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Harmonic analysis of equine hoof form and its matched symmetry

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Abstract

This study uses elliptic Fourier analysis (EFA), an outline method of shape analysis, for describing hoof contours symmetries in the Catalan Pyrenean Horse ("Cavall Pirinenc Català", CPC), a breed from the Spanish Pyrenees. Hoof outlines of 54 limbs (26 forelimbs and 28 hindlimbs, including the same number of left and right limbs) obtained from 15 CPC horses were compared using EFA. Symmetry was assessed in right-to-left harmonic differences. There appeared no contour differences between right and left hooves. So it can be concluded that CPC presents homogenous hoof shapes and a high level of symmetry in hoof sole outline. This study is the first to describe hoof sole outline and symmetry in unshod, young CPC horses, reared under semi-extensive conditions.

Introduction

Appropriate hoof preparation and shoe fit are integral to soundness and performance (Stashak et al. 2002), and their negative conformational traits, such as asymmetrical or 'uneven' forefeet, would possibly diminish performance (Ducro et al. 2009). It has been well documented (Ross 2003; Mansmann and vom Orde 2007) that some traditional equine husbandry practices, such as incorrect feeding, lack of, or excessive exercise, and poor and infrequent podiatric care, can have deleterious consequences on horse foot health. A horse can develop hoof asymmetry as a result of uneven weight bearing caused by a variety of issues, including asymmetrical movement, stance, and tendon tension, along with pain, even in foals (Van Heel et al. 2003) and although it is not always associated with lameness, asymmetry of the equine hoof should not be overlooked as a possible indication of previous, impending, or chronic lameness. The dominant front hoof is usually flatter and wider -with a tendency to run forward- because it tends to take more load, while the hoof on the non-dominant leg tends to grow more upright (Miethe 2008). However, the cause and effect relationship between hoof conformation and limb loading remains to be elucidated (Wilson et al. 2009). Often, the feral or wild horse foot model has been proposed as the ideal equine foot (Ovnicek et al. 1995; Jackson 1997) despite lack of detailed empirical investigation (Hampson et al. 2010). But contrary to popular belief, the feral horse foot type should not be used as an ideal model for the domestic horse foot (Hampson et al. 2010).

The Catalan Pyrenean horse ("Cavall Pirinenc Català", CPC) is a compact, broad-built, predominantly chestnut horse with rather short limbs (Jordana et al. 1995) with an small population (<4,600) (Infante 2008) located in the NE part of the Pyrenees, along the Catalan-French border (Fernández et al. 2009). It stands 145 to 160 cm (Jordana et al. 1995). Genetic analysis suggests that it is closely related to the Breton and Comtois breeds (Infante et al. 2010). Mainly bred today for meat production in Spain, it is reared outdoors throughout the year, normally not receiving additional food beside some low-quality straw in winter (Infante et al. 2010). When young horses are selected for slaughter, they are gathered in large paddocks and receive additional feeding with hay and concentrates during the last months before slaughter, at about 10-12 months of age ("poltres", admitted body mass about 350 kg). Animals of this breed do not receive any hoof care, trimming, or shoeing; therefore, their hooves must be considered naturally shaped. The assumption is that the free roaming lifestyle of this breed promotes ideal foot health due to long distances travelled, a varied natural diet, and an absence of some harmful impacts of domestication. Effectively, hoof wall problems are rather rarely encountered (Parés 2011), being the "splay foot" -the hoof wall flaring outwards- the most frequently found abnormality (pers. obs.).

Symmetry is a fundamental concept in the study of horse foot fitness as a hoof actually forms a mirrored pair with their opposing hoof (Weller et al. 2006). An evaluation by eye can only give an appearance of paired symmetry, so detailed analysis could reveal evidence of morphological asymmetries.

