The energy requirements of performance horses in training

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ABSTRACT: The aim of this study was to estimate the energy requirements of performance horses in active, variable training in the field. Sixty horses in England and Switzerland were measured over 2-wk periods and, for 15 of these, the measurement period was extended, ranging from 21 to 42 wk. Energy intake was estimated by measuring daily feed consumption. Energy output was measured using heart rate (HR) monitors during 608 training sessions, relating HR to volume of oxygen (VO_2) and converting VO_2 to energy. Field maintenance requirements were calculated by deducting the marginal energy cost of training from energy input. The mean field maintenance expenditure for performance horses with a normal temperament was found to be 0.118 MJ of metabolizable energy (ME) per kilogram of body weight (BW) per day (SD = 0.008, CI = 0.005, n = 60 horses). This result is between 1.9% (P = 0.086) and 20.9% (P < 0.001) greater than the official guidance found in the United States, France, Germany, and Holland. Heart rate monitoring of training revealed a mean energy expenditure (EE) per ridden session of 0.023 MJ ME (SD = 0.001, CI = 0.001, n = 175 training sessions). The mean daily EE for exercise based on a full week's training was 0.018 MJ ME/kg BW/d (SD = 0.005, CI = 0.001, n = 60 horses), representing a multiple of maintenance of 15.3%. This implies that the official guidance in the United States and France may overstate expenditure for exercise by 111% and 15%, respectively (P < 0.01). Daily EE between countries and within disciplines was consistent, allowing for the creation of user-friendly tables that can be used in budgeting the energy component of diets.

Key words: energy balance, equine, equine obesity, exercise, maintenance, nutrition model

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EQUATIONS USED IN THIS STUDY

Digestible energy (DE) was calculated according to the methodology of the NRC (2007, p. 4) where DE/Mcal/kg DM = 4.22 − 0.11 × (%ADF) + 0.0332 × (%CP) + 0.0012 × (%ADF^2).

Metabolizable energy (ME) was calculated from DE by deducting estimated renal losses (per gram of protein, 0.008 MJ were deducted from DE) and methane energy losses (per gram of crude fiber, 0.002 MJ were deducted from DE) according to Kienzle and Zeiner (2010) and Hipp et al. (2017).

Converting DE to ME for the purpose of comparing different national systems, the formula DE × 0.8318 = ME was used. This factor is the mean ME/DE ratio from the 60 diets in this study.

Unité Fourragère de Cheval (UFC) was converted to ME using INRA's ME value of 1 kg of barley, 12.05 MJ, and converting metabolic body weight (MBW) to body weight (BW) on the basis of a 500-kg horse.

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Energiewaarde paard (EWpa) is converted to ME using the CVB's ME value of 1 kg of oats, 11.4 MJ, and converting MBW to BW on the basis of a 500-kg horse.

Metabolizable energy expenditure (EE) during exercise (MEe) was calculated from Coenen's (2010) formula (MEe in J/kg BW/min) = [(0.0566 × $HR^{1.9955}$) – 68]. Sixty-eight joules ME/kg BW was this study's finding for the EE of standing still per minute.

INTRODUCTION

The energy requirements for the maintenance and training of performance horses have been assessed from feeding trials and indirect calorimetry trials. These include Winchester (1943), Wooden et al. (1970), Pagan and Hintz (1986a), Stillons and Nelson (1972), Anderson et al. (1983), Pagan and Hintz (1986b), Vermorel et al. (1990), Martin-Rosset and Vermorel (1991), Vermorel et al. (1997a), Vermorel et al. (1997b), and Coenen et al. (2011). More recently, authors have assessed the energy requirements for weight gain, including Cordero et al. (2013), Ferjak et al. (2017), and Zoeller et al. (2019).

There are currently four major sources of guidance for determining the energy requirements of horses in Europe and North America, which rely, to an extent, on the trials cited above. The most widely used for guidance for the EE for maintenance (metabolizable energy expenditure for maintenance, MEm) is that of National Research Council of the National Academies (NRC, 2007) and is based on DE. The German guidance (Coenen, et al. 2011) was updated and improved with the development of a ME system incorporating predictive equations for renal and methane energy losses based on MBW. France's system (INRA, 2012) is based on metabolic chamber and field studies and is the most comprehensively researched. It uses the UFC energy unit. In 2016, the CVB (Central Bureau, Livestock Feeding, Netherlands) adopted a net energy (NE) system (EWpa) for horses, which is similar to the French system and uses a standard value of oats as the energy unit (Blok, 2016). With the exception of the NRC (2007), the systems described above do not make recommendations based on training disciplines (such as racing, endurance, or the Olympic disciplines), even though disciplines can differ significantly in terms of their metabolic demand and the breed of horses involved. The NRC, INRA, and CVB recommendations for EE for exercise (Metabolizable energy expenditure for exercise [MEe]) are impractical for use by owners and trainers because it is difficult to map actual training to the systems. So far, none of the systems' guidance for the energy requirements of exercise is based on discipline-specific HR data gathered in the field.

Although equine HR monitors have been in use for over 20 yr, recent improvements in monitors and their software have increased accuracy and reliability for measuring HR, speed, pace, altitude, and location of horses in field training, enabling this study. The formulas for the conversion of HR to EE in horses using indirect calorimetry are well established (Coenen, 2010 and Robergs and Burnett, 2003), with further validation in the present study. Recommendations for MEe based on treadmill studies, in a lab, without a rider cannot take into account all the inherent variables associated with exercising horses outdoors. These shortcomings can be overcome by using HR monitors in the field.

The aim of this study was to monitor the energy requirements of Swiss and English horses in training for common levels of dressage, show jumping, and eventing (hereafter, referred to as the Olympic disciplines), developing a user-friendly/owner-centric method for monitoring EE in order to achieve energy balance throughout a long competition season.

The objectives of the present study were to:

1) estimate the energy intake of 60 horses across two countries;
2) estimate MEm and MEe to assess energy requirements, differentiating between disciplines and types of training; and
3) create new user-friendly tables to enable horse owners to estimate the maintenance and exercise requirements of their individual horses.

MATERIALS AND METHODS

Experimental Procedures Involving Animals

The experimental procedures were approved by the Royal Agricultural University's Animal Ethics Committee.

Approach

This study measured 60 horses for 2-wk periods with the primary aim of establishing the energy requirements of maintenance and exercise, differentiating between disciplines and types of training. Fifteen of those horses were chosen for extended measurement periods ranging from 21 to 42 wk with the primary aim of validating the findings related to the energy requirements of maintenance. Fifty-six of the horses were owned by their amateur riders. Thirty of the horses were kept in three yards in Switzerland and the other 30 were kept in three yards in England. All but one were professionally managed yards focused on competing at various levels in the disciplines detailed above. A profile of the horses by discipline is set out in the Table 1.

A summary of the breeds of the horses included in this study is set out in the Table 2.

All horses were individually stabled in their home boxes, with a mean area of 16 m^2, with 28 horses bedded on wood shavings or derivatives and the others bedded on wheat straw. Welfare assessments in accordance with the UK Department for Environment, Food and Rural Affairs (DEFRA) Code of Practice for the Welfare of Horses, Ponies, Donkeys and their Hybrids (DEFRA, 2018) were made on the first day the authors came into contact with a given horse and, then, weekly during body condition and BW recording. All horses were judged to be in appropriate health for their competitive demands.

Management of the Study

The 2-wk monitoring took place between the months of July and mid-December in 2016 and 2017 and between January and August in 2019. Five to six horses were included in each separate sequential cohort so that a single person could manage the entire study. With the exception of four inactive horses used as controls, all horses were in active training, with 33 in competition during the study. Horses were recruited on the conditions that 1) they had been in active, constant training over the previous 2 mo, 2) their training programmes, BW, and diets had been stable for the past 30 d, and 3) pasture did not constitute a material portion of their energy input.

In order to validate the maintenance requirement findings, 15 of the horses were selected for extended monitoring beyond the 2-wk periods. They were selected with the intention of achieving a balanced representation of the full 60-horse cohort in terms of country, discipline, and breed and included the four controls. Continued inclusion in the study ranged from 21 to 42 wk and was dependent on the sustained soundness of the horse and the length of time the owner maintained the horse in energy balance without its receiving a material level of energy from pasture.

Table 1. Description of horses included in this study

Discipline	*n*	Sex			Mean age	Age range	Mean BW	BW range	Mean BCS	BCS range	Competitive level			
		S	G	M	yr	yr	kg	kg	(1–9)	(1–9)	Int.	Nat.	Reg.	None
Dressage	10		9	1	10.8	4–16	637	582–737	6.1	5.0–7.0	6	2	2	0
Eventing	5		4	1	7.6	4–12	540	483–598	5.4	5.0–6.0	0	0	5	0
Show jumping	15		7	8	11.1	5–18	551	477–656	5.6	4.0–7.0	0	4	11	0
All rounders	26	1	18	7	11.9	5–22	566	378–692	6.1	4.0–7.5	0	0	3	23
Inactive	4		4		16.0	10–20	574	504–638	6.0	5.0–6.5	0	0	0	4
Total	**60**	**1**	**42**	**17**	**11.4**	**4–22**	**573**	**378–737**	**5.9**	**4.0–7.5**	**6**	**6**	**21**	**27**

G, gelding; M, mare; S, stallion.

