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Size and shape analysis of morphofunctional traits in the Spanish Arab horse

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ABSTRACT

The aim of this study was to analyse the morphology of the Spanish Arab horse using classical multivariate statistical tools and methods in the field of Geometric Morphometrics (GMM) in order to find size and shape differences between them. Our data consisted of 28 body measurements and 9 angles from 171 (58 males, 88 females and 25 geldings) Spanish Arab Horses with different breeding goals such as morphological show aptitude, endurance race aptitude and others, used for recreational activities.
The main difference between breeding goals was observed in the functional posterior triangle and in size and shape. The thin-plate splines of reference configurations for each breeding goal gave differences in the coordinates corresponding to the stifle. The analysis using relative warps did not give any significant difference whereas the same analysis using measurement showed a clear difference between animals bred for each objective. The analyses of morphofunctional traits carried out here did not reveal any significant differences between "shape" of animals bred for different purposes so far in the Spanish Arab horse. Whereas for "size" analysis the significant differences between morphological and endurance aptitude where observed in the posterior triangle. The results obtained here might be valuable for the selection scheme in order to differentiate individuals with a specific aptitude and select them.

1. Introduction

Conformation influences sports performance (Langlois et al., 1978; Langlois, 1979; Holmström et al., 1990), and the Arab horse is bred for its conformation which is a very important characteristic in this breed. To meet the standard requirements for this breed, conformation is assessed by expert judges during the ECAHO (European Conference of Arab Horse Organization) morphological shows, even though show judgements are basically subjective (Bowling and Ruvinsky, 2000).

Therefore, the implementation of objective methodologies assessing morphology is of major importance in the horse industry. One attempt is the development of a linear type assessment system. This methodology is based on the description of animal morphology on a biological scale, including the whole range in the analysed population (Samoré et al., 1997). Other new methodologies that avoid subjective assessments are based on morphometric information and focus on the variation of shape (Adams et al., 2004). Such method was applied just recently to compare the body shape of different horse breeds (Druml and Sölkner, submitted for publication) and Ankole Longhorn cattle breed (Ndumu et al., 2008). Generally, the geometric methods provide new objective variables that could be used in genetic evaluations.

The Arab horse was imported to Spain in the middle of XIXth century and mainly used for military purposes. Nowadays, as a remnant of the old military uses, the main sports application of the Spanish Arab Horse Breeder is endurance races. However, the breed is also well-known for its beauty and morphological harmony which many breeders select for type traits. Currently, the Spanish Arab Horse Breeder Association (AECCA) is developing a breeding program aimed at improving conformation traits and endurance performance.

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The aim of this study was to analyse the morphology of the Spanish Arab horse using both the classical statistical analysis based on morphological traits (zoometric measurements) and a Geometric Morphometrics Method (GMM). Distance or perimetric measurements imply, by their very nature, differences in size. GMM methods eliminate size factors and focus on the shape of individuals. Finally we investigated whether different breeding goals are best reflected by 'size' related and 'shape' variables (Rohlf and Marcus, 1993; Bookstein, 1996).

2. Materials and methods

2.1. Material

Our data consisted of 37 morphological traits from 171 Spanish Arab Horses (58 males, 88 females and 25 geldings) within an age range from 3 to 14 years. The following morphological traits were used:

- 15 distance measurements: Body length, Thoracic depth, Neck length, Scapula length, Arm length, Forearm length, Fore-cannon length, Back length, Loin Length, Croup length, Hip–stifle length, Buttock–stifle length, Leg length, Hind-cannon length and Head Length.
- 9 angular measurements: Neck angle, Shoulder angle, Elbow angle, Fore-pastern angle, Croup angle, Femur angle, Leg angle, Hock angle and Hind-pastern angle.
- 7 height measurements: Height at withers, After withers height, Height of withers (the difference in cm between height at withers and after withers height), Middle back height, Height at hip, Height at buttock and Height at dock.
- 4 width measurements: Thoracic width, Chest width, Croup width and Head width.
- 2 perimeters: Thoracic perimeter and Fore-cannon perimeter.

The measurements were taken in the field with zoometric stick and tape while the angle analysis was made with ImageJ program (Abramoff et al., 2004). For this purpose, green marks were put on specific anatomical reference points on the horse.

