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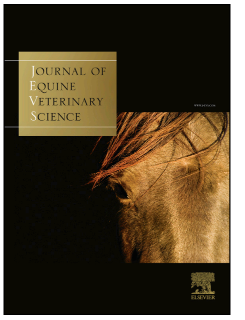

Equation for Predicting the Load-Pulling Capacity of Traction Equids

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Equation for Predicting the Load-Pulling Capacity of Traction Equids

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Abstract

This study proposed a loading capacity equation for urban cart-pulling equids. The research was conducted in two stages: the first developed the equation, and the second applied it by analyzing the zoometric structure of animals already employed in this activity. The equation was formulated by applying Newton's laws of motion, starting from an ideal model that did not consider dissipative forces, and the variables, such as friction force, animal morphological indices and maximum supported load, were subsequently added. Next, the equation was applied using body weight data for 228 pulling equids, including 49 horses (18 males and 31 females) and 179 mules (13 males and 166 females), estimating the mean body weight for each sex in both species. This evaluation also considered variations in terrain friction coefficients on different terrains. The value of 0,0015 was used as the friction coefficient for spherical bearings in the cart axles. The results were subjected to analysis of variance and means testing (Duncan's test at 5% probability) to establish the relationship between the resulting means for male and female horses and mules separately. The maximum load value obtained in these cases was approximately twice the animals' mean live weight. The findings of this study indicate that equations can be applicable and should be validated by additional experiments using alive equids.

Keywords: *Equus*, Load, Physics, Capacity.

1. Introduction

Equid breeding mainly focuses on athletics and recreation, pulling equids are still needed, which, contrary to expectations, are associated with large urban areas in Brazil, where many are present [1]. Many problems are associated with using cart equids in Brazil, often leading the activity to be viewed in a discriminatory manner by most of society. A study conducted by Souza [2] in the city of Rio de Janeiro addresses the need for legally regulating the activity and for providing environmental education and social assistance to the stakeholders involved to reduce harm to the animals due to misuse and lack of driver preparation.

Oliveira et al. [3] conducted a similar study in the city of Uberlândia, Minas Gerais state, and indicated that the activity's main problems were that drivers were unprepared and received no assistance and that the pulled load limits were unregulated, a factor that often damaged the animals' health and productive longevity.

The striking presence of animal-drawn carts in large Brazilian urban centers has recently led to municipal laws being enacted to adjust the activity to acceptable standards for most of the population. However, these actions almost always address vehicle and driver identification via license plates and drivers' licenses as a possible means to punish drivers involved in traffic accidents. All attempts to establish the loading capacity for cart-pulling animals are empirical and not backed by research. This creates risks for the activity, in the sense that in some cases the regulations can consider a maximum load that underestimates the capacity of the animals and economically makes the work unworkable, or in the opposite sense of overestimating the maximum load, inevitably promoting health risks and welfare of horses and mules using in this work.

Equids can be classified according to their suitability for a given task by analyzing existing relationships among animal body measurements [4]. Thus, zoometry studies generate evidence for analyzing the animals' productive suitability, which, for equids, always involves an aspect of the driving power produced. Mariz et al. [5] analyzed cart-pulling equids in the urban area of Arapiraca, Alagoas state-Brazil, and identified that mules (76%) were more prevalent than horses (21%) and asses (3%) and that the estimated weights varied significantly among these groups.

Among the many existing zoometric indices, some are useful for identifying suitable pulling equids, such as those listed below, per Astiz [4]. First is the conformation index or Baron's index, which uses the relationship between the square of the animal's thoracic perimeter and the withers height to determine an index that reflects whether the equid is suitable for pulling tasks when the resulting value is greater than or equal to 2.116. Another important index for determining productive aptitude is the dactyl-thoracic index, given by the relationship between the shin perimeter and the thoracic perimeter, for which values above 0.108 indicate individuals suited for pulling. Although considered valid in the equestrian environment for productive animal typification, neither of these two indexes can serve as a reference for solving the problem of maximum load supported by cart-pulling equids.

Recent studies have attempted to estimate equid loading capacities, either on the animal's backs, as described by Matsuura et al. [6], or in agricultural traction, as described by Spugnoli et al. [7]. In the latter case, equipment was developed for this purpose. It is possible, however, to attempt to formulate an equation using Newton's laws of motion to determine a load capacity index for traction equids. Rooney & Turner [8] started the theoretical study about the mechanics of horses pulling loads, showed than with a draft angle of zero, shafts parallel to the ground, evidencencing the horse must only exert a horizontal force to move the load. Hiraga & Sugano [9] conducted a review of the literature of research conducted between 1950 and 1960 in Japan with draft horses, and highlighted results of correlation between the live weight of the animals and the carrying capacity of the animals, regardless of whether they belong to races selected for traction. One of the results showed that ponies of approximately 200 kg could draw up to 1000 kg and double their weight during a working day.