BCS = body condition score utilizing the methodology of Henneke et al. (1983). Competitive levels: Int. = international, Nat. = national, Reg. = regional. "All rounders" refers to horses involved in dressage, jumping, and trail riding. Bold values indicate the most important data.

Table 2. Breeds of horses included in this study

Irish sporting horse	10
German Warmblood	9
Selle Francais	9
Dutch Warmblood	6
Swiss Warmblood	4
TB	4
Welsh	3
KWPN	2
Connemara × TB	2
Connemara	1
Cleveland Bay × TB	1
Danish Warmblood	1
Trakehner × TB	1
Fresian	1
ISH × Trakehner	1
Lusitanian	1
Oldenberg × TB	1
Registered Irish Draft	1
Trakehner	1
Welsh × Lusitanian	1
	60

Bold value indicates the total.

Horse Measurements

Body weight (using an Equiscales 3-part portable Equine Scale, Equiscales Ltd, Doncaster, UK), key dimensions (sternum height, heart girth, body length, and front pelvis width), and body condition score (BCS; nine-point scale of Henneke et al. 1983) were recorded for each horse on the day it entered the study on a weekly basis and on the day it exited the study.

Measurement of Energy Intake

Diets fed to each horse were the same individualized diets that had been fed for the 30 d prior to the study. Manufactured feed was rationed using standard measures (Stubbs scoops, etc.) and weighed (using an Allweigh, UK, 10-kg hanging scale). In 2016 and 2017, hay or haylage was stuffed in haynets and weighed (using the Allweigh scales and deducting the weight of the haynets). In 2019, hay was measured out using a "smart forage wagon" invented by the author and constructed by Equiscales Ltd, Doncaster, UK, which records the weight of the hay removed from the wagon to the nearest 10 g, which facilitated accurate measurement with minimal effort. The accuracy of the weights of nonforage feed and hay fed in haynets was controlled by the authors at the start of the study and then every 3 d throughout the study on a random basis to ensure that the correct quantities were being fed and to record refusals. The level of refusals of nonforage feed was 0 and the mean refusals of forage were deducted from total forage fed.

Thirty-two of the 60 horses (53%) were bedded on wheat straw. Based on the amount of hay refused, discussions with owners, and observation by the authors, straw consumption was estimated at 0, 1, or 2 kg/d. There was no significant difference between the measured energy consumption between the horses bedded on straw or wood shavings ($P = 0.409$).

Energy values were calculated in terms of ME since DE systems overestimate the energy value of forage by about 15% (INRA, 2012). All forage (20 different batches) was analyzed by the Irish Equine Centre (Naas, Republic of Ireland) which reported dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF) content, and ash. This data was used to calculate the DE content utilizing the methodology of the NRC (2007, p. 4), where $\text{DE/Mcal/kg DM} = 4.22 - 0.11 \times (\%\text{ADF}) + 0.0332 \times (\%\text{CP}) + 0.0012 \times (\%\text{ADF}^2)$. Digestible energy values were then converted to ME by estimating renal losses (per gram of protein, 0.008 MJ were deducted from DE) and methane energy losses (per gram of crude fiber, 0.002 MJ were deducted from DE) according to Kienzle and Zeiner (2010) and Hipp et al. (2017).

The energy values for processed feed for 23 of the Swiss horses were calculated using the same methodology as the forage calculations. The other 37 horses had a greater variation in processed feed (59 different feeds in total) and, consequently, the energy values were sourced from the manufacturers' published nutritional data. For four forage-based feeds, manufacturers disclosed ranges of energy values; in those cases, the value used was the mid-point of the range. These were limited to <10% of the diets of four horses. The remainder were reported as absolute values, not minimums. In, virtually, all cases, energy data was provided on a DE basis calculated by the manufacturers using formulae similar to that described above (NRC, 2007). These DE values were converted to ME using the formulas described above. The ME content of nonprocessed/nonforage feeds was derived from INRA's (2012) tables of chemical and nutrient composition of feedstuffs (principally apples and carrots mainly fed as treats).

Conventions Used in Both Studies

Metabolizable energy expenditure for maintenance (MEm) in this study is field maintenance expressed in MJ ME. It is defined here as the maintenance requirement of the horse over a 24-h period for all activities other than specific training activities. MEe in this study is the EE for exercise during specific training periods with a deduction of the EE of standing still (see below). MEm plus MEe equals the total energy expended by the horse. Time spent on horse walkers >30 min was classified as a training activity, whilst shorter sessions were included in field maintenance. All references to BCS use the nine-point scale of Henneke et al. (1983)

EE for Exercise

Estimated MEe, expressed in MJ ME, was based on data acquired during training using Polar equine heart rate (HR) monitors employing Polar H7 electrode units (Polar Electro Oy, Kempele, Finland), recording average HR, speed, pace, and GPS maps. These were fitted on the left side of the horse in accordance with the manufacturer's instructions with one paddle placed under the saddle and the other attached to the girth strap. These were connected via Bluetooth to the Polar watch on the rider's wrist. L'Oreal Lisse Unlimited Serum was used as a lubricant under the paddles (leaves no residue). Recording started when riders left the stable and stopped when they returned.

A diary of all training activities including duration was maintained for each horse. Every type of training session in the diary was monitored for each horse (hacking, longeing, arena work, jumping, work on a gallop (track), cross-country, and coached sessions). Most owners used a mix of three of these training methods (most commonly a combination of arena, longeing and hacking, or gallop if they had access to a track). The recorded sessions were used to estimate the total EE for each week the horse was included in the study. For the 15 horses included in the extended study, a significant number of the training sessions were repetitive with immaterial differences in measured MEe and, consequently, MEe could be estimated for certain types of sessions using the detailed diary entries and the previously collected data from the same horse. In total, 607 training sessions were monitored.

According to Frape (2010) and Coenen (2008), a strong relationship exists between oxygen (O_2) consumption and HR, and HR is more easily measured than O_2 consumption. A closer relationship exists with percentage of maximum HR (Frape 2010), and the best estimates of individual EE are produced by individual O_2 consumption/HR curves. It was impractical to measure maximum HR or O_2 consumption in a field setting with warmblood horses that were never pushed to their maximum HR. Consequently HR was converted to EE by applying Coenen's (2008) formula. The formula uses the assumption that the heat equivalent of O_2 at a respiratory quotient (RQ) of 0.84 is on average 20.1 J/mL volume of O_2 (VO_2). Using 569 paired data, Coenen (2008) defined a nonlinear relationship between VO_2 and HR ($r^2 = 0.911$). The resultant equation is: MEe (J/kg BW/min) = $0.0566 \times HR^{1 \cdot 9955}$, which was used in this study to calculate MEe. The RQ of 0.84, which corresponds to a mixed diet of carbohydrate, protein, and fat, is consistent with the diets in this study. The calculated EE reflects the adenosine triphosphate (ATP) production for muscle energy. According to Coenen (2010), we can take the calculated values as ME because the conversion of this chemically organized energy into kinetic energy is associated with high heat losses.

The anaerobic component of exercise was estimated whenever HR exceeded 170 beats per minute (bpm) using the methodology of Coenen (2010), which estimates the degree of anaerobic energy metabolism on the basis of lactate accumulation in the blood. Modeling a lactate accumulation curve allows the estimation of the portion of total EE that is anaerobic. The assumption was made that all horses in the study were of average fitness and, therefore, utilizing a curve corresponding to a lactate accumulation of 5.8 mmol/min when speed is 28.8 kph and HR is 180 bpm was appropriate.

Coenen's formulas yield an estimate total EE during exercise. MEe required a deduction for maintenance during the exercise bout to avoid double counting since EE of maintenance in this study is measured as the difference between total energy input minus energy expended for exercise. Winchester (1943) found that EE for standing was less than EE for horses in a lying position and so EE for standing was deducted. This was derived from respiratory studies by Fortier et al. (2015), Coenen (2010), Minetti et al. (1999), Eaton (1994), Winchester (1943), and INRA (2012). A standard rate of 68 J ME/kg BW/min (equivalent to 0.098 MJ ME/kg BW/24 h) was used. The result after the deduction for standing still, expressed in ME, is referred to below as "HR-derived MEe".

This study introduces a metric, "exercise ratio", which is calculated as the daily EE for exercise divided by the standard EE for 24 h. As calculated above, it allows for the comparison of training effort from week to week between individual horses and between groups of horses and can also be used on a daily basis to guide training for a week.

Comparison of MEe Findings With Other Studies

For all 56 horses in active training, MEe was computed using three methodologies: NRC (2007), INRA's (2012), and the HR-derived MEe described above. The results were compared to explore the range of outcomes depending on the system used.

The NRC methodology (NRC, 2007) required an analysis of time allocation to gaits, minutes trained, and average HR for a week's training in order to ascribe a workload category of light, moderate, heavy, or very heavy. Depending on the category, the following NRC equations were applied to arrive at MEe: for light work, DE (Mcal/d) = (0.0333 × BW) × 0.20; for moderate work, DE (Mcal/d) = (0.0333 × BW) × 0.40; for heavy work DE (Mcal/d) = (0.0333 × BW) × 0.60; and, for very heavy work, DE (Mcal/d) = (0.0363 × BW) × 0.90.