We made a classification of the individuals based on the aptitude in which the horses are bred (breeding goal). So we classified individuals bred for morphological shows ("beauty") those participants in morphological shows organized by ECAHO, where animals are evaluated for their beauty, correctness of legs, Arabic type and basic gaits. We identified as animals bred for endurance aptitude those participants in endurance racing. This is a sports competition where horses

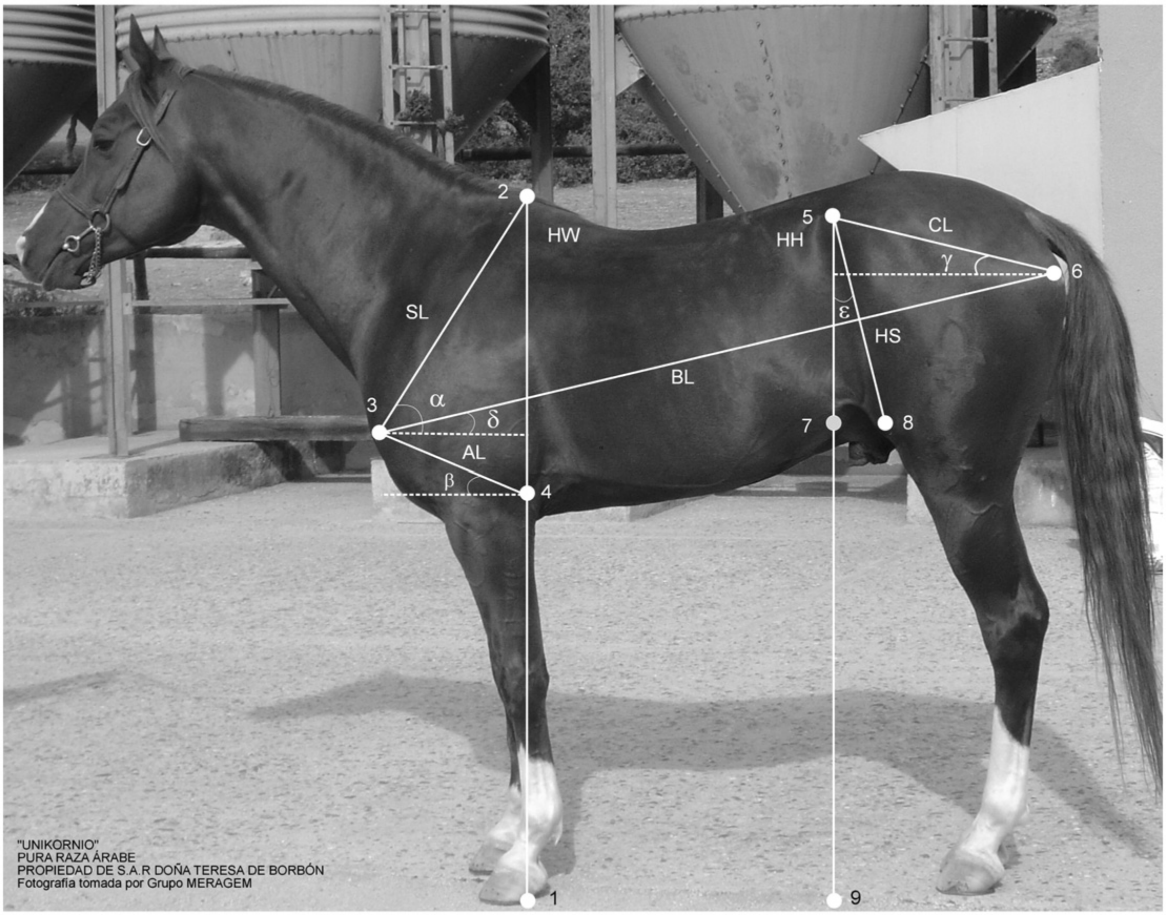

Fig. 1. Landmarks, measurements and angles used to derivate the nine coordinates used in the morphometric analyses. 1:ground1 ($x=0$, $y=0$), 2:withers ($x=0$, $y=HW$), 3:shoulder ($x=-\cos(\alpha)*SL$, $y=HW-\sin(\alpha)*SL$), 4:elbow ($x=0$, $y=HW-\sin(\alpha)*SL-\sin(\beta)*AL$), 5:hip ($x=\cos(\delta)*BL-\cos(\alpha)*SL-\cos(\gamma)*RL$, $y=HH$), 6:Buttock ($x=\cos(\delta)*BL-\cos(\alpha)*SL$, $y=HH-\sin(\gamma)*RL$), 7:semilandmark ($x=\cos(\delta)*BL-\cos(\alpha)*SL-\cos(\gamma)*RL$, $y=HH-\cos(\varepsilon)*HS$), 8:stifle ($x=\cos(\gamma)*RL-\cos(\alpha)*SL-\cos(\gamma)*RL+\sin(\gamma)*RL$, $y=HH-\cos(\varepsilon)*HS$) and 9:ground2 ($\cos(\delta)*BL-\cos(\alpha)*SL-\cos(\gamma)*RL$, $y=0$). Where, HW: Height at withers, HH: Height at hip, BL: Body Length, SL: Scapula Length, AL: Arm Length, CL: Croup Length, HS: Hip–stifle length, α: shoulder joint angle, β: elbow joint angle, γ: croup angle, δ: shoulder–buttock angle and ε: hip–stifle angle. * Lengths in metres and angles in radians.

have to race over long distances (even 200 km and more) in natural tracks undergoing several veterinary health checks during the race. The third level of the breeding goal was "others" including individuals without a clear aptitude, e.g. used for recreational activities.

2.2. Classical statistical analysis

A MANOVA was performed using 3 fixed effects in the model: gender (male and female), age class (≤4, 5, 6, 7, and ≥8 years old) and the breeding goal (morphological shows aptitude, endurance race aptitude and "others"). The model also included the two way interactions. Also, to analyse the structure in the relationships between the zoometric variables a Principal Component Analysis (PCA) was made.

To differentiate between the three mentioned breeding goals and to define the characteristics body measures resulting in the different aptitudes of the populations under study a canonical discriminant analysis (Lawley, 1959) was used.

