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EFFECT OF DENSITY AND WEIGHT OF LOAD ON THE ENERGY COST OF CARRYING LOADS BY DONKEYS AND PONIES

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ABSTRACT

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Two experiments were designed to compare the energy used in carrying loads by donkeys and ponies. In the first experiment 3 donkeys and 3 ponies were compared on treadmills in the UK. Density of load (lead shot or straw) had no significant effect on the energy cost of carrying loads; however, the energy cost of carrying a load decreased significantly ($p < 0.001$) as the weight of the load increased (in donkeys 6.44, 4.35 and 3.03 J/kg load/m, in ponies 5.82, 3.75 and 3.68 J/kg load/m, for loads of 13, 20 and 27 kg/100 kg liveweight (M) respectively). Differences between species were not significant. In the second experiment energy expenditures were determined in 3 donkeys carrying loads equivalent to 40 kg/100 kg M over gently undulating gravel tracks in Tunisia. Energy costs of carrying the load were 2.34 (SE 0.07) J/kg load/m. The results of both experiments showed that provided the load is balanced, density does not significantly affect the energy cost of carrying; however, as the weight of the load increased then the unit energy cost of carrying it decreased. This suggests that it is more efficient in terms of energy used to carry loads equivalent to 27 to 40 kg/100 kg M than it is to carry lighter loads of less than 20 kg/100 kg M.

INTRODUCTION

Considerable effort has been put into understanding the nutritional requirements of racehorses and sport horses in developed countries over the last 2 decades (Pearson, 1994). Unfortunately the nutritional needs of working equids in less developed countries have not received the same attention. Information on feeding donkeys, for example, is largely anecdotal. Donkeys, play a major role in the provision of rural and urban transport and other agricultural draught purposes and the lack of information has made it difficult to promote them as working animals in the tropics (see Fielding and Pearson, 1991). An understanding of the energy requirements of equids for work is necessary to develop recommendations on feeding to assist resource-limited farmers maintain healthy and productive working animals.

Diets of donkeys, as for most draught animals, are high in fibre and low in nitrogen with a metabolizability rarely above 0.4 for most of the year (Pearson and Dijkman, 1994). Animals have enough difficulty eating sufficient quantity of these diets to meet their maintenance requirements without meeting any extra demands for work. In equids, the effect on food intake in response to work and the resultant increase in energy demand appears largely to be determined by the nature of the diet. Increases in food intake over resting levels of proportionally 0.02 to 0.27, on a diet with a digestibility coefficient of 0.68, were found by Orton *et al.* (1985) when horses were exercised at 3.3 m/s for 1 h/day. On less digestible diets (0.55 and 0.47 respectively), Pearson and Merritt (1991) failed to record an increase in intake in donkeys that were exercised at 1 m/s for 4 h/day. Several workers in temperate areas have reported increased digestibility of relatively good quality diets by proportionally 0.06 to 0.20 as a result of light exercise in equids (Olsson and Ruudvere, 1955; Orton *et al.*. 1985; Worth *et al.*, 1987). More recently, it was reported that donkeys digested fibre more effectively than other equids (Pearson and Merritt, 1991). However, uncertainty still remains as to the influence of work on intake and digestibility of feeds by equids, particularly in hotter climates.

Few direct measurements are available on the energy requirements of equids during work (Brody, 1945; Thornton *et al.*, 1987; Sloet van Oldruitenborgh-Oosterbaan *et al.*, 1995). Energy requirements of resting donkeys and horses and those exercising at different speeds have been reported (e.g. Yousef and Dill, 1969a,b; Pagan and Hintz, 1986ab; NRC, 1989; Martin-Rossett *et al.*, 1994). However, information on load carrying in equids would assist in the calculation of their total nutritional requirements for pack work. Yousef and Dill (1969a) found that resting oxygen consumption in donkeys was similar to that in the horse and mule (Yousef and Dill, 1969b). They observed that an applied load was carried by the donkey almost as economically as it moved liveweight. Dijkman (1992) found donkeys more efficient at carrying applied loads, and moving liveweight, than oxen and buffaloes. He observed that negative gradients had a significant effect on energy consumption of donkeys (Dijkman, 1992). Pagan and Hintz (1986b), found that horses also seemed to use similar amounts of energy carrying applied load as moving the equivalent liveweight. Sloet van Oldruitenborgh-Oosterbaan *et al.* (1995) observed that increases in the heart rate of horses due to load carrying were similar whether horses carried a rider or a pack load of the same weight. Comparative studies of equid species have not been undertaken, nor have the effects of the density of the load on energy expenditure been investigated. In the present study the effects of weight and density of load on the energy expenditure for carrying loads and the differences between donkeys and ponies were assessed in a treadmill experiment in the UK. In addition, the effect of carrying loads on feed intake, digestibility and energy expenditure of donkeys was assessed during a field experiment in Tunisia.

