorcan attire, and the rider holding the reins in only one hand.

* Corresponding author: ge2sobem@uco.es
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Abbreviations used: FS (final score); HBV (hock back view); HLH (hind leg hooves); LSM (least square means); MM (Menorca movements).

Figure 1. Measurements and angles used in the analyses. HW: height at withers, HC: height at croup; BL: body length, SL: shoulder length, AL: arm length; CL: croup length, α: shoulder angle, β: arm angle, φ: croup angle; ε: stifle angle; ω: femur angle; θ: leg angle; δ: hock angle; HBV: hock back view and HLH: hind leg hooves. On the right: a specific movement consists of a sustained elevation of the horse's forelimbs, which is called "el bot".

The conformation is of primary interest to breeders and owners, since the overall body shape defines the limits of the range of movement, the function of the horse and its ability to perform (Mawdsley *et al.*, 1996; Rustin *et al.*, 2009). Therefore, the selection to improve the functionality could lead to changes in some morphological traits. For example, the hindlimb angulations like hock angle increased between 1984 and 1996 in riding horses (Holmström, 1994).

All breeding objectives for sport horses include functional conformation and movements as indicator traits for improving sport performance (Koenen *et al.*, 2004). The relationship between conformation and dressage ability was illustrated by Barrey *et al.* (2002). The sport performance is the result of a complex combination of conformational, physiological and behavioural traits, which may be heritable (Saastamoinen & Barrey, 2000). Therefore, certain conformation traits associated with the specific movements of Menorca Dressage could be used to carry out indirect genetic selection of animals.

Traits that are included in breeding programs must be correlated with their breeding goal, which may be performed in some disciplines of riding sport, and should be accurately measured early in the life of the animal (Holmström *et al.*, 1994). Furthermore, estimated relative economic values of selection criteria for sport horses are based on conformation, gaits, behaviour and health characteristics to achieve high sale prices (Koenen *et al.*, 2004). Thus, it is essential to know the genetic background that characterizes the ability to perform Menorca movements and its relationship with conformation traits. Moreover, it could be useful to develop an early selection for conformation traits in young Menorca animals, which may become with time a more sportive and competitive breed on the equestrian market. The aim of this study was to estimate the heritabilities of conformation and performance traits for Menorca Dressage in the Menorca Horse population.

Material and methods

Data

The conformation data consisted of 15 traits (Fig. 1), from 347 Menorca horses (200 males and 147 females), aged older than 3 years. These animals represent about one third of the population for this age range and located on the island of Menorca (surface area: 700 km^2).

The conformation traits were: (a) six height and length measurements (meters): height at withers, height at croup, body length, shoulder length, arm length and croup length; (b) seven angular measurements (degrees): shoulder angle, arm angle, croup angle, stifle angle, femur angle, leg angle and hock angle; (c) two binary measurements with two categories 0 and 1: hock back view (HBV) with category 0 as straight hocks and category 1 as cow-hocked and hind leg hooves (HLH) with category 0 as straight hooves and category 1 as splay-footed.

All the measurements were collected between December 2009 and January 2010 by the same trained qualifier, following the methodology described by Gómez *et al*. (2009). The heights and lengths were measured using a zoometric stick. The angles were obtained using the ImageJ program (Abràmoff *et al*., 2004). For this purpose, green marks were put on specific anatomical reference points on the horse, following Cervantes *et al*. (2009). The two binary traits were classified *in situ* by the trained qualifier standing behind the horse.

The performance traits were collected during the official Menorca Dressage competitions held between January 2009 and December 2010. In this type of dressage competition, 16-23 dressage traits are scored, with some of them (between 1-3 scores) are specifically for Menorca Dressage movements. The scores were on 1-10 scale with increments of 1. The score is given by 2 or 3 judges depending on the competition. The performance traits analyzed were the scores awarded specifically for Menorca movements (MM) and the final score (FS) obtained in the reprise. The FS is computed as an average of all recorded traits during the reprise and it was the determinant of the final ranking in competition. The MM is the average of the scores given specifically to the Menorca movement. In both traits, the horse performed the exercise guided by a rider. The information was collected in 27 competitions. A total of 1,550 performance records from 88 stallions with zoometric data were available for all age groups (Table 1). Note that the same horse could have records in different age group (4-5, 6-7 and older than 8). The entries were assigned to four levels of difficulty, based on the difficulty of the exercises included in the reprise and following the official rules of the Menorca dressage discipline (http://www.fhbalear.com/index.php?limitstart=24). Of the 65 riders, at least 33% participated with two or more different horses, and 30% of the horses performed with two or more different riders. The number of different combinations of 10 judges with the four difficulty levels of the exercises was 40, with a minimum of 3 records per combination. All horses performed at least twice, 49% participated less than 10 times, 15% between 11 and 20 times, 46% had between 11 and 50 records, and 5% participated more than 51 times.