2.3. Geometric morphometric analysis

Since a *Geometric Morphometric Method* (GMM) requires the positions of landmarks, a finite number of points along the outline of the shape, instead of longitudinal or angular measurements, we used the following 7 distance measures and 5 angles to reconstruct the shape of each individual.

Height at withers (HW), Height at hip (HH), Body Length (BL), Scapula Length (SL), Arm Length (AL), Croup Length (CL) and Hip–stifle length (HS); shoulder joint angle (α), elbow joint angle (β), croup angle (γ), shoulder–buttock angle (δ) and hip–stifle angle (ε) (Figs. 1 and 2a).

Landmark configurations obtained were superimposed on one another so that deviations of landmarks were minimized using the *Generalized Procrustes Analysis* (GPA) (Gower, 1975). This is the main part of GMM and eliminates non-shape variation like size and orientation of objects. A GPA procedure superimposes the single specimens according to some optimizing criteria: First, the configurations of all landmarks are scaled to obtain a unit centroid size of the shapes (centred in the gravity of all landmarks), after that the configurations are rotated to minimize the squared differences between landmarks obtaining the aligned coordinates (consensus configuration) (Fig. 2b) (Slice, 1999). The final 'shape variables' can be used for further statistical analysis or graphical representations instead of coordinates (Adams et al., 2004).

The relationships among coordinates are captured using appropriate functions. The thin-plate spline function (Bookstein, 1989) is used to express the difference between two configurations of landmarks as a continuous deformation adopting the form that minimizes bending energy. Variation among specimens is expressed as variation in the parameters of an interpolating function that compares a given specimen to the consensus configuration. This function is then decomposed into a number of geometrically orthogonal elements called principal warps. Superimposed specimens are then projected onto these principal warps to describe their deviations from the consensus configuration. These projections, the partial warps scores, describe the localized shape differences among the specimens studied and are then used in the multivariate analyses (Bookstein, 1991). They are a rotation of the Procrustes residuals

