ORIGINAL ARTICLE

May the force be with you: an investigation into logging methods using donkeys

João B. Rodrigues[a]*, Chris Garrett[a], Stuart L. Norris[a], Francisco Albuquerque[b],
Luis Queijo[b], João Paulo Coelho[b], Fiona Cooke[a], Andrew Judge[a]

ABSTRACT. Working equids represent major sources of energy worldwide, and assume an increasingly important role in line with increasing requirements for sustainable energy. The effectiveness of their contributions relies on welfare, especially in the case of donkeys that, due to their size, face more adverse working conditions compared to larger equids. In this study, heart rate and force exerted were monitored while logging using three methods: direct pull, sled, and vehicles. A swingle tree incorporating a dynamometer and data logger was developed for this project, allowing continuous recording of forces. It was hypothesized that logging techniques that suspend (partially or totally) the load from the ground, reduce the force exerted, thus reducing physical effort. This study also aimed to understand if heart rate can be used as an alternative proxy measure when pulling different loads using different methods. Results showed that the greatest force was measured during direct pull (369.66 N), requiring 20% greater force compared to the sled (299.10 N, $P < 0.001$), and 60% greater force than the vehicle (125.11 N, $P < 0.001$). The sled required an additional 58% of force compared to the vehicle ($P < 0.001$). This determines vehicles are the best option for reducing the force exerted by donkeys. Affordability and skills needed to work with this technique, however, are important considerations. Sleds represent a user-friendly solution; reducing the force needed when compared to direct pull, requiring less skills and equipment. The dynamometer proved an excellent method for force monitoring. Heart rate as a proxy measure for force didn't provide accurate data for lighter loads. Increasing load weight, followed by the increasing force requirements, correlation and explanatory power became greater, indicating that with heavier logs, or methods that display greater force requirements, heart rate may be used as a proxy method for force, but further studies are needed.

Keywords: Working donkeys, dynamometer, logging techniques, heart rate, animal welfare.

INTRODUCTION

Working equids still play a relevant role in industrial and agroforestry activities such as logging, and represent a major source of energy worldwide (Almeida & Rodrigues, 2017; Fernando & Starkey, 2004; Norris *et al.*, 2020), especially in low and middle-income countries (Norris *et al.*, 2020).

In recent years, a growing interest has been observed in the use of workings equids in high-income countries, as part of a general awareness of sustainable energy sources, and sound techniques in small-scale agriculture, forestry, and environment management (Rodrigues *et al.*, 2017). This, in turn, supports food security and economic self-reliance through a reduction in the consumption of external resources (Stringer, 2014). Such trends are likely to increase due to the recent global energy crisis affecting fossil fuels (Birol, 2022).

The effectiveness of the contributions made by working equids to future sustainability is reliant on their welfare, and one of the most important determinants for overall health and welfare is that of harness (Rodrigues, Garrett,

et al., 2021), combined with the weight and nature of the load, the quality of equipment used, general health, and the standard of animal training and management (Pearson & Krecek, 2006).

Among working equids, donkeys tend to be overloaded due to their smaller size, while working with equipment primarily designed for other species, causing inefficient use of animal power and directly affecting their health and welfare (Demelash & Woldemeskel, 2006; Rodrigues *et al.*, 2020).

This study aims to understand how the use of different methods during logging operations can reduce the work effort of working donkeys, thus creating knowledge to share with those who will benefit the most - donkey owners and users around the world.

The first hypothesis in the present study claims that the use of logging techniques that allow lifting and suspending (partially or totally) the load from the ground can reduce the force exerted by the donkeys (in Newtons - N), thus reducing the physical effort.

The second hypothesis asserts that there is a strong correlation between the force exerted by donkeys and heart rate (measured in beats per minute - BPM), considering other studies where heart rate and exercise intensity share a direct, linear relationship: the more intense the exercise, the higher the heart rate (Sloet Van Oldruitenborgh-Oosterbaan *et al.*, 2010). The aim is to understand if the latter could be used as a cost-effective alternative proxy measure force used to pull different loads using different methods.

MATERIALS AND METHODS

DONKEYS

Three healthy Zamorano-Leones gelding donkeys (ages 8, 10, and 13 years old) of similar size and phenotype were used in this study. Donkeys were selected based on their working skills, which must include being used to pull/ being hitched to a vehicle.

