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Original study

Usefulness of discriminant analysis in the morphofunctional classification of Spanish dog breeds

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Abstract

The aim of this study was to determine whether the classification of local Spanish breeds of dogs, based on morphological traits, matches or differs from the classification based on the dogs' breeding goals. A total of 15 biometric measurements and 10 functional indices were obtained in 1 365 dogs (709 females and 656 males). The dogs we measured belonged to 16 different breeds, 14 of which were officially recognized by the Spanish Royal Canine Society. Similar average values of morphometric traits and indices ($P<0.001$) were obtained in both sexes: the Ratonero Bodeguero Andaluz was the breed with the smallest format and the Pyrenean and Spanish Mastiff, the largest. In the case of the Fédération Cynologique Internationale (FCI) groups, significant differences ($P<0.001$) for morphometric traits were found, and in both sexes, the third group was the one with the smallest format and the second group, the largest. The differences obtained were more marked between all groups than within groups, and the morphological characteristics were similar, in accordance with the purpose for which the breeds were bred. Therefore, the existence of a morphologic pattern is accepted both in the breeds and the functional groups. Two as yet officially unrecognized breeds, the Orito and Paternino Hound, must be included in the fifth and the first FCI groups, respectively. When the Orito Hound is recognized, it will be added to the fifth FCI group and the word »hound« will be deleted from the name Paternino breed.

Keywords: morphometric traits, body indices, canine, canonical analysis, FCI groups

Abbreviations: FCI: Fédération Cynologique Internationale, LOE: Spanish Stud Book, RRC: Registry of Dog Breed, RSCE: Spanish Royal Canine Society

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Introduction

The relationship between body conformation and function has been widely observed for different animal species and breeds (Zaitoun *et al.* 2005, Yakubu *et al.* 2010, Latorre *et al.* 2011).

There are several organizations that control dog breeds (e.g. Fédération Cynologique Internationale [FCI], the Kennel Club and the American Kennel Club). These organizations are mainly in charge of the taxonomic classification of Canine Species and one of their functions is the characterization, breeding and promotion of dog breeds around the world. In Spain we have the Spanish Royal Canine Society (Real Sociedad Canina Española, RSCE), which has been a member of the FCI since 1912.

Following the FCI approach, dog breeds are mainly classified according to the purpose, morphology and kind of work for which they were intended.

In Spain, the approach and rules of the FCI when classifying and grouping dog breeds are also followed. The RSCE officially recognizes 21 Spanish local breeds of dogs. Nevertheless, only 12 of them are also internationally recognized by the FCI.

In different species of domestic animals, it has been observed that exploratory techniques applied to morphometric variables in domestic animals have allowed us to characterize many breeds and establish differences between populations of sheep (Traoré *et al.* 2008a, b), goats (Herrera *et al.* 1996, Dossa *et al.* 2007), cattle (Yakubu *et al.* 2010) and dogs (González *et al.* 2011) and to discriminate analysis methods (simple, stepwise, clustering and canonical) in the morphometric variables, thus allowing for differentiation among breeds and strains within species (Herrera *et al.* 1996, Capote *et al.* 1998, Crepaldi *et al.* 2001, Macciotta *et al.* 2002, Lanari *et al.* 2003, Rodero *et al.* 2003, Zaitoun *et al.* 2005, Dossa *et al.* 2007, Marrube *et al.* 2007, Vargas *et al.* 2007, Traoré *et al.* 2008a, b, González *et al.* 2001).

Several researchers have highlighted the existence of a possible relationship between morphometric traits and the purpose for which a population was bred over the years. There are studies about the characterization and relationship between Spanish dog breeds by morphological characters (Jordana *et al.* 1992a), biochemical polymorphism (Jordana *et al.* 1991, Jordana *et al.* 1992b, c), random amplified polymorphic DNA markers (Morera Sanz *et al.* 2001), microsatellite markers (Morera *et al.* 1999) and biometric traits (González *et al.* 2011). However, there has been no research into the relationship between body conformation and function in Spanish dog breeds.

The canine species is one of the animals which, over history, has shared its life more closely with man, since the domestication of the dog took place 100 000 years ago (Vilà *et al.* 1997). Over the centuries, the influence of man in the selection and breeding of this species has been very profound (changes of size, changes of coat colour, changes of character and behaviour, according to their function, etc.). This selective action has contributed towards determining different populations, depending on their kinds of functions (hunting dogs, guard dogs, livestock dogs, racing dogs, etc.)

The aim of this study was to determine whether the grouping of local Spanish dog breeds, obtained by discrimination of morphometric traits, matches up or differs from the classification based on the aptitude for which these breeds were bred, following the criteria and approach of the FCI and the RSCE.

Material and methods

Data collection

A total of 1 365 adult (over two year-old) dogs were studied, 709 females (F) and 656 males (M), belonging to sixteen different breeds (Table 1), two of which have not yet officially been recognized by the RSCE: the »Orito« and »Paternino« hound.

The dogs belong to group 1 (Sheepdogs and Cattle dogs), 2 (guarding and defending properties), 3 (Terriers), 5 (Spitz and primitive types), 6 (Scenthounds), 7 (Pointing dogs), 8 (Retrievers – Flushing dogs – Water dogs) and 10 (Sighthounds), according to the FCI classification. Following the criteria and approach developed through our research, the Orito and Paternino breeds were included within the fifth FCI group. The animals were identified individually, in order to avoid measuring any dogs twice, and were chosen randomly, to avoid animals from the same family. The animals subject to this study came from the main location area where each population occurs. These animals were also entered in the Spanish Stud Book (LOE according to its initials in Spanish) or in the Registry of Dog Breeds (or the RRC, according to its initials in Spanish). These are the two official record systems set up in Spain by the RSCE. Only those dogs entered in the LOE or RRC were chosen to be studied, since there is a proper record available of their ancestors over various generations. By contrast, the animals belonging to Orito and Paternino populations were chosen to be studied according to the criteria of the breeders who are members of the Breeders Associations in charge of the initial development of the breed, since there is still no official studbook for these two breeds.

Morphometric variables

A total of 15 body measures were taken following the procedure previously described by González *et al.* (2011). In Figure 1, the morphometric variables and their reference points are shown. These traits were studied by measuring bony prominences which are not affected by the conformation of the animal. The measurements (Table 2) were obtained by using a measuring stick, a caliper and a tape measure.