The use of image analysis has greatly increased in the last decades. The advantages of using image analysis are numerous: (i) visual hence inherently subjective evaluation can be overcome; (ii) measurements are totally independent of the expert and time; (iii) less straightforward parameters can be measured such as area, which is not possible manually; (iv) all data are available on a continuous scale, which simplifies statistical processing; and (v) many samples can be analysed by a fast and 'objective' (non-dependent of 'expert') method. When the morphology of objects is studied, two approaches can be followed: classical parameters and shape-describing methods such as elliptic Fourier (EF) descriptors (Rohlf and Archie 1984; White et al. 1988; Furuta et al. 1995). The former is easier to interpret whereas the latter incorporates all available variation. The landmark method (another shape-describing method) cannot be considered since hooves, in general, have no homologous type I (with homology provided by biologically unique patterns on the form) and type II (with homology provided only by geometric, not biological or

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histological, criteria) landmarks. EF analysis (EFA) is a powerful, though under-utilised, biometric tool that is particularly suited to the description of objects lacking homologous landmarks. The method is conceptually more parsimonious than more traditional biometric methods based on discrete linear and angular measurements and, most importantly, it captures a much higher proportion of the morphological information in object than analyses based on discrete measurements.

The objective of this study was to test the hoof sole shape symmetry in the CPC breed by means of an EFA, in order to do a functional contribution to the knowledge of this breed. It must be said that to author's knowledge, no research of the morphology of equine hooves based on EF descriptors report has been previously published.

Material and methods

At a commercial abattoir, 54 distal limbs (26 forelimbs and 28 hindlimbs, including the same number of left and right limbs) were obtained from 15 CPC horses immediately after normal slaughter between October 2009 and June 2010. The healthy and sound sampled horses were all approximately 1 year old and all were unshod; no hooves had received trimming or other podal interventions and hooves with gross lesions like hoof wall avulsions were not excluded from the study. At the abattoir, the limbs were disarticulated at the level of the carpus/tarsus and they were rinsed with water before measurements were performed.

Extraction of the hoof outline

The outline of each separate hoofprint was obtained by outlining the perimeter of the external hoof wall with a pen on paper. Subsequently, these drawings were photocopied, including a calibration square, and scanned as BMP files (Figure 1). Left images were rotated in order to obtain the mirrored image of the right one. Images were not magnified for analysis.

[enlarge]

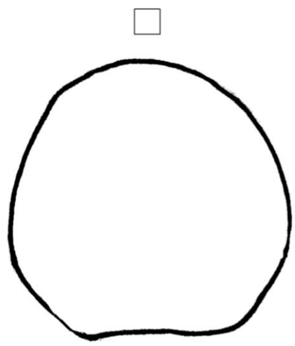

Figure 1. Example of a prepared image of a hoof to be studied. The white square is 1 cm x 1 cm.

EF descriptors

Image capture was carried out using the SHAPE software package developed by Iwata and Ukai (2002). Pictures were binarised (i.e., transformed into white for the contact outline and black for the background, in pixels) and the outlines of each continuous hoofprint (interface between the black and the white pixels) were automatically obtained and the area enclosed automatically calculated. On average, 2,137 points were obtained for each hoof. The coefficients of the EF descriptors were calculated based on the perimeter of the hooves, as described by Kuhl and Giardina (1982) and Iwata et al. (1998). Twenty harmonics were calculated in order to describe the contour. Each harmonic included x and y coordinates consisting of coefficients (ai, bi) and (ci, di), respectively (ith harmonic), where the coefficients ai and ci were the cosine coefficients, bi and di were the sine ones. The first harmonic was deleted for subsequent statistical analysis as they were used to normalize samples for position, size, and rotation.

Shape analysis

A non-parametric two-way NPMANOVA test (Non-Parametric Multivariate ANOVA, also known as PERMANOVA) (Anderson 2001) was used to detect significant difference between groups, based on any Euclidean distance measure. The significance was computed by permutation of group membership, with 9,999 replicates. The non-parametric Wilcoxon signed rank test was also used to test for median differences between right and left pairs. All statistics were done with the package PAST (Hammer et al. 2001).

	Sum of squares	d.f.	Mean square	F	p
Fore/hind	0.03449	1	0.03449	6.0094	0.0002
Right/left	0.00487	1	0.00487	0.84839	0.5016
Interaction	-0.00654	1	-0.00654	-1.1388	0.5766
Residual	0.28704	50	0.00574		
Total	0.31987	53			

Table 1. Results of two-way NPMANOVA (Non-Parametric Multivariate ANOVA) test. Permutation n=9,999.