This study proposed a load capacity equation for pulling equids and testing it theoretically using data by zoometric structure of animals already employed in this activity, to assist with regulating this activity in Brazil by establishing standards that enhance the use of these animals without endangering their welfare.

2. Materials and Methods

The research was approved by the Ethics Research Committee on Animal Use (CEUA), Federal University of Alagoas, in Maceió, Brazil (Protocol 0007/12) and performed in two stages:

- Developed the load capacity equation for pulling equids, which differed for horses and mules. The equation was formulated by applying Newton's laws of motion, starting from an ideal model that did not consider dissipative forces, and the variables, such as friction force, animal morphological indices and maximum supported load, were subsequently added.

- Apllication the equations to predict load capacity using body weight data from 228 pulling equids from Arapiraca, Alagoas state, Brazil, of which 49 were horses (18 males and 31 females) and 179 were mules (13 males and 166 females), in conditions of the Brazilian Northeast region.

The study of equid walking gaits considers that equids move in equal time intervals, ensuring that the motion is performed at a constant speed different from zero; thus, the problem can be discussed based on the principles of Newton’s second law and the resulting force. In the first moment, the motion has constant speed with acceleration equal to zero. Were considered the friction coefficient of distinct types of terrain, including asphalt (0.01), rough asphalt (0.011), rough cement (0.014), cobblestone (0.02), irregular stones (0.032), compacted gravel (0.045), compacted dirt (0.06), loose gravel (0.08), grass (0.1), loose sand (0.3) and clay (0.4), and the mean friction coefficient of these terrains (0.097). A friction coefficient of 0.0015 was used for the spherical bearings in the cart axles [10,11].

In order to allow the calculation of a series of body indexes, which were used to characterize the average productive type found in the equidae population analyzed, several zoomometric measures were taken, whether at the height of the withers (AC), height of croup (GA), body length (CC), croup length (CG), croup width in the ileum (LGil), chest width (LP), chest depth (ProT), thoracic perimeter (PerT) and perimeter of cannon (PerC) [5].

By means of the mathematical interrelations drawn between the zoometric measures obtained, a series of corporal indexes was calculated as Body Mass (MC), product of the thoracic perimeter raised to the cube by the constant 80; the Body Index (ICorp), relationship between the product of body length measurement with constant 100 and the thoracic perimeter; the Proportionality Index (IProp), dividing the product between the measure of the height of the withers and the constant 100, by the corporal length; the Conformation Index (IConf), relationship between the thoracic perimeter and the height of the withers; the Compass Index (IComp), relationship between body weight and height of withers; the dactythoracic index (Idt), relationship between the perimeter of the cannon and the thoracic perimeter; Index of Load in Back to Step (ICp), relation between the product of the thoracic perimeter squared with the constant 98 and the height of the withers; Index of Back Load to Gallop (ICg), given by the ratio of the product of the thoracic perimeter squared to the constant 56, and the height of the withers. The individuals were classified as longilineus (Body Index superior to 90, work in speed), mediolineus (between 86 and 88, intermediate work) and brevilineus (less than 85, force work) [4,5].

The means of the generated equations, which differed between the species due to their variable load-pulling capacities, were statistically analyzed by Duncan's test at 5% probability using the SAS statistical package.

3. Results and Discussion

-Development of equation

The friction force (f) is the sum of the friction force from the bearings (gears) and from the rolling tire (resistance to rolling on the ground). In this case, movement between the gears indicates that this force depends on the dynamic friction coefficient of the bearings. As the tire is not slipping, static friction force provides the limit value that the tire can support when on the verge of slipping. The friction force or rolling resistance that gives the value of the friction force acting on the system is obtained by replacing the static coefficient with the rolling resistance coefficient.

Thus, the system's overall friction coefficient is the sum of the kinetic (μk) and rolling resistance coefficients (μr). Since the gear bearings are spherical, μk has a value of 0.0015, whereas the μr values depend on the ground friction coefficient.

As motion occurs in the horizontal plane, the normal force (N) equals the weight force (W) due to the load; thus, we have:

$$Fca - \mu . M \cdot g = 0$$

To find the total mass (M), this term is isolated in the equation:

$$M = \frac{Fca}{(\mu k + \mu r).g}$$

where:

M = total mass in kilograms (kg) that the equid can pull by walking at a constant speed;

Fca = force produced by the equid in newtons (N);

μk = coefficient of kinetic friction between the bearings, dimensionless, whose value is 0.0015;

μr = coefficient of rolling resistance friction on the ground, dimensionless, varying by terrain: smooth asphalt (0.01), rough asphalt (0.011), rough cement (0.014), cobblestone (0.02), irregular stones (0.032), compacted gravel (0.045), compacted dirt (0.06), loose gravel (0.08), grass (0.1), loose sand (0.3), clay (0.4) and mean friction coefficient for all these terrains (0.097) [10/11];

g = gravitational acceleration at sea level, given in meters per second squared (m/s^2), having an approximate constant value of 9.8.

