The energy requirements of racehorses in training

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ABSTRACT: The aim of this study was to estimate the energy requirements of Thoroughbred racehorses in active training for flat racing. Twenty-two Thoroughbred racehorses in England were measured over periods from 6 to 15 wk, which included periods of active race training and temporarily reduced training. Energy intake was determined by measuring daily feed consumption. Energy output was measured using heart rate monitors during 730 training sessions, relating heart rate (HR) to oxygen consumption (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 during periods of active race training was 0.1731 megajoules (MJ) of metabolizable energy (ME)/kg of bodyweight (BW)/d (SD = 0.0174, CI = 0.0073, *n* = 22 horses, 193 wk). This result is 11% to 66% greater than the official guidance found in the United States, France, Germany, and the Netherlands. Heart rate monitoring revealed a mean energy expenditure for exercise of 0.0212 MJ ME/d (SD = 0.0049, CI = 0.0007, *n* = 22 horses) for racehorses in active race training, a result 70% to 82% below the official guidance. The total mean energy expenditure for racehorses in active race training was 0.1943 MJ ME/kg/d (SD = 0.0177, CI = 0.0078, *n* = 20 horses 193 wk), 4% to 22% less than the official guidance. Horses actively racing had a 12% higher maintenance requirement than those in training but not yet racing (*P* = 0.01). The 2- and 3-yr-old horses did not gain weight during active race training, but grew slowly during breaks in training. This study explores the factors affecting energy balance in racehorses, and provides updated findings for their maintenance and training requirements.

Key words: energy balance, equine, maintenance, nutrition model, racehorse, training

Transl. Anim. Sci. 2020.4:1-16
doi: 10.1093/tas/txaa196

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 × 0.866 = ME was used. This factor is the mean ME/DE ratio from the 22 diets in this study.

Unité fourragèr de cheval (UFC) was 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.

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Received May 22, 2020.
Accepted October 22, 2020.

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.

Metabolisable energy expenditure during exercise (MEm) was calculated from Coenen's (2010) formula (MEe in J/kg BW/min) = $((0.0566 \times HR^{1.9955}) - 68)$. 68 J ME was this study's finding for the energy expenditure of standing still/min).

INTRODUCTION

There are currently four major sources of guidance for determining the energy requirements of horses in Europe and North America. The most widely used guidance has been published by the National Research Council of the National Academies (NRC, 2007) and is based on digestible energy (DE). The German guidance (Coenen et al., 2011) was updated and improved with the development of a metabolisable energy (ME) system incorporating predictive equations for renal and methane energy losses, based on metabolic body weight (MBW). France's system (INRA, 2012) is based on metabolic chamber and field studies, and is the most comprehensively researched. It uses the Unité Fourragère de Cheval (UFC) energy unit. In 2016, the CVB (Central Bureau, Livestock Feeding, Netherlands) adopted a net energy (NE) system (Energiewaarde paard (EWpa)) for horses, which is similar to the French system and uses a standard value of oats as the energy unit (Blok, 2016). None of those systems were specifically designed for racehorses, although each one contains minor adaptations meant to address Thoroughbreds or racehorses in training.

Pagan et al.'s (2017) 2-mo study recorded the water, concentrate, and hay intake of Thoroughbred racehorses and is consistent with the NRC's (2007) recommendations. Fortier et al. (2015) measured the energy expenditure of training Standardbred trotters, finding that they consumed a mean of 11.5 MJ ME/d for exercise alone. Gallagher et al. (1992a) surveyed Thoroughbred trainers at a single Detroit racetrack and found DE intake to be consistent with the NRC (1989) recommendations. Gallagher et al. (1992b) also surveyed Standardbreds at that track finding the DE intake to exceed the NRC (1989) recommendations by 27%. Southwood et al. (1993) surveyed racing Thoroughbreds in Australia and found that their DE intake was 9.2% less than the NRC (1989) recommends. Energy-related challenges faced by racehorse trainers include maintaining energy balance in the face of changing training demands, reduced performance from weight loss including exercise induced inappetence (Gordon et al., 2006), overtraining syndrome (Evans, 2007; McGowan and Whitworth, 2008) and the effect of gastric ulcers on appetite (Murray et al., 1996; Lorenzo-Figueras and Merrit, 2002; Gordon et al., 2006).

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, enabling this study. The formulas for the conversion of HR to energy expenditure (EE) in horses using indirect calorimetry are well established (Robergs and Burnett, 2003; Coenen, 2010).

The aim of this field-based study was to monitor the energy requirements of Thoroughbred racehorses in active training for flat races. The objective was to provide up-to-date guidance for racehorse trainers and other interested parties on:

1. the energy intake of Thoroughbred racehorses, and
2. the partitioning of intake into energy for maintenance (MEm) and exercise (MEe).

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 22 Thoroughbred racehorses for periods ranging from 6 to 15 wk. All horses were stabled at a single flat-racing yard, licensed by the British Horseracing Authority and located in Lambourn, England. All horses were in training to compete in flat races (not National Hunt races) at racecourses across England and Wales. All training took place at the racehorse training facilities managed by Jockey Club Estates in Lambourn, the second largest training facility of its kind in the United Kingdom. All of the Lambourn gallops appropriate for flat race training were used to train the horses in this study. A total of 6 colts, 12 fillies, and 4 geldings were used in this experiment. Colts and fillies were 2–3 yr of age, while geldings were 4–7 yr old (Table 1).

