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Original Article

Relation between Hoof Area and Body Mass in Ungulates Reared under Semi-Extensive Conditions in the Spanish Pyrenees

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Abstract

The aim of this study was to compare hoof area and its relation to body mass in some domestic ungulates. Data from 58 horses, 9 cows and 14 goats demonstrated significant differences in hoof area. The ratio of body mass per limb to hoof area was significantly lower in goats than in horses and in cows. There was a high correlation between hoof pressure and body mass in all species, whereas the correlation between hoof area and body mass was high in goats but low in horses and cows.

Key words: Grazing, grassland, pressure, trampling

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Introduction

Livestock affect a pasture and its productivity not only by grazing, but also by accelerating soil erosion. The trampling effect of livestock causes soil compaction and decreases water infiltration in the soil, and trampling damage is most pronounced during wet conditions (Taddese *et al*., 2002; Chaichi *et al*., 2005).

The impact of trampling, which is dependent on soil and vegetation characteristics, but also on the species of animals grazing the pasture and the degree of overgrazing, has received considerable attention with regards to sustainable land management in specific ecosystems like the African savannas (Cumming and Cumming, 2003), Queensland National Park in Australia (Bennett, 1999) and New Zealand (Duncan and Holdaway, 1989).

Comparative studies have revealed significant differences in pressure underneath the foot between ungulates and other animals (Bennett, 1999; Duncan and Holdaway, 1989). Notwithstanding the fact that Ssemakula (1983) has reported lower pressure in sheep and goat than in oryx, eland and cattle, other researchers have demonstrated that in ungulates, hoof pressure is relatively constant over a wide range of body sizes (Cumming and Cumming, 2003).

The aim of this study was to compare the hoof area and its relation to body mass (BM) between horses, cows and goats reared semi-extensively in the Spanish Pyrenees. The hypothesis was tested that these ungulates present a similar ratio of body mass to hoof area, i.e. hoof pressure.

Materials and Methods

Measurements were performed on 58 horses of the *Cavall Pirinenc Català* breed (29 male, 29 female), 9 cows of the *Bruna dels Pirineus* breed (7 male, 2 female) and 14 male *Cabra de Rasquera* goats. All animals were reared outdoors throughout the year, ranging over rocky mountain pastures, not receiving any hoof care, trimming or shoeing. Therefore, their hooves must be considered *naturally* shaped.

Solar measurements were performed by outlining the perimeter of the distal hoof wall with a pen on paper and subsequently photocopying and scanning these images into dedicated image analysis software, as described by Parés and Oosterlinck (2011). The mean hoof area (cm^2) of the left fore and left hind hoof was considered as being representative for that animal. Subsequently, hoof pressure (kg/cm^2) was calculated as the ratio of the body mass per limb (total body mass divided by 4) to the previously obtained hoof area.

Ethical approval was not required as all horses and cows were measured post-mortem at a commercial abattoir, and live goats were measured without any invasive or painful procedure after informed consent of the voluntarily participating owner.

Statistical Analysis

Data were collated and prepared for statistical analysis using spreadsheet software (Microsoft Office Excel 2007) and statistical analysis was performed using IBM SPSS Statistics 19.0 with statistical significance set at $P < 0.05$. Shapiro-Wilk test, Q-Q plots and Kolmogorov-Smirnov test did not reveal significant deviations from normal distribution. Data are presented as means ± SD. To assess inter-individual variability, coefficients of variation (CV) were calculated as SD/mean x 100% for all variables. Given the unequal variance in the 3 samples, a non-parametric Kruskal-Wallis test with pair-wise comparisons using Dunn's test was performed to evaluate differences in body mass, area and pressure between the 3 species. Correlation between body mass and hoof area and between body mass per limb and pressure was assessed using Pearson's correlation coefficient.

Results and Discussion

Mean ± SD (range) body mass, hoof area and pressure per limb are presented in Table 1. All data were significantly different between the 3 species ($P < 0.001$). Coefficients of variation of body mass, hoof area and pressure are presented in Table 2.