The equation varies between horses and mules [12,13] since the inherent tractive force correlates with the animals' mass, thus generating two distinct correction factors that are applied as follows:

For horses:

$$M = \frac{1.88W}{(\mu k + \mu r).g}$$

For mules:

$$M = \frac{2.115W}{(\mu k + \mu r).g}$$

where:

W = calculated animal weight, which is the equid's body mass in kilograms (kg).

It is important to note that these equations are only valid for the horizontal plane and at constant walking speed since the speed would vary on any inclined plane, as the weight force in the direction of motion in this case is not zero.

-Application of the equations in horses and mules

Were used zoometric data for 228 pulling equids from Arapiraca, Alagoas state, Brazil, of which 49 were horses (18 males and 31 females) and 179 were mules (13 males and 166 females) were used to simulate results using the equation.

Analyzing the body indexes (Table 1), it is observed that the horses presented body indexes with values higher than the mules. According to the results of the body index (ICorp), horses and mules are classified as mediolineus (between 86 and 88, intermediate work), based on the classification of Astiz [4]. This indicates that all the animals used in the traction activity in the municipality of Arapiraca do not have adequate body index for this purpose, demonstrating the importance of an equation such as this being proposed, which can at least be used to draw a maximum reference load on the coupling.

Table 1

Body indexes calculated in urban traction equidae such as Body Mass (MC), Body Index (ICorp), Conformation Index (IConf), Compass Index (IComp), Thoracic Dactyl Index (Idt), Load Index to Step (ICdp) and Gallop Loading Index (ICdg).

	MC (kg)	ICorp	IConf	IComp	Idt	ICdp (kg)	ICdg (kg)
Mules	270±47.9b	86.4±3.8b	1.726±0.14b	2.0±0.31b	0.106±0.007	169±13.72b	96±7.84b
Horses	322±42.3a	86.7±3.02b	1.832±11.04a	2.3±0.21a	0.110±0.007	179±10.82a	102±6.18a
CV	16.68	4.22	7.66	13.63	6.35	7.66	7.66

Means followed by different letters in the same column differ statistically ($P < 0.05$) by the Skott-Knott test. C.V. - coefficient of variation (%).

Table 2 shows the estimated loading capacity (kg) of horses in Arapiraca, considering mean live weights for males and females and different terrains for locomotion.

Table 2

Estimated load capacity (kg) for male and female horses, according to body weight and terrain type, given by the equation developed for the species.

Terrain type (friction coefficient)	Males (kg)	Females (kg)
Smooth Asphalt (0.01)	5655.1±700.7a	5227±668.6b
Rough Asphalt (0.011)	5202.7±644.7a	4808.8±615.1b
Rough Cement (0.014)	4195.7±519.9a	3878.1±496.1b
Cobblestone (0.02)	3024.8±374.8a	2795.8±357.6b
Irregular Stones (0.032)	1941.3±240.6a	1794.3±229.5b
Compacted Gravel (0.045)	1398.6±173.3a	1292.7±165.4b
Compacted Dirt (0.06)	1057.5±131a	977.4±125b
Loose Gravel (0.08)	798±98.9a	737.6±94.3b
Grass (0.1)	640.7±79.4a	592.2±75.8b
Loose Sand (0.3)	215.7±26.7a	199.4±25.5b
Clay (0.4)	162±20.1a	149.7±19.2b
Mean Terrain Coefficient (0.097)	660.2±81.8a	610.3±78.1b

Means followed by different letters differ significantly per Duncan's test at 5% probability.

The mean body weight of the male horses was 339±26.3 kg and of the female horses was 313.3±43.9 kg kg, which led to the standardized response observed in the data where the loading capacity of the stallions was always greater than that of the mares, as the live animal weight is the equation element that reflects each individual's working capacity. Mares are preferred because they are also used for breeding, as with the mares, and are calmer, which facilitates traction work. This temperament is also seen in castrated horses, but castration is costly, and the animals cannot work for some time after the procedure. Another reason that owners report preferring females is that females do not have to stop pulling the carts to urinate, thus making it difficult when males require unscheduled stops in high traffic locations.

The animal's body mass classifies them as small or hypometric equids since they are below 350 kg [4]. Hypometric animals have also been described in other studies, such as by Paz et al. [14], who observed that the mean weight of traction horses in the city of Pelotas, Rio Grande do Sul state, was 321 kg, a value close to that of the horses in this study. These scarce data show that the type of horses used to pull carts in Arapiraca is similar to that in other localities.