The INRA methodology (INRA, 2012) is based on daily training and required an analysis of the time allocation to gaits and an assessment of intensity for each training session, differentiating between "open-air work" and work done in an arena. Actual work done was mapped to INRA's energy cost of 1 h of work (INRA, 2012, p. 237), expressed in UFC, which was multiplied by an elapsed time factor and converted to ME using the French standard ME value of 1 kg of barley, 12.05 MJ. For example, a "short, light ride" in the open air for 45 min would require 1.5 UFC × 45/60 × 12.05 = 13.6 MJ ME for a 500-kg horse.

In addition to the NRC and INRA methodology, the Dutch CVB (Blok, 2016) system was also compared. This is based on the findings of Pagan and Hintz (1986b) and provides a formula for converting speed into NE expenditure. The system requires the allocation of training time to speed bands that correspond to gaits. This was easily computed since Polar output includes elapsed time in customizable speed bands. Minutes spent in each speed band are multiplied by the appropriate EWpa factor. For example, the formula for ME expenditure at a trot for 1 min (guideline speed 240 m/min) is: MEe (J ME/min/kg BW) = 0.0392 Ewpa/1000 × 11,448 = 447 J, where the conversion factor from Ewpa to kJ ME is 11,448. From a practical perspective, this system is limited to training on a track or a gallop and, consequently, this methodology was applied to each of the 31 training sessions on a gallop and the resultant MEe was compared with this study's HR-derived MEe for those sessions.

EE for Field Maintenance

Energy expenditure for field maintenance was estimated by deducting the MEe from the ME value of total feed intake.

Data Analysis

Sixty different diets were analyzed over 457 horse weeks (∑ number of weeks each horse was included in the study), including 20 different batches of hay or haylage and 59 other feeds. Energy input was computed for 60 horses over the 2-wk periods and 176 complete training sessions were monitored with HR monitors for the 56 active horses during these periods. The MEe for the various gaits (walk, trot, canter, and gallop) was determined by identifying changes in speed to determine the gait and then aggregating the second-by-second MEe in each gait to compute means of MEe per minute per gait. For the 15 horses in the extended study, energy input and MEe were computed over 357 horse weeks and 432 complete training sessions were monitored with HR monitors. Inclusion of horses in the extended study was limited to periods during which they maintained energy balance, which was defined as those periods covered by a flat trend line on a graph of weight vs. MEm ($r^2 < 0.001$).

In order to compute the MEe for each horse, training session data from HR monitors was uploaded to Polar using the Polar Flow Synch Application (Polar Electro Oy, Kempele, Finland), and Excel spreadsheets (Microsoft Office Home and Business 2013) were downloaded from Polar Flow, which reported elapsed time, HR, speed, pace, cadence, altitude, distance, and temperature for each second recorded. This data was then entered into an Excel-based data sheet producing 46 different analyses, including second-by-second and meter-by-meter aerobic and anaerobic energy consumption by gait. Means of MEe per kilogram BW per minute and per meter were sorted by discipline, training activity, and gait.

Mean daily MEm was computed as the difference between energy intake and MEe for each horse. This was sorted by discipline, horse temperament, active or inactive training status, age, and BCS to provide the means underlying this study's conclusions for MEm. These were calculated on both an MBW and BW basis and to facilitate comparison with the four official systems that use different bases.

Statistical Justification of Sample Sizes

The statistical objective was for the margin of error to be acceptable in the context of equine diet formulation for healthy horses. A "margin of error" (MOE) was used to assess the reliability of the means and was calculated as the radius of the CI with α set at 0.05 and has been expressed as a percentage of the mean. A 5% MOE was considered acceptable for maintenance energy requirements, and a 20% MOE was chosen for exercise energy requirements (since MEe is generally limited to less than 20% of MEm). These choices dictated the sample sizes for the calculation of means.

Effect size was defined here as the mean difference between this study's findings and the NRC (2007) guidance and was estimated as >15% based on a pilot study involving four horses. Student's *t*-tests and analysis of variance were used for comparative analysis, with α set at <0.05. Sample size was dictated by setting the power ($1 - \beta$) at >0.8. Power was calculated using the formulas of Cohen (1988) and is detailed in Tables 6 and 10.

RESULTS

Training Regimes

The results of the monitoring of the training sessions were sorted by the main discipline for which the horse was being trained and are presented in Table 3 below. The table excludes the four inactive horses and the two oldest horses that were trained for significantly shorter periods than the others. All horses worked to weekly training programmes with a high degree of repetition week after week, with a mix of hacking, arena work, longeing, work on a gallop, or cross-country course if it was available and discipline-specific work (cross country, jumping, and dressage figures) with 1 or 2 d off. Therefore, the results in Table 3 are stated as weekly values, except for the last column. The last column is stated as the mean MEe per kilogram BW per day after deducting an estimate of EE for standing still and includes days off, making it the appropriate value to use as an estimate of the daily allowance for exercise in diet formulation.

With the exception of "eventing" (small sample size), the MOEs are all below 10% for duration, mean HR, intensity, distance, and mean MEe. The only significant variances between groups occurred in the categories "distance" and "allocation to gaits." There were no significant differences for EE between groups or within groups.

EE for Exercise

The results from the monitoring of the training sessions during the 2-wk study were sorted by training activity and are presented in Table 4 below. The sample comprises one training session for each type of work (activity) undertaken by each of the 56 horses in active training. Table 4 reports MEe after deducting an estimate of EE for standing still and, therefore, represents the marginal energy cost of training. The mean intensity and EE are higher for the sessions in Table 4 than the training regimes in Table 3 because Table 3 captures weekly training regimes and, therefore, includes days off.

With the exception of longeing, the MOEs for MEe expressed in joules per kilogram BW per minute are all <7%, underlining the potential for using this metric in calculating MEe for energy budgeting in diet formulation. Longeing was excluded from the analysis of differences between groups. It was by far the most intensive activity in terms of EE per minute of training; however, it was the least intensive in terms of EE per training session due to the shorter duration of longeing sessions.

MEe per minute was analyzed down to the level of the distinct gaits (walk, trot, canter, gallop, and "other", which includes dressage figures and jumping activities not fitting neatly into the description of the classic gaits). This is summarized in Table 5 below.

This Study's Results for MEe Compared to the NRC, INRA, and CVB Recommendations

The methodology of the NRC (2007), INRA (2012), and the CVB (Blok, 2016) was used to recompute the MEe for the 56 horses in active training during the short-term part of the study. These computations were compared to the HR-derived MEe in order to explore the range of outcomes depending on the system used. The results of this comparative analysis are set out in Table 6 below. The means of the individual differences between the official systems and the HR-derived MEe illustrate the wide range of outcomes that are solely a function of the choice of guidance system.

Nutrient Intake

The mean nutrient intake for each horse was sorted by the horse's principal training discipline and is presented in Table 7 below, which separates the data into the relative contributions of forages/chaffs and other feeds. Horses in training for specific disciplines consumed significantly less forage ($P < 0.05$) than the all-rounder and inactive horses. Mean EE for exercise in Table 7 is identical to that derived from the weekly training regimes (Table 3). Inactive horses were longed and exercised on a

Table 3. Weekly training regimes for 54 sporthorses in training for dressage, eventing, showjumping, and general sporthorse training: reporting means of duration, average HR, training ratio, distance, energy expenditure, and allocation of gaits per week

		Duration	Mean HR		Distance	Time allocation to gaits (% of session)				Mean MEe
Training discipline	*n*	min/wk	bpm	Exercise ratio	km/wk	Walk	Trot	Canter	Other	MJ ME/kg BW/d
Dressage	**10**	**262**	**96**	**19.5%**	**24**	**45%**	**12%**	**3%**	**41%**	**0.0180**
SD		39.5	7.8	4.5%	4.3	13%	11%	4%	24%	0.0038
MOE		5.4%	2.9%	8.3%	6.4%	10.4%	34.3%	41.0%	21.1%	7.6%
Eventing	**5**	**284**	**93**	**21.2%**	**31**	**62%**	**21%**	**8%**	**10%**	**0.0199**
SD		35	9	7.6%	7	11%	7%	3%	8%	0.0059
MOE		7.7%	5.9%	22.2%	14.4%	11.3%	21.0%	27.6%	51.4%	18.6%
Jumping	**15**	**331**	**92**	**23.3%**	**37**	**63%**	**19%**	**12%**	**6%**	**0.0208**
SD		79.1	7.2	6.7%	11.3	7%	5%	7%	6%	0.0063
MOE		6.4%	2.1%	7.7%	8.0%	3.2%	6.5%	15.3%	26.7%	8.1%
All rounders	**24**	**291**	**90**	**19.6%**	**33**	**63%**	**20%**	**12%**	**5%**	**0.0177**
SD		71.1	11.8	4.8%	6.6	15%	9%	7%	9%	0.0037
MOE		5.2%	2.8%	5.2%	4.3%	5.0%	9.2%	11.7%	36.2%	4.5%
All horses	**54**	**294**	**91**	**20.5%**	**32**	**59%**	**18%**	**9%**	**13%**	**0.0185**
SD		70.6	9.9	6.0%	9.6	14%	9%	6%	19%	0.0051
MOE		3.2%	1.4%	3.9%	4.0%	3.2%	6.6%	9.0%	18.5%	3.7%
P value		$P = 0.09$	$P = 0.40$	$P = 0.21$	$P \leq 0.01$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P = 0.20$

n = number of sessions, HR = heart rate in beats per minute. Exercise ratio = daily energy expenditure of exercise/the standard energy expenditure for standing still for 24 h. "Other" includes galloping, complex dressage figures, and jumping, which do not fall neatly into the walk, trot, and canter gaits. Table excludes two low-activity horses and four inactive horses. *P* values, with alpha set at 0.05, denote the significance of variation between the activities. Bold values indicate the most important data.