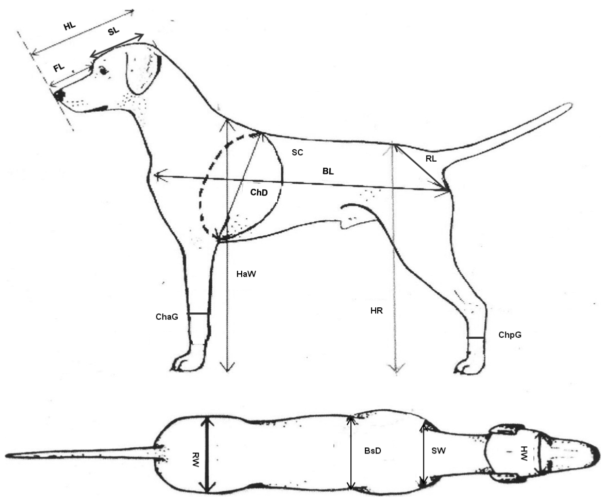


Figure 1
Body measurements used for morphologic characterization of dogs
Abbreviations of traits: see Table 1

Table 1
Classification of local Spanish dog breeds by group of FCI, number of animals sampled and information for each dog breed and sex

FCI group	Breeds	Abbreviation of breeds	Animal sampled		Number of Reference (FCI/RSCE)	Height at withers, cm[a]	
			Females	Males		Females	Males
Sheepdogs and Cattle Dogs (except Swiss Cattle Dogs) (1st)	Mallorcan Shepherd Dog or Ca de Bestiar	CAD	32	31	321 / 30. 08. 2002 / E	62-68	66-73
	Catalonian Shepherd Dog or Gos d'Atura	GOS	31	18	87 / 13. 09. 2004 / E	45-53	47-55
	Majorero	MAJ	31	33	402	≥ 54	≥ 56
Pinscher and Schnauzer – Molossoid Breeds – Swiss Mountain and Cattle Dogs (2nd)	Pyrenean Mastiff	MAP	35	37	92 / 30. 08. 2002 / E	≥ 75	≥ 81
	Spanish Mastiff	MAE	34	40	91 / 30. 08. 2002 / E	≥ 75	≥ 80
	Mallorcan Dogue or Ca de Bou	CAD	16	21	249 / 11. 12. 1996 / E	52-55	55-58
	Canary Dogue	PRC	54	36	346 / 15. 06. 2001 / E	56-62	60-66
Terriers (3rd)	Ratonero Bodeguero Andaluz	RAT	95	76	404	35-41	37-43
Spitz and Primitive types (5th)	Canarian Hound	POC	40	24	329 / 03. 11. 1999 / E	53-60	55-64
	Ibizan Hound or Ca Eivissenc	POI	36	31	89 / 04. 02. 2000 / E	60-67	66-72
Scenthounds and Related Breeds (6th)	Spanish hound	SAB	31	29	204 / 24. 07. 2000 / E	48-53	52-57
Pointing Dogs (7th)	Perdiguero of Burgos	PER	23	30	90 / 09. 11. 1998 / E	59-64	62-67
Retrievers – Flushing Dogs – Water Dogs (8th)	Spanish Water Dog	PEA	70	88	336 / 03. 09. 1999 / E	40-46	44-50
Sighthounds (10th)	Spanish Sighthound	GA	42	43	285 / 03. 06. 1998 / E	60-68	62-70
No officially recognized dog breeds	Orito Hound	PO	75	46			
	Paternino Hound	PAT	74	72			

[a]Range of height at withers of breed standard

Table 2
Body measurements

Trait		Description
Distance, cm		
Head lenght	HL	distance from the nape to the alveolar edge of the incisors I of the upper jaw bone
Height at withers	HaW	distance from the highest point of the processus spinalis of the vertebra thoracica to the floor
Body length	BL	distance from the most cranial point of the sternum to the most caudal point of the pin bone
Rump length	RL	distance from hips (*Tuber coxae*) to pins (*Tuber ischii*),
Height at rump	HR	distance from the rump (*ilium*) to the floor
Skull length	SL	distance from the nape to the occipital crest
Face length	FL	distance from the occipital crest to the lower lip
Width measurements, cm		
Head width	HW	distance between two zygomatic arches
Rump width	RW	distance from the left to the right point of hip
Shoulder width	SW	distance from left to right upper arm (*pars cranialis* of the *tuberculum majus humeri*)
Perimeters, cm		
Chest depth	ChD	distance from the left to the right point of the back
Back-sternal diameter	BsD	distance from dorsum to sternum
Shin circumference	SC	measured in place of the saddle girth
Chest anterior girth	ChaG	smallest circumference of cannon bone of the forelimb
Chest posterior girth	ChpG	smallest circumference of can bone of the hindlimb

Using these body measurements, a total of 10 body indices were estimated (Table 3).

Table 3
Estimated body indices

Index		
Body index	BI	BL×100/SC
Proportionality index	PrI	HaW×100/BL
Thoracic index	TI	ChD×100/BsD
Dactyl-thoracic index	DTI	ChaG×100/SC
Dactyl-costal index	DCI	ChaG×100/RW
Relative thickness of the cane bone index	RTCI	ChaG×100/HaW
Pelvic index	PI	RW×100/RL
Longitudinal pelvic index	LPI	RL×100/HaW
Transversal pelvic index	TPI	RW×100/HaW
Relative proportionality of the thorax index	RPTI	BsD×100/HaW

Statistical analysis

Following the main goal of this study, the first step was to describe each breed morphometrically from the resulting information from the main descriptive statistics (mean and corresponding standard error) of those fifteen morphometric variables and ten indices. An ANOVA and Tukey's test were carried out to analyse the effect of breed and sex.

Through the discriminant analysis, we obtained percentages of the correct attachment of animals to each breed, to which they had previously been assigned by classification matrices. We also obtained the Mahalanobis distances among the different breeds, which were represented using a cluster tree.

The second step was to group all the animals belonging to the same breed according to the classification established by the FCI in order to obtain the correlations between the shape and functional activities of these animals. As we had done in the case of breed, the descriptive statistic of each FCI group by sex and the effect of this factor by an ANOVA and Tukey's test were obtained. The percentages of correct assignment of individuals to each FCI groups were estimated too. Canonical procedures clarified the classifying breeds into groups and their results were expressed through the graphical representation of canonical coefficients. Statistical analysis was carried out using the software Statistica for Windows 8.0 (Statsoft, Inc., Tulsa, OK, USA).

