Development of a mathematical model for predicting digestible energy intake to meet desired body condition parameters in exercising horses

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ABSTRACT: Maintaining optimal body condition is an important concern for horse owners and managers as it can affect reproductive efficiency, athletic ability, and overall health of the horse; however, information regarding dietary requirements to maintain or alter BCS in the horse is limited. A recently developed model had high accuracy in predicting the energy required to alter BCS in the horse. However, the model was restricted to sedentary mares, while many horses are subject to physical work. The objective of this study was to expand the scope of that model to include exercising horses by incorporating previously published estimates of exercise energy expenditure and then testing the expanded model. Stock type horses ($n = 24$) were grouped by initial BCS (3.0 to 6.5) and assigned to treatments of light (L), heavy (H), or no-exercise control (C). Horses were fed according to the model recommendations to increase (I) or decrease (D) two BCS within 60 d. Thus, six treatments were obtained: HD, HI, LD, LI, CD, CI. Mean DE intake Mcal/d for each group was HD = 19.3 ± 0.90 , HI = 29 ± 0.84 , LD = 13.2 ± 0.54 , LI = 23.1 ± 1.39 , CD = 12.1 ± 0.79 , and CI = 21.9 ± 0.94 . BCSs were evaluated by three independent appraisers, days 0 and 60 values were used to calculate the average BCS

change for HD = -0.88 ± 0.24 , HI = 1.13 ± 0.24 , LD = -1.5 ± 0.29 , LI = 0.88 ± 0.38 , CD = -1.38 ± 0.13 , and CI = 1.35 ± 0.14 . Statistical comparison of final observed and model predicted values revealed acceptable precision when predicting BCS and BW respectively in control horses ($r^2 = 0.91, 0.98$) but less precision when predicting body fat (BF) ($r^2 = 0.51$). Model precision for BCS, BW, and BF respectively in lightly ($r^2 = 0.29, 0.85, 0.57$) and heavily ($r^2 = 0.04, 0.84, 0.13$) exercised horses was low. Model accuracy was acceptable across all treatments when predicting BW ($C_b = 0.97, 0.96, 0.98$). However, accuracy varied when predicting BCS ($C_b = 0.82, 0.89, 0.41$) and BF ($C_b = 0.80, 0.55, 0.87$) for the control, light, and heavy exercise groups, respectively. These results indicate that the revised model is acceptable for sedentary horses but the predictability of the model was insensitive to the exercising horse, therefore the exercise energy expenditure formulas incorporated into the model require revision. Packaging this model in a format that facilitates industry application could lead to more efficient feeding practices of sedentary horses, generating health, and economic benefit. Further investigation into energy expenditure of exercising horses could yield a model with broader applications.

Key words: body condition score, equine, exercise, nutrition model

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INTRODUCTION

Maintaining optimal nutritional status is an important managerial concern for horse owners and managers. In horses, previous research

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indicates that over- or under-nutrition can be detrimental to reproductive efficiency (Henneke et al., 1984; Cavinder et al., 2009), athletic ability (Kearns et al., 2002), and overall health (Hoffman et al., 2003; Adams et al., 2009). The BCS system was developed to help researchers and professionals better quantify the energy status or fatness of horses (Henneke et al., 1983); however, current NRC (2007) nutritional recommendations for horses are based on BW and studies investigating DE requirements to maintain or alter body condition in horses are limited and restricted to sedentary animals (Suagee et al., 2008; Cordero et al., 2013; Gill et al., 2017).

In the cattle industry, nutrition models have been created to estimate energy requirements based on body composition (Tedeschi et al., 2006a; Tedeschi and Fox, 2018), and this Ruminant Nutrition System model was recently revised and applied to horses (Cordero et al., 2013). Cordero et al. (2013) developed an equine nutrition model, with the goal of estimating the amount of DE required to alter BCS within a specified period. Body reserves models like Cordero's (2013) model rely on determining the total energy (TE) of the body and then adjusting the TE to achieve changes in overall BCS. Industry application of this model has the potential to create more efficient feeding practices both nutritionally and economically; however, this model was evaluated on sedentary horses at maintenance. Many horses in the United States are used for athletic activities such as racing, showing,

and recreation (American Horse Council, 2005). Therefore, the objectives of this study were to further expand upon the nutrition model developed by Cordero et al. (2013) to include exercising horses based on exercise energy expenditure estimates from previous research, and to apply the expanded model to evaluate the effectiveness in predicting changes in BCS for exercising horses.