At the commencement of the study, individual bodyweights (BW) were accurately obtained (354, 345, and 340 kg), using *The Donkey Sanctuary* nomogram (The Donkey Sanctuary, 2018).

The body condition score chart developed by The Donkey Sanctuary was used in this study. All donkeys presented an ideal body condition (BCS =3).

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

LOGGING OPERATIONS

Logs. Four logs of Scots pine (*Pinus sylvestris*) of 5 meters each were used in this study. Logs were prepared by a professional logger to present a known volume (Ministry of Forests, Lands and Natural Resource Operations, 2011): 0.03 m^3, 0.05 m^3, 0.07 m^3, and 0.1 m^3. The front aspect of the logs were rounded to reduce situations where they may become stuck, reducing the effect of the environment in the reading of the dynamometer.

Using a professional log volume –weight converter (Timberpolis, 2022)– the weight of the logs used were 26.4 kg, 44 kg, 61.6 kg, and 88 kg, respectively. These weights correspond to 8%, 13%, 18%, and 26% of the average BW of the three donkeys, respectively.

Logging techniques. Three logging techniques were applied, corresponding to the most common logging methods used in forestry:

– Technique 1: Direct pulling, with donkeys dragging logs (Figure 1);
– Technique 2: Forest sled made from recycled metal, with logs resting on the sled on one end, and dragged on the other end (Figure 2).
– Technique 3: Forest vehicles: a combination of a forecart (developed and manufactured by the first author) and two ATV log haulers manufactured by Iron Baltic© (Vatsla, Estonia), and adapted for this study. Logs are completely suspended on wheels (Figure 3). Any commercial forecart equipped with a tow ball and designed for a single equid use is valid for the purpose of this study.
Logging chains were used in all 3 techniques.

HARNESS

Collars. Three different collars were used in this study (Figure 4), based on previous results of pressure and area of contact obtained elsewhere (Rodrigues, Garrett, *et al.*, 2021). Collars with the best results within each group were selected:

• A **prototype collar**, developed by the harness makers' team involved in the project, designed specifically for donkeys to be adjustable, cheap, and easy to manufacture, using local materials.
• An adjustable commercial **full collar** designed for horses.
• A straight commercial **breast collar**, designed for horses.

All collars were checked and adjusted at the beginning of each transect by the harness makers' team, following standard protocols for harness fitting.

Harness. Techniques 1 and 2: collar, pair of traces, swingle tree, and a light trace carrier completed the harness system used. Technique 3: collar, pair of traces, swingle tree, cart saddle, breeching, and a belly band.

Force exerted by the equids
Load cell and data logger

The School of Technology and Management, Polytechnic Institute of Bragança (ESTiG-IPB) team developed a swingle tree with the dynamometer and the data logger incorporated, allowing a continuous recording of the pulling force exerted (N) by the equids during the work, with a frequency of 1 force measurement per second (Figure 5). The device was switched on and off immediately before and after each transect, respectively. Time and date were also recorded for each one of the transects and used as a reference to crossmatch with data provided by the Polar software, used for monitoring heart rate. All data were stored on a micro-SD card and downloaded to a laptop as csv. files. The design, implementation, and metrological characterisation of this device is published elsewhere (Coelho *et al.*, 2021).

HEART RATE DURING WORK

A horse heart rate sensor (Polar©) was attached to the donkey's harness and used to continuously monitor the heart rate of the equids during the transects, and during the recovery period, with a frequency of 1 BPM measurement per second. The recovery period started after a set of transects (please see *transects* section). In this study 44 bpm were considered as basal values for heart rate.

This system includes a GPS locator, allowing researchers to understand when the animals are in motion during the

Figure 1. Donkey being led during a transect, using the direct pull technique to move the log, and using a collar, a pair of traces, a trace carrier, a swingle tree, and a logging chain.

Figure 2. Use of the sled during the trials, with the front part of the log resting on the sled, greatly reducing the area of contact with the ground. The sled is a simple system, easy to manufacture, and is attached to the swingle tree via a "V" shape chain, in the front part.