Results

Morphometric characterization and differentiation of breeds

Table S1 shows the mean values of biometric measurements. The lowest mean values of height at withers were obtained by Ratonero Bodeguero Andaluz and the highest by both Mastiffs. Regarding length measures, the dog breed which showed the smallest format, both in head and body, was again the Ratonero Bodeguero Andaluz, and the Spanish Mastiff was also the dog breed which showed the largest format. Both Mastiff breeds also showed the most extreme results in relation to width, and the Ratonero Bodeguero Andaluz showed the lowest average for Shin circumference, with the Spanish Mastiff showing the highest average value. In contrast, two breeds which showed very different average HaW values (Catalonian Shepherd and Canary Dogue dog breeds), also showed a similar value for the relationship between the HaW and the HL. The general conformation is shown by different indices. Spanish dog breeds also showed a clear differentiation in body indices (Table S2). Through the body index, our results showed that the Ibizan Hound was the breed with the greatest body size and the Canary Dogue the smallest, with a difference among HaW and SC of 4 and 13 cm, respectively. The PrI index shows the difference between HaW and BL, and those animals with a similar value of both measures had a square format, as occurred in those breeds that showed a value in this index closer to 100. In contrast, breeds with rectangular format are obtained for those animals with a BL higher than HaW. This fact was more marked in the Spanish Sighthound and Spanish Mastiff than in the other breeds, where the difference between both measurements was over 10 cm. Both indices are related because those breeds with high values in BI had also high value in PrI, as occurred in the Ibizan Hound. Bone development is shown by the dactyl-thoracic, dactyl-costal and relative thickness of the cannon bone indices. The values obtained showed that the Paternino Hound and Spanish Sighthound breeds had lower bone development – the former breed had with lowest value in DCI and the latter in DTI and RTCI. In contrast, the breeds with the greatest bone development were the Spanish Water Dog for DTI, Spanish Hound for DCI and Canary Dogue for RTCI. In the same way, rump conformation is shown by both the longitudinal pelvic and transversal pelvic indices, and the Spanish Hound was the breed with the highest value in LPI, and Spanish Water Dog and Paternino Hound the breed with the highest values in TPI. Thus, there is a great development of the posterior third in those animals. In contrast, the Spanish Sighthound and the Ibizan and Canarian Hound were those with the smallest values in both pelvic indices. The thorax depth relative to the height at withers was evidenced by the relative proportionality of the thorax index (the higher values are linked to greater depth), where the highest value was obtained in the Spanish Sighthound and the lowest in the Ibizan Hound.

The ANOVA test showed a great differentiation between breeds in both sexes for biometric traits and body indices (Tables S1 and S2). However, the effect of sex showed the highest differences for biometric traits in the Spanish Sighthound, Spanish Water Dog, Canary Dogue and Pyrenean Mastiff breeds, with a difference in the mean value of each measure of at least of 1 cm, which in some cases reached 4 cm. In contrast, the smallest differences were shown in the Orito Hound, where the differences in biometric measures were below 1 cm in most of them. In the case of body indices, the differences between sexes were only statistically significant ($P<0.05$) for PrI and DTI in Ca de Bestiar, for DTI in the Pyrenean Mastiff and Orito Hound, and for BI in the Spanish Water Dog.

Morphometric characterization and differentiation relative to FCI groups

In each FCI group breeds can be found with different body conformation, although they have similar aptitude. For example, in the first group, which includes Ca de Bestiar, Gos d'Atura and Majorero, the highest mean values of all biometric traits in both sexes were found in Ca de Bestiar and the lowest in Gos d'Atura, with Ca de Bestiar also having the biggest head in relation to height (HL/HaW). In the case of the second group, which includes both Mastiffs, Ca de Bou and Canary Dogue, in females and males the largest format and the biggest head were found in the Spanish Mastiff, and the smallest in Ca de Bou. The last group which includes different breeds is the fifth, covering the Hounds, in which the Ibizan Hound showed the highest values in all biometric traits and in its relationship among HaW and HL; the Orito Hound was the lowest in these measurements and the Paternino in the case of the head size in its relationship with HaW.

Average values with standard errors of all animals classified according to the same function are shown by sex in Table 4.

As expected, the smallest mean values of biometric traits were found in the third group of FCI and the highest in the second group, with the exception of the FL measurement, which was bigger in the tenth group than second one. However, the head was found to be the smallest in relation to HaW in the sixth FCI group and bigger in the tenth.

Table 5 shows the mean values and effect of sex in body indices of FCI groups.

Table 4
Descriptive statistics (mean and standard error), analysis of variance and differentiation through Tukey's test for females for 709 females and 656 males of 8 FCI groups by 15 morphometric variables

