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Collar pressure mapping: an evaluation of seven collar types used on working donkeys in Europe

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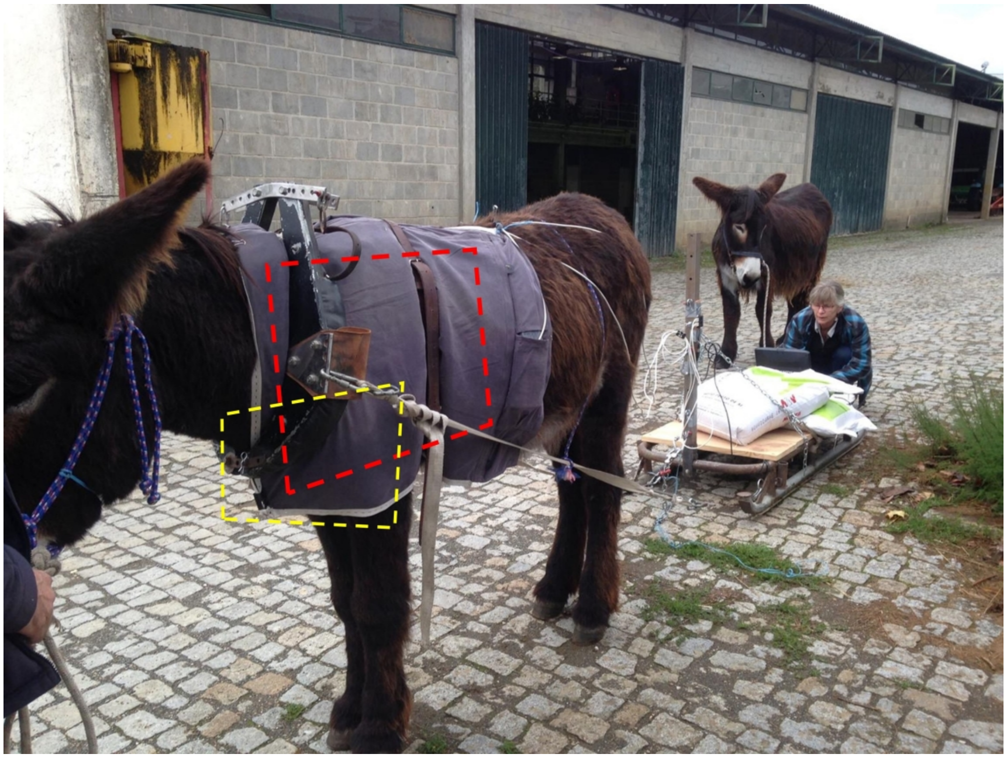
Abstract:	Background: Working donkeys represent an important source of energy worldwide. Poor working conditions and equipment affect their ability to work. Poorly designed, ill-fitted harness cause inefficient transfer of power and leads to health and welfare issues. Using technology to assess different types of collars provides a better understanding of those that are most efficient for working donkeys. Materials and Methods: Seven different collars were tested using pressure pads. Contact area, median, maximum and peak pressures were obtained for the whole collar and critical points. Eight donkeys pulled 20% and 40% of their body weight, using each collar, under controlled conditions. Results: Contact area and pressures vary between collars and effort, with design and expansion capacity of the collars playing a major role. Simple collars designed specifically for donkeys performed well, with full collars designed for horses also having good results. Due to reduced expansion capacity and contact in the critical points, the breast collars were the least effective. Conclusion: Design, appropriate padding and manufacturing materials, and adjustment capacity are key features for good collars, and such parameters are of paramount importance in terms of health and welfare for working donkeys.

Figure 1. Seven collars tested: collar 1: manufactured using canvas for external padding, wool for internal padding and fence post as hames. Collar 2: similar with collar 1 but using 50 mm black water pipe for the hames. Collar 3: manufactured externally with natural leather and internally with felt, having natural wool as padding material and metal hames. A leather bridge keeps the two parts together of the collar at the bottom. Collar 4: made of canvas and rawhide, filled with natural wool and straw, with curved metallic hames with adjustable hitching point. Collar 5: manufactured with large plywood hames, padding area of natural leather filled with natural wool. Collars 6 and 7: manufactured with beta/biothane/synthetic leather, and filled with sponge. A = front view and B = rear view.

338x131mm (300 x 300 DPI)



Donkey pulling the sled while using collar 5. Pressure pads in position, inside the protective slings (grey cover). Bags of sand of different weight were distributed on the sled and used to obtain the 20% and 40% of the BW of each of the donkeys used in this study. The red dashed line shows the position of the whole left pressure pad in position, under the collar. The second pad occupies the same region on the right side of the donkey. The yellow dashed line shows the position of the left half of the single pad used for collars 6 and 7. The remaining half is on the right side of the donkey, as a way to cover the contact area of collars 6 and 7 – shoulders and the breast region.