Like human athletes, there are periods when racehorses are not training for a race, and the rhythm

Table 1. Description of horses included in this study

Sex	Age in study	Weeks in study	BW	No. of races up to end of study	No. of races during study
Filly	2	11	432	6	5
Filly	2	15	431	5	4
Filly	2	15	423	5	5
Filly	2	15	435	2	2
Colt	2	15	478	1	1
Filly	2	15	481	0	0
Filly	2	6	489	0	0
Filly	2	10	448	0	0
Filly	2	13	508	0	0
Colt	3	13	517	1	1
Colt	3	13	479	0	0
Filly	3	13	448	5	0
Colt	3	13	449	2	2
Filly	3	13	438	2	1
Colt	3	13	479	0	0
Filly	3	13	501	1	1
Filly	3	13	483	0	0
Colt	3	10	493	0	0
Gelding	4	13	457	3	2
Gelding	4	13	475	3	3
Gelding	5	13	496	0	0
Gelding	7	13	527	34	3

BW, body weight.

of training is temporarily reduced. This could be in response to a less concentrated racing calendar (such as the winter season in the United Kingdom when flat racing is limited to five all-weather race courses), or to ease overtraining, or to provide a break for horses who have been racing extensively, or to allow for healing after a set-back, from which virtually all racehorses (and human athletes) suffer. Consequently, in order to examine the energy expenditure of exercise, this study sorted training into two categories, "active race training" and "reduced training." Active race training includes two subsets, a) horses actually racing and b) those preparing for their first race or coming back into training from a break.

All horses were individually stabled in individual boxes, with a mean area of 16 m^2 and in all cases they were bedded on wood shavings. Welfare assessments in accordance with the UK DEFRA Code of Practice for the Welfare of Horses, Ponies, Donkeys and their Hybrids (DEFRA, 2018) were made by the authors on the first day they came into contact with a given horse, with assessments continuing each time the horses were recorded during training. All stables licensed by the British Horseracing Authority are required to meet its minimum welfare requirements and are regularly inspected. All horses were judged to be in appropriate health for their competitive demands for the duration of their inclusion in the study.

Horse Measurements

Body weight (using an Equiscales three-part portable Equine Scale, Equiscales Ltd, Doncaster, UK), key dimensions (sternum height, heart girth, body length and front pelvis width) and Body Condition Score (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 individualized and developed by the trainer in consultation with the feed manufacturer's nutritional adviser. Manufactured feed (including chaff) was measured at each feeding. Refusals of concentrate feed were infrequent and were measured daily and assigned an energy content of 12 MJ ME/kg of gross weight, the mean energy value of all concentrate fed during the study. Aside from manufactured chaff, the forage provided was haylage of uniform quality from a single farm with a mean dry matter (DM) content of 74.7%. This was fed ad libitum and was weighed every time it was fed (5,404 forage feedings were weighed) using a Smart Forage Wagon (designed by the author and assembled by Equiscales Ltd, Doncaster, UK), which records the weight of the hay removed from the wagon to the nearest 100 g. Forage refusals were easily separated from the fine wood shavings bedding each morning, and where these were estimated to exceed 150 g, they were weighed and deducted from total forage fed. No consumption of bedding was observed. Time spent in grass paddocks by the horses in this study was limited so that the energy intake from pasture was negligible or zero.

Digestion trials to determine the energy content of feeds were not practical, since conducting them is laborious and expensive and, according to Pagan (1998), measuring the gross energy of the feces does not determine the DE of each individual feed but instead the overall digestibility of a mixed ration. Therefore, energy content was estimated based on the chemical composition of the feed. Energy values were calculated in terms of ME, since DE systems overestimate the energy value of forage by about 15% (INRA, 2011). Haylage samples were taken each time new haylage was delivered (infrequent). These were analyzed by the Irish Equine Centre (Naas, Republic of Ireland) which created quantitative analyses of nutritional parameters using near infra-red reflectance (NIR) spectroscopy, reporting DM, crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and ash contents. These data were used to calculate the DE content utilizing the dry forages formula of the NRC (2007, p. 4), where DE/Mcal/kg DM = $4.22 - 0.11 \times (\%ADF) + 0.0332 \times (\%CP) + 0.0012 \times (\%ADF^2)$. This formula was chosen due to its wide acceptance and the fact that it is based on chemical components of the diet that were available from the laboratory. Haylage with a DM content of 74.7% is preserved through a combination of drying and airtight storage and not by ensiling and formation of lactic acid with a subsequent pH decrease. According to Muller et al. (2018), Miyaji et al. (2008), Müller et al. (2009), and Muhonen et al. (2009), there is no significant difference between high DM haylage and hay as long as the plant material used is of the same origin, and therefore using this formula without adjustment is appropriate. Calculated DE values were 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 CV of the mean ME of the haylage deliveries was <1%, and consequently the mean ME value was used for all calculations of haylage energy content.

All processed feed was sourced from Bailey's Horse Feeds, Braintree, Essex, England. One sample (following the laboratory's sampling protocol) was obtained for each of the nine manufactured feeds and analyzed by the Irish Equine Centre using near-infrared reflectance (NIR) spectroscopy, reporting DM, ether extract, protein, crude fiber, and ash. The results were compared to the manufacturer's nutritional disclosure. There were no differences greater than 3%. Consequently, energy and protein values used in this study are based on Bailey's analysis, which was considered to be more accurate since it reflects mean values over thousands of feed bags. DE was converted to ME using the formulas described above.

Table 2 sets out the chemical composition and the energy content of the feeds used in this study.

Some of the horses in this study received medication specific to minor conditions diagnosed by a veterinarian. Any horse whose condition was serious enough to require a break from training was removed from the study. The most common medication prescribed was Gastrogard (Boehringer Ingleheim, Bracknell, UK) for the treatment of suspected gastric ulcers. No performance enhancing medication was administered. The medications administered had virtually no energy value, and they would not be expected to have had an effect on appetite with the possible exception of Gastrogard, which may have improved appetite through the elimination of gastric ulcers.

Conventions Used in Both Studies

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 energy expenditure for exercise during specific training periods less a deduction for the energy expenditure (EE) of standing still (see below). MEm plus MEe equals the total energy expended by the horse.