FCI group		HaW, cm	HR, cm	BL, cm	BsD, cm	ChD, cm	HL, cm	SL, cm
1st	Females	57.14 ± 0.61^{d}	56.80 ± 0.62^{d}	57.91 ± 0.62^{d}	22.44 ± 0.31^{c}	15.07 ± 0.24^{cd}	21.43 ± 0.19^{c}	12.87 ± 0.13^{c}
	Males	61.45 ± 0.73^{a}	60.88 ± 0.72^{d}	61.11 ± 0.72^{d}	24.66 ± 0.37^{c}	15.89 ± 0.25^{d}	22.60 ± 0.24^{c}	14.09 ± 0.15^{c}
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	0.02	< 0.001	< 0.001
2nd	Females	65.71 ± 0.70^{f}	66.36 ± 0.68^{f}	70.62 ± 0.81^{f}	28.52 ± 0.36^{e}	19.55 ± 0.25^{c}	24.44 ± 0.24^{e}	15.13 ± 0.12^{d}
	Males	71.22 ± 0.82^{c}	71.55 ± 0.84^{e}	75.62 ± 0.94^{f}	30.58 ± 0.38^{e}	21.55 ± 0.61^{f}	26.15 ± 0.28^{e}	16.36 ± 0.15^{d}
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001
3rd	Females	38.11 ± 0.20^{a}	37.31 ± 0.23^{a}	38.71 ± 0.34^{a}	15.00 ± 0.18^{a}	10.51 ± 0.18^{a}	15.21 ± 0.09^{a}	9.22 ± 0.09^{a}
	Males	40.65 ± 0.27^{c}	39.53 ± 0.31^{a}	39.93 ± 0.40^{a}	15.46 ± 0.26^{a}	10.96 ± 0.21^{a}	15.78 ± 0.19^{a}	9.64 ± 0.09^{a}
	P-value[1]	< 0.001	< 0.001	0.02	0.13	0.11	< 0.01	< 0.01
5th	Females	52.94 ± 0.63^{c}	52.47 ± 0.61^{c}	53.15 ± 0.57^{c}	19.72 ± 0.21^{b}	12.62 ± 0.14^{b}	19.31 ± 0.18^{b}	10.24 ± 0.13^{b}
	Males	55.89 ± 0.74^{d}	55.10 ± 0.72^{c}	56.17 ± 0.70^{c}	20.98 ± 0.26^{b}	13.20 ± 0.15^{b}	20.69 ± 0.24^{b}	11.01 ± 0.15^{b}
	P-value[1]	< 0.01	< 0.01	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001
6th	Females	48.94 ± 0.48^{bc}	49.23 ± 0.56^{c}	60.43 ± 0.57^{de}	22.90 ± 0.41^{c}	15.24 ± 0.28^{cd}	21.83 ± 0.37^{cd}	12.61 ± 0.25^{c}
	Males	52.24 ± 0.49^{de}	52.57 ± 0.54^{c}	63.40 ± 0.76^{de}	24.22 ± 0.38^{c}	16.35 ± 0.30^{d}	23.86 ± 0.20^{cd}	13.94 ± 0.23^{c}
	P-value[1]	< 0.001	< 0.001	< 0.01	0.02	< 0.01	< 0.001	< 0.001
7th	Females	60.61 ± 0.61^{de}	58.79 ± 0.78^{de}	60.43 ± 0.64^{de}	25.63 ± 0.75^{d}	17.26 ± 0.45^{d}	23.28 ± 0.25^{de}	13.13 ± 0.19^{c}
	Males	64.82 ± 0.36^{ef}	62.49 ± 0.46^{d}	64.59 ± 0.58^{de}	27.08 ± 0.41^{d}	17.27 ± 0.33^{e}	24.93 ± 0.20^{de}	14.58 ± 0.20^{c}
	P-value[1]	< 0.001	< 0.001	< 0.001	0.08	0.99	< 0.001	< 0.001
8th	Females	44.23 ± 0.29^{b}	43.76 ± 0.3^{b}	46.90 ± 0.55^{b}	19.45 ± 0.24^{b}	14.31 ± 0.21^{cd}	18.84 ± 0.20^{b}	10.31 ± 0.12^{b}
	Males	47.64 ± 0.22^{f}	46.89 ± 0.26^{b}	50.59 ± 0.42^{b}	20.94 ± 0.16^{b}	15.30 ± 0.16^{cd}	19.96 ± 0.16^{b}	11.18 ± 0.10^{b}
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
10th	Females	64.98 ± 0.33^{ef}	64.19 ± 0.34^{e}	65.02 ± 0.55^{e}	23.71 ± 0.24^{cd}	13.24 ± 0.26^{bc}	22.31 ± 0.16^{cd}	12.81 ± 0.14^{c}
	Males	68.40 ± 0.34^{b}	66.57 ± 0.39^{e}	67.83 ± 0.53^{e}	25.53 ± 0.23^{cd}	14.09 ± 0.25^{bc}	23.58 ± 0.15^{cd}	13.59 ± 0.15^{c}
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	0.02	< 0.001	< 0.001
P-value	Females[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Males[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Abbreviation of traits: see Table 2, [a, b, c, d, e, f] Means having different superscript letters within columns differ ($P \leq 0.001$), [1]ANOVA test between females and males, [2]ANOVA test between breeds for females and males

Table 4
Descriptive statistics (mean and standard error), analysis of variance and differentiation through Tukey's test for females for 709 females and 656 males of 8 FCI groups by 15 morphometric variables – continuation