254x190mm (300 x 300 DPI)

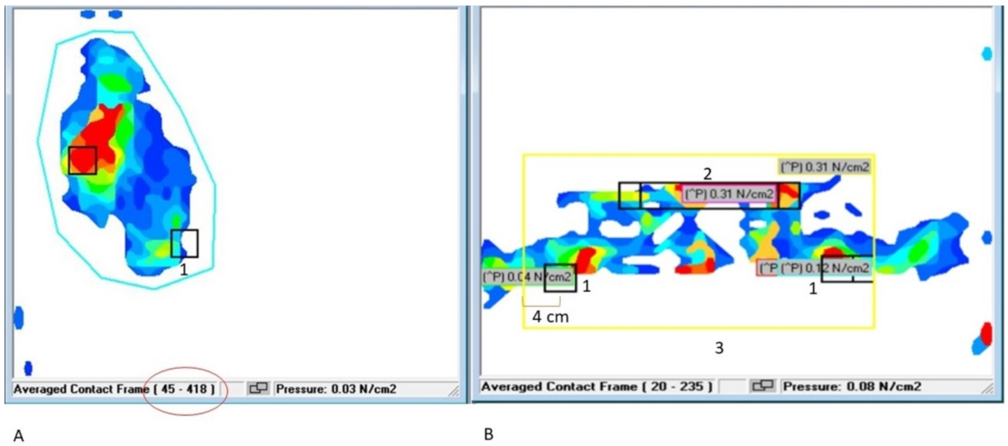


Figure 3. A: Left pressure reading of collar 1. The blue line indicates the study area, selected for each reading and marked in order to eliminate noise. The red circle indicates the frame interval, with the initial frames, corresponding to the digital landmarks, deleted. B: Pressure reading of collar 6, using a single pad. 1: 9 cm2 squares in the point of shoulders; 2: 45 cm2 rectangle in the trachea region; 3: area of study, passing 4 cm outside the midpoint of the square 1. Pressure was recorded in N/cm2.

254x114mm (300 x 300 DPI)

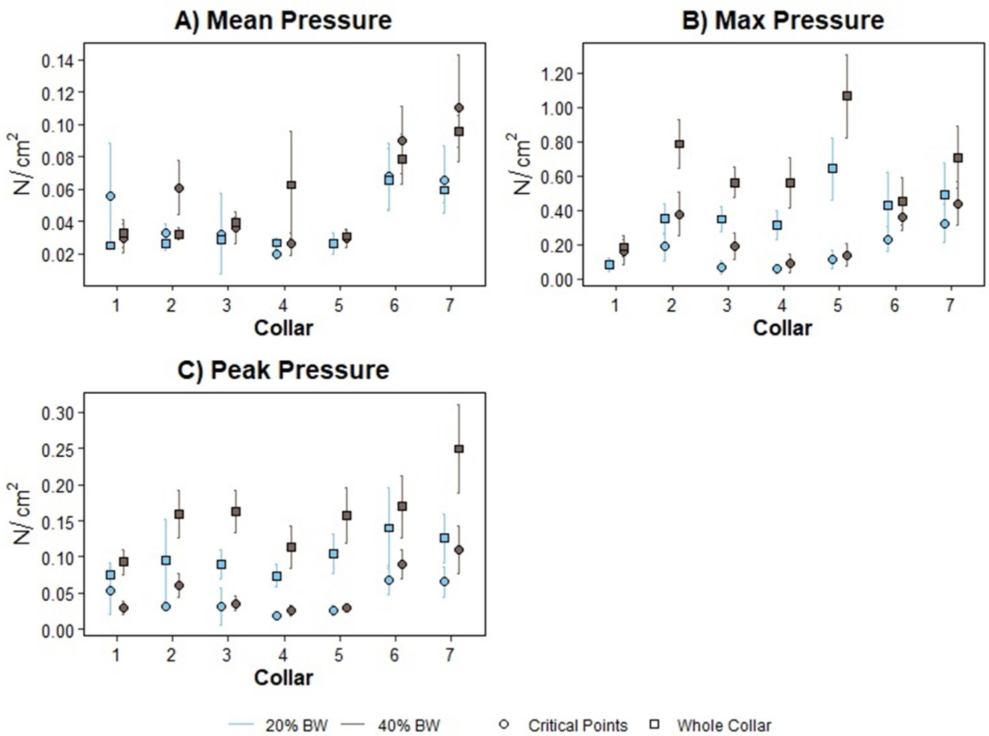


Figure 4. Comparison of pressure between collars and weights (colours) accross the whole collar and at the critical points (shapes) where the points represent the mean and the bars represent the upper and lower confidence intervals.

254x190mm (300 x 300 DPI)

Collar pressure mapping: an evaluation of seven collar types used on working donkeys in Europe

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Structured abstract

Background:

Working donkeys represent an important source of energy worldwide. Poor working conditions and equipment affect their ability to work. Poorly designed, ill-fitted harness causes inefficient transfer of power and leads to health and welfare issues. Using technology to assess different types of collars provides a better understanding of those that are most efficient for working donkeys.

Materials and Methods:

Seven different collars were tested using pressure pads. Contact area, median, maximum and peak pressures were obtained for the whole collar and critical points. Eight donkeys pulled 20% and 40% of their body weight, using each collar, under controlled conditions.

Results:

Contact area and pressures vary between collars and effort, with design and expansion capacity of the collars playing a major role. Simple collars designed specifically for donkeys performed well, with full collars designed for horses also having good results. Due to reduced expansion capacity and contact in the critical points, the breast collars were the least effective.

Conclusion:

Design, appropriate padding and manufacturing materials, and adjustment capacity are key features for good collars, and such parameters are of paramount importance in terms of health and welfare for working donkeys.