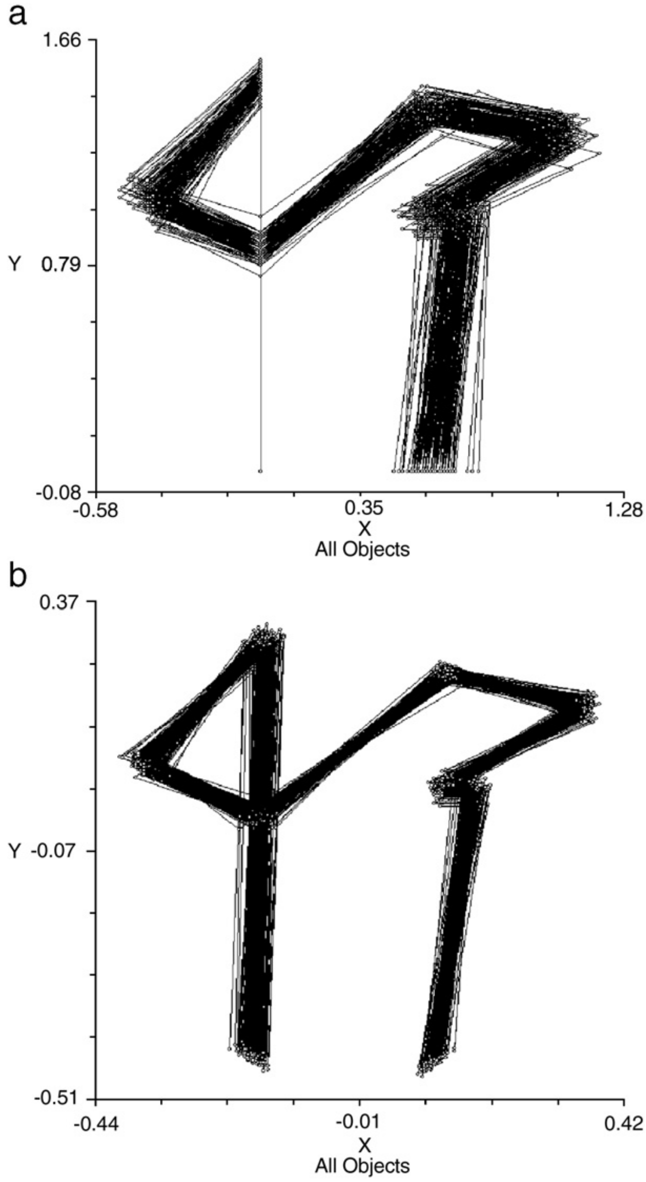

Fig. 2. Raw coordinates (Plot a) and aligned coordinates after procrustes superposition (Plot b) for Spanish Arab Horses individuals.

(the set of vectors connecting the landmarks of a specimen to corresponding landmarks in the consensus configuration after a Procrustes fit) around the Procrustes mean configuration. Partial warp scores from the thin-plate spline are defined as a suite of geometrically orthogonal shape variables describing local differences within a geometrical scale (Rohlf et al., 1996). The differences in landmark configuration between the mean shapes of each group are represented by local deformations plotted on an overlaid grid – the 'thin plate spline'. To visualize the differences between the three defined populations following the breeding goal under study the 'thin plate spline' methodology was chosen. Moreover, the partial warp scores can be used in a PCA to summarize the variation among the specimens (with respect to their partial warp scores) in as few dimensions as possible given some principal components that are called relative warps (Rohlf et al., 1996).

The 'shape variables', centroid size or relative warps, can be analysed using conventional methods of multivariate statistics. In our paper these variables were analysed using a

MANOVA structured by the fixed factors gender, age and breeding goal including two way interactions.

To develop this analysis we used tpsRewl v1.42 (by F. James Rohlf) and Morpheus et al. program (Slice, 1999). Complementary statistical analyses were made with SAS® for Windows.

3. Results and discussion

The statistical analysis made using the morphofuctional traits revealed that the factors: gender, age and breeding goal had significant effects specifically on some body measurements. Variables related to thorax and width or angle of the croup were found to be significantly higher in females, while variables such as leg length buttock–stifle length, fore-cannon length and fore-cannon perimeter were significantly higher in males (results not shown). From our results, we found that the Spanish Arab horse population is taller today than twenty years ago (Fuentes et al., 1987). This fact is more pronounced in females than in males. The variables of height were very similar to the Egypt Arab horse population (Sadek et al., 2006) whereas the thoracic and fore-cannon perimeter were higher and the chest width smaller than in our study.