Hoof area (cm^2) as a function of total body mass (kg) is presented in Figure 1. Body mass and hoof area were highly correlated for goats ($r = 0.868$; $P < 0.001$) while a lower correlation was

observed in horses (r = 0.391; P = 0.002). In contrast, there was no significant correlation between both variables in cows (r = 0.198; P = 0.610). Hoof pressure (kg/cm^2) as a function of body mass per limb (total body mass divided by 4) is presented in Figure 2. Hoof pressure and body mass per limb were highly correlated for cows and goats (r = 0.865 with P = 0.003 and r = 0.704 with P = 0.005, respectively), while the correlation in horses was slightly lower (r = 0.459; P < 0.001).

This study presents hoof area measurements of 3 ungulate species reared under semi-extensive conditions in the Spanish Pyrenees. In the present study, the variability and range in body mass was similar for the 3 species, with a CV between 13 and 19%, in agreement with the results reported by Ssemakula (1983). The animals in the present study had a ratio of maximum to minimum body mass of 1.82 (horses), 1.61 (cows) and 2.05 in goats. The smaller range of body mass in horses and cows may at least partially explain the lower correlation between body mass and hoof area in these species, as restricting a data range artificially lowers correlation.

Our results on hoof area in horses are similar as those reported previously (Parés and Oosterlinck, 2011). The variability in hoof area was lower in cows (CV 8%) than in horses and goats (CV approximately 15%) and the range in hoof area was smaller in cows (ratio of maximum to minimum hoof area 1.28) than in horses (ratio of 1.81) and goats (ratio of 1.74). Thus, the cows in the present study presented a relatively homogeneous hoof area compared to the horses and goats. This is in contrast with the results of Ssemakula (1983), who reported a higher variability in sheep, oryx and eland than in goat and cattle.

The variability in hoof pressure was lower in goats (CV 10%) versus horses and cows (CV 15-16%), together with a smaller range in goats (ratio of 1.31) than in horses (ratio of 2.04) and cows (ratio of 1.58). Hence, the ratio of body mass to hoof area, i.e. hoof pressure is relatively constant in goats. The latter finding is in contrast with the study of Ssemakula (1983) stating higher variability of hoof pressure in goats compared to cattle. It is difficult to compare our data with studies using other measuring equipment and/or animals of other breeds or different body sizes, as methodology is a major confounding factor. However, hoof pressure in our sample of goats (body mass 56 kg; pressure 0.59 kg/cm²) is close to the pressure of approximately 0.43 kg/cm² (Duncan and Holdaway, 1989) and 0.72 kg/cm² (Ssemakula, 1983) reported in smaller goats of 34 kg and 40 kg, respectively.

Besides the obvious differences in body mass and hoof area between the 3 species, the present study demonstrated significant differences in hoof pressure between horses, cows and goats, with goats the lowest pressure and cows having the highest pressure. The latter finding is in agreement with Ssemakula (1983). However, it has been stated that hoof area is proportionally greater in larger animals than in smaller animals, implying that pressure would be reasonably constant for ungulates over a wide range of body size (Cumming and Cumming, 2003).

In the authors' opinion, this discrepancy might be at least partially related to methodology. In this and the previous study (Parés and Oosterlinck, 2011), solar measurements were performed by outlining the perimeter of the distal hoof wall. It cannot be excluded that the more complex hoof area in even-toed ungulates (Perissodactyla) may be prone to overestimation compared to the relatively straightforward measurement in odd-toed ungulates (Artiodactyla). This measuring error in the interdigital area and associated overestimation of the hoof area would lead to a lower ratio of body mass to hoof area, i.e. pressure. Therefore, it would be interesting to directly compare hoof area measurements performed with our methodology (Parés and Oosterlinck, 2011) and with more sophisticated techniques like three-dimensional computer modelling.

Moreover, other variables such as food intake may be equally important as trampling for the total impact on the environment (Cumming and Cumming, 2003). Furthermore, our analysis did not allow measuring the exact interface between hoof and soil, but merely the perimeter of the weight-bearing surface.