Introduction

Many of the world's most urgent social and environmental problems can, in part, be addressed by simple, cost-effective, solutions that benefit some of the people in society who are most vulnerable. An example of such a community-based approach to the amelioration of these issues is the effective utilisation of working equids (1).

Working equids are still a major source of traction worldwide (2-4). They make significant contributions to agroforestry (5) and industrial activities (6), playing a key role in countries with low and middle-incomes (7) where animal energy represents a vast and extremely important sustainable power resource (8).

The effectiveness of working equids' contributions to future sustainability is reliant on their welfare and one of the most important determinants for overall health and welfare is that of harness. The way an equid is harnessed and hitched to an implement or vehicle also affects the animal's work efficiency (9). An equid's ability to work depends on a range of parameters: the weight and nature of the cargo, the load and pressure distribution in the contact areas of the harness with the body, the quality of equipment used, general fitness and how well the animals have been trained and managed (10).

Pearson et al. (11) described a good harness as being the one that efficiently transmits the animal's energy, while being padded so that the force is spread over a large area, and that it fits well, not causing skin lesions or trauma. Collars are responsible for moving the load and are an essential part in every harness system, regardless of the task. Full and breast collars are the most common types of collars used worldwide, but independently of the model all collars should respect Pearson's general description of a good harness.

Poorly designed, ill-fitted harness causes inefficient transfer of power from the equid to the equipment, leading to discomfort, fatigue, and the induction and exacerbation of pain. This results in frequent and unnecessary cutaneous and musculoskeletal injuries that ultimately decrease working efficiency and output. Adaptation of equipment primarily designed for other species, such as cattle yokes or horse collars being used with donkeys, may also be an issue if specific anatomical species differences are not taken into account (7, 9, 12-15).

For decades, there has been a lack of interest in animal traction, resulting in a general lack of research and accompanying advances in appropriate technologies (16). There is very little scientific research on pressure effects experienced by draft animals during load-bearing, and even less specifically focused on donkeys.

Therefore, this paper represents a research contribution to this field by attempting to utilise biomedical technology, in this case, pressure mapping. This technology is widely used in the field of human medical rehabilitation (17-19) and is used for saddle design for sports horses in response to the demands of the equine industry (20-22). However, the research presented here arose due to the recognition of the importance of applying such technology to the welfare of working donkeys, contributing to the development of better harness systems, by assessing the area and pressure distribution beneath differently designed collars.

For the present study, it was hypothesised that collars with a design that adapts to the anatomical characteristics of donkeys, combined with appropriate padding, manufacturing materials, and adjustability would result in a greater contact area and lower pressure being exerted on the critical points and across the whole collar area.

Materials and Methods

Location of the study

This study was performed in the campus of the Polytechnic Institute of Bragança (IPB), in the Northeast of Portugal. It was carried out under the Memorandum of Understanding between The Donkey Sanctuary and the IPB, focused on scientific projects to improve the health and welfare of working donkeys.

Donkeys

Eight healthy Zamorano-Leonês donkeys of similar size and phenotype were used in this study. The median age of the donkeys was 10 years, with a range of 7 to 13 years old.

At the commencement of the study individual body weights were accurately obtained and a mean weight of 330.5kg±7.75kg S.D. was established. . The body condition score chart developed by The Donkey Sanctuary was used in this study (23). All donkeys presented an ideal body condition (BCS =3).

A careful selection of animals with very similar phenotype (including ideal body condition) was essential as a way to minimise the bias in results due to individual differences between donkeys.

An experienced equid vet (JBR, first author) monitored donkeys' health and welfare throughout the study. A complete veterinary examination was performed before the transects, and basal hearth and respiratory rates were confirmed, ensuring fitness.

Donkeys were led during the transects and care was taken that the handler did not interfere with normal movement.

Collars

Seven different collars were tested (Figure 1):

Three prototypes, developed by the harness makers' team involved in the project:

- Two variants of the same full collar, designed for donkeys to be adjustable, cheap and easy to manufacture, using local materials (collars 1 and 2);
- One hybrid (neck-breast type) collar specifically designed for donkeys (collar 3).

Two commercial full collars designed for horses:

- Non-adjustable collar (collar 4).
- Adjustable collar (collar 5).

Two commercial breast collars designed for horses:

- Straight breast collar (collar 6)
- "V" shape breast collar (collar 7).

Full and breast collars are most commonly used by working equids globally. The commercial full collars used in this study were purchased from the manufacturer *Abel Ibáñez Marti, Artesanía en cuero y herraje* (Xativa, Spain). The commercial breast collars used in this study were purchased from Hispano Hípica (Salamanca, Spain). All collars were checked and adjusted at the beginning of each transect by the harness makers' team.

Figure 1.

Experimental design

Transects

Donkeys were hitched to a sled and led along 2x75 meters straight horizontal transects on a smooth cobbled yard (transect 1 and transect 2). These two transects were repeated while pulling 20% and 40% of their body weight, using each collar. Collars were trialled in the same sequence for each animal.

The sled was designed to allow variations in the anchor point, ensuring a correct angle of draft to each collar: those that contact with the rostral aspect of the scapula (collars 1 to 5) were used with a 90-degrees angle between the horizontal axis of the collar (corresponding to the hames) and the traces. For breast collars (collars 6 and 7), an angle of 180 degrees between the breast band and the traces was used.

A pair of traces, a swingle tree and a light trace carrier completed the harness system used in this study (Figure 2).