Mean, range and coefficient of variation of the 28 measurements and the 9 angles grouped by breeding goal are given in Table 1. The angles obtained the highest coefficient of variation (31.3%) and the heights the lowest (2.1%), but most of these variables were not significantly different between breeding goal groups. Only the hock angle had significant differences between animals bred for morphological shows and for endurance races. Some height variables, the neck length, the hip–stifle length, the hock angle and the thoracic perimeter in animals bred for morphological shows were higher than in endurance races horses. When we studied the functional posterior triangle of the horse composed of Croup length, Hip–stifle length and Buttock–stifle length (Table 1), that indicates the endurance aptitude of this breed (Fenaux, 1989), we obtained that animals bred for this aptitude have the Hip–stifle length shorter than the other two distances.

The performed MANOVA showed also statistical differences between animal bred for different breeding goals ($p<0.001$),

Table 1

Descriptive statistics for morphofunctional traits in each breeding goal group (morphological shows aptitude, endurance race aptitude and others) in the analysed population of the Spanish Arab horse.

	Morphological aptitude			Endurance aptitude			Others		
	Mean	Range	CV (%)	Mean	Range	CV (%)	Mean	Range	CV (%)
Measurements									
Height of withers	5.59^{a}	8.00	32.28	5.99^{a}	6.00	22.57	5.80^{a}	6.50	26.25
Height at withers	150.02^{a}	16.50	2.07	149.39^{a}	16.50	2.13	149.01^{a}	16.00	2.23
After withers height	144.43^{a}	14.50	2.15	143.39^{a}	17.00	2.26	143.21^{a}	13.50	2.14
Middle back height	142.57^{a}	11.50	2.13	141.95^{ab}	17.00	2.29	141.04^{b}	13.50	2.32
Height at hip	139.33^{a}	12.50	2.13	139.63^{a}	15.00	2.56	138.58^{a}	17.00	2.45
Height at buttock	129.71^{a}	18.00	2.72	128.33^{b}	15.00	2.53	127.36^{b}	18.50	3.23
Height at dock	143.47^{a}	14.00	2.36	141.22^{b}	14.00	2.27	141.86^{ab}	17.00	2.86
Body length	147.64^{a}	25.00	2.77	147.24^{a}	20.00	2.80	147.64^{a}	22.00	2.85
Thoracic depth	62.56^{a}	12.00	4.33	61.98^{a}	20.00	4.57	62.49^{a}	10.00	3.76
Thoracic width	53.46^{a}	14.00	6.20	51.18^{b}	19.00	7.17	53.74^{a}	17.00	6.89
Chest width	30.20^{a}	18.00	10.09	30.59^{a}	16.00	7.51	30.83^{a}	9.00	7.00
Neck length	69.47^{a}	20.00	6.32	67.59^{b}	14.50	4.87	70.43^{a}	25.00	8.50
Scapula length	60.64^{ab}	15.50	3.79	60.26^{a}	11.00	3.20	61.26^{b}	10.00	3.66
Arm length	34.00^{a}	7.00	4.19	34.44^{a}	8.00	5.11	34.06^{a}	7.00	4.85
Forearm length	41.25^{a}	16.00	6.29	40.99^{a}	10.00	4.16	40.40^{a}	14.00	6.26
Fore-cannon length	25.63^{a}	4.00	3.59	25.48^{a}	5.00	4.21	25.49^{a}	4.50	4.30
Back length	28.49^{a}	11.00	8.22	28.31^{a}	16.00	9.38	27.79^{a}	6.50	5.34
Loin length	28.67^{a}	14.00	8.88	28.37^{a}	7.50	5.95	29.15^{a}	12.00	8.49
Croup length	47.58^{a}	13.00	5.02	47.49^{a}	7.00	3.60	47.96^{a}	8.50	4.00
Croup width	49.03^{a}	12.00	4.89	49.56^{a}	11.00	4.60	49.34^{a}	10.00	4.31
Hip–stifle length	42.36^{a}	10.00	4.58	41.12^{b}	15.00	7.35	42.16^{ab}	14.00	8.22
Buttock–stifle length	47.10^{a}	7.00	3.61	46.89^{a}	9.00	3.81	46.36^{a}	12.00	4.98
Leg length	51.02^{a}	9.00	3.69	50.80^{a}	14.00	4.28	50.23^{a}	11.00	4.40
Hind-cannon length	34.74^{a}	6.00	3.82	34.78^{a}	7.00	5.07	34.55^{a}	7.00	4.18
Head length	54.76^{a}	10.00	3.92	55.02^{a}	7.00	2.83	54.61^{a}	6.50	3.04
Head width	20.62^{a}	4.50	4.58	20.87^{a}	5.00	3.70	20.57^{a}	4.00	4.70
Thoracic perimeter	180.02^{a}	32.00	4.17	171.72^{b}	37.00	3.56	179.26^{a}	37.00	5.42
Fore-cannon perimeter	18.74^{a}	4.00	4.91	18.68^{a}	3.00	3.89	18.92^{a}	3.50	4.76
Angles									
Neck	48.36^{a}	30.58	14.08	47.05^{a}	28.35	15.00	45.62^{a}	29.17	16.05
Shoulder joint	49.82^{a}	15.07	7.11	49.67^{a}	18.67	7.92	50.24^{a}	24.56	10.52
Elbow joint	30.97^{a}	17.67	13.47	30.74^{a}	16.22	10.73	31.30^{a}	21.94	18.09
Fore-pastern	56.94^{a}	23.50	8.93	57.16^{a}	24.44	10.98	55.77^{a}	22.34	7.56
Croup	11.55^{a}	17.03	32.59	12.64^{a}	13.43	29.04	12.99^{a}	13.34	29.26
Femur	63.43^{a}	19.64	7.31	62.05^{a}	22.44	8.25	63.25^{a}	21.20	8.34
Leg	56.20^{a}	21.51	9.46	55.84^{a}	24.75	9.03	54.30^{a}	16.85	7.64
Hock	140.63^{a}	27.29	3.10	138.59^{b}	26.60	3.63	140.10^{ab}	18.09	3.30
Hind-pastern	59.43^{a}	30.07	10.31	60.66^{a}	29.53	11.10	61.11^{a}	20.82	8.34