MATERIALS AND METHODS

Model Development

The basis of the Cordero et al. (2013) model is to quantify and alter the TE contained in the body using the equations in Table 1. The model developed by Cordero et al. (2013) was adapted from the concepts developed by Tedeschi et al. (2006a). Total energy is determined by quantifying body fat (BF) and body protein (BP) of the animal and then multiplying each by their heat of combustion (eq. 1; Table 1). Cordero et al. (2013) determined BF by ultrasonic measurement of rump fat thickness as described by Westervelt et al. (1976) and %BP was estimated to be 21.37% of fat-free mass based on data from previous studies. Data from an earlier study (Cavinder et al., 2009) were utilized to develop a weight adjustment factor to predict final BW when the desired change in BCS is achieved (eqs. 2 to 5; Table 1). The energy required to meet the change in body energy desired was determined by subtracting initial TE from final TE (eq. 6; Table 1). This body

Table 1. Equations used in the formulation of the mathematical nutrition model to predict DE intake of exercising horses based on body condition changes

Equation number	Equation	Unit	Source
1	$TE = (9.367 \times TF) + (5.554 \times TP)$	Mcal	Cordero et al. (2013)
2	$WAF = 1 - 0.0388 \times (5 - BCS [1-9])$	%	Cordero et al. (2013)
3	$SBW = FBW \times 0.96$	kg	Cordero et al. (2013)
4	$EBW = SBW \times 0.851$	kg	Cordero et al. (2013)
5	$fEBW = (iEBW \times WAF) / iWAF$	kg	Cordero et al. (2013)
6	$\Delta TE_i = TE_i - TE_{i-1}, i \geq 2$	Mcal	Cordero et al. (2013)
7	$\Delta TE < 0, \text{ then } \Delta ME = (\Delta TE \times 0.84) / 0.644$	Mcal	Cordero et al. (2013)
8	$\Delta TE > 0, \text{ then } \Delta ME = \Delta TE / 0.726$	Mcal	Cordero et al. (2013)
9	$\Delta DE = \Delta ME / 0.85$	Mcal	Cordero et al. (2013)
10	$DE_{\text{exlight}} = 0.0051 \times BW$	Mcal/h	Hintz et al. (1971)
11	$DE_{\text{exmoderate}} = 0.0125 \times BW$	Mcal/h	Hintz et al. (1971)
12	$DE_{\text{exheavy}} = 0.024 \times BW$	Mcal/h	Hintz et al. (1971)
13	$DE_{\text{exveryheavy}} = 0.039 \times BW$	Mcal/h	Hintz et al. (1971)
14	$DE_m = 155 \times BW^{0.75}$	Kcal	NRC (1978)
15	$DE_{\text{adj}} = DE_m + DE_{\text{ex}} - DE_i + \Delta DE$	Mcal/d	Final output for revised model

¹TE = total body energy; TF = total body fat; TP = total body protein; WAF = weight adjustment factor; SBW = shrunk BW; FBW = full BW; EBW = empty BW; fEBW = final empty BW; iEBW = initial empty BW; iWAF = initial weight adjustment factor; ME = metabolizable energy; DE_m = DE requirement for maintenance; DE_{adj} = DE adjustment required to meet the desired BCS; DE_{ex} = DE requirement for exercise; DE_i = initial DE intake; ΔDE = change in DE required to alter BCS as calculated by the original model.

energy represents an NE value; however, energy requirements for horses are most often expressed in terms of DE, and so efficiencies of conversion were applied (eqs. 7 to 9; Table 1).

To include the exercising horse, the Cordero's et al. (2013) model was altered to include energy expenditure of work equations developed by Hintz et al. (1971) for light, moderate, heavy, and very heavy exercise (eqs. 10 to 13; Table 1). Additionally, the Cordero's et al. (2013) model was only equipped to calculate the change in DE required to alter BCS; it did not take into account whether or not the horse in question was already on an increasing or decreasing plane of nutrition. To address this issue, the model was modified to include maintenance DE requirement (NRC, 1978) (eq. 14; Table 1). The final recommendation of the model was then calculated by summing the maintenance requirement, exercise requirement, and the change in energy as calculated by the model, then subtracting current energy intake (eq. 15; Table 1).

Model Application

Mature stock type horses ($n = 24$; 3 to 16 yr of age), with initial BW ranging from 400 to

569 kg (mean = 488 kg) and initial BCS of 3 to 6.5 (Henneke et al., 1983) were used in this study (Table 2). All horses were ridden approximately three to four times per week at a moderate intensity for at least 3 mo, followed by 3 wk of rest prior to the start of the study, thus all horses were of similar fitness level. Use of animals was approved by the Texas A&M University Institutional Agricultural Animal Care and Use Committee using guidelines set forth by the Federation of Animal Science Societies (2014).