Figure 3. Vehicles in use while carrying the 0.1 m³ log. Note that 2 logging arches keep the log fully suspended (rear and front logs). The front log is then attached to the forecart via a tow ball. Note the complete cart harness in place, using a breeching and a cart saddle.

Figure 4. Three collars tested: collar 1: manufactured using canvas for external padding, wool for internal padding, and fence post as hames. Collar 2: manufactured with large plywood hames, padding area of natural leather filled with natural wool. Collar 3: manufactured with beta/biothane/synthetic leather, and filled with sponge. A = front view and B = rear view.

transects, and link the dynamometer values with the heart rate values. Data obtained using the horse heart rate sensor (heart rate and GPS position) were extracted directly from its online software and downloaded as csv. files.

TRANSECTS

Donkeys moved the logs 100 meters in a straight, horizontal transect (confirmed using the altimeter incorporated in the Polar© software), along a forest floor. This distance is considered ideal when logging with equids in real conditions.

A total of 108 transects were carried out during the study, taking two weeks to complete all the transects.

Each donkey had a minimum resting period of 60 minutes between each set of transects (moving 4 logs using a specific collar and logging technique), ensuring full recovery from previous physical effort. Animals were kept in a small paddock, with access to shade, water, and hay.

A table was created where authors crossed the information donkey-collar-method, to guarantee a homogeneous distribution of the work performed by each animal within the timeline of the project. This parameter allowed to reduce to a minimum any possible overwork by one or more animals involved in the study.

Donkeys were led during the transects, ensuring a constant speed, with care taken to ensure that the handler did not interfere with normal movement.

STATISTICAL ANALYSIS

All statistical analysis was performed using R v3.6 (R Core Team, 2018) and RStudio v1.2 (Racine, 2012). Data transformations, summary statistics, and graphs were prepared using the R package tidyverse (Wickham *et al.*, 2019). A mixed model approach via restricted maximum likelihood generalized additive model (GAM) was used from the R package mgcv (Wood, 2001) to understand differences in force between load and method, whilst accounting for time. Time was treated as a cubic spline random effect; 10 knots was found to be appropriate with a k-index of 1.03 and a P-vale of 1. Initial exploration of the data showed that there was a significant difference between the donkeys (P = 0.01) and collars (P < 0.001) used in the trial. As such donkeys were included as a factor smoothed random effect to account for differences with 2 knots which was found to be the best optimization with a K-index of 1.01 and a P = 0.73. Collars were also included as a factor smoothed random effect to account for differences with 2 knots which was found to be the best optimization with a K-index of 0.99 and a P = 0.32. After optimization, the GAM model consisted of interaction between load and method with collar, donkey, and time as random effects. The resulting model fulfilled GAM assumptions, did not require transforming, and explained 83% of the variation. To explore the pairwise comparison and interaction difference in the GAM model Tukey-HSD test was applied (De Mendiburu & Simon, 2015). Tukey-HSD identifies significant differences between factor levels, the Tukey model was optimized to account for the unbalanced experimental design (De Mendiburu & Simon, 2015) and reports both groups and P-values for interactions between factor levels. The Tukey-HSD groups function in the R package agricolae (De Mendiburu & Simon, 2015) provides letter groups for treatments, where treatments or interactions between treatments share a letter, and groups mean are not significantly different from each other. All significance testing was carried out at the 0.05 level.