Measurements in cm and angles in degrees. The values with the same letter were not significantly different between the breeding goals ($p>0.05$).

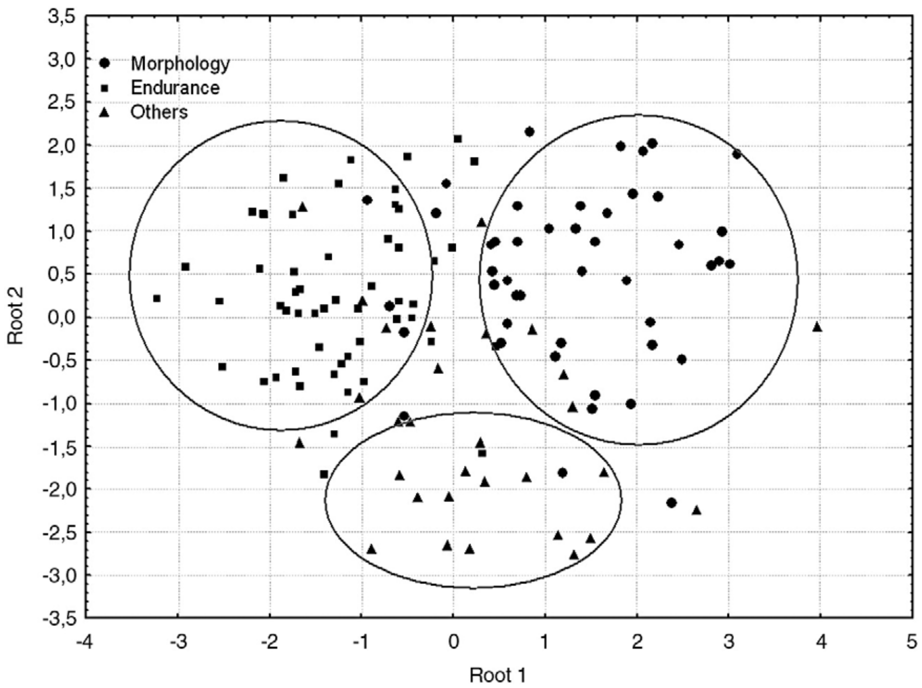

Fig. 3. Two first dimensions of canonical analysis for breeding goal factor in the studied Spanish Arab horse population using the morphofunctional traits.

gender ($p<0.001$) and age ($p<0.05$), but interactions between effects resulted non significant.