Energy Expenditure for Exercise (MEe)

Estimated MEe, expressed in MJ ME, was based on data acquired during training using Polar equine

Table 2. Chemical composition and energy content of feeds

	No. 10 Racehorse Mix	No. 16 Racing Light	No. 14 Low-cal Balancer	No. 19 Performance Balancer	No. 21 Ease and Excel	Outshine High fat Supplement	Alfalfa Blend	Haylage
Crude protein, g/kg/DM	130	120	160	260	130	125	150	92
Crude fiber, g/kg/DM	80	110	120	75	180	80	270	
Starch, g/kg/DM	320	260	80	60	80	190	37	
Oil, g/kg/DM	85	45	45	70	105	260	40	
Ash, g/kg/DM	60	75	150	150	80	70	11	66
Digestible energy, MJ/kg/DM	14.0	11.8	11.7	11.3	13.0	24.0	9.0	8.2
Metabolisable energy, MJ/kg/DM	12.8	10.6	10.2	9.0	11.6	22.8	7.2	6.6
Acid detergent fiber								382
Neutral detergent fiber								759

All feeds except haylage were manufactured and packaged by Bailey's Horse Feeds, Braintree, Essex, England.
MJ, megajoule; DM, dry matter.

heart rate 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. For walker and lunging sessions which excluded a saddle, a girth strap was used, manufactured by Polar as an alternative to the paddle design. Ille et al. (2014) compared the HR obtained from a Polar HR monitor to a simultaneously recorded electrocardiogram signal and found that the data were highly correlated irrespective of the recording system and recording time ($r > 0.99$, $P < 0.001$).

Racehorse training has a distinctly weekly cycle, and consequently the data related to the energy expenditure of training is presented here as either weekly data or daily means from weekly training. This way, days off are included in the means. A weekly diary of all training activities was maintained for each horse on the yard's record keeping system. Horses were trained 6 d/wk, with Sundays off, during which they spent 1-h on a horse walker. One walker session was recorded for each horse. Training sessions were monitored 3 d/wk for each week the horse was involved in the study, and included up to 10 different variations on the five gallops used, plus walker, lunging, and flatwork sessions. Since certain sessions were repeated during the week, previously recorded data could be used for the other three days. In total, 730 training sessions were monitored with the Polar equipment. Weekly records were compiled which included, for each day, the type of training, distance, duration, mean HR, top speed, MEe, and all nutrients consumed.

It was not possible to affix HR monitors to horses at race tracks. Consequently, MEe on race days was estimated using the metrics developed in fast training. Transport of the horse on race days was estimated from a number of transport sessions where Polar's girth strap HR monitor was attached to the horse during transport in order to derive a mean energy expenditure/kg BW/min of transport. Estimates of energy expenditure for warm-up and warm-down/kg BW/min were developed from similar activities in the training yard.

HR was converted to energy expenditure 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 VO_2. The resultant equation is: MEe (J/kg BW/min) $= 0.0566 \times HR^{1.9955}$, 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 energy expenditure reflects the ATP production for muscle energy. According to Coenen (2010), the calculated values can be taken 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 110 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. Modelling a lactate accumulation curve allows the computation of the portion of total energy expenditure which 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 of total EE during exercise, which includes maintenance energy expenditure during the exercise period, and therefore an adjustment is required to avoid double counting. Winchester (1943) found that EE for standing was less than EE for horses in a lying position. There are numerous studies which calculate the energy expenditure of standing including Fortier et al. (2015), INRA (2012), Coenen (2010), Minetti et al. (1999), Pagan and Hintz (1986), Eaton (1994) and Winchester (1943). A standard rate of 68 J ME/kg BW/min (equivalent to 0.098 MJ ME/kg BW/24 h) was deducted. The result after the deduction for standing still, expressed in ME, is referred to below as "HR Derived MEe."

This study introduces a metric, "training ratio," which is calculated as the daily energy expenditure for exercise divided by the standard energy expenditure for standing still for 24 h. 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.

Energy Expenditure for Field Maintenance (MEm)

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

Statistical Analysis

The horse was considered to be the unit of observation. Weekly values of all metrics for a single horse over the full period of study (e.g., intake, MEm, and MEe) were averaged. Each horse's training was sorted into periods of "active race training" and "reduced training" as described above, and weekly values for all metrics were averaged for these periods. This provided three sets of means for each horse: full period, active race training periods, and reduced training periods.

All data in tables and the text are presented as means, with CI's and sample sizes disclosed. The effect of time was evaluated by computing the CV and rate of change of each metric by horse/by week. Student's *t*-tests (two sample assuming equal variances) were used to determine significant differences between groups. Independent variables analyzed were: age, sex, active race training vs. reduced training, and within the active race training category, horses currently racing vs. horses, which had not yet raced. An a priori level of statistical significance was set at $P < 0.05$ for all tests.

RESULTS

Nutrient Intake

The mean dry matter and metabolizable energy intakes of the horses in this study are set out in Table 3.

Table 3 is presented on an "as fed" basis, measuring intakes, and consequently the ME values are aggregated. High concentrate diets would not necessarily be additive, as fiber digestibility may fall when the level of concentrate is elevated (Thompson et al., 1984). The racehorses in this study were fed haylage on an ad-lib basis throughout the day, all of which was recorded, including refusals. There was considerable variation in haylage intake, with a range of 0.0045 to 0.0134 kg DM/kg BW, and a CV of 23.6%. At the lower level, together with the chaff consumed, total forage provided only 18% of

Table 3. Mean dry matter and metabolizable energy intakes for 22 racehorses

	Mean dry matter intake/d			Mean ME intake/d		
	kg DM^{-1} kg BW^{-1} d	CI	As a % of Total diet	MJ ME^{-1} kg BW^{-1} d	CI	As a % of Total diet
Intake of haylage	0.0079	0.0008	40.3%	0.0529	0.0050	28.0%
Intake of chaff	0.0017	0.0001	8.9%	0.0152	0.0038	8.0%
Intake of concentrates	0.0100	0.0009	50.8%	0.1208	0.0133	64.0%
Total intake	0.0196		100.0%	0.1888		100.0%
Total for a 500 kg horse/d	9.8054			94.4119		
Intake of crude protein	0.0024	0.00031	12.0%			
Intake of starch	0.0025	0.00034	12.7%			

DM, dry matter; ME, metabolizable energy.

total energy, compared to a mean of 36% for all the horses in this study.

Training Regimes and Energy Expenditure for Exercise

Training regimes were tailored to each horse's temperament, ability, fitness, age, stage of training, perceived best distance, racing schedule, and recent injuries (if any). As described above, most of the horses were 2- to 3-yr old, being trained for sprinting and middle distances. Table 4 illustrates two training weeks for two different horse types (a 3-yr-old middle-distance horse and a 2-yr-old sprinter).