Table 4. Means of duration, exercise ratio, maximum speed, distance, mean HR, maximum HR, energy consumption, and allocation of training time to gaits for 56 sporthorses in training

		Duration	Exercise ratio	Max speed	Distance	Time allocation to gaits (% of session)				Mean HR	Max HR	ME Expenditure	
Training activity	*n*	min	%	km/h	km	Walk	Trot	Canter	Other	bpm	bpm	MJ/kg BW	J/kg BW/min
Flatwork, mean	**46**	**51.7**	**23.1%**	**21.9**	**5.6**	**57%**	**29%**	**12%**	**2%**	**90**	**168**	**0.0216**	**440**
SD		19.0	9.3%	7.4	2.3	10%	10%	9%	4%	13	29	0.0087	167
MOE		5.5%	6.0%	5.0%	6.1%	3%	5%	11%	38%	2.1%	2.6%	6.0%	5.6%
On the gallop	**36**	**49.0**	**25.9%**	**26.1**	**6.3**	**59%**	**26%**	**11%**	**4%**	**97**	**173**	**0.0241**	**516**
SD		12.5	7.6%	9.4	1.3	15%	10%	7%	9%	14	28	0.0070	181
MOE		4.3%	5.0%	6.1%	3.6%	4%	7%	10%	40%	2.4%	2.7%	4.9%	5.9%
Jumping	**22**	**53.7**	**25.5%**	**25.2**	**5.55**	**52%**	**14%**	**8%**	**26%**	**90**	**171**	**0.0236**	**442**
SD		22.8	14.4%	4.42	3.00	15%	11%	12%	20%	10	24	0.0133	109
MOE		9.4%	12.5%	3.9%	12.0%	6%	18%	32%	17%	2.4%	3.2%	12.5%	5.5%
Hacking	**42**	**53.4**	**24.4%**	**23.6**	**5.6**	**83%**	**11%**	**5%**	**0%**	**90**	**170**	**0.0226**	**436**
SD		14.2	11.1%	11.6	1.8	13%	12%	5%	1%	16	37	0.0102	190
MOE		4.1%	7.1%	7.6%	5.0%	2%	17%	15%	53%	2.7%	3.4%	7.0%	6.8%
Dressage	**24**	**46.5**	**22.8%**	**15.5**	**4.2**	**47%**	**21%**	**3%**	**28%**	**94**	**168**	**0.0214**	**457**
SD		11.7	9.6%	2.4	1.0	14%	21%	6%	29%	11	30	0.0090	129
MOE		5.3%	8.9%	3.3%	5.2%	6%	21%	42%	22%	2.5%	3.8%	8.8%	6.0%
Longeing	**18**	**31.1**	**19.1%**	**12.5**	**1.5**					**98**	**180**	**0.0181**	**609**
SD		7.7	7.3%	3.7	0.5					29	30	0.0067	251
MOE		6.1%	9.5%	7.3%	8.8%					7.5%	4.1%	9.3%	10.3%
All ridden activ.	**175**	**50.8**	**24.0%**	**22.5**	**5.5**	**63%**	**20%**	**8%**	**9%**	**92**	**170**	**0.0223**	**456**
SD		16.6	10.4%	9.09	2.06	19%	15%	9%	18%	14	31	0.0096	170
MOE		2.4%	3.2%	3.0%	2.8%	2.2%	5.4%	7.6%	15.5%	1.1%	1.4%	3.2%	2.8%
P value		**0.531**	**0.638**	**0.0001**	**0.004**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.079**	**0.984**	**0.686**	**0.189**

Exercise ratio = energy expenditure of exercise/the standard energy expenditure for standing still for 24 h; *n* = number of sessions; HR = heart rate in beats/min. Time allocation to gaits "other" includes galloping, jumping, and complex dressage sequences. Energy expenditure is after the deduction of the energy required for standing still. *P* values, with alpha set at 0.05, denote the significance of variation between the activities (longeing was excluded from this variation analysis). Allocation to gaits for longeing was not possible due to the inability of GPS to measure accurately the speed and distance of tight patterns. Values assume an adult female rider of average weight and intermediate to advanced competence. Bold values indicate the most important data.

Table 5. Marginal energy expenditure per minute, by gait, for 56 horses engaged in equestrian sport training

	Walk		Trot		Canter		Gallop		Other		
	EE/min	MOE	EE/min	MOE	EE/min	MOE	EE/min	MOE	EE/min	MOE	*n*
Flatwork	257	9.1%	601	6.0%	767	5.5%	1,089	4.8%			40
On the gallop	295	7.1%	615	6.5%	951	4.3%	1,128	5.7%			31
Jumping	245	5.9%	469	3.1%	689	3.0%			796	4.1%	20
Hacking	322	6.4%	808	6.8%	952	5.2%	861	4.2%			37
Dressage	322	9.2%	615	5.3%	589	4.0%			570	3.8%	22
Longeing	207	11.4%	351	10.0%	524	5.7%					20
Walker (calm)	226	8.4%									6
											176

EE, energy expenditure in joules of ME per minute per kilogram of bodyweight after deduction of energy required for standing still. "Other" includes jumping circuits or mixed dressage figures. Values assume an adult female rider of average weight and intermediate to advanced competence. Bold value indicates the total.

horse walker, which accounts for their low MEe. Mean MEe as a percentage of maintenance was 15.3% (includes days off).

The mean nutrient intake for each horse was sorted by the country in which the horse trained and is presented in Table 8.

There was a significant difference ($P < 0.001$) between the mix of forage/chaff and other feed (principally concentrate) between the two countries. Nevertheless, DM intake per kilogram BW did not differ between the two countries ($P = 0.707$) and there was no difference between the ME provision for the two groups ($P = 0.558$). This can be explained by the higher ME value of the UK forage, which included hay, haylage, and treated chaffs, whereas the only forage the Swiss horses were fed was hay.

EE for Field Maintenance

The field maintenance results for the 15 horses in the extended study are presented in Table 9 below.

All horses were in continual energy balance during the periods recorded, which is defined here as those periods covered by a flat trend line on a graph of weight vs. MEm ($r^2 < 0.001$). Intraweek variation of MEm for each horse (reported in the SD and CV columns) was low with a mean CV of 7.8% and is principally a function of changes in training demands. Despite the considerable variation in horse age and activity, the coefficient of variation of MEm per kilogram BW per day between horses was low. There was no difference between the mean MEm per kilogram BW per day of the inactive (control) horses and the active horses ($P = 0.915$). No seasonal variation ($P > 0.05$) in MEm was noted. There was no correlation between age and MEm (correlation = −0.031, $n = 60$). There was no difference between the horses in the 2-wk study and the extended study ($P = 0.690$). Referring to Table 7 above, there were no significant differences in MEm between disciplines ($P = 0.26$). The foregoing provides confidence that the EE for maintenance value of 0.1182 MJ ME/kg BW/d can be used for all horses involved in the Olympic disciplines on a mixed diet comprising between 60% and 85% forage, regardless of discipline, age, season, or active or inactive status.

This Study's Findings for MEm Compared to the Official Recommendations

The methodologies of the NRC (2007), Kienzle et al. (2010; German), INRA (2012), and the CVB

Table 6. Comparison of energy expenditure of exercise computed using the methodology of four different systems

	System used to calculate energy expenditure of exercise (MEe)			
	NRC (2007)	INRA (2011)	CVB (Blok, 2016)	HR-derived MEe
Mean daily MEe (MJ ME/d)	22.5	12.4	9.00	10.8
SD	6.3	4.07	3.98	2.76
CI	1.7	1.13	1.35	0.76
MOE	3.9%	4.6%	5.1%	3.5%
Mean of individual differences between				
Official system and HR-derived MEe	111.0%	15.4%	−29.3%	
SD of the differences	51.3%	31.5%	14.4%	
CI	14.2%	8.73%	5.2%	
MOE	6.4%	28.3%	8.8%	
$P(T \leq t)$ two-tail	1.06E-19	0.008	0.001	
Power $(1 - \beta)$	0.999	0.990	0.999	
Number of sessions	174	174	30	174
Number of horses	56	56	30	56

NRC (2007)—converted from DE to ME by multiplying DE by 0.8318, the mean ME/DE ratio from the 60 diets in this study. INRA (2011)—UFC converted to ME using INRA's ME value of 1 kg of barley, 12.05 MJ, and converting MBW to BW on the basis of a 500-kg horse. Blok (2016)—EWpa converted to ME using the CVB's ME value of 1 kg of oats, 11.4 MJ, and converting MBW to BW on the basis of a 500-kg horse. It was only practical to use the CVB system for sessions on a gallop or track, hence the lower number of sessions evaluated.