Table 1: Mean ± SD (range) body mass, hoof area and hoof pressure

Variable	Horses (n = 58)	Cows (n = 9)	Goats (n = 14)
Body mass (kg)	364.6 ± 46.7 (260-476.1)[a]	442.3 ± 72.1 (355.3-572.3)[b]	56.6 ± 10.8 (37.0-76.0)[c]
Hoof area (cm^2)	128.6 ± 19.4 (94.4-171.0)[a]	69.0 ± 5.7 (60.1-76.9)[b]	23.9 ± 3.5 (16.6-28.9)[c]
Pressure (kg/cm^2)	0.72 ± 0.11 (0.50-1.02)[a]	1.61 ± 0.27 (1.27-2.01)[b]	0.59 ± 0.06 (0.52-0.68)[c]

[a, b, c] within the same row, values with different superscript letters differ significantly ($P < 0.001$)

Depending on hoof and soil characteristics, the hoof wall, the sole and/or other anatomical regions may contribute to the weight-bearing function. Finally, contact area may change during locomotion and more sophisticated techniques like pressure plate analysis can be used to perform dynamic evaluation of hoof contact area (Oosterlinck *et al*., 2011).

Table 2: Coefficient of variation (CV; %) of body mass, hoof area and hoof pressure of the 58 horses, 9 cow and 14 goats

CV (%)	Horses	Cows	Goats
Body mass	12.8	16.3	19.0
Hoof area	15.1	8.2	14.5
Pressure	15.4	16.5	9.6

Based on our results of the lower hoof pressure in goats and similar findings of Ssemakula (1983), it is speculated in areas susceptible to trampling damage, a grazing population with goats may have a lower ecological impact than with cows. However, stock density and the total number of animals, together with their daily distance travelled should be considered as well (Ssemakula, 1983; Cumming and Cumming, 2003). Moreover, the preferable species may also be dependent on other factors like the economical context and climatologic aspects. The study of livestock communities affecting protected environmental areas deserves further investigation, as sustainability is becoming a key-concept (Cumming and Cumming, 2003).

Conclusion

In conclusion, this study demonstrated that goats have a lower ratio of body mass to hoof area (i.e. hoof pressure) compared to horses and cows. As such the former species may be more suitable as grazing animals in areas prone to trampling damage. Further research is needed to combine these morphological data with other factors that may affect the environmental impact of livestock communities.

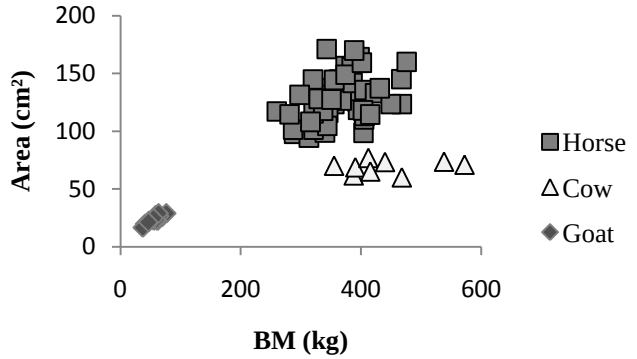

Fig. 1: Hoof area (cm^2) as a function of total body mass (BM; kg) of 58 horses, 9 cows and 14 goats.

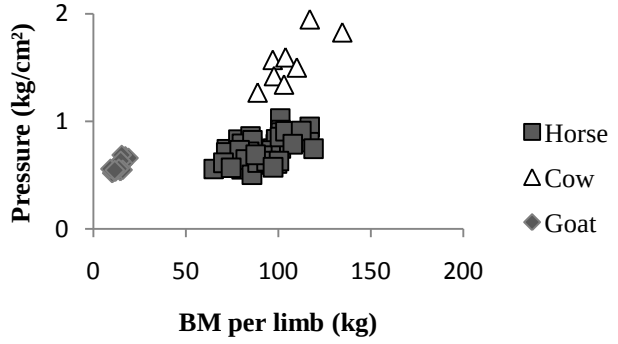

Fig. 2: Hoof pressure (kg/cm^2) as a function of BM per limb (total BM divided by 4) of 58 horses, 9 cows and 14 goats.

Conflict of interest statement

None of the authors of this paper has a financial or personal relationship with other people

or organisations that could inappropriately influence or bias the content of the paper.

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