Although work programs for horses in training for flat racing in the United Kingdom and Ireland vary and are a function of the available facilities, the work programs set out in Table 4 are indicative. As described above, there were periods when horses' training was reduced. Horses in "active race training" normally trained 6 d/wk on the gallops. Horses in "reduced training" were normally active 6 d/wk, but their training consisted of walker, hacking (trotting), and easy cantering. Of the 22 horses in the study, only seven were maintained in full race training for the entire duration of the study. However, of the 15 that experienced "reduced training" at some point, this was limited to 1–3 wk for nine of them. Table 5 sets out the means for key metrics observed in all monitored training sessions, segregated between "active race training" and "reduced training."

Over the course of this study, 730 training sessions were monitored for 22 horses. Table 6 summarizes these sessions by the type of facility used.

Table 7 summarizes the correlations between training metrics. The energy expenditure of training (MEe) is highly correlated to both distance and duration, with a slightly lower correlation to maximum speed. The correlation to mean HR is low. As would be expected, distance, and duration are highly correlated. The correlation between the training ratio and MEe is 1.0, since the training ratio is simply MEe/kg BW/d divided by a constant, the standard energy for standing still. The negative correlation between weekly changes in MEe and weekly changes in the training ratio reflects a decrease in appetite as the horses in intensive training trained even harder.

Energy Expenditure for Field Maintenance

The field maintenance expenditure for the 22 horses in the study is presented in Table 8.

All horses were in continual energy balance during the periods recorded, which is defined in this study as those periods covered by a flat trend line on a graph of weight vs. MEm ($r^2 < 0.001$). The mean interweek CV of MEm for each horse was 10.7%, and is principally a function of changes in training demands. Despite the considerable variation in training programs, the coefficient of variation of MEm/kg BW/d between horses was low (11.3%). Differences between groups are illustrated in Table 9.

Field maintenance had a low positive correlation to the training ratio ($r = 0.25$), time spent training ($r = 0.13$), mean HR during training ($r = 0.29$), distance covered during training ($r = 0.29$), and MEe ($r = 0.23$).

DISCUSSION

Discussion: Energy Expenditure for Exercise (MEe)

Table 10 compares the MEe, MEm, and total energy requirements from this study to the four leading sources of guidance.

Compared to the leading studies in the United States (NRC, 2007), Germany (Coenen et al., 2011), France (INRA, 2012), and the Netherlands (Blok, 2016), this study's finding for the MEm of racehorses in active race training is 11% to 66% higher. The findings for MEe are 82% lower than the NRC (2007) and 78% lower than both INRA (2012) and the Dutch guidance. The findings for the total energy requirement are between 4% and 22% lower. This study's results for MEe were 1.8% greater than Meixner et al.'s (1981) study which calculated energy expenditure for each gait from oxygen consumption and the oxygen debt arising from anaerobic expenditure. Southwood et al. (1993) surveyed Thoroughbred trainers in Australia, reporting mean total intake of 129 MJ DE/d, 15.6% more than this study. Gallagher et al. (1992a,b) surveyed Thoroughbred trainers in the United States, reporting mean total DE intake 28.1% more than this study.

The significant differences between the level of MEe recommended by the official sources and this study can be partially explained by differences in exogenous factors and the definition and calculation of MEe. The NRC (2007), for example, would not account for activities such as travel in MEm. To a greater extent than in the United Kingdom, U.S. horses compete in a wide variety of environmental conditions (cold, hot, humid) that increase

Table 4. Weekly average training programs for a 3 YO (middle distance) and a 2 YO (sprinter)

Date	Gallop name	Surface	Incline %	Activity	Intensity %	Duration Min.	ME e MJ ME	Mean HR bpm	Distance km	Top Speed kph
Gelding middle-distance (9F), BW = 485 kg, age 37 months (3YO)										
Sunday				walker	2.0%	46.9	1.0	54.3	1.8	6.3
Monday	The Long	Polytrack	2.0%	8 F canter	32.2%	64.0	15.3	94.4	8.5	45.9
Tuesday	The Short	Ecotrack	2.4%	5 F Canter	27.6%	65.1	13.1	88.4	7.7	39.0
Wednesday	The Short	Ecotrack	2.4%	5 F Canter	48.9%	74.6	23.2	103.3	10.4	56.1
	The Long	Polytrack	2.0%	5 F Gallop						
Thursday	The Short	Ecotrack	2.4%	5 F Canter	27.6%	65.1	13.1	88.4	7.7	39.0
Friday	Folly Road	Fibresand	2.8%	7 F Canter	16.1%	32.0	7.7	93.4	4.0	37.9
Saturday	The Short	Ecotrack	2.4%	5 F Canter	48.9%	74.6	23.2	103.3	10.4	56.1
	The Long	Polytrack	2.0%	5 F Gallop						
Weekly totals					**29.0%**	**422**	**96.6**	**91.1**	**50.5**	**56.1**
Fillie Sprinter (5–6F), BW = 436 kg, age 29 mo (2YO)										
Sunday	Day off			Walker	2.0%	46.90	0.9	54.3	1.8	6.3
Monday	Folly Road	Fibresand	2.8%	7 F canter	16.1%	32.00	6.9	93.4	4.0	37.9
Tuesday	The Short	Ecotrack	2.4%	5 F Canter	41.5%	72.90	17.7	98.8	9.9	43.7
	Fisher's Hill	Activ Track	5.5%	5 F Canter						
Wednesday	Folly Road	Fibresand	2.8%	7 F canter	16.1%	32.00	6.9	93.4	4.0	37.9
Thursday	The Short	Ecotrack	2.4%	5 F Canter	41.5%	72.90	17.7	98.8	9.9	43.7
	The Long	Activ Track	5.5%	5 F Canter						
Friday	Folly Road	Fibresand	2.8%	7 F canter	16.1%	32.00	6.9	93.4	4.0	37.9
Saturday	The Short	Ecotrack	2.4%	5 F Canter	48.9%	74.60	20.9	103.3	10.4	56.1
	The Long	Polytrack	2.0%	5 F Gallop						
Weekly totals					**26.0%**	**363**	**92.6**	**57.5**	**44.0**	**56.1**

Intensity, duration, MEe, mean HR, distance, and top speed values are mean values for all horses in the study (from Table 6).