FCI group		FL, cm	HW, cm	SW, cm	RW, cm	RL, cm	SC, cm	ChaG, cm	ChpG, cm
1st	Females	8.55 ± 0.14^{bc}	11.21 ± 0.11^{d}	12.54 ± 0.20^{c}	9.35 ± 0.16^{b}	15.73 ± 0.22^{d}	70.03 ± 0.92^{d}	11.05 ± 0.14^{d}	10.43 ± 0.10^{d}
	Males	9.08 ± 0.10^{bc}	12.29 ± 0.14^{e}	13.40 ± 0.26^{cde}	9.52 ± 0.18^{c}	16.73 ± 0.26^{d}	75.41 ± 0.95^{de}	12.18 ± 0.14^{d}	11.52 ± 0.15^{de}
	P-value[1]	< 0.01	< 0.001	< 0.01	0.46	< 0.01	< 0.001	< 0.001	< 0.001
2nd	Females	9.19 ± 0.16^{d}	13.58 ± 0.09^{e}	16.76 ± 0.22^{e}	11.67 ± 0.22^{c}	18.64 ± 0.23^{e}	86.78 ± 0.85^{e}	14.26 ± 0.12^{f}	13.38 ± 0.14^{e}
	Males	9.72 ± 0.17^{d}	14.60 ± 0.11^{f}	18.21 ± 0.25^{f}	12.57 ± 0.23^{d}	20.15 ± 0.29^{e}	93.24 ± 1.05^{f}	15.62 ± 0.16^{f}	14.70 ± 0.18^{f}
	P-value[1]	0.02	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001	< 0.001	< 0.001
3rd	Females	5.78 ± 0.07^{a}	8.50 ± 0.08^{a}	8.29 ± 0.13^{a}	6.35 ± 0.13^{a}	10.61 ± 0.15^{a}	47.22 ± 0.45^{a}	7.33 ± 0.06^{a}	6.77 ± 0.06^{a}
	Males	6.10 ± 0.08^{a}	9.18 ± 0.07^{a}	8.71 ± 0.14^{a}	6.51 ± 0.14^{a}	11.34 ± 0.18^{a}	49.13 ± 0.53^{a}	7.89 ± 0.08^{a}	7.11 ± 0.07^{a}
	P-value[1]	< 0.01	< 0.001	0.03	0.40	< 0.01	< 0.01	< 0.001	< 0.001
5th	Females	9.35 ± 0.07^{d}	9.43 ± 0.06^{b}	11.28 ± 0.15^{b}	9.06 ± 0.13^{b}	13.92 ± 0.16^{c}	58.48 ± 0.47^{b}	9.36 ± 0.07^{b}	8.71 ± 0.07^{bc}
	Males	9.82 ± 0.09^{de}	10.18 ± 0.09^{b}	12.36 ± 0.20^{b}	10.07 ± 0.67^{bc}	15.02 ± 0.19^{c}	61.71 ± 0.56^{b}	10.10 ± 0.08^{b}	9.94 ± 0.50^{b}
	P-value[1]	< 0.001	< 0.001	< 0.001	0.09	< 0.001	< 0.001	< 0.001	< 0.01
6th	Females	9.19 ± 0.15^{cd}	10.41 ± 0.1^{c}	12.97 ± 0.38^{cd}	7.94 ± 0.38^{ab}	14.52 ± 0.25^{cd}	64.90 ± 0.83^{c}	11.18 ± 0.26^{cd}	9.77 ± 0.14^{bcd}
	Males	9.59 ± 0.14^{cde}	11.39 ± 0.16^{cd}	14.01 ± 0.32^{de}	7.89 ± 0.32^{b}	15.88 ± 0.26^{cd}	69.62 ± 0.95^{c}	11.46 ± 0.1^{de}	10.58 ± 0.11^{cd}
	P-value[1]	< 0.001	< 0.001	0.04	0.92	< 0.001	< 0.001	0.38	< 0.001
7th	Females	10.07 ± 0.19^{e}	10.82 ± 0.12^{cd}	13.97 ± 0.55^{b}	8.84 ± 0.38^{ab}	15.35 ± 0.28^{d}	74.42 ± 1.03^{d}	11.93 ± 0.12e	10.95 ± 0.14^{cd}
	Males	10.80 ± 0.40^{de}	12.09 ± 0.17^{de}	15.61 ± 0.30^{e}	9.18 ± 0.32^{bc}	16.78 ± 0.24^{d}	79.54 ± 0.81^{e}	13.14 ± 0.15^{e}	11.81 ± 0.15^{e}
	P-value[1]	0.13	< 0.001	< 0.01	0.50	< 0.001	< 0.001	< 0.001	< 0.001
8th	Females	8.16 ± 0.15^{b}	8.83 ± 0.12^{a}	12.34 ± 0.27^{bc}	9.53 ± 0.45^{b}	12.88 ± 0.19^{b}	58.96 ± 0.55^{b}	10.23 ± 0.13^{c}	9.56 ± 0.13^{bcd}
	Males	8.57 ± 0.12^{b}	9.49 ± 0.11^{a}	13.24 ± 0.28^{cd}	9.61 ± 0.37^{c}	13.82 ± 0.20^{b}	61.61 ± 0.51^{b}	10.93 ± 0.10^{c}	10.10 ± 0.10^{c}
	P-value[1]	0.03	< 0.001	0.02	0.89	< 0.01	< 0.001	< 0.001	< 0.001
10th	Females	9.89 ± 0.14^{e}	10.00 ± 0.09^{b}	11.38 ± 0.16^{b}	8.46 ± 0.22^{ab}	15.23 ± 0.17^{d}	66.93 ± 0.45^{c}	9.19 ± 0.14^{b}	8.69 ± 0.13^{ab}
	Males	10.57 ± 0.14^{e}	10.55 ± 0.11^{c}	11.97 ± 0.13^{bc}	9.16 ± 0.22^{bc}	16.59 ± 0.21^{d}	70.21 ± 0.57^{cd}	9.75 ± 0.11^{b}	9.17 ± 0.09^{b}
	P-value[1]	< 0.001	< 0.001	< 0.01	0.03	< 0.001	< 0.001	< 0.01	< 0.01
P-value	Females[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Males[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	P-value[1]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Abbreviation of traits: see Table 2, $^{a, b, c, d, e, f}$ Means having different superscript letters within columns differ ($P \leq 0.001$), [1]ANOVA test between females and males, [2]ANOVA test between breeds for females and males

Table 5
Descriptive statistics (mean and standard error), analysis of variance and differentiation through Tukey's test for females for 709 females and 656 males of 8 FCI groups by 10 functional indices