GAM models for heart rate (BPM) were also constructed using the same procedure as above. Time was treated as a cubic spline random effect; 10 knots was found to be appropriate with a k-index of 1.01 and a P-vale of 0.49. Donkeys and collar were included as a factor smoothed random effect to account for differences with 2 knots which was found to be the best optimisation with a K-index of 1 and a P-vale of 0.74 for donkeys and K-index of 1 and a P-vale of 0.55 for collars. The resulting model fulfilled GAM assumptions, did not require transforming, and explained 86% of the variation.
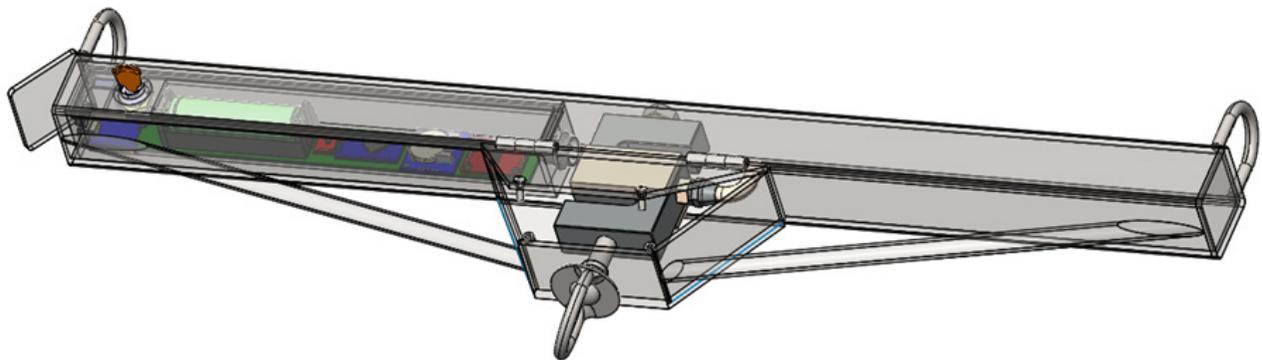

Figure 5. Swingle tree with dynamometer and data logger incorporated.

Pearson's correlation test was used to evaluate the association between force and BPM to understand if BPM could be used as a cost-effective alternative proxy measure for force used to pull different loads using different methods. Pearson correlation was chosen as a linear dependence between two variables (BPM and force), as it is a parametric correlation test BPM and force were tested for normality using Anderson-Darling Test. As both BPM and force were not normally distributed both were Box Cox transformed before the Pearson correlation test.

RESULTS

The greatest force was measured using the direct pull method (369.66 N) which required 20% greater force compared to the sled (299.10 N, P <0.001) and 60% greater force than the vehicle (125.11 N, P <0.001). The sled required an additional 58% of force compared to the vehicle (P <0.001, Figure 6A) There was a significant increase in the force exerted when moving the greater loads (P <0.001, Figure 6B). There was an increase of 24% force measured between $0.03m^3$ (183.57 N) and $0.05m^3$ (243.18

N), with an increase of 16% force between $0.05m^3$ and $0.07 m^3$ (291.83 N). A 34% increase in force required was observed between $0.07m^3$ and $0.1m^3$ (439.48 N, P<0.001).

Greater BPM was observed when using either the sled or the direct pull methods to transport logs compared to using the vehicle (P < 0.001, Figure 6C). Independent of the method used to transport the load, as the load increased, the BPM of the donkeys significantly increased (P < 0.001, Figure 6D). BPM increased 5% between pulling $0.03m^3$ and $0.05m^3$, 10% between pulling $0.05m^3$ and $0.07m^3$, and 12% between pulling $0.07m^3$ and $0.1m^3$.