MJ ME, megajoules of metabolisable energy; bpm, beats/min, BW, bodyweight, YO, years old.

Includes a 60 kg rider and 8 kg racing tack.

Table 5. Summary of 283 wk of racehorse training: means of duration, mean HR, distance, training ratio, and energy expenditure

	Mean	SD	CI	CV	MOE
Active race training: *n* = 193 wk					
Duration: min exercised/wk	333	75	11	23%	1.6%
Mean HR, BPM	89	13	2	15%	1.0%
Weekly distance trained, km	39	20	2.9	53%	3.7%
Training ratio	22%	5.0%	0.7%	23%	1.6%
MEe, MJ ME/kg BW/d	0.0212	0.0049	0.0007	23%	1.6%
Reduced training: *n* = 90 wk					
Duration: min exercised/wk	273	68	14	25%	2.6%
Mean HR, BPM	79	14	3	18%	1.8%
Weekly distance trained, km	20	8	2	37%	4.0%
Training ratio	11%	4.1%	0.9%	40%	3.9%
MEe, MJ ME/kg BW/d	0.0105	0.0042	0.0009	40%	4.2%

Horses in "active race training" normally trained 6 d/wk on the gallops.

Horses in "reduced training" were normally active 6 d/wk, but their training consisted of walker, hacking (trotting), and easy cantering.

Training ratio is the energy expenditure of a training session divided by the standard energy expenditure of standing still for 24 h, 0.098 MJ ME/kg BW.

HR, heart rate in BPM; BPM, beats per minute; MEe, metabolizable energy expenditure for exercise; includes a 60 kg rider and 8 kg racing tack; BW, bodyweight; MOE, margin of error.

MEe. The NRC's (2007) estimates of MEe for racehorses are based on actual time on the track under saddle and would not account for postexercise periods when the horse is being bathed, hand walked, etc. Different approaches to the efficiency of the use of energy during exercise would also explain differences. The NRC (2007) notes that the conversion of DE during high intensity exercise is less efficient, estimating that the efficiency of the use of DE for strenuous exercise is 30%, and INRA (2012) reports an efficiency of 15% to 20% for work.

There are also significant differences in training approaches. In the United States and Australia, most racehorses are trained at a racetrack or on a flat track, not on hillside gallops. National Hunt racehorses are trained more for stamina than speed. The horses in this study followed a regime similar to other flat racehorses in the United Kingdom and Ireland with training taking place 6 d/wk and racing once every 2–3 wk. Training typically involves a warm-up on a horse walker, followed by ridden walking and trotting (usually on the way to the gallop), then one or two pieces of canter or speed work (5–8 furlongs each, separated by a walk) followed by recovery at a walk on the return to the stables. The mean duration of training (excluding hacking or round pen work) was 45.5 min/d (SD = 7.1, n = 598), however, only 6.7% of that time (24.5% of the energy) was spent in canter or gallop. The fast work was intense, but 75% of the work was not. As a consequence, total energy expended in training was a minor proportion of total energy intake. As a percentage of maintenance, it was only 12.1%, but to put this into context, this study's MEm is significantly greater than the official guidance.

Field Maintenance Requirements

MEm for the periods of active race training was 31.5% greater than the requirement recommended by the NRC (2007), 34.9% greater than INRA, 11.2% greater than Coenen et al. (2011), and 66.3% greater than the Dutch (Blok, 2016) recommendation. In terms of the total energy requirement, the NRC's (2007) was 28.7% greater, INRA's (2012) was 15.6% greater, and the Dutch (Blok, 2016) was 4.3% greater. Only the NRC (2007) and INRA (2012) mention specific recommendations for the MEm of racehorses. Coenen et al. (2011) and Blok (2016) mention the Thoroughbred breed.

MEm in the present study included all normal activity over an extended period but also included transport (except to races, which was included in MEe), turn-out, ground training, grooming, shoeing, and veterinary/osteopathic treatments. Time spent on horse walkers was considered to be MEe. A notable feature of this study's findings is the relatively low CV for maintenance requirements of 11.3%, despite the fact that the training regimes ranged from preparation for a first race, to regular racing, to reduced training during downtime. Mean MEm during all periods of active training was 7.5% greater than periods of reduced training. MEm

Table 6. Summary of 701 training sessions for 22 flat racehorses at Lambourn, England, disclosing: mean duration, training ratio, maximum speed, distance, anaerobic energy expended, average heart rate, and energy expenditure by gait