MATERIALS AND METHODS

Experiment 1

Animals and management

Three adult donkeys (*Equus asinus*) weighing 230, 196 and 172 kg respectively, and 3 adult ponies (*Equus caballus*) weighing 220, 184 and 174 kg respectively were used. The animals were in good body condition (body score 7, Pearson and Ouassat, 1996). The study was carried out at the Centre for Tropical Veterinary Medicine, University of Edinburgh in 1995/1996. The donkeys and ponies were housed together in a pen in an open-sided shed. Hay was provided *ad libitum* throughout the trial. The animals, which had been previously trained to walk on a treadmill, were tethered while on the treadmill and walked readily, maintaining slack lead ropes at all times. The range of daily ambient temperatures was 15 to 23°C, relative humidity from 68 to 90% during the summer months and 10 to 15°C, relative humidity from 70 to 85% during the winter months.

For carrying loads, a leather saddle pack frame with metal handles weighing 11.7 kg was used. Some animals required a crupper around the tail to stabilize the frame. A Dexion slotted angle iron tray of 4 cm height with an aluminium floor was fashioned and placed on top of the saddle frame to hold the loads. Loads were balanced equally over each side of the saddle and secured with elastic cords during a work session.

Experimental methods

In the first part of the experiment, repeated minute oxygen (O_2) consumption readings were taken for each pony and donkey in each session while standing or walking at 0.8 m/s on the treadmill. Three replicates were carried out for each animal. For each activity measurements were taken when animals had reached a steady rate of oxygen consumption, which was generally achieved after 5 to 10 min.

The sequence of activities in a session was as follows: standing 10 min, walking 15 min, standing 10 min and walking 15 min.

In the second part of the experiment energy expenditure of ponies and donkeys was measured during walking and carrying of loads. Loads of 2 different densities (lead shot and barley straw) and 3 different weights, 13, 20 and 27 kg/100 kg liveweight (M) were used. Each session involved measurement of one density of load.

The sequence of activities in a session was as follows: walking unloaded for 15 min, walking with the first load for 15 min, walking with the second load for 15 min, walking with the final load for 15 min and walking unloaded for 15 min.

Heavy loads ranged from 51 to 64 kg, medium loads from 34 to 47 kg and light loads from 22 to 32 kg. The order of the loads was randomized: the order in the first replicate was heavy, medium, light: for the second medium, light, heavy; and for the third light, medium and heavy.

Experiment 2

Animals and management

Four entire male adult donkeys (*Equus asinus*), weighing 183, 175, 162 and 150 kg respectively, were used in the experiment. The experimental observations were made at the Ecole Supérieure d'Agriculture, Mateur, Tunisia from October to December 1993. The donkeys were kept in individual pens and received a daily diet consisting of 1 kg of crushed barley, *ad libitum* wheat straw and water (Table I). The amount of straw offered was about 50% in excess of expected daily intake. The animals were trained and familiarized with the general experimental procedures over a 3 week period. During this time the animals were also accustomed to the diet. The daily ambient temperature ranged between 10 and 26°C. Relative humidity ranged between 52 and 100%.

During the carrying experiments, donkeys wore a locally manufactured pack saddle and carried balanced loads, consisting of bags filled with sand to the required weight.