There were significant interaction effects between the force required to pull the different loads and methods used (P <0.001, Figure 7A). At a load of $0.03m^3$, there was no significant difference in the force required between directly pulling and transporting the load using a sled (P = 0.99). However, significantly less force was required to transport the $0.03m^3$ load using the vehicle with 43% less force than the sled (P<0.001) and 41% less force than directly pulling (P<0.001) the load. When transporting $0.05m^3$, directly pulling required 49% (P <0.001) greater force and transporting the load using a sled required 40% (P
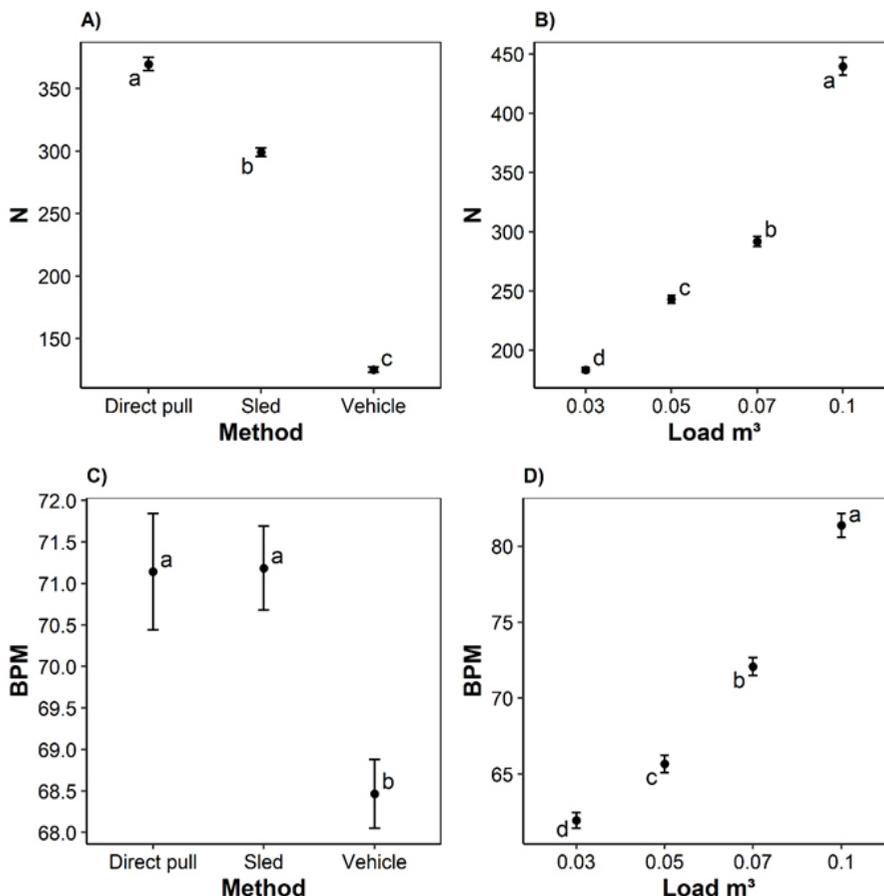

Figure 6. Points represent the mean, and the error bars represent the upper and lower confidence intervals for A) force (N) for each method of transportation, B) force for the different loads, C) Beats per minute (BPM) for the different transportation methods, and D) BPM for the different loads. Letters represent Tukey-HSD groups where different letters on each plot denote significantly different groups at the 0.05 level.

<0.001) more force than transporting $0.03m^3$ using the same method. There was no significant increase in force required to transport $0.05m^3$ using the vehicle compared to transporting $0.03m^3$ (P = 0.83) with only 4% more energy required to move the larger load. At a load of $0.05m^3$, as with transporting $0.03m^3$, the vehicle required the least energy to transport the load (120.77 N), which was 51% less (P <0.001) than using the sled, and 72% less effort than using the direct pull method (P <0.001). At $0.05m^3$ using the direct pull method required 20% greater effort to transport $0.05m^3$ than using a sled (P <0.001). When transporting $0.07m^3$, both the direct pull (24%) and sled (21%) methods required significantly more force than transporting $0.05m^3$ (P <0.001). However, there was no significant increase in force required to move $0.07m^3$ compared to $0.05m^3$ using the vehicle (1%, Figure 7A). At $0.07m^3$, the direct pull method required 21% more force than the sled (P <0.001), and 67% more force than the vehicle (P <0.001). Transporting $0.1m^3$ required the greatest force for all three methods and required significantly more force than transporting $0.07m^3$. At $0.1m^3$, the direct pull required the greatest force, which was 26% greater than using a sled (P <0.001), and 76% more force than using a vehicle (P <0.001).

Significant interaction effects were also observed for the BPM of donkeys when pulling different loads using different transportation methods (P < 0.001, Figure 7B). At $0.03m^3$ the greatest BPM was observed using the vehicle, which was significantly greater than using either the sled or the direct pull method (P < 0.001). When pulling $0.05m^3$ there was no significant difference in BPM between any of the methods (P >0.05), although the BPM did significantly increase when using the direct pull method and pulling the greater load (P < 0.001). When pulling $0.07m^3$ both the direct pull and sled transportation methods resulted in a greater BPM than observed when using the vehicle (P < 0.001). At $0.07m^3$ the BPM significantly increased compared to when pulling $0.05m^3$ (P < 0.001). When transporting $0.1m^3$ the direct pull method resulted in the greatest BPM, with the sled resulting in lower BPM compared to the direct pull, but greater BPM than using a vehicle (P < 0.001). When moving from a load of $0.07m^3$ to $0.1m^3$, the BPM using both the sled and the direct pull method significantly increased (P < 0.001) however, there was no significant increase using the vehicle (P = 0.26).