			Training				Energy expenditure (J ME)/m/kg BW					
Training (gradient, distance)	*n*=		Duration min	Ratio %	Max speed kph	Distance km	Walk J ME	Trot J ME	Canter J ME	Gallop J ME	Anaerobic EE % of total EE	Avg HR BPM
The Short (2.4%, 5F) + Fisher's Hill (5.5%, 5F)	54	Mean	72.9	41.2%	43.7	9.9	4.3	3.8	5.3	4.1	7.0%	98.8
		CI	2.0	1.8%	0.9	0.7	0.2	0.3	0.3	0.3	0.9%	4.5
The Long (2%, 8F)	95	Mean	64.0	32.6%	45.9	8.5	3.7	3.3	5.5	4.8	11.3%	94.4
		CI	2.8	2.0%	2.2	0.3	0.4	0.3	0.6	0.7	2.5%	3.2
Folly Road (2.8%, 7F)	309	Mean	32.0	16.2%	37.9	4.0	3.7	4.4	4.4	4.3	9.4%	93.4
		CI	0.7	0.5%	0.5	0.0	0.1	0.1	0.1	0.1	0.5%	1.2
2× Folly Road (2.8%, 7F)	4	Mean	41.6	29.4%	45.1	6.7	4.7	5.3	5.8	3.8	9.8%	110.8
		CI	5.0	7.2%	3.0	0.3	1.8	2.8	2.8	0.8	3.8%	11.1
Kingsdown (3.2%, 8F) warm-up + fast gallop	7	Mean	75.6	53.6%	55.0	10.4	5.1	None	3.8	2.6	13.7%	111.9
		CI	6.1	7.7%	3.1	0.5	0.7	None	1.1	0.7	5.1%	9.1
The Short (2.4%, 5F) + The Long (2.8%, 8F), fast	59	Mean	74.6	48.7%	56.1	10.4	4.9	3.9	5.8	4.9	10.0%	103.3
		CI	1.8	3.3%	1.9	0.5	0.3	0.3	0.4	0.6	4.5%	4.1
The Short (2.4%, 5F)	62	Mean	65.1	28.1%	39.0	7.7	3.5	3.3	5.1	4.7	8.0%	88.4
		CI	2.4	2.9%	1.7	0.2	0.3	0.4	0.5	0.6	1.8%	3.0
The Short (2.4%, 5F) + stalls training	8	Mean	71.2	37.9%	39.5	8.6					5.1%	86.8
		CI	5.9	4.5%	2.0	0.4					1.4%	21.1
Hack	58	Mean	45.0	14.5%	14.0	5.0	3.3	3.1				84.1
		CI	2.3	1.9%	0.5	0.3	0.6	0.3				4.5
Walker then ridden in round pen	18	Mean	27.5	9.8%	13.0	1.6	3.8	3.7	2.8			88.6
		CI	4.4	1.8%	0.8	0.2	0.6	0.7	2.0			6.4
Walker, then lunged in round pen	4	Mean	41.9	24.0%	15.7	2.6						95.0
		CI	5.8	7.6%	4.2	0.2						10.2
Walker on day off, nervous	13	Mean	59.5	34.6%	5.1	1.9						103.2
		CI	5.6	6.7%	0.5	0.4						8.3
Walker on day off, mod. nervous	7	Mean	57.8	15.5%	5.4	2.1						74.7
		CI	11.5	2.1%	0.7	0.5						6.2
Walker on day off, calm	3	Mean	46.9	2.0%	6.3	1.8						**54.3**
		CI	3.6	1.1%	0.7	0.5						14.5
Total number of sessions	**701**											

n, number in sample; intensity, MEE for the session/standard EE of standing for 24 h (0.098 MJ ME/kg BW/24 h); BW, body weight; HR, heart rate; BPM, beats per minute; EE, energy expenditure.
Anaerobic energy expenditure was calculated according to the methodology of Coenen (2010) as described in the Materials and Methods section.
Includes a 60 kg rider and 8 kg racing tack.

during periods when horses were racing was 11% higher than the other periods of active training. MEm for periods of active training but not racing was almost exactly the same for the reduced training periods (0.9% greater). Therefore, the only significant difference found was between currently racing horses and all the others. This infers that only a significant increase in training intensity will increase overall metabolism (as reported by INRA, 2012), with small changes in training having a limited effect on maintenance. However, this increase in general metabolism does not appear to be linear. Individual horses with a training-induced increase in general metabolism exhibit fluctuations in their maintenance expenditure related to changes in training. Table 7 discloses training correlations. The change in weekly training intensity (training ratio) was negatively correlated to changes in weekly MEm for the horses in active race training (already at a high general level of maintenance energy). There were negative correlations (r's between –0.09 and –0.93) for 19 of the 22 horses, with a mean r for those horses of –0.49. This is evidence that for racehorses already in training, when they train harder (increased training ratio), they tend to consume less maintenance energy, at least during a transition period. The horse that trained the hardest (highest training ratio) ate the least haylage (only 20% of her ME input), had the highest mean MEm/kg/BW (0.2107), the highest MEe/kg/BW (0.0243) but experienced a high negative correlation (r = –0.68) between further increases in the training ratio and changes in her high MEm requirements. These findings are consistent with those of Gordon et al. (2006), who found that as a training regime for Standardbred horses increased, they began to consume less of a total mixed ration offered on an ad libitum basis. They called this "training-induced energy balance mismatch." This can be accompanied by short-term fatigue. This should be distinguished from "overtraining," which is a syndrome similar to chronic fatigue, associated with reduced performance that is not corrected by several weeks of rest. Overtraining reduces appetite and BW, and involves a loss of interest in exercise (Evans, 2007; McGowan and Whitworth, 2008).

It is also possible that the increased training led to an increase in gastric ulceration. Gastric lesions are highly prevalent in Thoroughbred racehorses in training (Murray et al., 1996). In their study, 93% of the 67 racehorses suffered from gastric ulceration, and the severity increased with the intensity of training. The yard used for the present study was a low-stress environment and feeding occurred throughout the day with chaff fed before exercise. Nevertheless, the training would be expected to produce the increases in gastric pressure, reduced volume and lower pH which Lorenzo-Figueras and Merritt (2002) found to contribute to squamous mucosal lesions in the proximal portion of the stomach. Gordon et al. (2006) concluded that these contributed to the lower DE intake in their exercising horses. This is one possible explanation for why fit horses may consume less feed when training is increased.

The horses in this study were being trained for flat racing in the United Kingdom, where the majority of horses racing are 2- to 3-yr old. Eight of the horses were between 27 and 29 mo old ("2-year-olds") during the study, with five of these running in one or more races during the study. Ten of the horses were between 31 and 37 mo old

Table 7. Energy expenditure of exercise correlations

	r
Duration/ME e	0.913
Mean HR/ME e	0.294
Distance/ME e	0.947
Distance/duration	0.970
Max speed/ME e	0.770
Weekly change in ME e/weekly change in training ratio	–0.343

ME e, energy expenditure of exercise.

Table 8. Energy expenditure for field maintenance for 22 racehorses in training for flat racing

			Energy expenditure for field maintenance				
			Mean MJ ME	**SD** MJ ME	**Conf. Int.** MJ ME	**CV**	**MOE**
Type of training	n (horses)	wk	kg BW/d	kg BW/d	kg BW/d	%	%
Active race training	20	193	0.1731	0.0174	0.0076	10.1	2.2
Reduced training	15	90	0.1609	0.0161	0.0077	10.0	2.4
Combined	22	283	0.1694	0.0192	0.0080	11.3	2.4

ME, metabolizable energy; BW, body weight; MOE, margin of error.