Pretrial measurements of BCS, BW, and RF thickness were obtained and were reevaluated every 2 wk throughout the 60-d trial. Rump fat thickness was assessed with ultrasound and extrapolated to BF as described by Westervelt et al. (1976). BCSs were determined through a visual and tactile appraisal conducted by three independent, experienced individuals as described by Henneke et al. (1983) and these scores were averaged to determine the recorded BCS. Because of statistical design requirements along with practical and ethical reasons, horses that entered the study at a low BCS ($\text{BCS} \leq 5$) were randomly assigned to groups CI, LI, and HI; while horses with an initial high BCS ($\text{BCS} \geq 5$) were randomly assigned to groups CD,

Table 2. Initial values for horses ($n = 24$) utilized to test the revised nutrition model

Exercise protocol	Age	Gender	BW (kg)	BCS _{initial-desired}	%BF _{initial}	Breed
Heavy	8	m	424.11	6 to 4	10.61	QH
	9	g	548.85	6.5 to 4.5	12.40	QH
	8	g	564.27	5.5 to 3.5	11.55	QH
	6	m	502.58	6 to 4	11.65	QH
	4	g	471.74	4 to 6	10.33	QH
	4	m	442.71	4 to 6	11.27	QH
	7	g	502.13	4 to 6	10.52	QH
	12	g	465.84	4.5 to 6.5	9.86	PT
Light	4	g	498.50	5 to 3	10.24	QH
	8	m	470.38	6 to 4	13.06	QH
	10	g	569.26	6.5 to 4.5	13.15	QH
	15	g	561.09	5.5 to 3.5	12.40	QH
	6	m	431.37	4.5 to 6.5	10.61	QH
	3	g	400.07	3 to 5	9.30	QHX
	16	m	497.14	4 to 6	9.67	QH
	10	g	539.77	3.5 to 5.5	9.39	QH
Control	16	g	502.58	5.5 to 3.5	10.61	QH
	5	g	440.44	5.5 to 3.5	13.25	QH
	4	m	472.19	5.5 to 3.5	10.24	QH
	12	m	486.25	5.5 to 3.5	10.43	QH
	6	m	452.23	5 to 7	11.27	QH
	13	g	467.65	4 to 6	11.74	AP
	8	g	483.08	4 to 6	11.84	QH
	13	g	526.17	3.5 to 5.5	9.39	QHX

m = mare; g = gelding; QH = Quarter Horse; QHX = Appendix; AP = Appaloosa; PT = Paint.

LD, and HD. Group CI ($n = 4$) received no exercise and was fed to increase by two BCS; group CD ($n = 4$) received no exercise and was fed to decrease two BCS; group LI ($n = 4$) received light exercise and was fed to increase by two BCS; group LD ($n = 4$) received light exercise and was fed to decrease by two BCS; group HI ($n = 4$) received heavy exercise and was fed to increase by two BCS; and group HD ($n = 4$) received heavy exercise and was fed to decrease by two BCS. All groups were fed according to the revised [Cordero's et al. \(2013\)](#) model predictions to achieve BCS gain or loss of 2 scores in 60 d.

Exercise

Exercise was conducted under saddle at the Texas A&M Equestrian Center in a covered arena from June through August. Riders were assigned to horses so that rider weights were consistent for each horse through the duration of the study. Protocols were designed to mimic the descriptions of workloads outlined in the [NRC \(2007\)](#) and are outlined in [Table 3](#). Exercise protocols were carried out on the rail in a group setting so that duration at each gait could be exact. During each exercise bout, one horse in the group was fitted with an heart rate (HR) monitor (Polar, Bethpage, NY) to evaluate the intensity of the exercise protocols. A total of four HR data collections were accomplished for each horse and all HR data were utilized to calculate means ([Table 4](#)). Horses received 12 h of individual turnout each week in a dry lot run.

Diet Characterization

Diet consisted of forage (Coastal bermudagrass, 89.9% DM) and pelleted concentrate (13% CP pelleted feed, Brazos County Producer's Co-Operative

Association, Bryan, TX). Samples were obtained by random core sampling of forage, and random grab samples of concentrate. All samples were submitted to a commercial laboratory for chemical analysis. The DE was determined as described by [Pagan \(1998\)](#) using the following equation:

$$\text{DE} = 2,118 + 12.18 \times \text{CP} - 9.37 \times \text{ADF} - 3.83 \times \text{HC} + 47.18 \times \text{EE} + 20.35 \times \text{NSC} - 26.3 \times \text{ASH},$$

where DE, kcal/kg of DM; CP, % of DM; ADF, % of DM; HC is hemicellulose, % of DM; EE is ether extract (i.e., fat), % of DM; NSC is non-structural carbohydrates (e.g., starch and sugars), % of DM; and ASH is non-organic matter, % of DM.