The performed Principal Component Analysis showed that the first factor explained a 21.36% of the total variance and grouped height traits that represent the general size of the horse. The second factor explaining the 8.52% of variance included the thoracic variables. Angles related to functionality traits are represented by second and third factors (6.15% of variance).

The canonical discriminant analysis using the analysed traits show the differences of conformation according to the breeding goals (Fig. 3). The R squared canonical correlation between the canonical variable defining the first axis (x) was 0.59. This axis discriminated between morphological and endurance aptitude. The second axis (y) discriminated between those and the third aptitude ("others") with a R squared canonical correlation of 0.37.

With regards to the correlation between the canonical variable and each of the traits, the most discriminatory traits for the first canonical variable were: thoracic perimeter (0.451), thoracic width (0.337), height at dock (0.242), hock angle (0.234) and neck length (0.217). All these showed significant differences between endurance and morphological aptitudes (Table 1). Even though the second canonical variable graphically distinguishes the group of "others" from the rest, none of the most discriminatory traits for this axis provided significant difference between the group of "others" and both "endurance" and morphological ("beauty") aptitudes when analysed independently under MANOVA.

To complement the classical analysis of the traits we use the Geometric Morphometric Method (GMM). The final obtained 'shape variables', centroid size and relative warps were used for further statistical analysis or graphical representations.

The MANOVA based on relative warps did not show evidence of significant differentiation between breeding goals either. Furthermore, the ANOVA results using centroid size did not show any significance in any factor included in the model (results not shown). That means that the global shape of Spanish Arab horses is not influenced by the different breeding goals. A reason for this fact could be found in the polyvalent functionality of the Arab horse and the fixation of morphological traits in this breed.

The three most important relative warps (principal components of a PCA over partial warps) explain 43.95%, 18.91% and 11.06% of the total variance, higher values than those obtained with the PCA using the morphofunctional traits.

Table 2 includes the variances of each landmark for aligned configuration of all individuals. These values were lower than those obtained by Druml and Sölkner (submitted for publication) using different breeds, which seems logical. The highest variances were found for the shoulder, also found by Druml and Sölkner (submitted for publication), then followed by elbow joint, height at withers and stifle.

The thin-plate splines of consensus configurations for each breeding goal were compared in order to see the difference in the overall shape (Fig. 4, plot a, b and c). The main difference was obtained in the coordinates corresponding to the stifle. This is shown in Fig. 4 (plot a) where a difference between beauty type and endurance type is observed for the stifle's

Table 2
Variance ($s^2x = x$ value; $s^2y = y$ value; $s^2 = $ total) of the single procrustes aligned landmarks.

	Landmark	s^2x	s^2y	s^2
Shoulder joint	3	0,000147	0,000117	0,000264
Elbow	4	0,000129	0,000092	0,000221
Height at withers	2	0,000142	0,000073	0,000216
Stifle	8	0,000111	0,000104	0,000214
Ground 1	1	0,000141	0,000072	0,000213
Semilandmark	7	0,000078	0,000108	0,000186
Ground 2	9	0,000106	0,000074	0,000180
Buttock	6	0,000043	0,000135	0,000178
Hip	5	0,000082	0,000068	0,000150