Table 9. Comparative maintenance energy consumption

	MEm	Difference	*P*-value
Geldings	0.1707	2.7%	0.286
Fillies	0.1754		
Two year olds	0.1757	2.4%	0.319
Three year olds and older	0.1717		
All periods of active race training	0.1731	7.5%	0.020
All periods of reduced training	0.1609		
Periods of active race training, currently racing	0.1803	11.0%	0.012
Periods of active race training, preparing for first race	0.1623		
Periods of active race training, preparing for first race	0.1623	0.9%	0.419
All periods of reduced training	0.1609		

MEm, maintenance energy consumed/d, MJ ME/kg BW/d.

Table 10. Comparison of the results of this study for the energy expenditure of training and maintenance of racehorses to leading studies

			MJ ME/kg BW/d		
Source	Horse type	Activity	MEe: EE for Exercise	Maintenance Requirement	Total energy Requirement
This study	TB racehorses	Active flat race training	0.0212	0.1731	0.1943
This study	TB racehorses	Reduced training	0.0105	0.1609	0.1714
US: NRC (2007)[a]	TB racehorses	Racing TB's, very heavy work	0.1185	0.1316	0.2501
US: NRC (2007) [a]	TB, SB, QH, Endurance	Race training, middle stages	0.0724	0.1207	0.1932
France: INRA (2012) [b]	TB/Standardbred	Very intense competition, racing	0.0964	0.1283	0.2247
Netherlands: Blok (2016) [c]	TB mare/gelding	Eventing, trot and racing sport, Class IV	0.0986	0.1041	0.2028
Germany: Coenen et al. (2011)[d]	Thoroughbred	Fully trained		0.1556	

[a] United States: NRC (2007): p. 26—converted from DE to ME by multiplying DE by 0.866, the mean ME/DE ratio from the 22 diets in this study.

[b] France: INRA (2011): p. 25—UFC converted to ME by using the ME value of 1 kg of barley, 12.05 MJ, converting MBW to BW on the basis of a 500 kg horse, adding 35% correction for "exercising TB/Trotter" status. Table 6.18 recommends equivalent of 0.2008 MJ ME/kg BW/d.

[c] Netherlands: Blok (2016): p. 7—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 adding 0.021 EWpa/kg MBW/d supplement for working status.

[d] Coenen, et al. (2011)—thoroughbred guidance used. Converted MBW to BW on the basis of a 500 kg horse. 15% correction for "fully-trained" status.

ME, metabolizable energy; BW, body weight; MEe, energy requirement for exercise; TB, Thoroughbred; SB, Standardbred (trotters); QH, Quarter horse.

("3-year-olds"), with four of these racing during the study. Published studies of the nutritional requirements of Thoroughbreds up to 24 mo old are abundant, however there are very few which report on requirements during the crucial 24- to 48-mo-old period for flat racehorses. According to Staniar (2013), Thoroughbreds are still growing at the age of two, but very slowly, with 2-yr olds reaching 85% to 89% of their mature BW and 3-yr olds having reached 95%, with withers height and cannon bone circumference maturing even faster. INRA (2012) estimates 83% at 24-mo and 95% at 36 mo. Hintz (1979) found that Thoroughbreds reached 80% of mature BW at 18 mo. The NRC's (2007) equation yields very similar results and they note that the maintenance requirement of horses at 24 mo is the same as their "elevated" requirements for mature horses. Although not specifically addressing Thoroughbreds, for young horses aged 30 to 36 mo, INRA (2012) recommends MEe of 6.2 UFC/d (equivalent to 0.1556 MJ ME/kg BW/d on the basis of 1 UFC = 12.05 MJ ME), which is within 10% of the result of this study. Horses in flat races are normally significantly younger than horses in National Hunt racing or harness racing, with 2- and 3-yr olds continuing to mature during training, which may explain the higher MEm results of this study compared to others.

A distinction should be made between the maintenance requirements of these young horses and their energy requirements for growth. As noted above, the horses in this study did not gain weight during their 3 mo participation in the study. The 2-yr olds had a mean weight loss of 1.3% (SD = 2.2%) during the study, while the 3YO's had a mean loss of 0.9% (SD = 2.1%). Examining the weekly weights from the inception of our study until 1 yr later, the young horses did gain weight, but very slowly: the 2-yr olds gained a mean 5.8% (SD = 1.9%) and the 3-yr olds gained 2.6% (SD = 3.1%). Applying the NRC's (2007) formulae (1)–(3), expected growth would have been 9.6% and 3.4%, respectively. When yearlings commence flat race training in the United Kingdom at about 20 mo old, they lose the adipose tissue gained for the yearling sales, and gain muscle. When the training progresses towards intensive training for a first race, weight gain ceases. Normally, 2-yr olds are given a break away from the racing yard at some point in the first year of training, and it is then that they gain weight (D. Kubler, Kübler Racing, personal communication, 17 May 2020). The calculated values for MEm in this study do not include energy required for weight gain, because the horses in training (even temporarily reduced training) did not gain weight. This is obviously also a function of effective diet management: feeding the appropriate energy to match the intensity of training. For the young horses on a break, away from the training yard, NRC's (2007) equation 1-1 for MEm and 1-2 for weight gain would apply.