Donkeys recovered to basal values of heart rate (after a set of transects) within the first 5 minutes of the recovery period.

When comparing BPM and force exerted there was a weak correlation (r^2 = 0.36, P <0.001), indicating that using BPM would not be accurate as a proxy measure for the force exerted whilst transporting different loads using different methods. The sled method had a lower explanatory power for the relationship between BPM and
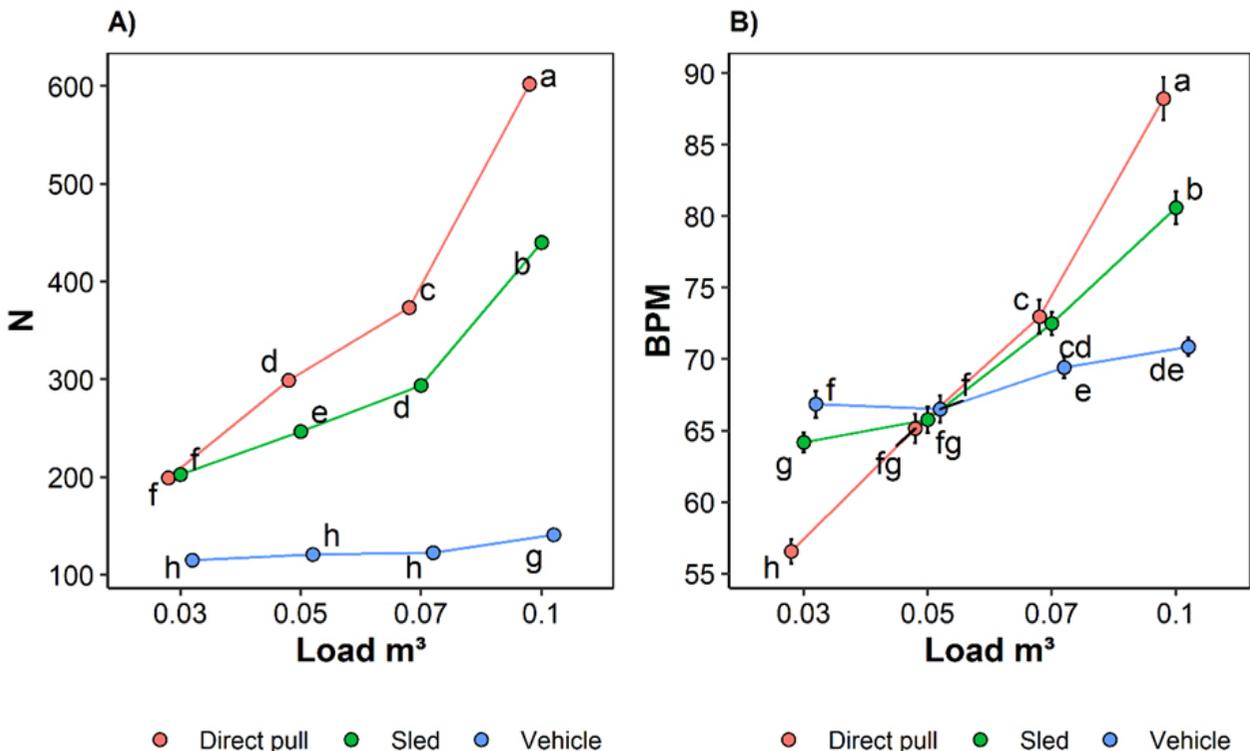

Figure 7. Interaction between the three methods and all loads. Points represent the mean A) force (N) and B) Heart rate in beats per minute (BPM). Error bars represent the upper and lower confidence intervals. Letters denote Tukey-HSD groups based on GAM results. Where letters are different there is a significant difference at the 0.05 level.

force ($r^2 = 0.30$, P <0.001), the direct pull method had a greater explanatory power of BPM and force ($r^2 = 0.58$, P <0.001), with the vehicle method having the lowest explanatory power between BPM and force ($r^2 = 0.061$, P = 0.007). The correlation between BPM and force for the different types of transportation method suggest that BPM has a weak to moderate use as a proxy measure for force. However, as the force required increases (Figure 7A) the explanatory power becomes greater.