Results for forage on a DM basis were CP = 12 %DM; lignin = 6.6 %DM; ADF = 37.8 %DM; NDF = 68 %DM. Results for concentrate on a DM basis were CP = 17.8%; ADF = 13.7%; and NDF = 27.1%. Animals were fed 1% BW in forage per day; custom mixed pelleted feed was added to meet the gap between the DE available in forage and the DE recommended by the revised [Cordero et al. \(2013\)](#) model. There were five horses, all being exercised and expected to increase in BCS, for whom the model recommended DE could not safely be met, where concentrate is fed at no more than 0.5% BW per meal, with forage and pelleted feed alone. For these individuals, the concentrate was top dressed with 0.54 kg/d of corn oil (DE = 9.19 Mcal/kg; [NRC 2007](#)) to meet the DE requirement safely. Horses were fed individually in stalls equipped with hay and grain combo stall feeders. Feedings were twice daily, spaced 12 h apart. Clean water was offered ad libitum. Refusals were collected, weighed, and recorded after each feeding; and DE intake was calculated by subtracting orts DE from the DE offered. Mean DE intake and DMI for each group are outlined in [Table 5](#).

Statistical Analysis

The final BCS, BW, and BF were compared with model predicted values to assess model precision and accuracy as discussed by [Tedeschi \(2006b\)](#) using the Model Evaluation System (MES) (<http://www.nutritionmodels.com/mes.html>, accessed on April 23, 2018). Briefly, the coefficient of determination (r^2) was evaluated as a good indicator of the precision of the model. Mean bias (MB) represents the mean difference between observed and predicted values and is an indicator of model accuracy ([Tedeschi, 2006b](#)). This statistic also provides information about model over or under

Table 3. Exercise protocols designed to mimic the [NRC \(2007\)](#) descriptions of exercise and conducted under saddle at the Texas A&M University Equestrian Center

	Exercise protocol	
	Light	Heavy
Walk, min	18	12
Sitting trot, min	11	14
Extended trot, min	12	16
Lope, min	4	9
Extended Lope, min	0	9
Total Duration, min	45	60
No. of rides per week	3	4

Table 4. Mean HR values observed during exercise for heavy and light exercise at each gait and over time

Gait	Mean HR		Mean HR combined				P-value			
	Heavy exercise	Light exercise	T1	T2	T3	T4	Ex	Time	Ex × Time	ΔBCS
Walk	83.47	74.27	86.69	81.20	72.89	76.01	0.060	0.035*	0.183	0.251
Sitting trot	117.46	108.26	125.69	114.91	106.45	105.74	0.230	0.132	0.091	0.182
Extended trot	130.59	129.49	146.63	136.81	124.48	115.58	0.932	0.010*	0.061	0.669
Lope	146.53	154.01	167.41	156.99	141.69	138.33	0.092	0.001*	0.060	0.609
Extended lope	169.00	—	184.32	180.34	151.69	159.65	—	0.018*	—	0.406
Total	124.09	109.14	136.87	131.13	120.37	113.92	0.007*	0.012*	0.066	0.281

* $P \leq 0.05$ significant.

T1 = time1; T2 = time2; T3 = time3; T4 = time4; Ex = exercise groups (none, light, and heavy); ΔBCS = groups being fed to increase or decrease in BCS according to the model.

Table 5. Mean DE intake and DMI for control and exercise groups fed to increase or decrease in BCS according to the model

Group	Mean DE intake (Mcal/d)	Mean DMI (kg/d)	Mean DE intake (kcal/kg BW/d)
HD	19.3 ± 0.90	7.7 ± 0.37	38.0 ± 0.64
HI	29 ± 0.84	9.8 ± 0.12	61.6 ± 0.82
LD	13.2 ± 0.54	5.9 ± 0.21	25.2 ± 0.98
LI	23.1 ± 1.39	8.8 ± 0.50	49.5 ± 0.38
CD	12.1 ± 0.79	5.4 ± 0.28	25.3 ± 1.0
CI	21.9 ± 0.94	8.4 ± 0.35	45.7 ± 0.91

H = heavy exercise; L = light exercise; C = nonexercised; D = fed to decrease BCS; I = fed to increase BCS.

prediction, with a positive MB indicating model under prediction and a negative MB signifying model over prediction. Modeling efficiency (MEF) offers a measure of goodness of fit by quantifying the proportion of variation between the observed values and model-predicted values explained by the linear regression. The closer the MEF is to 1, the better the fit (Loague and Green 1991; Mayer and Butler 1993). The mean square error of prediction (MSEP) is a reliable and common estimate of the accuracy of a model, with a low MSEP denoting greater accuracy (Bibby and Toutenburg 1977). Maximum error (MAE) is the maximum difference between observed and model predicted values. The concordance correlation coefficient (CCC) is a product of the correlation coefficient estimate and the bias correction factor, with values closer to 1 indicating greater precision and accuracy of the model. The bias correction factor (C_b) is a measure of how far the best fit line varies from 45°, therefore, being an indicator of accuracy. Regression analysis was conducted in order to evaluate the response of each variable BCS, BW, BF, rump fat thickness (RFT), and HR to treatment and time using PROC GLM of SAS (SAS Inst., Cary, NC). To quantify the relationship among BF and BW to BCS, mixed model analysis was conducted with horse assigned as the random variable. Evaluation of the solution for fixed effects yielded eqs 1 to 2.