The pedigree information was obtained from the breed's Studbook (http://men-incecca.tragsatec.es/men-incecca/caballos/fichaProducto.xhtml) and provided by the Breeders Association. The number of records in the pedigree file was 3,735.

Methodology

The genetic parameters for the two performance traits (MM and FS) were estimated following this univariate linear model:

$$y = Xb + Zu + Wr + Mp + e$$

$$\text{with, } \begin{pmatrix} u \\ r \\ p \\ e \end{pmatrix} \sim \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} G & 0 & 0 & 0 \\ 0 & R & 0 & 0 \\ 0 & 0 & P & 0 \\ 0 & 0 & 0 & S \end{pmatrix}$$

where, $G = A\sigma_u^2$, $R = I_r\sigma_r^2$, $P = I_p\sigma_p^2$, $S = I_e\sigma_e^2$ and y is the observations vector, b represents the systematic effects of age (grouped in three as in Table 1), the competition and the judges together with the level of difficulty of

Table 1. Structure of the performance data analyzed in Menorca horses with the number of performance records (n), number of horses per age range (nh), ranges, total means and means of the scores obtained by age groups and level of the exercise (Level 1-Level 4)

Age (years old)	Performance trait	L1	L2	L3	L4	Total	Scores ranges
4-5	n	369	77	20	0	466	
	nh	33	10	3	0	46	
	MM[a]	6.0	6.4	6.3	—	6.2	3.0-8.0
	FS[a]	6.1	6.4	6.1	—	6.2	4.6-7.5
6-7	n	97	215	150	78	540	
	nh	9	20	20	5	54	
	MM[a]	5.6	6.4	6.6	6.5	6.3	3.0-8.3
	FS[a]	5.9	6.3	6.3	6.2	6.2	4.5-7.5
≥8	N	273	109	65	97	544	
	nh	15	13	11	6	45	
	MM[a]	6.2	6.2	6.5	6.6	6.4	4.0-8.0
	FS[a]	6.0	6.0	6.1	6.3	6.1	4.0-7.1

[a] MM is the score obtained for Menorca movements and FS is the final score obtained in the exercise.

the exercise, u is the vector of direct additive genetic effect, r represents the random effect of the rider and p the permanent environmental effect of the horse (no genetic effect of the animal that influences its performance), with X, Z, W and M their respective incidence matrices. A was the numerator relationship matrix, I_r (I_p, I_e) the identity matrix of equal order to the number of rider (horses, records), σ^2_u (σ^2_r, σ^2_p, σ^2_e) the additive genetic variance (rider, horse, residual).

Genetic parameters for conformation traits were estimated following a similar univariate linear model in which b only included the age (four levels: 3, 4-5, 6-7 and higher or equal to 8 years old) and sex effect; the random effects r and p were removed.

The two additional categorical conformation traits (HBV and HLH) were analysed using a threshold model with the same effects and assumptions for the underlying variable similar to the previous model. For these dichotomous traits, the observed phenotype ($P_i = 1$ or 0) was assumed to be:

$$P_i = \begin{cases} = 1 \text{ if } y_i > T \\ = 0 \text{ if } y_i \leq T \end{cases}$$

where y_i is an observation of the vector y gathering the corresponding underlying variables to which the linear model was fitted, and T is the unknown threshold also to be estimated.

Marginal posterior distributions of all traits were estimated by using the Gibbs sampling algorithm (TM program; Legarra *et al*., 2008). Prior distributions for vector b were assigned as bounded uniform prior distribution and the variance components σ^2_u, σ^2_r, σ^2_p and σ^2_e were scaled inverted chi-squared distributions ($v = 2$ and $S = 0$) to perform as a flat prior distribution. A total Gibbs chain length of 1,000,000 samples for each analysis was defined, with a burn-in period of 100,000 and a thinning interval of 100. The R program (Ihaka & Gentleman, 1996) was used to check the convergence of the Gibbs chain, the need for additional rounds of burn-in to be discarded and to draw up the marginal posterior distributions of the heritabilities and genetic correlations.

