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THE EFFICIENCY OF UTILIZATION OF DIGESTIBLE ENERGY DURING SUBMAXIMAL EXERCISE

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Introduction

Two methods can be employed to calculate energy requirements for work: the factorial (analytical method) and the global method (feeding experiments) (Martin-Rosset and Vermorel, 2004). The factorial method estimates the energy cost of a specific bout of exercise based on its intensity and duration. This energy cost is then converted into a feeding recommendation based on an estimation of the efficiency of utilization of feed energy for exercise. The global method measures the amount of feed energy required by horses to maintain constant body weight while performing a specific amount of daily exercise.

The 1989 NRC uses both methods to describe the energy requirements for exercise. The global method of calculation was used by Anderson et al. (1983), where Quarter Horses were fed to maintain constant body weight while exercising at different intensities on a treadmill. These data were incorporated into an equation that estimates digestible energy requirements based on body weight and distance traveled. The NRC also cited a factorial equation from Pagan and Hintz (1986) that estimated digestible energy (DE) requirements based on measurements of energy costs at different speeds that were calculated from calorimetry measures made on horses walking, trotting, and cantering on a track. In this equation, DE requirements above maintenance were estimated assuming that the efficiency of utilization of DE for work was 57%. This value was based on the assumption that, since body fat is the primary substrate for energy generation in horses during low-intensity exercise, the DE efficiency value for fattening was also appropriate for exercise.

Both methods of calculating energy requirements have weaknesses. The exercise performed in the Anderson et al. (1983) study took place on an inclined treadmill, so translating it to other forms of work is questionable. The Pagan and Hintz (1986) study used oxygen consumption in horses exercised with and without riders, so its exercise intensity can be more easily applied to other types of exercise where VO2 has been measured or to horses ridden on flat ground. However, its predication of DE requirements was based on an assumption of efficiency of utilization of DE for work that was not validated with body weight measurements. Therefore, we designed a study to utilize both factorial and global methods to 1) determine the DE requirements for a measured amount of exercise; 2) determine the efficiency with which DE was utilized for work; and 3) develop a new equation to predict digestible energy requirements for exercise.

Materials and Methods

Three Thoroughbred geldings (520 kg ± 3.6 kg) were used in a 3x3 Latin square design. Each 35-day period was divided into a rest phase (14 days) and an exercise phase (21 days). During the rest phase of each period the horses were housed in box stalls with a minimum of 5 hours of turnout per day in a small paddock. Horses were muzzled while turned out to prevent grazing. During the exercise phase of each period, the horses performed a standardized regime of exercise on a high-speed treadmill and a mechanical horse walker. During this exercise phase, the horses continued to receive the same amount of turnout as during the rest phase.

EXERCISE SCHEDULE

During the exercise phase of each period, the horses performed an identical schedule of exercise on a high-speed treadmill and mechanical walker. The weekly exercise schedule consisted of 6 days of exercise on either the treadmill or the walker followed by a day with no forced exercise. The horses exercised every other day on the high-speed treadmill. This exercise bout consisted of a 5-min walk, 20-min trot (4 m/s), 6-min canter (7 m/s), 20-min trot (4 m/s), 6-min canter (7 m/s), and 5-min walk followed by a 15-min warmdown period on the walker. The trot and canter work was done at a 3-degree incline. On the alternate three days the horses exercised at 1.5 m/s for 1 hour on the mechanical walker.

NET ENERGY EXPENDITURE

During the third week of each exercise period, oxygen consumption was measured using indirect calorimetry during the last day of treadmill exercise. The amount of oxygen consumed above maintenance was estimated by subtracting 3 ml/kg BW/min from each oxygen consumption measurement. This is the amount of oxygen that horses would normally consume at rest. Oxygen consumption on the walker was assumed to be the same as when the horses walked at the same speed on the flat treadmill. Net energy expended during exercise was calculated by multiplying total oxygen consumption above maintenance by 4.863. This is the known energy equivalent per liter of O_2 consumed at a respiratory quotient of 0.85 (Maynard and Loosli, 1969).

DIETS AND DE INTAKES

The horses were fed a diet of unfortified sweet feed (45% cracked corn, 45% whole oats, and 10% molasses) and grass hay at a forage-to-grain ratio of 65:35. The horses also received 120 g of a vitamin-mineral supplement (Micro-Phase, KPP), 50 g loose salt, and 60 g electrolytes (Summer Games, KPP) daily. The digestible energy content of the diets was determined in each horse in a 5-day complete collection digestibility trial prior to the beginning of the first experimental period. The DE content of the diets equaled 2.26 ± .01 Mcal/kg on an as-fed basis.