RESULTS

Time

Body parameter measurements over time and regression analysis are outlined in Table 6. By design, there was a significant effect of ΔBCS and ΔBCS by day interaction on all body parameters, as animals were specifically fed to increase or decrease BCS through the duration of the study. When evaluating these two groups individually, there was a significant linear day impact on BCS, BF, and RFT for both groups with a trend towards significance for BW ($P \leq 0.1$). There was also a significant exercise by ΔBCS interaction for BW ($P = 0.05$), BF ($P = 0.004$), and RFT ($P = 0.004$).

Body Condition Score

The BCS data for all animals ($n = 24$) and corresponding model predictions for BCS had moderate precision ($r^2 = 0.37$; $P = 0.002$) and an MAE of two BCS units (Figure 1). Meaning that, when all animals are included, the model accounted for 37.3% of the variation in observed BCS values and at least one horse did not change BCS for the duration of the study. The MB was -0.083 BCS units indicating that the model, on average, over-predicted the final BCS. There was a systematic bias in

Table 6. Variables measured approximately every 2 wk during 60-d feeding trial¹

	Days					Orthogonal contrasts	
	Day 0	Day 14	Day 28	Day 42	Day 60	Linear	Quadratic
Treatment to increase BCS							
Mean BCS	4	4.29	4.67	5.1	5.1	<0.001	0.34
Mean BW	473.3	485.7	490.1	494.5	501.2	0.11	0.81
Mean BF	10.43	10.33	10.73	11.12	11.51	0.001	0.36
Mean RFT	0.38	0.36	0.45	0.53	0.62	0.001	0.36
Treatment to decrease BCS							
Mean BCS	5.75	5.38	4.96	5	4.5	<0.001	0.83
Mean BW	503.4	499.9	487	485.2	482.6	0.15	0.79
Mean BF	11.63	11.5	11.1	10.8	10.64	0.003	0.94
Mean RFT	0.64	0.61	0.52	0.46	0.43	0.003	0.94
<i>P</i> -values							
	Ex	ΔBCS	Ex × ΔBCS	d × ΔBCS	d × Ex	d × Ex × ΔBCS	
Mean BCS	0.14	<0.001	0.17	<0.001	0.34	0.5	Mean BCS
Mean BW	0.53	0.04	0.05	0.02	1	0.98	Mean BW
Mean BF	0.89	<0.001	0.004	<0.001	0.05	0.32	Mean BF
Mean RFT	0.89	<0.001	0.004	<0.001	0.05	0.32	Mean RFT

¹BCS (1 to 9); BW (kg); BF = body fat percentage; RFT = rump fat thickness (cm); Ex = exercise (none, light, heavy); ΔBCS = change in BCS groups (increasing, decreasing); d = day of feeding.

Figure 1. Scatterplot of observed vs. model-predicted BCS values for all horses. The equation is Observed = $3 \pm 0.51 + 0.3 \pm 0.1 \times$ predicted; $r^2=0.373$; $N = 24$.

which the slope was significantly different than one ($P < 0.001$) and the partition of the MSEP indicated that systematic bias was responsible for 63% of the MSEP (Figure 1) and the root of the MSEP was 20% of the observed average.

Mixed model analysis indicated that the relationship among observed and model predicted values for BCS ($P = 0.41$), BW ($P = 0.43$) and BF ($P = 0.52$) were not significantly impacted by increasing or decreasing BCS groups, so to evaluate the predictability of the model for exercised versus nonexercised horses, the observed and predicted BCS values were organized into three data sets. Groups CI and CD were

combined into a data set ($n = 8$) which represents the nonexercised control horses, and MES statistical analysis resulted in an r^2 value of 0.91 ($P = 0.00025$) with an MAE of one BCS unit. Groups LI and LD were combined into a data set ($n = 8$) of lightly exercised horses, resulting in an r^2 value of 0.57 ($P = 0.166$) with an MAE of 1.5 BCS units. Groups HI and HD were combined ($n = 8$) to represent heavily exercised horses, resulting in an r^2 value of 0.04 ($P = 0.652$) with an MAE of 1.5 BCS units. Complete statistical results for nonexercise, light exercise, and heavy exercise datasets are outlined in Table 7.