Each donkey had a minimum resting period of 60 minutes between each set of transects, ensuring full recovery from previous physical effort.

Figure 2.

Area and pressure data

The pressure and area of contact were assessed through the use of Pressure Mapping Sensors (Tekscan® 1533), connected to a Durabook® laptop embedded in the sled. Each electronic mat is thin and flexible with an 876.3 x 666.8 mm surface area (589.3 x 707.1 mm for the matrix), with 1920 individual pressure-sensing elements and a sensor spatial resolution of 0.5 cm^2. The mats were calibrated and then zeroed at the beginning of each transect. Mats were placed inside protective slings, and adjusted individually beneath each collar, ensuring full contact between the collar and the sensel matrix. Two pads were used to measure collars 1 to 5, one at each side on the donkey's scapula region. Collars 6 and 7 needed one mat to cover shoulders and the breast region (figure 2).

Critical points

The harness and vet teams defined the critical points considered for each one of the collars: shoulder (scapulohumeral) joints for all seven collars, and the trachea region for collars 6 and 7. Critical points were selected based on the most common locations for skin system alterations and airflow blockage.

Digital pressure was applied on the pressure pads at the critical points before each transect, as a way to identify these regions later in the pressure maps. The trachea region was covered with the breast collar and was not possible to reach, so digital pressure was exerted in the manubrium of the sternum. Both anatomical structures are in the sagittal plane of the donkey, allowing indirect identification of the position of the trachea. The corresponding frames of the digital pressures were used only for anatomical landmark purposes and were not included in the data. These landmarks allow the creation of predefined areas of study for the critical points mentioned above and were defined by the authors as the minimum area that guarantees the inclusion of such points: a box area of 3x3 = 9 cm^2 for each shoulder (Figure 3); and a box area of 3x15 = 45cm^2 for the trachea region (Figure 3B).

For collars 6 and 7, the contact area lateral to the shoulders slightly varied from donkey to donkey, due to small variations in the position of the edge of the single pad used. To correct for this and to ensure consistency in the readings, a rectangular area of study was established. Vertical lines running 4 cm beyond the midpoint of the square, thereby marking the critical point of the shoulders, delineated this area. It was from this area that the readings for these two were registered, (Figure 3B). The selected area represents the effective pulling area for breast collars.

Figure 3.

Definitions of the parameters recorded

- Contact area (Area): total area of the loaded sensels inside the matrix, including left and right side for collars 1 to 5 (cm^2);
- Mean pressure (Pmean): calculated dividing the mean force (recorded by the sensels) by the contact area (Newton/cm^2) (24);
- Peak pressure (Ppeak): calculated dividing the highest forces (recorded by the sensels) by the contact area (Newton/cm^2). Peak pressure represents the highest pressure value recorded by each sensor over the entire transect (24);
- Maximum pressure (Pmax): Greatest pressure on the "Peak Contact Pressure" chart (Newton/cm^2) (24).

Pmean, Ppeak and Pmax were obtained for whole collars and critical points. As Ppeak is measured across all sensels and Pmax is the maximum pressure measured by a single sensel in the peak contact pressure area both Pmean and Pmax can exceed Ppeak.

Statistical Analysis

All statistical analyses were performed using R v3.6 (25) and RStudio v1.2 (26). Data transformation, summary statistics, and graphs were prepared using the R package tidyverse (27). Measurements of Pmean, Pmax and Ppeak for the whole collar included the sum of the pressure exerted on the left and the right side of the collar. Measurements of Pmean, Pmax and Ppeak at the critical points were calculated as the mean of the pressure exerted on the left and right shoulders and the trachea (collar 6 and 7 only) by the collar. Once the whole collar and critical points pressure were known, further analysis to test differences between collars, loads and critical points was carried out whilst using transect as a fixed effects blocking factor. As some of the pads failed to provide measurements during the experiment, the two-way type III ANOVA was chosen to account for the unbalanced design and understand interaction differences between the types of collars, the loads pulled and the critical points for each of the pressure response variables. The type III ANOVA was also the most appropriate test in these circumstances as it avoided the use of multiple tests and therefore maintained probability of type-1 errors at 5%. Before the analysis took place, data were tested for normality assumptions and Box-Cox transformed where necessary to conform to assumptions (28). Further post-hoc Tukey-HSD tests were performed on mean, maximum, and peak pressures for collars and loads and the interaction between collars and loads where significance had been established (29) with Tukey-HSD unbalanced model parameters were set to account for unbalance in experimental design to ensure probabilities were consistent. The Tukey-HSD test provided letter groups between interaction factors of collar, load and critical points, where letters are different between the individual factor levels there are significant difference at the P-value of 0.05. For example a factor group that has been assigned group 'a' would be significantly different to all other factor groups that do not contain an 'a'.

Ethical approval

This study adheres to UK animal welfare legislation and Regulations including the Animal Welfare Act 2006 and was reviewed and approved by The Donkey Sanctuary, Sidmouth, Devon, UK. The Donkey Sanctuary follows a rigorous research review process and does not permit invasive research of any kind, or any study that compromises animal welfare. The protocol was approved by the Ethics Committee of The Donkey Sanctuary under project code 2018-AIM2-PRT.

All donkeys in this project regularly work in agroforestry activities, so the effort required for this study was within their normal tolerance.