During each period the horses were fed one of three feed intakes that supplied digestible energy intakes that ranged from near maintenance (16-17 Mcal DE/d) to 200% maintenance (Table 1). The sweet feed and supplements were fed in two meals at 6:30 AM and at 4 PM. Nosebags were used to prevent feed wastage. The grass hay was offered in three portions, two fed with the sweet feed and the third portion fed at 10 PM. All hay fed throughout the trial was taken from the same batch.

Table 1. Feed and DE intakes during each period.

	Period	*Sweet feed intake (kg)*	*Hay intake (kg)*	*Caloric intake (Mcal DE/day)*
Horse 1	1 Rest	4.0	8.0	27.2
	1 Exercise	4.0	8.0	27.2
	2 Rest	3.0	6.0	20.4
	2 Exercise	3.0	6.0	20.4
	3 Rest	2.5	5.0	17.0
	3 Exercise	3.5	7.0	23.0
Horse 2	1 Rest	5.0	10.0	33.6
	1 Exercise	5.0	10.0	33.6
	2 Rest	3.8	7.5	25.3
	2 Exercise	3.8	7.5	25.3
	3 Rest	2.5	5.0	16.8
	3 Exercise	4.0	8.0	26.9
Horse 3	1 Rest	4.0	8.0	27.4
	1 Exercise	4.0	8.0	27.4
	2 Rest	3.0	6.0	20.5
	2 Exercise	3.0	6.0	20.5
	3 Rest	2.5	5.0	17.1
	3 Exercise	3.5	7.0	23.9

BODY WEIGHT MEASUREMENTS

Horses were weighed daily before their 6:30 AM feeding. Average daily body weight changes during each phase of each period were estimated by regression analysis of body weight vs. days on trial. Weights from the first three days of each phase were not included in the analysis because weights may have fluctuated during this time due to changes in feed intake from the previous period.

Results

Body weight changes vs. caloric intake are listed in Table 2 and depicted graphically in Figure 1. When the horses were unexercised, they gained weight at every level of energy intake. During exercise the horses lost weight at all but the highest DE intake. Regression analysis of these data suggests that these horses would require 30.57 kcal DE/kg BW/d to maintain body weight at rest and 61.46 kcal DE/kg BW/d to maintain body weight during exercise. For a 500-kg horse this translates to 15.3 Mcal DE/d for maintenance and 30.7 Mcal DE/d for exercise.

Table 2. Body weight changes and DE intake.

	Period	*Avg BW (kg)*	*Avg BW change (kg/d)*	*Caloric intake (Mcal DE /day)*	*Avg BW change (g/kg BW/d)*	*Caloric intake (kcal DE/kg BW/d)*
Horse 1	1 Rest	522	1.112	27.24	2.130	52.2
	1 Exercise	525	-0.200	27.24	-0.381	51.9
	2 Rest	531	0.264	20.43	0.497	38.5
	2 Exercise	532	-0.475	20.43	-0.893	38.4
	3 Rest	522	0.097	17.025	0.186	32.6
	3 Exercise	516	-0.415	23.835	-0.804	46.2
Horse 2	1 Rest	522	1.288	33.6	2.468	64.4
	1 Exercise	525	0.037	33.6	0.070	64.0
	2 Rest	533	0.479	25.312	0.899	47.5
	2 Exercise	531	-0.346	25.312	-0.652	47.7
	3 Rest	523	0.325	16.8	0.621	32.1
	3 Exercise	517	-0.194	26.88	-0.375	52.0
Horse 3	1 Rest	508	1.147	27.36	2.258	53.9
	1 Exercise	510	-0.037	27.36	-0.073	53.6
	2 Rest	510	0.054	20.52	0.105	40.2
	2 Exercise	510	-0.353	20.52	-0.692	40.2
	3 Rest	503	0.114	17.1	0.227	34.0
	3 Exercise	501	-0.279	23.94	-0.557	47.8

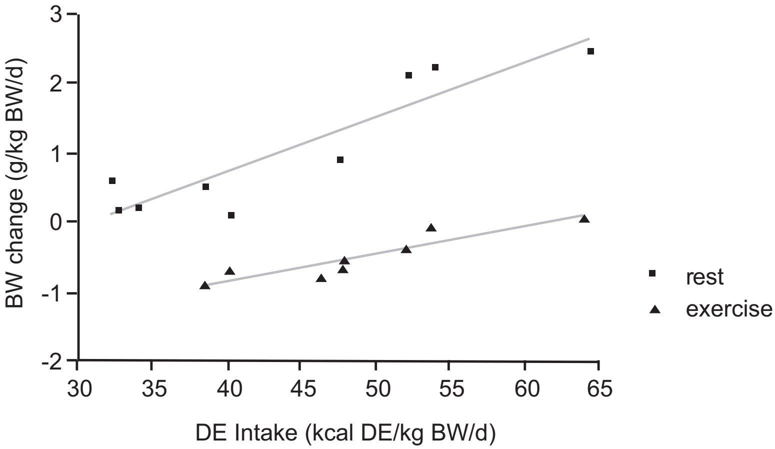

Figure 1. Body weight changes and DE intake.