TABLE I
Chemical comparison of foodstuffs and refusals on dry matter (DM) basis in experiment 2

	DM (%)	CP (g/kg DM)	NDF (g/kg DM)	GE (MJ/kg)
Wheat straw	92.7	54	729	17.8
Crushed barley	92.3	98	340	18.4
Refusals	92.9	26	777	18.0

Experimental methods

Donkeys were divided into 2 groups which worked (W) for 2 weeks followed by 2 weeks rest (NW) or vice versa, during a 4 week experimental period. During the 5 day/week working treatment, donkeys carried 40% of their body weight (saddle + applied load) whilst walking on a 400 m. slightly undulating, gravel track. Total distance walked was 10 km/day, divided into a 6 km walk in the morning and a 4 km walk during the afternoon. During the working periods, resting animals were not allowed to eat, to keep the access time to the food equal during both treatments. Donkeys undergoing the working treatment alternately wore the modified Oxylog equipment during the morning or afternoon part of the 10 km walk, so that each animal was monitored on every working day for its O_2 consumption during work. Prior to the start and at the end of the working period, O_2 consumption whilst standing was obtained during a 20 min measurement period.

Measurements

Oxygen consumption was measured using a Mach I Oxylog portable breath-by-breath oxygen analyser (P.K. Morgan Ltd, Kent, UK). This instrument, originally designed for use with humans (Humphrey and Wolff, 1977), has been modified to suit measurement of O_2 uptake in draught animals (Lawrence *et al.*, 1991; Dijkman, 1993). The animals wore an airtight mask fitted with 3 inlet and outlet valves and a turbine flowmeter which measured the volume of each breath. The flow through the meter could be changed by opening or closing the inlet valves as required so that during exercise all valves were open and during rest only one was open. After each breath a small reciprocating pump takes samples of air entering and leaving the mask. The samples were passed into separate reservoirs containing a solid desiccant which gave 'running average' O_2 concentrations which were measured using 2 polarographic O_2 electrodes linked differentially. The electronic system calculated and displayed total O_2 consumption and total volume of inspired air at STP after making corrections for atmospheric temperature, pressure and humidity, which were recorded manually on data sheets.

The Oxylog was calibrated using standard gases (N_2 and O_2) and a standard pump in experiment 1 before, at regular intervals during, and after the experiment, and in experiment 2 immediately before leaving for, and after returning from, Tunisia.

The energy consumption was calculated from the gaseous exchange assuming a relationship of 20.7 kJ of energy spent per litre of O_2 consumed (Brouwer, 1965). The energy costs of the different activities were defined according to Lawrence and Stibbards (1990):

The energy cost of walking E_w (J/m walked per kg M) = [energy used while walking − energy used while standing still]/[distance walked (m) × liveweight (kg)].

The extra energy used for carrying loads while walking E_c (J/m walked per kg carried) = [energy used while walking with a load − energy used while walking at the same speed but unloaded]/ [distance travelled (m) × load carried (kg)].

Actual rates of energy consumption (W/kg $M^{0.75}$) whilst standing and walking were also calculated.

In experiment 1 the distance travelled on the treadmill was calculated from the number of revolutions of the treadmill belt multiplied by its length. In experiment 2 the number of circuits completed of a measured track in a given time were recorded. The animals completed 6 km in the morning and 4 km in the afternoon. Liveweight of each animal was recorded weekly during both experiments.

In experiment 2 food and water intake were measured daily. In addition, faecal output was measured over two 5 day periods corresponding to the W and NW treatments for both groups of animals. Samples of feed and faeces were taken for the determination of dry matter (DM), crude protein (CP), neutral detergent fibre (NDF) and gross energy (GE).

The data obtained in experiment 1 were subjected to an analysis of variance using GENSTAT (Lawes Agricultural Trust, 1990). In the analyses the total sum of squares was partitioned into 2 strata representing variation between animals and variation within animals. Overall equid effects were estimated and tested from the between-animal stratum. Load and density effects and interactions were estimated and tested from the within-animal stratum in a split-plot. Results of the intake and digestibility data in experiment 2 were analysed using a paired t-test (Lawes Agricultural Trust, 1990).

RESULTS

Experiment 1

The rate of energy expenditure by the donkeys and ponies while standing and walking on the treadmill is given in Table II. When the results were expressed per unit of metabolic liveweight there was no significant difference between species. The energy cost of walking was higher in the ponies than in the donkeys, but the difference was not significant (Table II).