FCI group		BI	PrI	TI	DTI	DCI	RTCI	PI	LPI	TPI	RPTI
1st	Females	83.26 ± 0.84^{a}	98.85 ± 0.79^{a}	67.47 ± 1.06^{ab}	15.86 ± 0.17^{a}	120.62 ± 2.7^{ab}	19.37 ± 0.22^{a}	59.81 ± 1.59^{a}	27.56 ± 0.35^{bc}	16.41 ± 0.46^{ab}	39.32 ± 0.41^{c}
	Males	81.45 ± 0.86^{a}	100.80 ± 0.83^{a}	65.14 ± 1.41^{a}	16.21 ± 0.19^{a}	130.71 ± 2.80^{a}	19.88 ± 0.24^{a}	57.33 ± 3.59^{a}	27.24 ± 0.37^{ab}	15.56 ± 0.94^{ab}	40.24 ± 0.42^{c}
	P-value	0.11	0.05	0.10	0.08	< 0.01	0.04	0.07	0.42	0.03	0.15
2nd	Females	81.56 ± 0.69^{a}	93.39 ± 0.65^{b}	69.13 ± 0.87^{a}	16.52 ± 0.14^{bc}	126.62 ± 2.27^{bc}	21.85 ± 0.18^{b}	63.36 ± 1.31^{ab}	28.43 ± 0.29^{a}	17.83 ± 0.38^{b}	43.34 ± 0.34^{a}
	Males	81.21 ± 0.68^{a}	94.44 ± 0.65^{b}	70.65 ± 1.1^{bc}	16.83 ± 0.15^{a}	128.01 ± 2.22^{a}	22.07 ± 0.19^{b}	63.56 ± 2.84^{b}	28.44 ± 0.29^{bcd}	17.72 ± 0.74^{abc}	43.03 ± 0.34^{b}
	P-value	0.69	0.12	0.37	0.05	0.61	0.32	0.92	0.98	0.78	0.33
3rd	Females	82.43 ± 0.83^{a}	98.98 ± 0.79^{b}	70.42 ± 1.05^{a}	15.61 ± 0.17^{a}	119.44 ± 2.73^{ab}	19.26 ± 0.22^{a}	60.12 ± 1.58^{a}	27.85 ± 0.35^{ac}	16.68 ± 0.46^{ab}	39.35 ± 0.40^{c}
	Males	81.66 ± 0.89^{a}	102.31 ± 0.86^{b}	72.06 ± 1.46^{bc}	16.12 ± 0.19^{a}	124.62 ± 2.91^{a}	19.44 ± 0.25^{a}	57.77 ± 3.73^{a}	27.86 ± 0.39^{abc}	16.04 ± 0.97^{ab}	37.99 ± 0.44^{a}
	P-value	0.53	0.01	0.43	0.02	0.13	0.46	0.14	0.97	0.20	0.05
5th	Females	90.86 ± 0.54^{b}	99.85 ± 0.51^{a}	65.07 ± 0.68^{b}	16.12 ± 0.11^{ab}	108.17 ± 1.78^{d}	18.01 ± 0.14e	66.53 ± 1.02^{b}	26.53 ± 0.23^{b}	17.56 ± 0.30^{ab}	37.55 ± 0.26^{b}
	Males	90.85 ± 0.59^{b}	99.81 ± 0.57^{a}	64.02 ± 0.97^{a}	16.37 ± 0.13^{a}	109.66 ± 1.93^{b}	18.31 ± 0.17e	68.36 ± 2.47^{c}	27.09 ± 0.26^{a}	18.40 ± 0.65^{bc}	37.82 ± 0.2^{a}
	P-value	0.99	0.96	0.41	0.21	0.59	0.28	0.66	0.14	0.43	0.53
6th	Females	93.41 ± 1.46^{bc}	81.13 ± 1.38^{d}	67.05 ± 1.84^{ab}	17.25 ± 0.29^{cd}	148.53 ± 4.79e	22.91 ± 0.39^{bc}	55.22 ± 2.76^{a}	29.75 ± 0.61^{a}	16.26 ± 0.80^{abc}	46.89 ± 0.71^{d}
	Males	91.37 ± 1.44^{bc}	82.66 ± 1.39^{c}	67.85 ± 2.37^{abc}	16.50 ± 0.31^{a}	150.83 ± 4.71^{c}	22.02 ± 0.41^{bc}	49.87 ± 6.04^{d}	30.46 ± 0.63^{d}	15.16 ± 1.58^{abc}	46.46 ± 0.71^{d}
	P-value	0.23	0.28	0.70	0.11	0.80	0.25	0.13	0.40	0.28	0.72
7th	Females	81.48 ± 1.70^{a}	100.48 ± 1.60^{ac}	67.81 ± 2.14^{abc}	16.08 ± 0.34^{abc}	139.76 ± 5.56^{c}e	19.72 ± 0.45^{a}	58.60 ± 3.21^{ab}	25.35 ± 0.71^{bd}	14.60 ± 0.93^{ac}	42.28 ± 0.82^{a}
	Males	81.43 ± 1.42^{a}	100.52 ± 1.36^{a}	64.10 ± 2.33^{abd}	16.56 ± 0.31^{a}	147.62 ± 4.63^{c}	20.29 ± 0.40^{ac}	54.74 ± 5.94^{a}	25.90 ± 0.61^{a}e	14.16 ± 1.55^{ab}	41.78 ± 0.70^{bc}
	P-value	0.97	0.98	0.09	0.16	0.28	0.13	0.32	0.34	0.58	0.68
8th	Females	79.70 ± 0.97^{a}	95.00 ± 0.92^{cd}	73.84 ± 1.22^{c}	17.42 ± 0.19^{d}	121.12 ± 3.19^{abc}	23.17 ± 0.26^{c}	73.24 ± 1.84^{c}	29.22 ± 0.41^{a}	21.67 ± 0.54^{d}	44.00 ± 0.47^{a}
	Males	82.63 ± 0.83^{a}	94.72 ± 0.80^{b}	73.20 ± 1.36^{c}	17.84 ± 0.18^{c}	124.47 ± 2.71^{a}	22.98 ± 0.24^{b}	68.69 ± 3.47^{c}	29.06 ± 0.36^{cd}	20.18 ± 0.91^{c}	44.01 ± 0.41^{bd}
	P-value	0.04	0.84	0.59	0.20	0.55	0.61	0.21	0.80	0.25	0.99
10th	Females	97.31 ± 1.26^{c}	100.17 ± 1.18^{a}	56.00 ± 1.58^{d}	13.73 ± 0.25e	111.19 ± 4.11^{ad}	14.17 ± 0.33^{d}	55.70 ± 2.37^{a}	23.47 ± 0.53^{d}	13.06 ± 0.69^{c}	36.51 ± 0.61^{b}
	Males	96.76 ± 1.18^{c}	101.00 ± 1.14^{a}	55.34 ± 1.94^{d}	13.89 ± 0.26^{b}	109.02 ± 3.87^{b}	14.25 ± 0.34^{d}	55.28 ± 4.96^{a}	24.27 ± 0.51e	13.41 ± 1.30^{a}	37.34 ± 0.59^{a}
	P-value[1]	0.67	0.45	0.67	0.45	0.61	0.75	0.83	0.05	0.47	0.10
P-value	Females[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Males[2]	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	P-value[1]	0.30	0.14	0.90	< 0.001	< 0.01	0.02	0.48	0.20	0.73	0.25

Abbreviation of indices: see Table 3, [a,b,c,d]Means having different superscript letters within columns differ ($p \leq 0.001$). [1]ANOVA test between females and males, [2]ANOVA test between breeds for females and males

The tenth group was that with the highest body size and the group with the smallest body size was the eighth in the case of females and the second in males. The difference between the HaW and SC is only 2 cm in the tenth FCI group but in the other two FCI groups, it was 14 and 22 cm, respectively. The proportional index (PrI) indicates the existence of a difference between HaW and BL, and both measurements were similar in the first, third, fifth, seventh and tenth FCI groups, corresponding with a square format (HaW = BL). Meanwhile, in the case of the other FCI groups, the length was greater than the height of the animals, with a rectangular format. Relative to bone development, the eighth and sixth groups were those with the largest bone development for DTI and RTCI, and DCI, respectively. In the case of both pelvic indices, LPI and TPI, the highest values were found in the sixth and eighth groups, respectively. The last index, relative proportionality of the thorax, was higher in the sixth group in both sexes than the other groups.

As we expected, significant differences ($P<0.001$) for morphometric traits and body indices were found by analysis of variance among the eight groups of dogs studied in both sexes. The effect of sex in FCI groups was statistically significant ($P<0.05$) in the majority of measurements. However, in the case of indices, it was only different in the first FCI group for DCI, RTCI and TPI, in the second FCI group for PrI and DTI, and in the eighth FCI group for PrI. As occurs in the case of breeds, the males had bigger mean values of biometric traits than females, which was even more marked in distance measurements (over 4 cm in some cases) and in the second FCI group.