DISCUSSION

GENERAL CONSIDERATIONS

Poor working conditions may lead to health and welfare issues affecting working equids (Demelash & Woldemeskel, 2006; Farhat *et al.*, 2020; Norris *et al.*, 2020; Rodrigues *et al.*, 2020). To ensure the welfare of working donkeys they must work within their physical capacity while respecting their health and mental boundaries. It is, therefore, fundamental to welfare to quantify and provide insights into the load profile of donkeys while carrying out tasks and identify solutions when needed.

An important aspect to consider is that the draft capacity of an animal tends to increase in line with its body weight (Watson, 1983), and as such, horses (and mules to a lesser degree) are preferred for forestry activities compared to donkeys (Rodrigues, Raw, *et al.*, 2021). However, in many places donkeys are the only possible (or chosen) option, and in those cases, it is easier to overload them beyond their working capacity due to their lower weight compared to horses and mules, highlighting the importance of the solutions tested.

Logging methods. Direct pull, using a swingle tree and skidding chain where animals drag the log behind them is the most common technique used in logging operations and the most efficient in terms of the time needed to move the logs between two points at short distances. Although, results obtained in this study highlighted that these are also the most demanding in terms of force and heart rate (Figure 6A, C).

The use of vehicles (a combination of forecart and log haulers) proved to be the technique where the donkeys needed less force to move the load, demonstrating an even more noticeable difference as the weight increases, due to the presence of wheels and complete lack of contact between log and soil (Figure 7A).

Some technical aspects, however, deserve a deeper reflection: the correct harness needed to move (and brake) a vehicle is more complete in comparison to the one used for direct pulling techniques used only to move the load. Apart from the breast or full collar, traces, and swingle tree used in the direct pull, the cart saddle needs to be added, as it takes the vertical force of the weight when it occurs. Breeching must also be used to prevent

the vehicle from running forward into the animal when it stops, and a belly band is required to prevent the cart from tipping backward when an unbalanced load is applied (Damerow & Rice, 2008; Ellis *et al.*, 1980; Leslie, 2015; Pearson *et al.*, 2003).

It is common to see working donkeys with incomplete and ill-fitted harness (Pearson *et al.*, 2003), and the more complex the harness system is, the more likely it is that important parts for its correct functioning are missing. In turn, this increases the likelihood of inefficient transfer of power, leading to discomfort, fatigue, and even body injuries that ultimately decrease working efficiency and output (Demelash & Woldemeskel, 2006; Farhat *et al.*, 2020; Rayner *et al.*, 2020; Rodrigues *et al.*, 2020).

The skills needed to load the logs in the log haulers, and then the ability to drive and manoeuvre the complete set into the forest are also aspects to consider. Aware of the need for training, The Donkey Sanctuary developed an online training platform –The Donkey Academy– where scientific findings, such as the ones reported in this paper, can be communicated via simple, clear, online educational resources, enabling better dissemination of knowledge with other professionals, donkey owners and handlers worldwide (Rodrigues, 2022).

The price of the equipment is another key aspect to consider: the cost of the complete set of vehicles exceeds 2100 € (approximately 2215 USD). Despite being of favorable pricing compared to conventional machinery used in forest management, it is a very high price for most donkey owners and handlers (Watson *et al.*, 2020), considering the world distribution of donkeys (Norris *et al.*, 2021; Starkey & Starkey, 2000). While there are online resources explaining the process of making similar implements from recycled material in detail (Log Splitters plans, 2022), the high price and skills required for manufacturing remain important considerations.

Sleds proved to be a good option to reduce the force needed to move the load, with differences about direct pull gradually increasing with increasing log weight. This technique reduced the area of contact of the log with the ground, by lifting the front part of the log, thus reducing the friction and resistance between the log and the ground, as only the sled runners and the last portion of the log were in contact with the floor (Figure 7A).

The force required for logging also depends on the soil conditions, although there is less influence when compared to tillage operations, where other aspects such as working depth or implement used may play a major role (Batey, 2009; García-Tomillo *et al.*, 2017; Schmidt, 2022). During the direct pull, logs contact the soil throughout its length, so such conditions can play a more relevant role.