In evaluating the loading-pulling capacity of these animals according to the supporting terrain type, it is interesting that the values vary extensively, ranging from loads that are much greater than the animal's live weight, as with traction on smooth asphalt, for which the value is up to 16-fold, to loads that are much smaller than the animal's live weight, as with the pulling capacity on clay, for which the value is less than half the animals' live body weight.

These situations are produced by the physical aspects of the cart pulling process, where the major determinant of the maximum weight supported is given by the capacity of the pulling agent (the animal) to remove the vehicle from the state of inertia. Thus, in terrain conditions where the friction force, which is contrary to the traction movement, is small, this capacity increases greatly, while the inverse condition occurs when this friction force is large.

Table 3 presents the estimated loading capacity (kg) data for mules in Arapiraca, Alagoas state, Brazil, considering mean live weights for males and females and different terrains for locomotion.

Table 3

Estimated loading capacity (kg) for male and female mules, according to body weight and terrain type, given by the equation developed for the species.

Terrain Type (friction coefficient)	Males (kg)	Females (kg)
Smooth Asphalt (0.01)	4419±697.7b	5120.9±895.5a
Rough Asphalt (0.011)	4065.5±641.9b	4711.2±823.9a
Rough Cement (0.014)	3278.6±517.7b	3799.3±664.4a
Cobblestone (0.02)	2363.6±373.2b	2739.1±479a
Irregular stones (0.032)	1517±239.5b	1757.9±307.4a
Compacted Gravel (0.045)	1092.9±172.6b	1266.4±221.5a
Compacted Dirt (0.06)	826.3±130.5b	957.6±167.5a
Loose Gravel (0.08)	623.5±98.4b	722.6±126.4a
Grass (0.1)	500.7±79.1b	580.2±101.5a
Loose Sand (0.3)	168.6±26.6b	195.3±34.2a
Clay (0.4)	126.6±20b	146.7±25.7a
Mean Terrain Coefficient (0.097)	515.9±81.5b	597.9±104.6a

Means followed by different letters differ significantly per Duncan's test at 5% probability.

The mean body weight of the male mules was 235.5±26.4 kg and of the females was 272.9±48.6 kg, which also led to the standardized response observed in the data where the loading capacity of the female mules was always higher than that of the males, the inverse situation to that for the horses. Female mules are preferred because they are calmer, which facilitates traction work.

In Arapiraca, the selection of female mules is also more judicious than that of males, as evidenced by the greater body weight of females than males. Based on mean live weight, the mules studied were also small or hypometric, as they weighed less than 350 kg [4].

Assessment of the load-pulling capacity of the mules according to supporting terrain shows a pattern similar to that in Table 3 since the terrain friction coefficients are the same.

Notably, in both tables, the load values obtained considering the mean terrain friction coefficient are important since they represent a hypothetical average situation that theoretically would give the animals satisfactory working conditions when facing diverse terrains throughout the day. The maximum load value obtained in these cases is approximately twice the mean live weight of the animals, which generates a very comfortable limit, as the animals are not bearing all this weight force on their backs.

4. Conclusion

The equations may be applicable and should be verified by additional physiological and biochemical tests considering the mean terrain coefficient, as well as variables such as number of hours worked and situations with sloped terrain.

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Conflict of Interest

Conflict of interest none.

Author Contributors

Tobyas Maia de Albuquerque Mariz, Pierre Barnabé Escodro, Carolyny Batista Lima, Jéssyka Emmanuelly Silva dos Santos and Andrezza Caroline Aragão da Silva: Experimental execution and adequacy of equations

Emerson de Lima and Samuel Albuquerque: Proposition and development of the equations.

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HIGHLIGHTS

Manuscript title: Equation for Predicting the Load-Pulling Capacity of Traction Equids

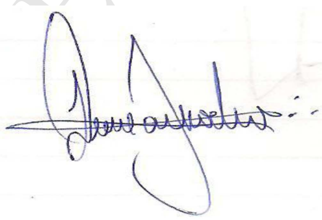
The paper intituled **Equation for Predicting the Load-Pulling Capacity of Traction Equids** seeks to fill a gap with regard to the load capacity for traction equids, being able to be enumerated as highlights of the research:

- Development of a physical equation to calculate the load capacity taking into account the body mass of the animal, structural characteristics of the cart and soil type.

- Application of the equation in 288 equids, being 179 mules, of traction activity for human subsistence in the Alagoas state, Brazil.

- The research makes potential future projects in the physiology of the exercise of traction animals and animal welfare.

- Possibility of establishing regulatory norms for load capacity of the urban traction equids in developing countries, since the number of animals in the cities used for the transportation of people and freight is still high, under conditions of mistreatment.



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