(Blok, 2016) were used to recompute the MEm for all 60 horses during the short-term part of the study. These values were compared to the findings of this study in order to explore the range of outcomes depending on the system used. The results of this comparative analysis are set out in Table 10 below.

Maintenance accounted for 86.7% (SD = 3.2%, CI = 0.009%, $n = 56$) of the energy used by the horses in active training in this study. There were no significant differences between the results using the NRC recommendations and the HR-derived MEm in this study ($P = 0.087$). However, using the German recommendations for moderately trained horses would have resulted in a 10.4% understatement of MEm ($P < 0.00001$), using the INRA recommendations would have resulted in an 8.9% understatement ($P < 0.00001$), and using the CVB recommendations would have resulted in a 20.9% understatement ($P < 0.00001$). In terms of total EE, using the NRC system to measure both MEm and MEe for the 60 horses in the study results in a mean 13.2% (SD = 13.9%, CI = 3.8%, $n = 60$, $P < 0.0001$) overstatement of total EE (since it significantly overstates MEe). Using the INRA system results in a mean 5.2% (SD = 11.7%, CI = 3.2%, $n = 60$, $P < 0.0001$) understatement (since it significantly understates MEm).

DISCUSSION

Methodology

Previously published studies examining EE for maintenance are predominantly based on feeding trials with inactive horses or horses kept in metabolic chambers. These include Winchester (1943), Wooden et al. (1970), Stillons and Nelson (1972), Pagan and Hintz (1986a), Vermorel et al. (1990), Martin-Rosset and Vermorel (1991), Vermorel et al. (1997a), and Vermorel et al. (1997b). Although energy balance studies using metabolic chambers or stalls to measure heat production via indirect calorimetry produce highly accurate results, by their nature, they are limited to 4 or 5 d duration, cannot be run on days when the horse is exercising, do not take place in a field setting, and place the horse in an unnatural state of forced inactivity. Furthermore, the cost of the methodology precludes large sample sizes.

The methodology used here allows the measurement of actual 'real-life' training and maintenance over extended periods with large sample sizes and, therefore, takes into account the normal everyday stresses and strains that can influence EE, which are impossible to reproduce either in a metabolic chamber (maintenance) or on a treadmill (exercise). This, in turn, provides a better understanding of variation and produces results with a lower MOE and high statistical power. It also facilitated the long-term monitoring of training regimes across several different disciplines and demonstrated that, despite variations in season, discipline, and country, training and maintenance demands remained remarkably similar from day to day.

The Equine HR monitors and their related software used here have improved over the past

Table 7. ME and DM intake by type of feed: in total, for exercise and for maintenance for 60 performance horses

		Source of ME		ME content of feeds		Total DM intake		Total ME intake		ME intake for exercise		ME intake for maintenance	
		%		MJ ME/kg DM		kg DM/kg BW/d		MJ ME/kg BW/d		MJ ME/kg BW/d		MJ ME/kg BW/d	
Training discipline	*n*	Mean	MOE	Mean	MOE	Mean	MOE	Mean	MOE	Mean	MOE	Mean	MOE
Dressage	10												
Forage and chaff		61.7%	11.1%	7.1	2.1%	0.013	11.1%	0.090	11.3%	0.0116	15.5%	0.0783	11.0%
Other feed		38.3%	18.7%	11.2	4.0%	0.005	15.8%	0.056	17.5%	0.0066	15.8%	0.0492	17.9%
Total		100.0%				0.018	3.8%	0.146	2.2%	0.0182	6.9%	0.1275	2.4%
Eventing	5												
Forage and chaff		71.8%	11.6%	7.1	2.7%	0.014	12.1%	0.102	20.8%	0.0146	17.8%	0.0873	16.2%
Other feed		28.2%	22.2%	10.3	9.6%	0.004	19.2%	0.040	14.4%	0.0054	20.0%	0.0346	22.6%
Total		100.0%				0.018	7.3%	0.142	9.1%	0.0199	13.0%	0.1220	11.8%
Showjumping	15												
Forage and chaff		60.2%	6.8%	6.5	1.8%	0.014	6.3%	0.089	11.9%	0.0121	6.0%	0.0766	8.2%
Other feed		39.8%	22.9%	9.8	4.0%	0.006	10.8%	0.059	7.5%	0.0090	15.7%	0.0497	11.4%
Total		100.0%				0.019	3.4%	0.147	3.6%	0.0210	7.8%	0.1263	3.7%
All rounders	26												
Forage and chaff		77.2%	4.0%	6.7	1.4%	0.015	4.5%	0.101	5.1%	0.0130	6.7%	0.0884	5.1%
Other feed		22.8%	13.6%	9.5	2.9%	0.003	14.1%	0.030	13.7%	0.0039	15.6%	0.0259	13.7%
Total		100.0%				0.018	2.7%	0.131	2.5%	0.0170	5.6%	0.1143	2.6%
Inactive	4												
Forage and chaff		70.3%	10.6%	6.5	3.0%	0.013	17.0%	0.088	19.2%	0.0019	52.4%	0.0860	20.2%
Other feed		29.7%	22.9%	9.8	4.5%	0.004	27.2%	0.037	29.6%	0.0016	51.2%	0.0356	28.8%
Total		100.0%				0.017	11.5%	0.125	10.6%	0.0035	51.8%	0.1216	10.9%
All horses	60												
Forage and chaff		69.1%	4.9%	6.7	1.4%	0.014	5.0%	0.095	3.9%	0.0126	4.8%	0.0835	4.1%
Other feed		30.9%	10.9%	10.0	2.9%	0.004	11.0%	0.043	8.3%	0.0059	10.0%	0.0371	8.2%
Total		100.0%				0.018	2.7%	0.138	1.9%	0.0185	4.0%	0.1206	2.0%

Mean ME intake for exercise for "all horses" excludes "inactive horses."

Table 8. ME and DM intake by type of feed, in total and for maintenance, for 60 performance horses in the United Kingdom and Switzerland

	Source of ME (%)		Total DM intake (g/kg BW/d)		DM intake for maintenance (g/kg BW/d)		ME content of feeds (MJ ME/kg DM)		ME for maintenance (MJ ME/kg BW/d)
	Mean	MOE	Mean	MOE	Mean	MOE	Mean	MOE	
UK horses (n = 30)									
Forage and chaff	82.5%	2.7%	16.2	4.2%	14.3	4.4%	7.1	0.8%	0.1007
Other feed	17.5%	2.7%	2.3	11.2%	2.0	11.1%	9.7	4.0%	0.0195
Total	**100.0%**		**18.5**	**3.1%**	**16.3**	**3.4%**			**0.1202**
Swiss horses (n = 30)									
Forage and chaff	55.3%	4.2%	12.1	4.2%	10.5	4.2%	6.4	1.3%	0.0668
Other feed	44.7%	4.2%	6.1	5.8%	5.3	5.6%	10.2	2.0%	0.0544
Total	**100.0%**		**18.2**	**2.2%**	**15.8**	**2.1%**			**0.1211**

Bold values indicate the totals.

10 yr to the point where they are highly accurate: Ille et al. (2014) compared the HR obtained from a Polar HR monitor to a simultaneously recorded electrocardiogram signal for 14 Haflinger mares and found that the data were highly correlated irrespective of the recording system and recording time ($r > 0.99$, $P < 0.001$).

Training Regimes

The key metrics of weekly training regimes for four different disciplines (Table 3) illustrated a low level of variation. Aside from four dressage horses, all of the horses in this study were trained by their amateur owners, who were either students or in full-time unrelated work and, therefore, faced time constraints on training sessions. There was only so much time devoted to daily training before the rider, the horse, or both became fatigued or ran out of time (mean training time for all horses was 51 min (SD = 16.6, CI = 2.48, n = 175). As a consequence of this low level of variation, it is possible to create generalized formulas for the EE of exercise with low margins of error.

EE for Exercise

In terms of daily training activities (Table 4), although maximum speed and distance were significantly different between activities, the other key metrics were not, except for longeing. Longeing tended to be the chosen activity on those days when the trainer had less personal time for training. Given that it is by far the most intense activity in terms of EE per minute, this represents the optimal use of limited time.