Density of the load had no significant effect on the energy cost of carrying loads on the treadmill when the load carried was between 13 and 27 kg/100 kg M, however, the energy cost of carrying a load decreased significantly ($p<0.001$) as the weight of the load increased (Table III). There was no significant difference between species in the energy costs of carrying loads under these conditions (Table III).

Experiment 2

Due to an unforeseen exchange of one of the animals allocated to this experiment with another, measurements of energy expenditure were only carried out on 3 animals, because the face mask did not fit the second animal. The energy costs of walking over

TABLE II
The mean liveweight and the energy used for standing and walking at 0.8 m/s on a treadmill by donkeys and ponies

	No. of animals	n	Donkeys	Ponies	SED
Liveweight (M kg)	3	9	196	192	22.8
Energy used when standing (W/kg $M^{0.75}$)	3	9	4.06	3.72	0.51
Energy used when walking (W/kg $M^{0.75}$)	3	9	7.38	7.29	0.26
Net energy cost of walking (J/m/kg)	3	9	1.15	1.25	0.11

SED, standard error of the difference

TABLE III
Mean energy costs of carrying 13 (light), 20 (medium) and 27 (heavy) kg/100 kg liveweight loads of two different densities, high (lead shot) and low (straw) by donkeys and ponies (J/kg carried/m)

		Light	Medium	Heavy	Mean	Significance of effects[a]	
Donkeys	Lead shot	6.85	4.80	2.99	4.88	Equid	ns
	Straw	6.03	3.91	3.08	4.34	Load	***
	Mean	6.44	4.35	3.03	4.61	Density	ns
						SED[b]	
Ponies	Lead shot	5.48	3.82	3.40	4.23	Equid	0.52
	Straw	6.17	3.69	3.97	4.61	Load	0.45
	Mean	5.82	3.75	3.68	4.42	Density	0.88

[a]There were no significant interactions between means. [b]SED, standard error of the difference

TABLE IV
Dry matter intake (DMI), apparent dry matter digestibility coefficient (DMD) and water consumption (WI) of 4 donkeys in Tunisia during working (W) and resting periods (NW) (M = liveweight)

	DMI (g/kg $M^{0.75}$/day)		DMD		WI (L/kg $M^{0.75}$/day)	
Animal	W	NW	W	NW	W	NW
	89.8	104.5	0.58	0.65	0.22	0.27
2	114.5	113.9	0.66	0.61	0.32	0.32
3	91.7	100.0	0.71	0.68	0.24	0.20
4	98.5	110.2	0.73	0.52	0.30	0.31
Mean	98.6	107.2	0.67	0.62	0.27	0.28
Difference (NW–W)	8.6		–0.06		0.01	
SE of difference (3 d.f.)	3.3		0.06		0.02	
t-Test probability	0.08		0.41		0.80	
LSD (5% level)	10.5		0.19		0.06	

LSD, least significant difference

TABLE V
Apparent digestibility coefficients of neutral detergent fibre (NDF), crude protein (CP) and gross energy (GE) of four donkeys in Tunisia during working (W) and resting periods (NW)

	NDF digestibility		CP digestibility		Digestibility of GE	
Animal	W	NW	W	NW	W	NW
	0.63	0.67	0.38	0.55	0.54	0.63
2	0.67	0.63	0.59	0.55	0.63	0.60
3	0.76	0.70	0.57	0.56	0.70	0.64
4	0.77	0.51	0.61	0.48	0.72	0.48
Mean	0.71	0.63	0.54	0.54	0.65	0.59
Difference (NW−W)	−0.08		0.00		−0.06	
SE of difference (3 d.f.)	0.05		0.06		0.06	
t-Test probability	0.31		0.96		0.46	
LSD (5% level)	0.16		0.19		0.19	

LSD, least significant difference

the undulating gravel track by 3 donkeys in Tunisia, 1.35, 1.40 and 1.36 J/m/kg M for each of the donkeys respectively (mean 1.37 J/m/kg M, SE 0.05), were higher than that measured in experiment 1 on the level surface of the treadmill. Energy costs of carrying a load equivalent to 40 kg/100 kg M were 2.50, 2.47 and 2.06 J/kg carried/m for each of the donkeys respectively (mean 2.34 J/m/kg carried, SE 0.07). These values were lower than those seen in donkeys in experiment 1.