Body Fat Predictions

Final observed and model predicted values were compared in order to test the predictability of the model with regards to BF (Figure 2). When all data points ($n = 24$) were included the $r^2 = 0.37$ ($P = 0.004$) with an MAE of 3.39% and MB of -0.90% . Data were also evaluated for groups subjected to no exercise ($n = 8$; $r^2 = 0.51$; $P = 0.048$), light exercise ($n = 8$; $r^2 = 0.74$; $P = 0.03$), and heavy exercise ($n = 8$; $r^2 = 0.13$; $P = 0.387$; Table 7).

The mixed model analysis with horse assigned as the random variable was conducted to determine the relationship between BF and BCS ($n = 120$). Analysis of the fixed effects revealed a significant BCS ($P < 0.0001$) and BCS × exercise effect ($P = 0.007$). Evaluation of the solution for fixed effects yielded eq. 1 ($r^2 = 0.5$, $P < 0.0001$).

$$BF = (8.3556 + a_1) + (0.5233 + b_1) \times BCS \quad 1$$

where for sedentary horses parameters = 0; for light exercise $a_1 = -2.9249$ and $b_1 = 0.5985$; for heavy exercise $a_1 = -0.9914$ and $b_1 = 0.2593$.

BW Predictions

Observed final and model predicted values were compared in order to test the predictability of the model with regards to BW (Figure 3). When all values ($n = 24$) were included the $r^2 = 0.91$ ($P = 0.00001$), MAE = 31.91 and MB = 4.52. Data were also evaluated for groups subjected to no exercise ($n = 8$; $r^2 = 0.98$; $P = 0.00001$), light exercise ($n = 7$; $r^2 = 0.88$; $P = 0.001$), and heavy exercise ($n = 8$; $r^2 = 0.84$; $P = 0.001$) (Table 7).

The mixed model analysis also indicated a significant relationship between BW and BCS ($P < 0.0001$), but the relationship was not exercise dependent ($P = 0.481$). Equation 2 has the linear

relationship between BW and BCS observed in the current subject pool:

$$BW = 409.93 + 16.4724 \times BCS \quad 2$$

Exercise

Mean temperature and humidity for each exercise bout was 29.19 ± 3.64 °C, 67.47%, respectively. Mean HR was 124.09 ± 23.32 and 109.14 ± 18.55 bpm for the heavy and light exercise groups, respectively. Analysis of variance revealed that the total mean HR was significantly different between the light and heavy exercise groups ($P = 0.007$), but mean HR for each gait was not significantly different between exercise protocols (Table 4). The combined mean HR across both exercise protocols did decline significantly over time at each gait with the exception of sitting trot, indicating that horses did adapt to the exercise protocols (Table 4). There were no significant exercise by time interactions

Table 7. Model evaluation system (MES) statistical results for groups CI and CD (Control) groups LI and LD (light exercise) and groups HI and HD (heavy exercise)

	BCS			BF			BW		
	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy
r^2	0.91	0.57	0.04	0.51	0.74	0.13	0.98	0.88	0.84
MAE	1.00	2.00	1.50	3.27	2.67	3.39	21.7	31.9	29.3
MB	-0.06	-0.07	0.13	-0.91	-1.42	-0.43	4.05	5.24	4.37
MEF	-0.06	-0.23	-19.27	-0.63	-2.16	-1.45	0.90	0.74	0.73
MSEP	0.53	0.68	1.19	2.23	2.51	2.04	144	374	339
CCC	0.52	0.61	0.22	0.69	0.69	0.66	0.80	0.78	0.82
C_b	0.82	0.89	0.41	0.80	0.55	0.87	0.97	0.96	0.98

r^2 = coefficient of determination; MAE = maximum error; MB = mean bias; MEF = model efficiency; MSEP = mean square error of prediction; CCC = concordance correlation coefficient; C_b = bias correction factor.

Figure 2. Scatterplot of observed vs. model-predicted percent body fat for all horses. The equation is Observed = $5.7 \pm 1.7 + 0.4 \pm 0.14 \times$ predicted; $r^2 = 0.322$; $N = 24$.

Figure 3. Scatterplot of observed vs. model-predicted BW values for all horses. The equation is Observed = $97 \pm 30.2 + 0.8 \pm 0.06 \times$ predicted; $r^2 = 0.887$; $N = 24$.

and no significant impact of increasing or decreasing BCS groups was observed (Table 4). Thus indicating that the decrease in HR over time at each gait was not different between the light and heavy exercise protocols nor was it different for horses fed to increase or decrease in BCS.