Sleds can be pulled over rough terrain, work well in traversing slopes (where a vehicle might tip over), and are much easier to manoeuvre inside the forest. Being low to the ground, they are very easy to load up, and more stable than vehicles (Koroleff & Bryant, 1925; Langsner, 1978).

From a harness point of view, the same harness used to move the logs using direct pull is used with the sled. This is an advantage, as the sled can be used as a quick complementary logging method when the load to be moved is too heavy for the donkey, without the need to change harness or hitch the donkey to a vehicle.

Sleds do have issues on downhill runs, due to the lack of a braking system. In such situations, and depending on the slope of the terrain, the higher friction observed during direct pull can be an advantage, by slowing down the log. When the logs are pulled downwards, the pulling capacity of the animal's increases, so direct pull may be the best option (Ferris, 2019).

The sled used in this study was manufactured using scrap metal, based on existing models (Langsner, 1978). The manufacturing price is very low, and the degree of complexity of the construction process is much simpler when compared to the log haulers.

The present study provided relevant information about how the use of logging techniques that allow lifting and suspending (partially or totally) of the load from the ground can reduce the force exerted by the donkeys (thus reducing the physical effort), corroborating the first hypothesis raised in the present study.

Vehicles are by far the best options in terms of reducing the force exerted by donkeys, but the technical aspects mentioned must be considered. Sleds represent an easy-to-use solution that reduces the force needed to move logs.

The weight of the logs used in the present study (in terms of the percentage of BW of the donkeys) was somewhat conservative, considering the real working conditions donkeys may face while logging, however, they were enough to highlight differences between techniques.

Use of dynamometer and animal welfare. The dynamometer proved to be an excellent method to assess and monitor the force exerted by donkeys during forestry work using different techniques, and thus a good tool to monitor animal welfare. Overloading donkeys while pulling is still a common bad practice worldwide, directly affecting their health and welfare (Demelash & Woldemeskel, 2006; Rodrigues *et al.*, 2020).

The results obtained here open the door to further studies focused on determining the "cut-off" weight load acceptable according to the logging technique, or in any other activity where donkeys are used to pull loads.

Such a method, however, does not allow real-time results, and therefore it is not possible to adapt or correct the work being carried out at that moment. As such, operators must be very aware of early signs of fatigue in donkeys, such as slowing down, stopping, abnormal behavior, reluctance to move, increasing respiratory rate, and excessive sweating (Jagjiwan *et al.*, 2013). Despite this current limitation, further work will look at transmitting information from the dynamometer to a tablet/smartphone for real-time monitoring.

Heart rate as a proxy measure for force. Heart rate monitoring (measured in BPM) is being increasingly used to assess exercise and fitness in pleasure and sport horses (Kingston *et al.*, 2006; Williams *et al.*, 2019), but few studies seem to be focused to assess workload and physical state in working equids.

The use of HR as a proxy measure for the force exerted whilst transporting different loads using different methods did not provide good results for all the tests performed in the present study, thus rejecting the second hypothesis formulated.

Limitations of the study. The reduced number of donkeys used in this study may be also considered a limitation. Although, the authors believe that the high number of transects performed by the animals somehow compensates for this limitation. The careful selection of the donkeys based on their working skills results in the reduction of similar donkeys available for the present study. All three donkeys used in this study regularly work in agroforestry activities using these logging techniques. It is important to highlight that donkey´s physical and mental state can also affect HR, with an untrained, excitable animal spiking faster and higher than a calm, trained, steady animal (The Donkey Sanctuary, 2018), so behavior and unpredictable external factors may have a direct influence in the heart rate results if the selection of animals is not judicious.

Regarding the use of heart rate as a proxy measure for force, the fact that the first logs were so light, representing 8% and 13% of the body weight, may have affected the results obtained for HR, with the physical effort required to move the 0.03 m^3 and 0.05 m^3 logs being higher when using sled and vehicle, due to the weight of the implements, and this factor may explain the higher HR observed for these techniques.

With the weight of the logs increasing, followed by the increasing force requirements, the correlation and the explanatory power became greater, so these results indicate that with heavier logs or methods that display greater force requirements, BPM may eventually be used as a proxy method for force, but further studies are needed.

COMPETING INTERESTS STATEMENT

The authors declare that they have no competing interests.

ETHICS STATEMENT

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.

AUTHOR CONTRIBUTIONS

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