The most common gait was walking (62% mean allocation). However, excluding hacking, it falls to 54%, with a mean of 27 min walking out of 51 min mean total session duration, most of which was walking during recovery. Eaton (1994) note that for 1 h after moderate training, O_2 consumption remains at 10% above presession consumption. According to the NRC (2007), most studies have not accounted for the energy costs of an elevated, postexercise metabolic rate in their calculations of energy use. It suggests that the maintenance requirement may need to be increased by 10% for some horses to account for this. In this study, measurement was from the moment the rider left the stables until the moment she returned and, therefore, warm down is included in the MEe findings. This study's methodology of computing maintenance as the difference between total intake

Table 9. Individual field maintenance requirements for 15 horses while in a state of constant BW (energy balance)

						Energy expenditure for maintenance				
						Mean	SD	CV	CI	Mean
Horse	Breed	Training status	Weight	Age	Weeks in study	MJ ME/kg BW/d	MJ ME/kg BW/d	%	MJ ME/kg BW/d	MJ ME/kg MBW/d
UK1	Irish × Trakehaner	Dressage	647	12	34	0.109	0.021	19.3%	0.0070	0.570
UK2	Dutch warmblood	Dressage	650	10	42	0.130	0.019	14.3%	0.0056	0.661
UK3	TB	All rounder	549	10	28	0.126	0.007	5.8%	0.0027	0.580
UK4	Irish sporting horse	Dressage	650	17	27	0.107	0.003	3.0%	0.0012	0.561
UK5	Welsh Sec. D	Inactive/control	523	20	13	0.082	0.017	20.6%	0.0093	0.394
UK6	Danish Warmblood	Dressage	582	10	12	0.093	0.009	9.3%	0.0049	0.455
UK7	Cleveland Bay × TB	Dressage	737	9	12	0.127	0.043	6.5%	0.0244	0.659
UK8	KWPN	Inactive/control	630	9	9	0.136	0.012	8.5%	0.0076	0.683
UK9	Trakehaner × TB	All rounder	667	20	13	0.087	0.006	7.3%	0.0035	0.443
UK10	TB	Eventing	483	5	12	0.183	0.009	4.8%	0.0049	0.859
Swiss1	Irish sporting horse	All rounder	637	18	43	0.113	0.007	5.9%	0.0064	0.571
Swiss 2	German warmblood	Inactive/control	510	16	32	0.121	0.001	1.1%	0.0026	0.584
Swiss 3	Dutch warmblood	Inactive/control	644	17	31	0.119	0.001	0.6%	0.0017	0.596
Swiss 4	Swiss warmblood	All rounder	513	22	21	0.128	0.004	3.2%	0.0046	0.610
Swiss 5	Selle Francais	Jumping	572	8	28	0.112	0.008	7.0%	0.0175	0.604
Mean			**600**	**14**	**24**	**0.1182**		**7.8%**		**0.5887**
SD						0.023				0.107
CV						19.7%				18.2%
CI ($P < 0.05$)						0.013				0.058
MOE						5.4%				4.9%

Bold values indicate the totals.

Table 10. Comparison of maintenance recommendations

Source	Activity level	Horse type	Maintenance requirement: MJ DE kg BW/d	UFC kg BW/day	EWpa kg BW/d	MJ ME kg BW/d	MJ ME kg MBW/d	Comparison to this study[e]: % over/under	$P(T \le t)$ two-tail	Power
This study (2 weeks)		Olympic disciplines				0.1205	0.5853	−1.1%		
This study (long-term)		Olympic disciplines				0.1180	0.5920			
NRC (US)[a]	Sedentary	All horses	0.1267			0.1054		−10.7%		
NRC (US)[a]	Average voluntary	All horses	0.1392			0.1158		−1.9%	0.08675	0.68
NRC (US)[a]	Elevated voluntary	All horses	0.1517			0.1266		7.3%		
German[b]	Fully trained	Warmbloods				0.1294	0.6120	3.4%		
German[b]	Moderately trained	Warmbloods				0.1122	0.5304	−10.4%	1.25E-05	0.99
INRA (French)[c]	Working period	Riding horse category		0.0373		0.1141	0.5394	−8.9%	8.02E-06	0.99
CVB (Dutch)[d]	Working horses	Non-TB mare/gelding			0.0411	0.0991	0.4685	−20.9%	1.45E-13	0.99

[a]NRC (2007; US)—converted to ME by multiplying DE by 0.8318, the mean ME/DE ratio from the 60 diets in this study.

[b]Coenen et al. (2011; German)—converted MBW to BW on the basis of a 500-kg horse plus 2% supplement for turnout status.

[c]INRA (2011; France)—UFC converted to ME using the ME value of 1 kg of barley, 12.05 MJ, and converting MBW to BW on the basis of a 500-kg horse plus 5% for a "riding" horse and 15% for working.

[d]Blok (2016; Dutch)—EWpa converted to ME using the ME value of 1 kg of oats, 11.4 MJ, and converting MBW to BW on the basis of a 500-kg horse plus 5% supplement for working status.

[e]Overcompared or undercompared to the ME/kg MBW finding of this study, except NRC, which is compared to ME/kg BW.

and MEe would fully account for elevated postexercise metabolic rates.

Mean session HR was not significantly different between activities. It was significantly less than the NRC (2007) HRs for light exercise and the light exercise sessions devised by Zoller et al. (2019) intended to replicate the NRC's "light" example. Mean HR is a poor metric for evaluating the intensity of training because it is correlated with the time spent in walk. Furthermore, the relationship between HR and EE is exponential and HR does not take into account anaerobic EE. Calculated mean anaerobic EE as a percentage of total expenditure for the horses training on a gallop in this study was 3.4% (SD = 2.3%, CI = 0.8%, n = 32), and 2.7% (SD 0 1.8%, CI = 0.6%, n = 38) for those in a flatwork session. An alternative method of evaluating the training effort between sessions is the "exercise ratio" metric developed here (EE for exercise divided by the standard EE of standing still for 24 h). It allows for the comparison of training effort from session to session, week to week, between individual horses, and between groups of horses and can also be used on a daily basis to guide aerobic training.

Since the calculated EE had low margins of error, riders can use the tables from this study to estimate the EE of training. Riders who train their horses approximately 5 h/wk with a gait allocation broadly similar to Table 3 (or a mean HR close to 90 bpm) can add 0.0185 MJ (18.5 J) ME/kg BW/d (9.25 MJ ME/d for a 500-kg horse) to the maintenance requirement to maintain energy balance with a small MOE (3.7%). Riders can estimate of the energy expenditure of a training session by multiplying minutes trained × the appropriate figure in the last column of Table 4 × BW. Alternatively, riders can record the time spent in each gait during a given training activity and, using Table 5, multiply the EE by gait by the number of minutes in each gait. Adding the products together will yield an approximation of MEe. This is very similar to the methodology recommended by Coenen (2010) for measuring the EE of a given training session.

This Study's Results for the MEe Compared to the NRC, INRA, and CVB Recommendations and Other Studies

Applying the best fit of the 56 exercise programmes to the NRC (2007) system, 74% of the programmes fell into the NRC's "medium" category, which would call for supplemental energy equal to 40% of maintenance. The NRC recommendations exceeded the HR-derived MEe 100% of the time, that is, for all horses in the sample, implying that following the NRC recommendations would result in feeding over twice the energy required for exercise.

Even if all 56 exercise programmes were classified in the NRC's "light" category (which would call for supplemental energy of 20% of maintenance), the NRC recommendations would exceed the HR-derived MEe for 41 of the 56 horses. The mean weekly MEe for horses in active training in this study was only 15.3% of maintenance (CI = 0.012%, SD = 4.6%, n = 55).

Applying the best fit of the 56 exercise programmes to INRA's (2012) system, INRA's recommendations exceeded the HR-derived MEe for 37 of the 56 horses in the study. The INRA results were far closer to this study's results than the NRC values. However, the SD is high: the INRA recommendations differed from the HR-derived MEe by a magnitude of >25% for 42% of the horses.

Comparing this study's mean EE for each gait (Table 5) to the CVB system (Blok, 2016), the CVB system under-estimates the EE of walk (−52%) and trot (−39%) and over-estimates the EE of canter (+11%) and gallop (+7%). On the whole, it under-estimated MEe compared to the HR-derived MEe.

Anderson et al.'s (1983) results for the MEe of four horses exercising at mean HRs of 135 bpm was significantly higher than the results found here; however, they involved 20-min sessions on inclined treadmills without a break, a level of training found infrequently in the present study. Hintz et al.'s (1971) findings for equitation horses were 20% higher than the findings of this study; however, the mean duration of their sessions was 84 min vs. a mean of 51 in the present study and, therefore, walking accounted for proportionally less EE in their study. INRA's (2012) current guidance for MEe for each gait is based on INRA (1984). Their EE for walk, trot, and gallop are 12%, 23%, and 86% higher than the present study. This can be partially explained by their speeds being faster and their horses carrying a load of 100 kg (rider + tack + apparatus) compared to a mean load of 82 kg for the present study. It is also possible that these horses were competing at a higher level than the horses in the present study.

Nutrient Intake

Total DM intake per kilogram BW was almost identical across all groups of horses; however, total ME intake was not. Inactive horses had the lowest ME intake per kilogram BW, followed by the all-rounder horses. Horses in training for specific disciplines (dressage, jumping, and eventing) had the highest ME intakes. Total ME intake is correlated with the exercise ratio. Horses in training for specific disciplines consumed significantly less forage than the all-rounder horses and inactive horses. Trainers of horses in specific disciplines delivered the greater energy requirement by feeding more concentrate, not more forage, even though mean forage consumption was 14 g/kg BW/d (SD = 4, CI = 1.4, n = 40), well below the upper limit of maximum voluntary hay intake of 20 g/kg BW established by Dulphy et al. (1997). Although there were no significant differences in DM or ME intake for maintenance between the Swiss and the UK horses, the UK horses were fed a significantly higher portion of forage and chaff, which was higher in energy content than the Swiss forage. This can be explained by the fact that the provision of forage in Switzerland was exclusively hay, whilst horses in the UK were fed a mix of chaff, haylage, and hay.