Results

Table 1 reports the results of the comparisons between fore and hindlimbs, and right and left limbs. There appeared only differences between fore and hindlimbs shapes. The Wilcoxon test revealed no differences between right and left median pairs (W<<<0.0001, p=0.655).

[enlarge]

In figure 2, a step by step reconstruction of the hoof outline for the first three PC, for fore and himblimbs appears. This picture indicates that the contour variation is mostly

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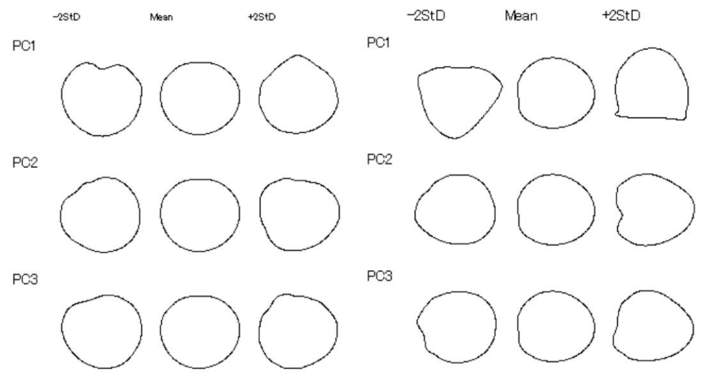

Figure 2. Step by step reconstruction of the hoof outline for the first three PC, for fore and hindlimbs (top and bottom, respectively). Mean contour appears in the middle column. This picture indicates that the contour variation is mostly explained by the first principal component. PC1 (28.92% of the total observed variance) was a good measure of the general appearance of the hoof. Differences between fore- and hindlimbs were related to the heel bulbs and toe.

explained by the first principal component. PC1 (28.9% of the total observed variance) was a good measure of the general appearance of the hoof. Differences between fore and hindlimbs were related to the heel bulbs and toe.

Discussion

In the present investigation, the quantitative analysis of hoofprints (outline) was devised. This study is the first to describe symmetry of fore- and hindhooves of CPC horses based on EFA. Overall, the method appears to be easy to perform and inexpensive (it requires neither special hardware nor specialised personnel). The quantitative evaluation, performed with a well-known and verified mathematical method (the EF series), allows the assessment of the intrasubject asymmetry in hoofprint outline in a normal sample of young horses. The fact that post-mortem samples were studied allowed the avoidance of any possible movement of the hoofprint, so the outline was recorded when a stable posture acquired.

No significant degree of left-right asymmetry was seen in CPC horses' hooves. Our results indicate that, despite the absence of regular hoof care, the horses had enough left-right hoof symmetry to not impede a normal biomechanical action. We can suppose that the high level of symmetry may at least partially be attributed to the continuous, free movement on a variety of substrates, a varied diet, and natural selection in a harsh environment where asymmetric conformation and lameness are associated with less chance of survival. Thus, the CPC breed is considered a well-balanced horse. The obtained results agree with those of Parés and Oosterlinck (2012) in the same breed; they identified no relevant laterality.

Now it will be interesting to evaluate the degree of asymmetry in other hoof conformational traits such as toe and heel angle in this breed, which were not analysed in this research.

Conclusion

In conclusion, this study is the first to describe hoof sole outline and symmetry in unshod, young CPC horses, reared under semi-extensive conditions. This breed presents homogenous hoof outlines and a high level of symmetry in hoof sole outline. A limitation of this study is that only young horses aged approximately 1 year were included. Hoof morphology may change with increasing age, and no conclusions can be obtained from our data for the early or very late stages of horse development. However, it has been shown that asymmetry in hoof conformation can already be detected in foals (Van Heel et al. 2003). Evidently, objective of this research could have very much power if analysis were done in limbs submitted to charge. Horses naturally load their limbs, specially if the animal is moving. This can be taken as suggestion for the future, because to compare the form of the hooves before and after load should be extremely interesting.

Given the homogeneous results in the sample, we believe that the reported results have adequate power. Although extrapolation of these results to older horses should be performed judiciously, our results open the way to perform further research on horses over a wide range of breeds and ages.

Declarations

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