To avoid the influence of non random distribution of the data the mixed model was used. A General Linear Model and least square means (LSM) were performed for conformation traits comparing males and females. The basic statistical analysis of the different traits was performed using the "Statistics for Windows" version 8.0 package (StatSoft Inc, 2007; http://www.statsoft.com). To analyses the pedigree of participants, the equivalent complete generations (Boichard *et al*., 1997) and the inbreeding coefficient for animals included in the analysis were computed with ENDOG v4.8 (Gutiérrez & Goyache, 2005).

Results

The pedigree had an average of equivalent complete generations of 3.19, with a minimum of 1.43 and a

Table 2. Least square means (in meters) and coefficients of variation (CV) for conformation measurements and frequencies (% in category 1) for conformation faults in 347 Menorca horses

Variables	Males		Females	
	Mean	CV (%)	Mean	CV (%)
Height at withers	1.62	3.01	1.58	2.58
Height at croup	1.48	2.96	1.46	3.14
Body length	1.59	3.76	1.59	3.09
Shoulder length	0.64	4.43	0.61	5.71
Arm length	0.38	5.77	0.37	5.71
Croup length	0.53	5.88	0.52	5.53
Shoulder angle	55.80	7.53	59.16	7.64
Arm angle	30.03	19.00	28.64	23.90
Croup angle	16.57	31.24	19.66	26.74
Stifle angle	122.72	6.71	124.43	6.61
Femur angle	64.88	8.83	64.16	8.98
Leg angle	58.56	9.41	60.40	11.19
Hock angle	136.52	5.39	136.05	4.01
Hock back view (cow-hocked)	40.60%		54.8%	
Hind leg hooves (splay-footed)	86.00%		93.20%	

maximum of 4.45. The average of inbreeding coefficient was 3% for the individuals included in the analyses. The descriptive statistics (least square means and coefficients of variation) of conformation traits are shown in Table 2. Males had higher LSM for heights and lengths than females for all the analyzed traits, except for body length. For angulations, females had higher values than males, except for arm, femur and hock angles. Coefficients of variation of body traits were low to moderate (2.96-5.88% in males and 2.58-5.71% in females), characterizing a highly homogeneous population, except for angulation measurements where the CVs were moderate to high (5.39-31.27% in males and 4.09-26.74% in females). Arm and croup angles varied most and height at withers varied least. The frequencies for hooves conformation were unbalanced, with over 80% of the population in category 1 (splay-footed). However, the proportion of individuals for hock conformation in the two different categories was similar.

Table 3 shows the mean and standard deviations of the marginal posterior distribution for the heritabilities, as well as the ratios between the additional random environmental effects and the phenotypic variances. Given the Bayesian nature of the analyses, no standard errors of parameters were available but standard deviation of their marginal posterior distribution that, usually, trend to be much higher. Thus, to facilitate the interpretation of the results, the marginal posterior distributions were described by providing the 95% highest probability density intervals and the probabilities of the heritability to be in the low range (lower than 0.15), medium (higher than 0.10 or higher than 0.15 and lower than 0.40) or in the higher range (higher than 0.40). All heritabilities for heights and lengths were high (0.43-0.75), those for angulations and categorical traits were low to moderate (0.10-0.36), and those for performance traits were moderate (0.13-0.21). The estimated ratios for the additional random environmental effect of the rider were 0.26 (MM) and 0.33 (FS). The ratios for the permanent environmental effect of the horse were not important.

Discussion

The genetic relation between conformation and functional performance traits is already well known (Koenen *et al.*, 1995; Schroderus & Ojala, 2010). Thus, Menorca breeders tend to select animals based on conformation to achieve a good performance for Menorca or Classic dressage. This selection could lead to an abusive use of some animals with a specific conformation. And an insufficient knowledge of the influence of conformation on performance and health could result in an inappropriate selection of horses for breeding (Holmström & Philipsson, 1993). Therefore, it seems necessary to study the genetic background between conformation and Menorca Dressage. Otherwise, the selection should be made with caution in these types

Table 3. Mean and SD (in brackets) of the marginal posterior distributions for the heritabilities and the ratios between the additional random environmental effects and the phenotypic variances included in the univariate model fitted for all the evaluated traits