Most of the required energy for horses in these disciplines can be met from forage, with the UK horses obtaining 83.9% (SD = 12.3%, CI = 4.9%, n = 24) of their total energy requirement from forage, with 38% of those horses deriving >90% of their energy from forage. The only supplements required for any of the horses in both studies were copper, selenium, zinc, and sodium. The UK horses met all of their maintenance requirements (except the minerals listed above) on a mean diet of 15 g DM of forage/kg BW/d (SD = 3.2, CI =1.3, n = 24; 17 g "as fed") and 2 g of average concentrate feed/kg BW/d (SD = 1.0, CI = 0.5, n = 24). Jansson et al. (2012) note that, by selecting forage with proper energy and CP content, forage-only diets may provide 100% of the protein and energy requirements of athletic horses.

Vermorel et al. (1990, 1997a) found that all-forage diets required 14.4% and 16.6%, respectively, more ME than a 60% hay/40% concentrate diet due to the different efficiencies of ME utilization. Likewise, Karlsson et al. (2000) found that the expected DE of a diet composed of 40% hay and 60% oats should have been 63% of gross energy (GE), compared with the value of 58% measured, corresponding to a difference of 8% in DE. They suggested that predominantly cereal-based diets may result in a depressed precaecal starch breakdown (citing Kienzle, 1994) and, hence, transfer of too much starch into the hindgut, lowering the microbial fermentation of the fiber components. However, they noted a small increase in the digestibility of fiber in a 80% hay/20% oats diet compared to 100% hay, suggesting that this may be explained by a stimulation of the hindgut microbial activity and fiber digestion by a small amount of concentrate. The mean diet in this study was 69% forage and 31% other feeds (MOE of 4.9%), many of which included pelletized forage. Given the low level of variation in the mix of forage/concentrate in the diets of performance horses, at this level, it can be assumed that the digestibility of the rations is equivalent to the weighted sum of the nutrients supplied (Martin-Rosset et al., 1994). The findings here would not be valid for 100% forage diets, nor would they be valid for diets where >35% of the diet is derived from grain.

Field Maintenance Requirements

This study's findings are consistent with the NRC (2007) recommendations for horses with average or elevated voluntary activity levels. The German (Coenen et al. 2011), French (INRA, 2012), and Dutch (Blok, 2016) recommendations are all lower than this study. The confinement studies were all lower as could be expected: Wooden et al. (1970) were 13% lower, Stillions and Nelson (1972) were 4.6% lower, Vermorel et al. (1990) were 0.6% lower for a mixed diet, Martin-Rosset and Vermorel (1991) were 2.5% lower for horses in summer and 5.6% lower overall, Martin-Rosset et al. (1994) were 2.1% lower, Vermorel et al. (1997a) were 2.9% lower for a diet comparable to the mean of this study, and Vermorel (1997b) were within 0.9% for a comparable diet. For unconfined horses, Anderson et al. (1983) were 2% higher and, applying the equation of Pagan and Hintz (1986a) to the 566 kg mean weight of the horses in this study, the results were exactly equal.

Metabolizable energy expenditure for maintenance in the present study included all normal activity over an extended period but also included transport, turn out, ground training, grooming, shoeing, and veterinary or osteopathic treatments (time spent on horse walkers >30 min was classified as a training activity, whilst shorter sessions were not). This explains why some of the official recommendations were lower than the findings of this study. Adding this study's formulas for field maintenance and MEe together provides owners with complete guidance for their horse's energy requirements.

A notable feature of this study's findings is the low CV for maintenance requirements when expressed as MJ ME/kg BW/d or MJ ME/kg MBW/d. The results indicate that the requirements for maintenance and exercise of sport horses in training can be predicted with a relatively high level of precision if they are tailored to discipline and type of training, respectively. This is illustrated by the case of the six Thoroughbreds (TBs) included in this study (10% of the sample). According to INRA (2012), the CVB (Blok, 2016), and Coenen et al. (2011), TBs require higher maintenance energy per kilogram BW than warmbloods; however, the TB requirement in this study was not significantly higher. This may be explained by the fact that they were involved in similar training regimes and their mean BCS in this study was 5.8 (CI = 0.21, SD = 0.74, n = 6) compared to a mean of 5.9 for the other horses (CI = 0.26, SD = 0.91, n = 60), whereas the mean BCS for TBs in racing training is 4.0–5.0 (Pagan et al., 2009). This supports Blaxter's (1989), Kearns et al.'s (2002), and Coenen et al.'s (2011) assertions that the energy requirement for maintenance is mainly linked to lean metabolic body mass. Precision may be enhanced when recommendations are tailored to a given discipline, not breed, if the BCS within the discipline is relatively homogenous.

Six of the horses in this study were characterized as having a nervous, high voluntary activity level. Members of this group were noticeably active in their boxes and during turn out and exhibited switching behavior, as described by McBride et al. (2017), which was more frequent than the other horses. The field maintenance requirement of 0.1400 MJ ME/kg BW/d (CI = 0.014, SD = 0.74, n = 6) of these horses was 18.6% higher than the other horses. More work needs to be done in this area, but it appears that, consistent with NRC (2007) recommendations, horses with a nervous disposition evidenced by high-level switching behavior and/or relatively higher nocturnal variation in HR require a higher level of maintenance energy. The NRC (2007) recommends feeding 9% more for nervous horses. Based on the present study, an additional 15% of ME may be justified for nervous horses. Stereotypic behavior, such as cribbing, weaving, or box kicking, may also increase the maintenance requirement.

Blaxter (1989) and Kearns et al. (2002) conclude that O_2 consumption is more closely related to lean body mass than BW. There were four horses in this study with a BCS score >7.5. Their field maintenance requirement was 24% lower than the other horses at 0.0912 MJ ME/kg BW/d (CI = 0.0108, SD = 0.0135, n = 4). Data from this study and Dougdale et al.'s (2012) study support the suggestions of Bines et al. (1969) and the NRC (2007) that obesity constrains gut capacity and decreases metabolic energy requirements. Although the overweight animals in this study were horses, not ponies, and the sample size of four is small, the results are consistent with Coenen et al. (2011) and the other work cited above and would suggest that overweight horses require less energy per kilogram BW, with MEm limited to 0.0900 MJ ME/kg BW/day.

Martin-Rosset and Vermorel (1991) found that MEm was lower for horses approximately 11-yr old than for horses approximately 4-yr old. This study found no correlation between age and MEm. They also found that horses require 8.2% more ME in the summer than in winter. The present study took place year-round, and the mean MEm here is within 0.3% of the mean in their study. There would be some merit in feeding 4% less ME in the winter and 4% more in the summer.

Each of the official systems calls for an upward adjustment from base maintenance for horses in “a normal level of activity” or “active training”. Even with this adjustment, the German, French, and Dutch systems understate the energy requirement of maintenance when compared to this study, which found no difference in maintenance requirements between the active and inactive horses. Kearns et al. (2002) found that the fat content of a fully trained sports horse was 5% compared to 20% for an untrained one. It would be expected that the active horses would have a higher MEm than inactive ones if the energy requirement for maintenance is mainly linked to lean metabolic body mass (Coenen et al., 2011). However, the mean BCS score for the inactive horses in this study was 6.2 (CI = 0.07, SD = 0.43, n = 4), almost identical to other 56 horses, which may explain the lack of a difference between the active and inactive horses.

CONCLUSION

The mean field maintenance expenditure for performance horses with a normal temperament was found to be 0.118 MJ of ME/kg BW/d (SD = 0.008) with a low level of variation between horses. This is greater than the official guidance found in the United States, France, Germany, and The Netherlands, even when the guidance is adjusted for turn-out and activity status. Heart rate monitoring of training revealed a mean estimated EE per ridden session of 0.023 MJ ME (SD = 0.001, CI = 0.001, n = 175 training sessions). The mean daily EE based on a full week’s training was 0.018 MJ ME/kg BW/d (SD = 0.005, CI = 0.001, n = 60 horses) representing a multiple of maintenance of 15.3%. There were no significant differences for EE between groups of horses being trained for different disciplines. Despite the large size of this study, few of the horses were trained as intensively as the examples in the guidance. Most of the required energy for horses training in dressage, show jumping, and moderate eventing can be met from forage, with the UK horses obtaining 83.9% (SD = 12.3%, CI = 4.9%, n = 24) of their total energy requirement from forage and 38% of those horses deriving >90% of their energy from forage. Feeding an additional 15% over maintenance energy for horses in training and maintaining a high forage component of c. 85% is likely to deliver the required performance while maintaining horses in energy balance.

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This study was a joint effort by the two authors M.M.-C. and M.E. The original research question and concept was developed by M.E., the study was designed jointly, M.E. analyzed the data, and the article was jointly written.

Conflict of interest statement. The authors confirm that there are no conflicts of interest.

LITERATURE CITED

Anderson, C. E., G. D. Potter, J. L. Kreider, and C. C. Courtney. 1983. Digestible energy requirements for exercising horses. J. Anim. Sci. 56:91–95. doi:10.2527/jas1983.56191x.

Bines, J. A., S. Suzuki, and C. C. Balch. 1969. The quantitative significance of long-term regulation of food intake in the cow. Br. J. Nutr. 23:695–704. doi:10.1079/bjn19690077.

Blaxter, K. L. 1989. Energy metabolism in animals and man. Cambridge University Press, Cambridge, UK.

Blok, M. 2016. The EWpa system, the actualised Dutch net energy system for horses. Central Bureau Livestock Feeding (CVB), Product Board Animal Feed, Lelystad, The Netherlands. http://www.docslides.com/the-ewpa-system [accessed September 30, 2018].