Application of discriminant analysis for breeds and FCI groups

Table S3 shows the assignment percentages, higher in females than in males (90 % vs. 86 %). Correct assignment ranged from 65.22 to 98.95 % in females and 50.00 to 98.98 % in males. When each breed was analysed separately, percentages of assignment over 95 % were found in four breeds in the case of females (Spanish Sighthound, Spanish Water Dog, Canary Dogue and Ratonero Bodeguero Andaluz) and in three breeds in the case of males (Spanish Water Dog, Spanish Hound and Ratonero Bodeguero Andaluz). In contrast, we found some breeds which showed a greater number of errors in the assignment of individuals to their population: Perdiguero of Burgos (65.22 % in females), and Gos d'Atura (50 % in males).

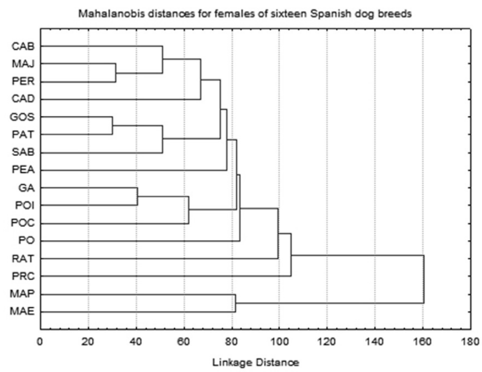
When the animals are grouped according to their functional groups, the percentage of correct assignment of individuals to their functional group was 87.62 % for females and 84.71 % in males (Table 6).

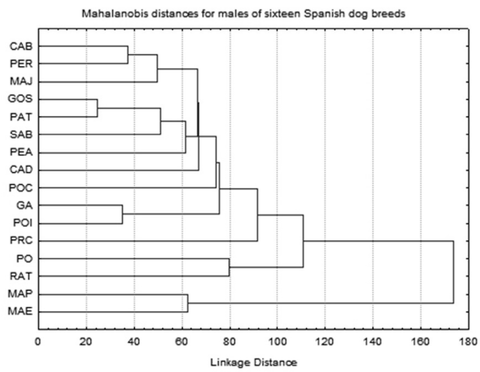
The highest number of correct assignments was found in the Terrier Group (third FCI group) (> 98 %) in both sexes, followed closely by the Molossian (second FCI group) in the case of females (94.96 %) and Hounds (tenth FCI group) in males (97.67 %).

The second step in the application of discriminant analysis was to obtain the Mahalanobis distances among the breeds and FCI groups (Figures 2 and 3). As regards breeds, the biggest distances were found between the Pyrenean Mastiff and Spanish Mastiff in comparison with the Ratonero Bodeguero Andaluz. On the other hand, the closest breeds according to the values obtained through the morphometric study were the Ibizan Hound and Spanish Sighthound. In addition, the Mahalanobis distances between groups highlighted a larger morpho-structural difference between the animals of the second (Molossoids) and third

Table 6
Classification (percentage of accuracy ratio) for 709 females and 656 males of 8 FCI groups by 15 morphometric variables

FCI Groups	Sex	Percentage	1st	2nd	3rd	5th	6th	7th	8th	10th
1st	Females	77.66	73	7	2	9	0	1	2	0
	Males	74.39	61	5	3	6	3	2	2	0
2nd	Females	94.96	6	132	0	0	0	1	0	0
	Males	91.04	9	122	0	0	0	2	1	0
3rd	Females	98.95	0	0	94	1	0	0	0	0
	Males	98.68	0	0	75	1	0	0	0	0
5th	Females	85.78	0	0	2	193	5	1	3	21
	Males	77.91	0	0	4	134	2	1	10	21
6th	Females	87.10	1	0	0	2	27	0	1	0
	Males	93.10	0	0	0	1	27	1	0	0
7th	Females	56.52	9	0	0	1	0	13	0	0
	Males	50.00	13	1	0	0	0	15	1	0
8th	Females	90.00	1	0	1	4	0	1	63	0
	Males	88.64	1	0	1	7	1	0	78	0
10th	Females	83.33	4	0	0	3	0	0	0	35
	Males	97.67	0	0	0	1	0	0	0	42
Total	Females	87.62	94	139	99	213	32	17	69	56
	Males	84.71	84	128	83	150	33	21	92	63

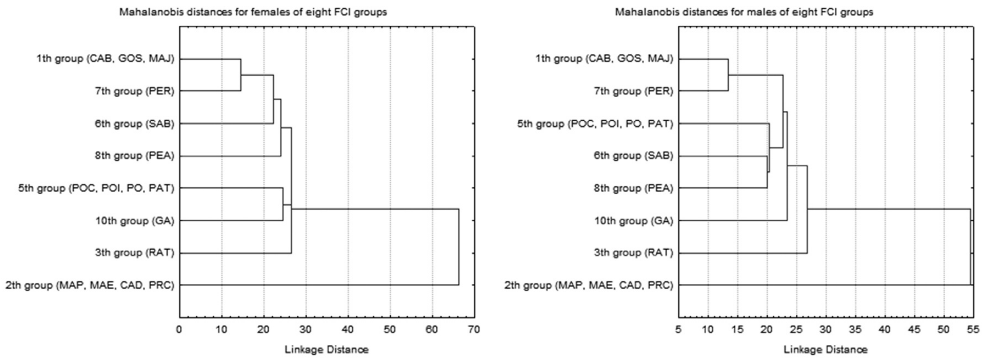




Abbreviation of breeds: see Table 1

Figure 2
Mahalanobis distances for 709 females and 656 males of sixteen Spanish dog breeds

(Terriers) FCI groups. However, the animals belonging to the first (Sheepdogs) and seventh (Pointing dogs) FCI groups were the closest. Both Mahalanobis distances were significant ($P\leq0.001$) (data no presented).

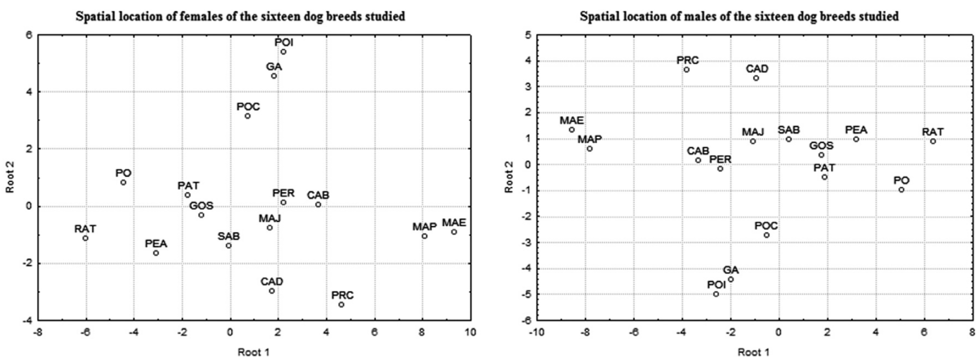


Abbreviation of breeds: see Table 1

Figure 3
Mahalanobis distances for 709 females and 656 males of eight FCI groups

The spatial location of the sixteen breeds according to the values obtained in the canonical analysis can be seen in Figure 4.