The dry matter intake (DMI), dry matter digestibility (DMD) and water consumption (WI) by the 4 donkeys during the working and non-working periods are given in Table IV. The analysis showed no significant differences between animals. Likewise, the differences observed in DMI, DMD and WI between the 2 periods were not statistically significant. Treatments also had no significant effects on the digestibility of NDF, CP and GE (Table V).

DISCUSSION

Standing energy expenditures (3.72 to 4.06 W/kg $M^{0.75}$) were similar to resting values reported by Pagan and Hintz (1986a) in horses at zero energy balance (3.32 to 3.60 W/kg $M^{0.75}$) and reported by Yousef and Dill (1969a) in donkeys standing on 2% gradients (about 4.6 W/kg $M^{0.75}$). However, in the present experiment, firstly the standing energy expenditures reported were related to total M and not to empty body mass and secondly the energy expenditure measured while the animals were standing included the heat increment.

The energy cost of walking on a level treadmill by the donkeys (1.15 J/m/kg M) and ponies (1.25 J/m/kg M) in the present study was consistent with the findings of others for small equids walking on level surfaces: donkeys 0.97 J/m/kg M (Dijkman, 1992), donkeys 1.2 J/m/kg M (Yousef *et al.*, 1972), Shetland ponies 1.06 J/m/kg M (Smith *et al.*, 1994), which generally are lower than for horses, 1.6 J/m/kg M (Hoffman *et al.*, 1967) and for cattle and buffalo walking on treadmills, 2.0 to 2.6 J/m/kg M (AFRC, 1990; Lawrence and Stibbards, 1990).

Anecdotal evidence (McCarthy, 1986) suggests that donkeys have nutritional requirements that are 15% below those of horses. The results in the present study suggest that energy requirements for maintenance of donkeys and British native ponies of similar liveweights (about 192 to 196 kg) are not very different. Since energy costs of carrying loads were also similar in the 2 types of equid in the present experiment, it would seem that small British native ponies and donkeys may have very similar energy requirements. The apparently lower feed requirements for donkeys compared to horses may be at least partly explained by their seemingly greater ability to digest poor quality feeds than the other equids (Pearson and Merritt, 1991; Cuddeford *et al.*, 1995). The current experiment suggests small British native ponies may be similar in their nutritional requirements to the donkey.

The higher energy cost of walking in the donkeys in Tunisia when walking on undulating gravel tracks (experiment 2) compared to that in the donkeys walking on the level firm surface of the treadmill (experiment 1) is consistent with the observations in other animals that energy costs of walking increase as the surface on which the animals walk becomes more uneven and less firm. Dijkman and Lawrence (1997) observed a 6-fold increase in the energy cost of walking in oxen walking on water-logged clay soil, up to hock deep, compared with the energy cost of walking on a firm level surface.

Although the donkeys in experiment 2 were able to select from a generous allowance of straw (about 150% of expected *ad libitum* intake daily), intake and digestibility results of experiment 2 were inconclusive and reports by other authors of increases in food intake and digestibility by equids on forage diets (Olsson and Ruudvere, 1955; Orton *et al.*, 1985; Worth *et al.*, 1987) due to exercise could not be confirmed. Hence, further work will be required to quantify the influence of diet quality and exercise on intake and digestibility in working equids.

In the present study, energy costs of moving applied loads on the level were significantly ($p < 0.001$) greater in ponies and donkeys than energy costs of moving liveweight. This agrees with observations of Dijkman (1992) in donkeys walking on level treadmills with and without loads equivalent to 5 to 18 kg/100 kg M, even when movement of the load was minimized.

The density of the load had little effect on the energy cost of carrying, provided the load was balanced on the back of the animal (Table II). In the current studies when the load shifted and put the animal off balance, which happened twice during the experiments, then the energy cost of carrying the load increased almost 3-fold (personal observation).