Conformations traits		[a]$\mathbf{h^2}$		**HPD95**	[c]**P1**	[c]**P2**	[c]**P3**	[c]**P4**
Height at withers		0.75 (0.10)		(0.57-0.87)	0	100	0	100
Height at croup		0.68 (0.13)		(0.45-0.83)	0	100	2	98
Body length		0.75 (0.10)		(0.56-0.87)	0	100	0	100
Shoulder length		0.49 (0.11)		(0.30-0.63)	0	100	21	79
Arm length		0.44 (0.13)		(0.22-0.62)	1	100	37	62
Croup length		0.43 (0.12)		(0.23-0.58)	1	100	40	60
Shoulder angle		0.10 (0.07)		(0.00-0.17)	80	42	20	0
Arm angle		0.36 (0.11)		(0.17-0.50)	3	100	63	34
Croup angle		0.23 (0.10)		(0.07-0.36)	25	89	70	5
Stifle angle		0.28 (0.14)		(0.07-0.46)	18	92	62	20
Femur angle		0.11 (0.08)		(0.00-0.19)	74	45	25	0
Leg angle		0.16 (0.09)		(0.02-0.28)	50	70	48	2
Hock angle		0.19 (0.11)		(0.03-0.32)	39	79	57	4
Hock back view		0.21 (0.14)		(0.00-0.36)	40	73	50	10
Hind leg hooves		0.10 (0.07)		(0.00-0.18)	77	44	23	0
Performance traits	[a]h^2	[b]r^2	[b]p^2					
Menorca movements	0.13 (0.07)	0.26 (0.07)	0.07 (0.06)	(0.03-0.22)	65	66	35	0
Final score	0.21 (0.09)	0.33 (0.08)	0.08 (0.07)	(0.07-0.33)	25	90	73	2

[a] h^2 is the heritability for the direct genetic effect. [b] r^2 and p^2 are the ratio between the environmental effect (rider or the horse) and the phenotypic variances; HPD95: 95% highest probability density intervals. [c] P1, P2, P3, P4: probability (%) of heritability being < 0.15, > 0.10, [0.15-0.40] and > 0.40, respectively.

of breeds with low census and little amount of performance data (Zechner *et al.*, 2001; Druml *et al.*, 2008).

All the estimated heritabilities obtained for conformation traits were in agreement with other authors. The heritabilities for the conformation (heights and lengths) traits were similar to those obtained in the Italian Haflinger and Noriker draught horse breeds (Miglior *et al.*, 1998; Druml *et al.*, 2008), but higher than those obtained from the oldest European breeds such as the Spanish Purebred and Lipizzan (Molina *et al.*, 1999; Zechner *et al.*, 2001; Gómez *et al.*, 2009). The slight disagreement in the estimated heritabilities may be interpreted not only as differences between populations, but also as differences in the definition of traits, or in the methodology used.

For angular traits, the heritabilities were low to moderate, which were similar to those reported for the oldest European breeds such as the Lipizzan horses (0.00 to 0.16; Zechner *et al.*, 2001) and the Noriker draught breed (0.02 to 0.31; Druml *et al.*, 2008).

The definitions of HBV and HLH as binary traits may affect the type of analysis and the heritability estimations, but non-linear models would lead to an increased response from selection, because they describe more accurately the structure of the data (Meijering & Gianola, 1985). Moreover, advantages of threshold over linear models have been shown with simulated data (Hoeschele, 1988). The literature is scarce on the analysis of binary conformation traits using threshold analysis in horses, because conformation traits are usually recorded on a continuous scale (Koenen *et al.*, 1995; Suontama *et al.*, 2009; Schroderus & Ojala, 2010).

For the performance traits analyzed here, the heritabilities were in agreement with other authors (Ricard *et al.*, 2000; Viklund *et al.*, 2010), even though all the comparisons were made with caution because of the small amount of data. Fitting rider effect in the models has been often controversial when analyzing sport performance in horses (Kearsley *et al.*, 2008; Bartolomé *et al.*, 2013). Kearsley *et al.* (2008) analysed penalty records for dressage competitions and found lower variances (expressed as a ratio of the phenotypic variance) for the effect of the rider (0.12 to 0.18) than in Menorca Dressage competitions (0.26 and 0.33), suggesting a higher variability among Menorca riders.

To conclude, some of the heritabilities obtained in this study indicate that the analyzed traits could be used as an efficient tool for selecting breeding horses. The results might suggest that there is a tendency of some conformation traits to affect performance in this breed. Characteristics such as shoulder angle and hindlimbs traits could be relevant traits given their importance for dressage ability. It could be hypothesized that a specific conformation, mainly on hindlimbs, which could be considered as a defect or not useful in other sport competitions, could give good performance in some Menorca Dressage movements. However, it is essential to gather much more data to explore the relationship between these variables and dressage performance in greater depth and thus make a precise choice of the breeding criteria.

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