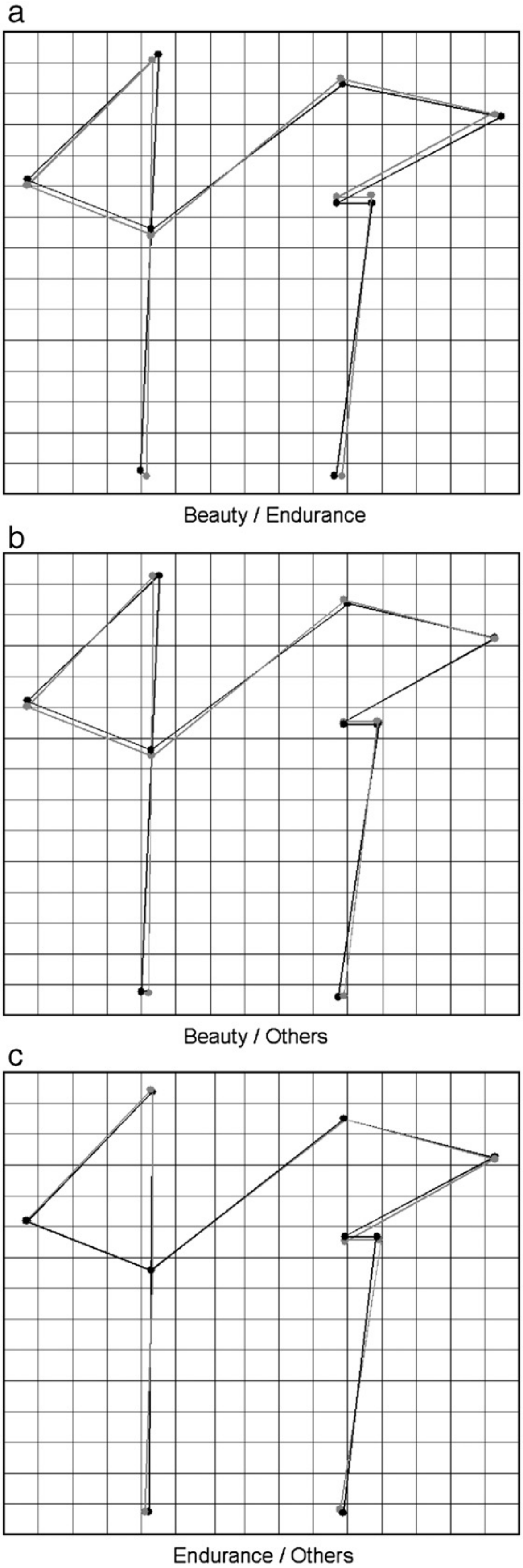

Fig. 4. Consensus configuration of morphological show aptitude (black) versus Endurance race aptitude (grey) (Plot a), morphological show aptitude (black) versus Others (grey) (Plot b) and Endurance race aptitude (black) versus Others (grey) (Plot c).

coordinate. This agrees with the results obtained in the previous statistical analysis showing that in endurance horses the Hip–stifle length was shorter than in show horses. We also noticed visual differences in shoulder and elbow joint. Fig. 4 (plot b and c) shows that animals classified as "others" are halfway between the two breeding goals, in the forequarter body they are similar to "endurance" horses and in the hindquarter are similar to "beauty" horses.

However, the general overview of torsos of the animals we studied seems to be similar between goals. The main difference was observed in the functional posterior triangle and in terms of both size and shape. The fact that our results do not show any significant difference in the overall shape could be interpreted as the differences are produced rather by size traits.

The Spanish Arab horse population was founded mainly using founders from the Middle East, Poland, United Kingdom and Egypt and today the Spanish Arab population is open to registered animals from different Arabs horse populations (Cervantes et al., 2008). Therefore, the genetic flow between different Arab populations could overlap the morphological differences in the mixed progeny. Also, the breed was imported for military purposes (Maxwell, 1995) and as a remnant, breeders look for functionality in the conformation of the horse and not only beauty. This fact can also explain the lack of differentiation between breeding goals. The Arab Horse is a very ancient breed and its conformation is a result of the adaptation process where the good morphology ("beauty") and endurance aptitude are present at the same time.

4. Conclusions

The analyses of morphofunctional traits using Geometric Morphometrics methods has shown that it can be useful to describe the morphology of a breed or compare between different morphotypes. In our case the GMM method did not reveal the existence of significant differences between "shape" of animals bred for different purposes so far in Spanish Arab horse. Whereas for "size" analysis the significant differences between morphological and endurance aptitude where observed in posterior triangle. The results obtained here might be valuable for the selection scheme in order to differentiate individuals with a specific aptitude and select them.

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