Results

Transects

In total, two hundred and twenty-four transects were carried out, with 112 at 20% and 112 at 40% of the donkeys' body weight. The pressure pad used to assess collars 6 and 7 was damaged when donkey 8 (the last one in the trials) was pulling, resulting in missing data from eight of the 224 transects. Overall, there were no significant differences between the two 75 meter transects across the whole collar or at critical points for each collar and bodyweight combination ($P>0.3$).

Area of contact

Collar 1 had the greatest contact area when pulling both 20% and 40% of body weight. Collars 6 and 7 had the least contact areas for loads pulled. Collars 1 to 5 significantly increased the contact area when pulling 40% of their body weight compared to pulling 20% (P-value <0.05), however collars 6 and 7 showed no significant increase in contact area in the same comparison (*P*-value >0.05, Table 1).

Table 1

Whole collar pressure

Across the whole collar, there was a consistent trend for greater pressure recorded when donkeys pulled 40% of their body weight (Table 2). There were also significant interaction differences between collar, load and pressures exerted (Pmean *P*-value = 0.04, Pmax *P*-value = 0.04, Ppeak *P*-value = 0.03, Table 2). Collar 7 was the only collar where significantly greater Pmean was recorded when comparing moving 40% and 20% of their body weight (P<0.001). In contrast, collars 6 and 7, which exerted a greater Pmean when compared with collars 1 to 5, were not significantly different to each other when pulling 20% or 40% of their body weight (Table 2). Values for Pmax (P<0.001) and Ppeak (P<0.001) were significantly greater for collar 2 when pulling 40% of their body weight compared to pulling 20% of their body weight. Ppeak was significantly greater for collar 7 when pulling 40% of their body weight compared to pulling 20% of their body weight (P<0.001), but Pmax was not significantly different (P=0.675, Table 2).

Table 2

Pressure on critical points

There was no significant difference in Pmean exerted on the shoulders by the different collars; however, at the trachea collar 6 exerted the greatest Pmean when pulling 20% of their body weight (*P*-value = 0.011) whereas collar 7 had the greatest Pmean when pulling 40% of their body weight (*P*-value = 0.022), with a similar trend being observed for Ppeak (Table 3). Collars 1, 3, 4 and 5 showed the smallest mean increase in Pmean when pulling the heavier load (Table 3). Collar 4 had the lowest mean Ppeak pressure when pulling 20% and 40% of their body weight, whereas collar 2 had the greatest Pmean increase (Table 3). Collar 4 and 5 had the smallest mean increase between pulling 20% and 40% of their body weight in Ppeak (Table 3).

Table 3

Pressure on whole collar and critical points

There were differences in the loading across the collars and for the critical points (*P*-value = 0.043, Figure 4). Pmean and Pmax for collar 1 were greater at the critical points than across the whole collar when pulling 20% of their body weight, however, when pulling 40% of their body weight the Pmean across the whole collar was greater than at the critical points (*P*-value = 0.48, Figure 4). This was not the case for Ppeak, where the largest pressure was observed across the whole collar for both loads (Figure 4). Collar 2 showed no difference in the Pmean or Pmax when pulling 20% of their body weight (*P*-value = 0.56), however, when pulling 40% Ppeak and Pmax were greater across the whole collar compared to the critical points (*P*-value <0.001). While this was also the case for collar 3 for Pmax and Ppeak (*P*-value <0.05), the Pmean showed no difference in mean pressure (*P*-value = 0.99). For collar 4, the greatest pressures were observed across the whole collar compared to the critical points (*P*-value <0.05, Figure 4). This was also true for collar 5, however, there was less difference between Pmean across the whole collar compared to Pmax and Ppeak. Collars 6 and 7 both concentrated the greatest Pmean at the critical points, however the greatest Pmax and Ppeak was exerted across the whole collar (Figure 4).

Figure 4.

Discussion

Recent studies have highlighted a high prevalence of open wounds and scars amongst working equids, directly linked to working conditions, including poorly designed and incorrect use of equipment (9,13,14,30). Such studies corroborate the importance of the present research, and the need to understand what constitutes a good collar.

Donkeys and horses have anatomical differences in fat distribution and neck morphology (15), with donkeys presenting an "8" transversal shape due to a more prominent neck crest, while horses present an "egg" shape. Such anatomical differences were taken into consideration by the harness team who developed collars 1 to 3. These collars performed better in terms of area of contact for 20% of their body weight than those designed for horses (collars 4 and 5) and, additionally, collars 1 and 2 having better results for 40%. Hames on collar 3 were designed considering the "8" shape of the donkey's neck, but are only attached at the top of the collar, and not in the lower part (Figure 2). As a result, the collar slightly bent forward when pulling 40% of their body weight, losing its initial shape and losing contact with the lower part, thereby affecting its performance. This explains why collar 4, even though it had a "horse-neck" shape, had a greater area of contact for 40% than collar 3. However, it should be noted that the increase in the contact area observed in collar 4 is due to its large padding system, which, when pulling 40% of body weight, promotes more contact on the lateral aspect of the scapula and, to a much lesser extent, in the narrower area of the donkeys' neck. The intensity of the sweat marks observed on the collar provides visual evidence (Figure 2, 4B).