Coenen, M. 2008. The suitability of heart rate in the prediction of energy consumption, energy expenditure and energy requirements for the existing horse. In: Saastamoinen, M., and W. Martin-Rosset, editors, Nutrition of the exercising horse. EAAP publication No. 125. Wageningen (The Netherlands): Wageningen Academic Publishers; p. 139–146.

Coenen, M. 2010. Remarks on the benefits of heart rate recordings. Proceedings of the 2010 Kentucky Equine Research Nutrition Conference. Kentucky Equine Research.

Coenen, M., E. Kienzle, I. Vervuert, and A. Zeyner. 2011. Recent German developments in the formulation of energy and nutrient requirements in horses and the resulting feeding recommendations. J. Equine Vet. Sci. 31:219–229. doi: 10.1016/j.jevs.2011.03.204.

Cohen, J. 1988. Statistical power analysis for behavioural sciences, 2nd ed. New York (NY): Lawrence Erlbaum Associates, Publishers.

Cordero, V. V., C. A. Cavinder, L. O. Tedeschi, D. H. Sigler, M. M. Vogelsang, and C. E. Arnold. 2013. The development and evaluation of a mathematical nutrition model to predict digestible energy intake of broodmares based on body condition changes. J. Anim. Sci. 91:2169–2177. doi:10.2527/jas.2011-4659.

DEFRA. 2018. Code of practice for the welfare of horses, ponies, donkeys and their hybrids. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700200/horses-welfare-codes-of-practice-april2018.pdf [accessed August 27, 2019].

Dulphy, J., W. Martin-Rosset, J. Dubroeucq, J. M. Ballet, A. Detour, and M. Jailler. 1997. Compared feeding patterns in ad libitum intakes of dry forages by horses and sheep. Livest. Prod. Sci. 52: 49–56. doi:10.1016/S0301-6226(97)00113-9.

Eaton, M. 1994. Energetics and performance. In: D. Hodgson and R. Rose, editors, The athletic horse. Philadelphia (PA): W. B. Saunders Company; p. 49–61.

Ferjak, E. N., C. A. Cavinder, D. D. Burnett, C. M. Argo, and T. T. N. Dinh. 2017. Body fat of stock-type horses predicted by rump fat thickness and deuterium oxide dilution and validated by near-infrared spectroscopy of dissected tissues. J. Anim. Sci. 95:4344–4351. doi:10.2527/jas2017.1676.

Fortier, J., G. Deley, A. G. Goachet, and V. Julliand. 2015. Quantification of the energy expenditure during training exercises in standardbred trotters. Animal. 9:793–799. doi:10.1017/S1751731114003139.

Frape, D. 2010. Equine nutrition and feeding. 4th ed. Chichester (UK): Wiley-Blackwell.

Henneke, D. R., G. D. Potter, J. L. Kreider, and B. F. Yeates. 1983. Relationship between condition score, physical measurements and body fat percentage in mares. Equine Vet. J. 15:371–372. doi:10.1111/j.2042-3306.1983.tb01826.x.

Hintz, H. F., S. J. Roberts, S. W. Sabin, and H. F. Schryver. 1971. Energy requirements of light horses for various activities. J. Anim. Sci. 32:100–102. doi:10.2527/jas1971.321100x.

Hipp, B., K-H. Süum, A. Zeyner, G. Goren, and E. Kienzle. 2017. Renal energy excretion of horses depends on renal hippuric acid and nitrogen excretion. J. Anim. Physiol. Anim. Nutr. 1–7. doi:10.1111/jpn.12756.

Ille, N., R. Erber, C. Aurich, and J. Aurich. 2014. Comparison of heart rate and heart rate variability obtained by heart rate monitors and simultaneously recorded electrocardiogram signals in non-exercising horses. J. Vet. Behav. 9:341–346. doi:10.1016/j.jveb.2014.07.006.

INRA. 1984. L'alimentation des animaux monogastriques, 1st ed. Versailles (France): INRA Publications; p. 282.

INRA. 2012. Equine nutrition: INRA nutrient requirements, recommended allowances and feed tables. Wageningen (The Netherlands): Wageningen Academic Publishers.

Jansson, A., M. Saastamoinen, and J. E. Lindberg. 2012. In: Saastamoinen, M., M. J. Fradinho, A. S. Santos, and N. Miraglia editors, Forages and grazing in horse nutrition. EAAP publication No. 132. Wageningen (The Netherlands): Wageningen Academic Publishers; p. 289–302.

Karlsson, C., J. E. Lindberg, and M. Rundren. 2000. Associative effects on total tract digestibility in horses fed different ratios of grass hay and whole oats. Livest. Prod. Sci. 65:143–153. doi: 10.1016/S0301-6226 (99) 00178-5.

Kearns, C. F., K. H. McKeever, H. John-Alder, T. Abe, and W. F. Brechue. 2002. Relationship between body composition, blood volume and maximal oxygen intake. Equine Vet. J. Suppl. 34:485–490. doi: 10.1111/j.2042–3306.2002.tb05470.x.

Kienzle, E. 1994. Small intestinal digestion of starch in the horse. Rev. Méd. Vét. 145(2):199–204.

Kienzle, E., and A. Zeyner. 2010. The development of a metabolisable energy system for horses. J. Anim. Physiol. Anim. Nutr. 94:e231–e240. doi:10.1111/j.1439-0396.20.

Martin-Rosset, W., and M. Vermorel. 1991. Maintenance energy requirement variations determined by indirect calorimetry and feeding trials in light horses. J Equine Vet Sci. 11-1:42–45. doi: 10.1016/S0737-0806(06)81246-3.

Martin-Rosset, W., M. Vermorel, M. Doreau, J. L. Tisserand, and J. Andrieu. 1994. The French horse feed evaluation systems and recommended allowances for energy and protein. Livest. Prod. Sci. 40–1:37–56. doi: 10.1016/0301-6226(94)90264-X.

McBride, S., M. Parker, and K. Roberts. 2017. Applied neurophysiology of the horse: implications for training, housing and welfare. Appl. Anim. Behav. Sci. 190:90–101. doi: 10.1016/j.applanim.2017.02.014.

Minetti, A. E., L. P. ArdigO, E. Reinach, and F. Saibene. 1999. The relationship between mechanical work and energy expenditure of locomotion in horses. J. Exp. Biol. 202(Pt 17):2329–2338.

NRC. 2007. Nutrient requirements of horses. 6th rev. ed. National Research Council of the National Academies; Natl. Acad. Press, Washington, DC.

Pagan, J. D., and H. F. Hintz. 1986a. Equine energetics. I. Relationship between body weight and energy requirements in horses. J. Anim. Sci. 63:815–821. doi:10.2527/jas1986.633815x.

Pagan, J. D., and H. F. Hintz. 1986b. Equine energetics. II. Energy expenditure in horses during submaximal exercise. J. Anim. Sci. 63:822–830. doi:10.2527/jas1986.633822x.

Pagan, J., O. Martin, N. Crowley, and K. L. Hooks. 2009. Relationship between body condition and metabolic parameters in sport horses, pony hunters and polo ponies. J. Equine Vet. Sci. 29(5):418–420. doi: 10.1016/j.jevs.2009.04.117.

Robergs, R., and A. Burnett. 2003. Methods used to process data from indirect calorimetry and their application to VO_2 max. J. Exerc. Physiol. 6(2):44–57.

Stillions, M. C., and W. E. Nelson. 1972. Digestible energy during maintenance of the light horse. J. Anim. Sci. 34:981–982. doi:10.2527/jas1972.346981x.

Vermorel, M., W. Martin-Rosset and J. Vernet. 1990. Energy utilisation of two diets for miantenance by horses; agrMEment with the new French net energy standards. J Equine Vet Sc. 10(6):449–452. doi: 10.1016/S0737-0806(06)80142–5.

Vermorel, M., W. Martin-Rosset and J. Vernet. 1991. Energy utilisation of two diets for maintenance by horses; agrMEment with the new French energy system. J Equine Vet Sci. 11:33–35. doi: 10.1016/SO737-0806(06)80142–5.

Vermorel, M., W. Martin-Rosset, and J. Vernet. 1997a. Energy utilization of twelve forages or mixed diets for maintenance by sport horses. Livest Prod Sci. 47:157–167. doi: 10.1016/S0301-6226(96)01402-9.

Vermorel, M., W. Martin-Rosset, and J. Vernet. 1997b. Digestive and energy utilisation of two diets by ponies and horses. Livest Prod Sci. 51(1997):13–19. doi: doi:10.1016/S0301-6226(97)00108-5.

Winchester, C. F. 1943. The energy cost of standing in horses. Science. 97:2505. doi:10.1126/science.97.2505.24.

Wooden, G. R., K. L. Knox, and C. L. Wild. 1970. Energy metabolism in light horses. J. Anim Sci. 30:544–548. doi: 10.2527/jas1970.304544x.

Zoller, J. L., C. A. Cavinder, D. Sigler, L. O. Tedeschi, and J. Harlin. 2019. Development of a mathematical model for predicting digestible energy intake to meet desired body condition parameters in exercising horses. J. Anim. Sci. 97:1945–1955. doi:10.1093/jas/skz041