Table 3 illustrates the quantity of oxygen consumed and NE expended by a horse during one day of treadmill exercise and one day of exercise on the walker. Average daily NE expenditure was calculated by multiplying these values by 3 (the number of days of each type of exercise) and dividing by 7 (number of days in a week). Table 4 contains the average daily NE expended by each horse during each exercise period. The horses expended an average of 7.87 ± .26 kcal NE/kg BW/d above maintenance during exercise. This equals 3.94 Mcal NE/d for a 500-kg horse.

Table 3. Oxygen consumed and NE expended by one horse during one day of treadmill exercise and one day of exercise on the walker.

	Type of exercise	*Speed (m/s)*	*VO_2 ml/kg/min*	*Extra O_2 consumed ml/kg/min*	*BW*	*Extra O_2 consumed l/min*	*NE Kcals/ min*	*Exercise duration (min)*	*NE expended per exercise period (Kcals)*
Treadmill day	walk (flat)	1.5	16.25	13.25	510	6.76	32.87	5	164.33
	trot (3°)	4.0	45.87	42.87	510	21.86	106.32	5	531.58
	trot (3°)	4.0	40.16	37.16	510	8.95	92.15	5	460.75
	trot (3°)	4.0	44.41	41.41	510	21.12	102.70	5	513.48
	trot (3°)	4.0	46.65	43.65	510	22.26	108.27	5	541.34
	canter (3°)	7.0	71.41	68.41	510	34.89	169.67	6	1018.02
	trot (3°)	4.0	44.39	41.39	510	21.11	102.65	5	513.27
	trot (3°)	4.0	43.62	40.62	510	20.71	100.73	5	503.67
	trot (3°)	4.0	40.16	37.16	510	18.95	92.15	5	460.75
	trot (3°)	4.0	43.73	40.73	510	20.77	101.02	5	505.08
	canter (3°)	7.0	72.79	69.79	510	35.59	173.09	6	1038.57
	walk (flat)	1.5	17.06	14.06	510	7.17	34.87	5	174.34
	walk (walker)	1.5	16.66	13.66	510	6.96	33.87	15	508.00
Walker day	walk	1.5	16.66	13.66	510	6.96	33.87	60	2032.01

Table 4. Daily NE expenditure above maintenance during exercise.

Horse	*Period*	*NE (kcal/d)*	*BW (kg)*	*NE (kcal/kg BW/d)*
Horse 1	1	4473	525	8.52
	2	4433	532	8.33
	3	4795 5	516	9.29
Horse 2	1	4298	525	8.19
	2	3954	531	7.45
	3	3501	517	6.77
Horse 3	1	3824	510	7.50
	2	3842	510	7.53
	3	3635	501	7.26

One way to calculate the efficiency of utilization of DE for work is to divide the extra amount of DE required for work (DE_{work}-$DE_{maintenance}$) by the NE expended for that work. Using this method, the DE from this study would have been used with an efficiency of just 25.5% (Table 5). This is a much lower efficiency than the value of 57% used in the equation of Pagan and Hintz (1986). Martin-Rosset and Vermorel (2004) suggested that exercise increased the maintenance energy requirement by 10-20%. Increasing the maintenance DE requirement by 10% results in an efficiency of DE for work of around 28% (Table 5).

Table 5. Efficiency of utilization of DE for work.

	Maintenance DE (kcal/kg BW/d)	*Exercise DE (kcal/kg BW/d)*	*DE (work) (kcal/kg BW/d)*	*NE (kcal/kg BW/d)*	*DE efficiency*
Maintenance	30.57	61.46	30.89	7.87	25.5%
110% Maintenance	33.63	61.46	27.83	7.87	28.0%

The amount of DE required per kg of body weight gain was very different at rest vs. during exercise. Horses required 25.6 Mcal DE per kg of gain during exercise, but only 12.8 Mcal DE/kg of gain at rest. If the efficiency of utilization of DE for gain during rest equaled 57%, then each kg of gain would equal 7.3 Mcal/kg. If the same energy content of gain was used for exercise, then the efficiency of DE for gain would equal 28.5%. This study suggests that the efficiency of utilization of DE by horses for work is significantly lower than during rest. This is contrary to the assumptions currently used to calculate energy requirements for work factorially. More research is needed to determine the various factors that affect this efficiency. Particularly, the effects of breed, diet composition, and exercise duration and intensity warrant further investigation. Until these factors can be quantified, the global method of calculating energy requirements is preferable in developing practical feeding standards for performance horses participating in different disciplines.

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