Although the area of study was delimited for collars 6 and 7, such a procedure was required to ensure consistency of readings obtained in terms of area of contact. Nevertheless, it is important to mention that the selected area corresponded to the effective area of pulling (breast and shoulders), and significant and non-significant differences in the area of contact from 20% to 40% of their body weight were observed (respectively for collars 1-5 and collar 6-7), highlighting the lack of extension and adaptation capacity of the breast collars.

Davies (31) highlighted that on a horse, the greater the contact area a collar affords, the better it is at reducing mean pressure. The same author also stated that padding materials with good compressive indices and deformation capacities tended to provide better pressure distribution.

In the present study and in terms of pressure, an increase was observed from 20% to 40% of their body weight for collars 1 to 5, but padding and manufacturing materials had a direct influence on Pmean, with no significant variations observed for these collars when comparing the two different percentages of body weight.

Collars 1 to 5 had their padding area filled with natural wool, which, as force increases, can adjust to the anatomy of the rostral aspect of the scapula. This allows, in theory, a better pulling capacity (32).

Collars 6 and 7 exerted higher pressure, and although only collar 7 presented significantly greater Pmean when moving 40%, collar 6 and 7 had a very similar response. Greater Ppeak indicates a lack of cushioning and lower Ppeak indicates better cushioning (24), indicating a better adjustment to the donkey's anatomy and a reduced risk of skin damage. Collar 6 and 7 showed higher values for Ppeak, presenting the least cushioning at 20%, with collar 7 maintaining the trend at 40%. Davies (31) obtained similar results in a study performed with horses, with a straight breast collar showing the highest Ppeak, when compared with full collars.

Several studies focusing on the applied forces and pressure distribution for riding equipment showed that local high-pressure points may induce skin lesions of different degrees in horses, including perfusion disturbances (21), in a similar physio-pathologic mechanism described for human decubitus ulcers (33-35). Consequently, the reduction in nutrient and oxygen supplies may eventually lead to tissue ischaemia and necrosis. For a working equid, bone-muscle transition areas are especially prone to such lesions (21) and, in these areas, subcutaneous lesions may even occur prior to the visible skin lesions. This is due to shear stress, which represents the motion of underlying bone and subcutaneous tissue relative to the skin. Furthermore, friction and moisture may increase the likelihood of developing pressure sores (21, 22, 36).

For riding saddles, withers are one of the most affected regions. For collars, shoulders were assumed to be the critical points. This was in part due to anatomical similarities between regions, and also that skin lesions were reported to affect shoulders (13). Farhat et al. (14) reported around 40% of open wounds affecting shoulder and breast, in donkeys used to pull carts in Egyptian brick kilns. Such lesions may be associated with the widespread use of collars manufactured by non-professionals not meeting the minimum operational requirements. The scapulohumeral joints of donkeys are more prominent than those of horses, and when combined with low body condition scores (37, 38) may exacerbate the prevalence of observed lesions.

Margentino (39) stated that a breast collar should be positioned so as not to impede motion or breathing capacity. Several studies focussing on the upper respiratory tract of equines highlighted that any source of pressure or obstruction in the upper airways will affect breathing, working capacity, and performance. Causes of such respiratory stress include anatomic position of the head and neck, infectious and non-infectious respiratory diseases, and traumatic and mechanical blockage (40-42).

For collars 6 and 7, the trachea was considered a critical point, as even at rest, close contact occurs between the collars and the skin. Due to their design, collars 1, 2, 4 and 5 do not contact the trachea region, so the trachea was not considered a critical point.

The design of collar 3 presented a clear gap in the lower breast band in the trachea area. Although no pressure data were obtained for the trachea region for collar 3, close field observations established that there was no contact when the donkeys were at rest, or when they walked with head and neck in a normal position. The bilateral use of pressure pads did not afford data for the trachea region (Figure 2), and this can be considered a limitation of this study for this specific collar and critical point. However, the loss of contact observed in the lower part of collar 3 when pulling heavier loads, because of initial shape loss, corroborated the lack of contact with this critical point.

Contact with the shoulders was recorded in all collars, though collars 1,2,3,5 and 7 did not contact this area when donkeys were standing. However, contact came about due to normal walking movements. If such contact happens, the ideal situation is that pressure is spread across the whole collar and this is especially the case in relation to Ppeak. Observations for collars 1 and 2 indicated that this was the case, demonstrating an even spread of pressure, thereby reducing strain on those areas that may cause harm to the donkey. While this was also the case for collar 3 for Pmax and Ppeak, the Pmean showed no difference in mean pressure, indicating that pressure was evenly distributed across the collar. Collars 4 and 5 presented the greater Pmean across the whole collar when compared to the critical points, with less difference between Pmean for collar 5. However, collar 5 presented a much greater difference for Pmax and Ppeak in the whole collar loads, indicating that this collar was better able to spread the load across the whole collar area and did not concentrate pressure on the critical points.

Collar 7 is a “V” shaped breast collar, primarily designed to avoid the trachea and the shoulders regions and, in theory, provide better adjustment. When comparing collars 6 (straight breast collar) and 7, it is interesting that such desired characteristics are not generally observed: collar 6 has a larger contact area for both 20% and 40%, indicating that “V” shape breast collars may not adjust well to donkeys. In terms of pressure, although collar 7 may work well for lighter weights, exerting less pressure on the trachea for 20% of body weight, data showed that at heavier work the collar caused higher pressure in the trachea region, probably due to the loss of the original shape. This pressure will act as a mechanical blockage and affect the airflow, as previously described. The present study took into account the correct angle of draft for different collars, but in real working conditions, this angle may not be considered, which may exacerbate the pressure on the trachea. Further studies of incorrect draft angles are needed.