That the energy cost of carrying per unit of load went down as the weight of the load increased from 13 to 20 kg/100 kg M in the first experiment and was lower in experiment 2 when loads of 40 kg/100 kg M were carried on tracks, suggested that it is more efficient in terms of energy use to carry heavier loads than it is to carry light loads. When the energy cost of walking is also included then the difference in efficiency of energy use becomes even greater between heavy and light loads. Obviously there is a limit to the carrying capacity of the donkey. However, in practice over long distances loads do not seem to be much higher than 40 kg/100 kg M. Wilson (1991) reported that donkeys (about 120 kg liveweight) used by commercial hauliers in Ethiopia carried loads equivalent to about 50 kg for long distances. Over shorter distances it is reasonable to assume that loads may be greater (up to 80 kg, personal observation) but not commonly so.

Thus, when recommending the most efficient use of donkeys and ponies for carrying loads, it is clear from the current experiments that carrying 40 kg/100 kg M is a more efficient use of energy than carrying lighter loads. Much heavier loads, however, may be near the limit of the carrying capacity of the animals, increasing the risks of injury and ill-health. Provided the load is balanced on the back of the donkey or pony then the density of the load does not seem to have a significant effect on its carrying capacity.

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Effet de la densité et du poids des charges sur le coût energétique nécessaire pour le transport des charges par des ânes et des poneys

Résumé – Deux expériences furent organisées pour comparer l'énergie nécessaire pour le transport de charge par des ânes et des poneys. Trois ânes et 3 poneys furent suivis dans la première expérience pour des exercices de routine au Royaume-Uni. La densité des charges (Plomb ou paille) n'a pas d'effet significatif sur le coût énergétique nécessaire, cependent ce coût diminue de façon significative avec la baisse de la charge ($p < 0{,}001$) (chez les ânes 6,44; 4,35 et 3.03 J/kg de poids/m, chez les poneys 5,82; 3,75 et 3,68 J/kg de poids/m pour des poids respectivement de 13, 20 et 27 kg/100 kg de poids vivant (M). Aucune différence ne fut significative entre les deux espèces. Dans la deuxième expérience, 3 ânes portant des charges de 40 kg/100 kg de poids vivant furent suivis en Tunisie sur des chemins en gravier, légèrement ondulés. Les coûts énergétiques furent de 2,34 ($\pm 0{,}07$) J/kg de poids/m. Les résultats des deux expériences montrèrent que la densité n'affecte pas de façon significative le coût energétique tant que la charge est centrée. cependant si le poids de la charge augmente, le coût énergétique par unité diminue. Ce travail suggère donc qu'en terme d'efficacité les coûts énergétique sont équivalents pour des charges de 27 à 40 kg/100 kg de poids vivant mais plus importants pour des charges inférieures à 20 kg/100 de poids vivant.

Efecto de la densidad y el peso de la carga en el coste energético del tranporte de carga en burros y ponis

Resumen – Se diseñaron dos experimentos para comparar la energía consumida por burros y ponis durante el transporte de cargas. En el primer experimento se compararon 3 burros y 3 ponis utilizando cintas transportadoras en el Reino Unido. La densidad de la carga (plomo o paja) no tuvo efecto significativo sobre el consumo de energía; sin embargo, el coste energético por kilogramo de carga transportada disminuyó significativamente ($p < 0{,}001$) conforme aumentó el peso de la carga (en burros 6,44, 4,35 y 3,03 J/kg de carga/m, en ponis 5,82, 3,75 y 3,68 J/kg carga/m, para cargas de 13, 20 y 27 kg/100 kg de peso vivo (M) respectivamente). No hubo diferencias significativas entre ambas especies. En el segundo experimento se determinó el consumo de energía en 3 burros que transportaban cargas equivalentes a 40 kg/100 kg M en terreno con desniveles suaves en Túnez. El coste energético fue de 2,34 (SE 0,07) J/kg carga/m. Los resultados de ambos experimentos demostraron que – siempre y cuando la carga esté equilibrada – la densidad no afecta significativamente al consumo de energía; no obstante, el coste energético por kg de carga disminuye conforme el peso de la carga aumenta. Esto sugiere que en términos energéticos es mas eficiente transportar cargas equivalentes a 27–40 kg/100 kg M que transportar cargas de menos de 20 kg/100 kg M.