As for the two populations or breeds not officially recognized, the Orito and the Paternino Hound, only the former was located in the same spatial area of the dogs belonging to group 5, in which this breed would be integrated according to their function. However, the spatial localization of the Partenino was among other Hound breeds and the Gos d'Atura.



Abbreviation of breeds: see Table 1, Each of the axes refers to means of canonical values in the discriminant analyses.

Figure 4
Canonical representation of 709 females and 656 males in the sixteen Spanish dog breeds

Discussion

We evaluated the morphological characteristic of Spanish dog breeds and FCI groups in which they are included. The differentiation of canine breeds has been determined by natural selection and selection by human. Our results have shown that the chosen set of morphometric traits is suitable for characterizing individual dogs and for differentiating between breeds. Similar morphometric values can be found in those animals which belong to the same breed population, according their quantitative differences. Therefore, this implies the existence of a possible specific morphologic pattern for each population. The existence of this pattern is determined by quantitative information of each of the variables and indices, and by the relationships between them. Height at withers values found for the Orito Hound and Spanish Water Dog can be taken as an example (Table S1). These values were very similar; nevertheless, the values related to the length of the head were different in these two breeds. Thus, in this case is easy to check that the Orito Hound has a smaller head than the Spanish Water Dog, both quantitatively and proportionally.

The similar or different mean values in biometric traits could be due to the origin and function of the breeds. According with Morera *et al.* (1999) among the Spanish dog breeds, the degree of genetic differentiation was low, although only two breeds were coincident with our study (Spanish Sighthound and Water Dog). In other research by Jordana *et al.* (1991) a marked relationship, both morphological and biochemical, between Gos d'Atura and Ibizan Hound was found. In accordance with Jordana *et al.* (1992b) who found high genetic differences between some Spanish breeds (Pyrenean Mastiff, Spanish Hound and Ibizan Hound, Gos d'Atura and Ca de Bestiar), the high correct assignment percentage recorded in our study could be due to the great differentiation of breeds and could confirm the high discriminatory power of morphological measurements (Dossa *et al.* 2007). This differentiation between breeds is marked in a cluster tree, where formation of groups could correspond to the relationship between the different morphological characteristics and the function. The distribution of the breeds in the cluster shows the influence of two possible factors, function and breed origins. By the distribution in cluster trees and plotting through canonical variables, the Orito Hound shows a body conformation similar to other hound breeds, while Paternino is closer to Gos D'atura than other hounds. This fact could be due to the different uses, primarily for rabbit hunting in the case of Canarian, Ibizan and Orito Hounds, whilst Paternino was used to help deer and boar hunters.

The Spanish Greyhound is the only breed that appears with a slight uncertainty in its classification, since it is very close in shape and structure to the Canarian Hound, due to their common origin. This result agrees with those obtained by Jordana *et al.* (1992c) in nine Spanish dog breeds.

The relationship between morphology and function is commonly used and fixed in the standards of the dog breeds. The classification of the animals in each of the breeds studied was performed based on the data expressed in the Studbook of each one, and according to information revealed by their pedigrees. In the case of the Orito and Paternino Hounds, the animals were classified according to the criteria of their respective Breeders' Organizations.

Thanks to the information provided by morphometric variables, the quantified breed factor allows us to ascribe all the animals within the different groups of breeds, according to the morphologic differences shown by these animals. Therefore, each breed is a morphologically differentiated element, but they are grouped according to the FCI classification where each group contains dogs that were bred for a specific purpose.

In order to gather further knowledge about this approach, all the animals raised to carry out the same function need to be included in the same group, which are already classified by the FCI into ten different groups.

These new groups of animals classified according to their function show high levels of correct assignment to the groups established by FCI. If the existence of a morphologic pattern for each breed is accepted, then the existence of a common pattern related to the function (guard, shepherd, hunting, etc.) is also accepted, constituting a supra-breed pattern.

The fifth FCI group, the only group that included no recognized breeds, was the only one that showed a different distribution by cluster tree in both sexes. In males, this group is linked with the sixth and eighth FCI groups, and is close to the first and seventh FCI groups, while in females this group in linked with the tenth FCI group. This fact could be due to the similarity in the format of the Paternino Hound with Gos d'Atura in both sexes, and the Ibizan Hound and Spanish Sighthound in the case of females. This similarity between a hound and a sheepdog could relate to the Paternino's speciality of helping humans in deer and boar hunting, while the similarity between two other breeds, the Ibizan Hound and Spanish Sighthound, lies in the use of both breeds for rabbit hunting. Despite these errors in distribution of FCI groups in the cluster tree, this did not lead to any confusion in the assignment of individuals of the fifth FCI group with that group that included the Gos d'Atura, in both sexes. However, we tried repeating the cluster tree for the FCI group including the Paternino Hound in the FCI first group, due to its similarity with Gos d'Atura; however, due to the extension of this work, the data were not presented. The results of this new analysis showed that the fifth FCI group is linked to the tenth in both sexes and the first is linked to the seventh, which is exactly what occurs in the case of including the Paternino in the group of hounds. The differences between different groups of animals according to their function, with the exception of fifth FCI group, confirm the correct classification set up by the FCI to take into account quantitative and qualitative differences in the morphostructure of dogs belonging to different groups.

In conclusion, according to the information obtained from morphometric traits and functional indices, the sixteen Spanish dog breeds studied and eight functional groups are different but these differences are more marked between all groups than within groups. Thus, the morphological characteristics are similar, according to the function for which the breeds were bred. Therefore, the existence of a morphologic pattern is accepted for both breeds and functional groups.

Both breeds which have not yet been officially recognized, the Orito and Paternino Hound, must be included in the fifth and first FCI groups, respectively, because through morphometric traits, the similarity was greater with some breeds of each group than with breeds of the remaining groups. This fact will have its application when the Orito Hound is included in the fifth FCI group, when it is recognized and the word »hound« is eliminated from the name of the Paternino breed.

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