Anaerobic Energy Expenditure

This study utilized the methodology of Coenen (2010) to estimate anaerobic energy whenever HR exceeded 110 BPM. The estimates ranged from 5.1% of total MEe for stalls training to 13.7% for sessions which included fast work on a track with a 3.2% gradient. Coenen's equation requires an estimate of the fitness of the horse, expressed as the quantity of lactate per liter of blood at a given HR and speed. This study modelled anaerobic expenditure using a blood lactate curve assuming 5.8 mmol lactate/L at a speed of 29 kph and an HR of 180 BPM, a rate which is considered to be "average fitness" by Coenen (2010). The worst case error from using an incorrect lactate curve assumption would occur during the most demanding work. This study's methodology would overstate MEe for a very fit horse (concentration of 3.8 mmol/L) during a fast work session by 5.7%, and understate MEe for an unfit horse (11.8 mmol/L) by 9.2%. The latter case would be unlikely, as unfit horses were not trained in fast work until they became fit. Lacombe et al. (2001) studied muscle glycogen depletion and replenishment, reporting a maximal accumulated oxygen deficit during fast training of 106 mL O_2 equivalent/kg BW. At the generally accepted rate of 20.1 J/mL O_2 (Blaxter, 1989), this would equate to 0.0021 MJ ME/kg BW. Aside from the most intensive sessions, this is in-line with the anaerobic expenditure estimated here. The repletion of muscle glycogen stores related to the accumulated oxygen deficit created during a fast work training session does not occur within 24 h. However, by including an estimate of anaerobic energy expenditure in the estimate of total MEe, and deducting MEe from total intake to arrive at MEm, the creation of the oxygen deficit is properly classified here as MEe.

Because Coenen's equation estimates the percentage of energy expenditure which is anaerobic based on HR, not speed, it does not capture the total energy expended at the initiation of a piece of fast work. According to Eaton (1994), at the onset of exercise, VO_2 lags energy expended, and energy is supplied anaerobically. This is met by O_2 stores in the body and anaerobic supply (Eaton, 1994). Eaton estimates that during fast work at a work intensity of 125% of maximal oxygen uptake (VO_{2max}), horses can reach 50% of VO_{2max} in 11 s, and 75% in 20.8 s. Coenen (2010) agrees that this period of oxygen deficit at the onset of work is measured in seconds and concludes that it is of minor consequence. This study investigated ten pieces of fast work to determine the difference between the aerobic energy expended at the start of a sprint (based on HR) and the energy that would be expected based on speed, and found that the oxygen deficit at the start of a sprint can be up to 5% of the entire MEe. This was not accounted for in this study, and could be responsible for a small (<5%) underestimation of MEe for fast work sessions, but would not have a material effect on the overall findings. During flat race training and racing, this level of oxygen debt is likely to take place only at the onset of a sprint, but for National Hunt racing, as well as polo and show jumping, it is likely to play a greater role due to the multiple spurts of high intensity exercise demanded by these sports.

Methodology

Previously published studies examining energy expenditure for maintenance are predominantly based on feeding trials with inactive horses or horses in a confined space such as a metabolic chamber. These include Winchester (1943), Wooden et al. (1970), Hintz et al. (1971), Stillons and Nelson (1972), Pagan and Hintz (1986), Vermorel et al. (1990), Martin-Rosset and Vermorel (1991), Vermorel et al. (1997a) and Vermorel et al. (1997b). In the feeding trials, bomb calorimeters were used to determine gross energy and DE was determined by the heat of combustion of the feces, producing more accurate results than this study, which relied on the formulas created in those studies. By their nature, such studies are limited to 4–5 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. The cost of the methodology precludes large sample sizes.

The methodology used here allows the measurement of actual "real-life" training and maintenance of racehorses over extended periods with a large sample size and therefore takes into account the normal every-day stresses and strains that can influence energy expenditure 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 margin of error and high statistical power.

Using HR as the basis of measuring energy expenditure integrates any signal which induces a change in metabolic effort. In particular, the slope of a track or the up and downhill on a cross-country course, the weight of the rider and tack, additional weights applied for racing, soft turf, riding against the wind, etc. will be recognized by HR if there is a change in demand for oxygen. On the contrary, this parameter is compromised if horses are excited or suffer from disease (Coenen et al., 2011).

A shortcoming of this study's methodology is that, in a quest for extended duration and a large sample size, the entire sample was sourced from one training yard. Since flat racehorse training in the United Kingdom is highly standardized, and because the study took place in the second largest training center in the United Kingdom, any resulting bias should be limited. The age profile of the horses included in this study was broadly similar to the overall profile of United Kingdom flat racehorses in training as reported by the British Horseracing Authority (2020). The advantage of using a single yard was the reduction in the variation of exogenous factors.

CONCLUSION

The mean field maintenance expenditure for racehorses in training for flat racing was found to be 0.1694 MJ of metabolizable energy/kg of bodyweight (BW)/d (SD = 0.0192). The maintenance requirement for horses actively racing was 11% higher than the others. The overall result is 11% to 66% greater than the official guidance for Thoroughbreds in work found in the United States, France, Germany, and the Netherlands, and can be partially explained by the relative youth of flat race horses and the general increase in metabolism that takes place as they train intensively. It also reflects the considerable variation in the definition of maintenance in the literature. Including those actively racing, the level of variation in MEm was low (CV of 10.7%) reflecting the homogeneity of the population. Since the young horses in this study did not gain weight, there was no need to provision for average daily gain, however the young horses gained weight slowly when given a break. Heart rate monitoring of training revealed a mean estimated energy expenditure for training of 0.0212 MJ ME/kg BW/d (SD = 0.0049), based on a week's training. This represents a multiple of maintenance of only 12.3%, substantially lower than the official guidance. This can partially be explained by the higher maintenance requirement in this study, the different approaches to training across the world, as well as assumptions used for the efficiency of energy use during periods of intense training. Overall, the total mean requirement for racehorses in active race training is 0.1943 MJ ME/kg BW/d (SD = 0.0177), which is 4.2% to 22.3% less than the official guidance. Twenty-two racehorses were monitored over 283 horse weeks, and 730 training sessions were measured with HR monitors, making this the most comprehensive field-based study of its kind undertaken to date.

Racehorses in training for flat racing exhibit a unique mix of characteristics affecting energy requirements, including their youth, breed, changing body composition, variations in training, the demands of racing, and frequent alterations to high starch diets. This study only begins to unravel the complex dynamics influencing energy balance in the racehorse.

FUNDING

In order to ensure absolute objectivity, this study was entirely self-funded by the authors.

AUTHOR CONTRIBUTION

This study was a joint effort by the two authors, Prof. Meriel Moore-Colyer and Mark Ebert. The original research question and concept was developed by Ebert, the study was designed jointly, Ebert analyzed the data and the article was jointly written.

Conflict of interest statement. The authors declare that they have no conflict of interest with any organization regarding this manuscript.

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