In a study focused on comparing different collars, the selection of donkeys with very similar phenotypes was essential as a way to minimise the bias in results due to individual differences between donkeys. Although, these Zamorano-Leonês donkeys represent a working donkeys population, with an important role in terms of transportation and subsistence agriculture for local farmers. These donkeys are very similar to other large European breeds of donkeys also used for working purposes, and all suffer from the lack of research and accompanying advances in appropriate technologies in terms of animal traction.

The results of the present study are valid for these breeds, but authors are confident that the results obtained here are also relevant to improving the health and welfare of working donkeys in countries with low and middle-incomes, so further studies are needed using donkeys with different phenotypes and making the necessary adjustments in the selected collars.

Collars were trialled in the same sequence for each animal, with at least 60 minutes resting period between each set of transects. This ensured the equids fully recovered from previous physical effort, and reduced any potential source of bias to a minimum.

Percentages of body weight used in the present study were somewhat conservative, considering the real working conditions donkeys may face while performing their daily tasks. However, they were enough to highlight differences between collars, the impact of different models in the critical points, and to extrapolate for higher percentages of body weight.

An important consideration is the price of manufacturing, with collars 1 and 2 costing around 15 times less than collar 3, and 30 times less than collar 4 and 5 (costing around 20, 300 and 600 euros, respectively). The harness makers' team even proposed the recycling of cylindrical parts of clothing, such as jeans, for the padding structure of collars 1 and 2, reducing the price of manufacturing even more.

Although the method used to obtain data was appropriate in terms of technology, after a week of work in controlled and correct field working conditions, the pressure pads suffered severe damage through wear, thereby reducing data intake towards the end of the experiment. This fact highlights that future studies need to take into account the robustness of the equipment, and direct adaptations of pressure pads primarily designed for humans need to be used with caution, especially if used in working conditions, where the force exerted on the equipment is much greater.

Conclusion

Collars 1 and 2 proved to be efficient, providing a good area of contact due to the padding system, combined with correct design. However, the greater flexibility of collar 2 (due to the type of hames used) indicates that Pmean and Ppeak are greater at lower loads and Pmax is greater compared to collar 1 on critical points. Pressure in the shoulders did not represent a problem. Hybrid collars may be effective for light work with donkeys, but less so for heavier work. If collars designed for horses need to be used with donkeys, those with adjustment capacity should be preferred. As a way to adapt the collar to the shape of the neck of donkeys, it should be combined with narrower padding systems in the lower part and wider in the top, and with good padding material such as wool. Collar 5 provided all of the aforementioned characteristics.

In the case of the breast collars, and when no other collar is available, is important to ensure correct adjustment, correct manufacturing material and as much padding as possible to compensate for the lower adaptation capacity. Based on the results obtained, the best design for a breast collar for donkeys is straight, but with a clear gap created for the trachea, allowing a better adjustment of the collar in the breast area while avoiding pressure on shoulders and trachea.

Given the global importance of working equids, the acquisition of evidence-based scientific knowledge regarding these animals is a powerful tool to improve their health and welfare, ensuring that data obtained in this study can be effectively used in harness design wherever working donkeys are present.

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List of tables

TABLE 1:

Collar	Area cm² (±S.D.)					
	20%			40%		
1	829.9	(162.4)	c	1074.0	(104.3)	a
2	778.6	(221.8)	c	966.1	(183.5)	ab
3	632.8	(118.0)	d	836.3	(128.3)	c
4	614.5	(135.2)	de	876.9	(120.0)	bc
5	543.8	(156.9)	def	775.5	(111.9)	c
6	444.9	(31.2)	fg	531.8	(45.3)	defg
7	415.6	(76.9)	g	507.1	(56.2)	efg

Table 1. Area of contact between collars and donkeys. The sum of the left and right side of full collars and prototypes were used, to give a mean total contact area for each collar when pulling 20% and 40% of body weight. Letters denote Tukey HSD groups, where different letters between collars and loads represent significant differences ($p<0.05$).

TABLE 2:

Measure	Collar	Mean (LCI -UCI)	
		20% BW	40% BW
Mean Pressure (Pmean) (N/cm²)	1	0.02 (0.02-0.03)^{ab}	0.03 (0.02-0.04)^{ab}
	2	0.03 (0.02-0.03)^{ab}	0.03 (0.03-0.04)^{bcd}
	3	0.03 (0.03-0.03)^{ab}	0.04 (0.04-0.04)^{ab}
	4	0.03 (0.02-0.03)^{a}	0.06 (0.03-0.10)^{abc}
	5	0.03 (0.02-0.03)^{ab}	0.03 (0.03-0.03)^{ab}
	6	0.07 (0.05-0.08)^{de}	0.08 (0.06-0.09)^{ef}
	7	0.06 (0.05-0.07)^{cde}	0.10 (0.09-0.11)^{f}
Max Pressure (Pmax) (N/cm²)	1	0.08 (0.06-0.10)^{a}	0.19 (0.13-0.25)^{ab}
	2	0.35 (0.26-0.44)^{bcd}	0.79 (0.65-0.93)^{e}
	3	0.35 (0.28-0.42)^{abc}	0.56 (0.48-0.65)^{cde}
	4	0.32 (0.23-0.40)^{ab}	0.56 (0.41-0.71)^{bcd}
	5	0.64 (0.46-0.82)^{bcd}	1.07 (0.82-1.31)^{de}
	6	0.43 (0.24-0.62)^{bcd}	0.45 (0.31-0.60)^{de}
	7	0.49 (0.31-0.67)^{cde}	0.71 (0.53-0.89)^{de}
Peak Pressure (Ppeak) (N/cm²)	1	0.08 (0.06-0.09)^{ab}	0.09 (0.08-0.11)^{ab}
	2	0.10 (0.04-0.15)^{ab}	0.16 (0.13-0.19)^{cde}
	3	0.09 (0.07-0.11)^{ab}	0.16 (0.13-0.19)^{bcde}
	4	0.07 (0.06-0.09)^{a}	0.11 (0.08-0.14)^{abc}
	5	0.10 (0.08-0.13)^{ab}	0.16 (0.12-0.19)^{abcd}
	6	0.14 (0.08-0.20)^{abcd}	0.17 (0.13-0.21)^{de}
	7	0.13 (0.09-0.16)^{abcd}	0.25 (0.19-0.31)^{e}

Table 2. Mean, max and Peak pressure (N/cm^2) for each collar under 20% and 40% of the equids body weight. Lower confidence intervals (LCI) and upper confidence intervals (UCI) are within brackets next to the mean. Letters denote Tukey HSD groups where different letters between collars and loads represent significant differences ($p<0.05$). Analysis of variance was performed on each pressure measure separately but for both 20% and 40% of body weight together.

TABLE 3:

Measure	Collar	20% BW		40% BW	
		Shoulder (LCI - UCI)	**Trachea (LCI - UCI)**	**Shoulder (LCI - UCI)**	**Trachea (LCI - UCI)**
Mean Pressure (Pmean) (N/cm^2)	1	0.11 (0.05-0.18)^{ab}		0.12 (0.08-0.16)^{abc}	
	2	0.06 (0.05-0.07)^{ab}		0.12 (0.09-0.15)^{abc}	
	3	0.06 (0.01-0.12)^{ab}		0.07 (0.05-0.1)^{ab}	
	4	0.04 (0.03-0.05)^{a}		0.05 (0.04-0.07)^{ab}	
	5	0.05 (0.04-0.07)^{ab}		0.06 (0.04-0.07)^{ab}	
	6	0.09 (0.04-0.15)^{ab}	0.11 (0.07-0.15)^{de}	0.14 (0.07-0.21)^{bcd}	0.13 (0.10-0.16)^{e}
	7	0.10 (0.04-0.16)^{ab}	0.10 (0.06-0.13)^{cde}	0.11 (0.05-0.18)^{abc}	0.22 (0.17-0.26)^{f}
Max Pressure (Pmax) (N/cm^2)	1	0.17 (0.08-0.27)^{ab}		0.32 (0.14-0.50)^{abc}	
	2	0.37 (0.22-0.52)^{abcd}		0.76 (0.59-0.92)^{cde}	
	3	0.13 (0.05-0.22)^{ab}		0.38 (0.18-0.58)^{abcd}	
	4	0.12 (0.05-0.19)^{a}		0.18 (0.06-0.30)^{ab}	
	5	0.22 (0.10-0.35)^{ab}		0.28 (0.14-0.42)^{abc}	
	6	0.39 (0.13-0.65)^{abcd}	0.30 (0.2-0.41)^{cdef}	0.70 (0.46-0.94)^{cdef}	0.38 (0.27-0.50)^{ef}
	7	0.63 (0.2-1.06)^{bcde}	0.35 (0.22-0.47)^{def}	0.68 (0.30-1.06)^{abcde}	0.64 (0.49-0.78)^{f}
Peak Pressure (Ppeak) (N/cm^2)	1	0.10 (0.04-0.17)^{ab}		0.12 (0.08-0.16)^{abc}	
	2	0.06 (0.05-0.07)^{ab}		0.12 (0.09-0.15)^{abc}	
	3	0.06 (0.01-0.12)^{ab}		0.07 (0.05-0.1)^{ab}	
	4	0.04 (0.03-0.05)^{a}		0.05 (0.04-0.07)^{ab}	
	5	0.05 (0.04-0.07)^{ab}		0.06 (0.04-0.07)^{ab}	
	6	0.09 (0.04-0.15)^{ab}	0.11 (0.07-0.15)^{de}	0.14 (0.07-0.21)^{bcd}	0.13 (0.10-0.16)^{e}
	7	0.10 (0.04-0.16)^{ab}	0.10 (0.06-0.13)^{cde}	0.11 (0.05-0.18)^{abc}	0.22 (0.17-0.26)^{f}

Table 3. Mean, max and Peak pressure (N/cm^2) at the critical points for each collar under 20% and 40% of the equids body weight. Left and right shoulder pressure was summed to give a total mean, max and peak pressure for both shoulder. Only collars 6 and 7 had Trachea pressure measurements recorded. Lower confidence intervals (LCI) and upper confidence intervals are within brackets next to the mean. Letter denote Tukey HSD groups where different letters between collars, loads and critical points represent significant differences ($p<0.05$). Analysis of variance was performed on each pressure measure separately but for both 20% and 40% of body weight and areas of the equid together.