DISCUSSION

The adjusted model is reliable for predicting DE requirements to meet desired BCS in sedentary horses, but is less precise when applied to exercising horses, with the predictability of the model being especially insensitive to horses in heavy exercise. The exercise protocols for the current study were developed based on the descriptions of exercise in the NRC (2007). The NRC authors indicate that previous research, including the equations developed by Hintz et al. (1971), was utilized to develop the NRC exercise categories; however, the NRC (2007) offers more specific detail to define each category which is why these descriptors were used. Exercise descriptions indicate that light and heavy exercise would have mean HR of 80 and 110 bpm, respectively. The NRC (2007) emphasized that these HR values are consistent with the work descriptions for each category but should not be used to define that category. This is likely because many factors can affect HR during a given exercise bout, including the size of the animal, the environment, level of fitness, or the terrain. It is probable that due to these factors the observed HR for both light and heavy exercise groups were higher than the NRC suggested HR at 109 ± 18 bpm for light exercise and 124 ± 23 bpm for heavy exercise. Statistical tests for ANOVA did reveal that the HR ($P = 0.007$) was significantly different between light and heavy exercise groups. This statistical difference coupled with the fact that the exercise protocols were specifically designed to match the descriptions published by the NRC (2007) lead to the conclusion that these protocols adequately reflect the standards of light and heavy exercise. Certainly, the development of descriptive levels of exercise to fit all equine activities is extremely difficult due to the vast number and intensities of exercise that equine athletes are expected to perform. A more continuous representation of exercise intensity using individual HR may result in greater precision across all activities; however, the currently available information regarding DE requirements for exercise is based on light, moderate, heavy, and very heavy exercise categories which are why these designations were utilized in the current study.

Linear regression between BCS and BW indicated that a 16.47 kg change in BW was required for each change in BCS, and the mean change in BW per change in BCS was 3.4% of the mean BW (eq. 2). Unfortunately, the use of linear equations to predict BW based on BCS is not practical across the population due to large differences in body size in different breeds of horses. However, this relationship when applied to the subject pool in the current study does allow for the determination of the average change in BW% per change in BCS, which could potentially have a greater application across different sizes of horses.

Regression analysis including all subjects revealed that there was a significant day by Δ BCS interaction for BCS, BF, ($P < 0.001$), and BW ($P = 0.04$), indicating that overall the animals did respond as expected to the increasing or decreasing BCS treatments (Table 6). The significant interaction between Δ BCS and day was expected by design. There was also a significant Δ BCS by exercise interaction observed for BW ($P = 0.05$), BF ($P = 0.004$), and RFT ($P = 0.004$). We would expect that the interaction between exercise and Δ BCS would not be significant if the equations used to predict exercise energy expenditure were adequate. When each Δ BCS group, increasing and decreasing, was evaluated independently a significant linear change over time was observed for BCS, BF, and RFT with a trend towards significance for BW, again indicating that the animals performed as expected in each group. A further statistical analysis was applied to determine the precision and adequacy of the mathematical model.

Mathematical models are useful tools to further our understanding of complex biological systems and aid in the decision-making process (Tedeschi, 2006b; Tedeschi et al., 2014). Statistical evaluation of the model utilized in the current study yielded results very similar to those reported by Cordero et al. (2013) when only sedentary horses were included in the analysis. Cordero reported r^2 values of 0.907, 0.607, and 0.944 when comparing observed to model predicted values for BCS, BF, and BW, respectively, in nonexercising mares. Correspondingly, evaluation of only control horses in the current study revealed r^2 values of 0.908, 0.505, and 0.985 for BCS, BF, and BW, respectively. These results indicate that the model offers an acceptable level of precision for predicting BCS and BW in nonexercising horses; however, the model in its current state is less precise when predicting BF. This could be due to inconsistencies related to estimating the whole BF from RFT.

The estimation of whole BF using rump fat thickness is a prevalent practice when evaluating equine body composition (Henneke et al., 1983; Cavinder et al., 2009; Cordero et al., 2013) because it allows for non-terminal assessment and due to ease of application in a research setting. However, the reliability of using RFT as an estimator of the whole BF has been called into question more recently. The limited number and variety of subjects utilized when validating the method has led researchers to search for a non-invasive whole body assessment, such as isotope dilution (Dugdale et al., 2011). Ferjak et al. (2017) found that equine BF assessment using deuterium oxide was more strongly correlated to actual BF measured postmortem than was BF extrapolated from rump fat thickness (Ferjak et al., 2017). Previous studies have reported that the relationship between BCS and BF extrapolated from RFT is positive and linear (Henneke et al., 1983; Cordero et al., 2013); while postmortem evaluations have yielded an exponential relationship to actual BF (Martin-Rosset et al., 2008; Dugdale et al., 2011). Application of a more accurate, nonterminal assessment technique such as tracer dilution could give a more precise indication of the relationship between BF and changing BCS, and eventually leads to a more producer-oriented method of estimating BF thus making the model more applicable in the industry.

Statistical evaluation revealed that the adjusted model is less precise with regard to exercising horses. The MAE for BCS prediction indicated that one horse did not change BCS for the duration of the study. This individual was the youngest in the group and BW did increase by 13.4 kg, the authors hypothesize that this horse may have been utilizing energy for growth instead of fat deposition. He also exhibited pacing behavior in the stall which would account for additional energy losses. Comparison of observed to model predicted values for BCS, BF, and BW revealed that model precision for heavy and light exercise groups is lower than the sedentary group alone, except BF for the light exercise group which is higher than the control group (Table 7). However, the MEF is also furthest from 1, the MSEF is highest, and C_b is the lowest for the light exercise group as well. This indicates that, while the precision may be higher, the accuracy of the model is lower when predicting BF for the light group when compared with control or heavy exercise. Similarly, the accuracy of the model for predicting BF and BW in heavy exercise horses was higher than control as indicated by C_b , but the r^2 values showed that precision was much lower for both BF

and BW when compared with control (Table 7). When predicting BCS in control and heavy exercise groups, the accuracy of the model dropped (C_b) from 0.82 to 0.41, precision dropped (r^2) from 0.91 to 0.04, leading to a decreased overall adequacy of the model (CCC) from 0.52 to 0.22. These values support the conclusion that the systematic bias observed in BCS prediction may be attributed to the fact that the predictability of the model was insensitive to the heavy exercise group (Figure 1). Furthermore, regression analysis for all animals revealed a significant exercise by Δ BCS interaction for BW, BF, and RFT, indicating that within each BCS group exercise impacted the change in these body parameters. This significance would not be expected if the equations incorporated into the model were adequate at predicting the DE requirement of exercise. Overall, the difference in model predictability between the control and exercised groups; as well as the significant exercise by Δ BCS interaction confirm that the equations utilized to predict energy expenditure of exercise to expand the Cordero model may not be accurate and further revision is required.

The equations developed by Hintz et al. (1971) were utilized in altering the model to include exercising horses; however, testing revealed that the model does not offer acceptable precision when predicting body parameter changes for the exercising horse. More recent studies have focused on using HR as a predictor for oxygen utilization which yields an estimate of net energy expenditure (Eaton et al., 1995; Coenen, 2008). Certainly, this method would yield a more individualized energy estimate applicable in a variety of situations. However, the use of HR monitors is not always available to the average horseman. Incorporation of such equations into the model could potentially yield greater precision for exercising horses; however, it may also limit the ability of the average end user to utilize the model. Additionally, the output of these equations is VO_2 (mL/kg/min) which must then be converted to a net energy value and then a DE value. The efficiency of conversion from DE to NE for exercising horses is not well defined and has ranged from 20% to 50% in the limited previous research available (Pagan et al., 2005; NRC 2007). Factors such as breed, environment, diet composition, and exercise intensity could impact the efficiency of conversion and may be responsible for the range in reported values (Potter, 2004; Pagan et al., 2005). Variation in model predictability could also be attributed to the observed significant decrease in mean total HR over time for each exercise group, indicating

an adaptation to training. This adaptation could have impacted energy expended during each exercise bout and also contributed to model inaccuracy for the exercising horse. Further investigation into the DE required to support equine exercise that can be applied across a wide variety of situations could potentially lend greater precision to the model.

Also, it may be prudent to reevaluate the BF predictive equations utilized in the model which rely on a previously quantified relationship between BCS and BF. The data used to generate the original equation were gathered from sedentary mares with BCS ranging from 5 to 8 (Cavinder et al., 2009). The results of the current study indicate that the relationship between BCS and BF changes with exercise. Incorporation of the equation developed from the current data into the model could increase the precision of the model for exercising horses. However, even when exercise is accounted for only 50% of the variation in BF could be explained by BCS, again suggesting that evaluation of the relationship between BCS and BF using a whole BF assessment technique could lend more specificity to the equations.

Further information about the relationship between BF, RFT, and BCS could help to make the model more precise with regards to predicting BF. Still, the repeatability of results between the research conducted by Cordero et al. (2013) and the current study lends further credence to the reliability of the model for sedentary animals. Packaging this model in a format that facilitates industry application could lead to more efficient feeding practices of sedentary horses, which would be of health and economic benefit. Still, as mentioned previously, the majority of horses are subjected to some form of athletic activity, and the model in its current state is not reliable when applied to the exercising horse. The likely source of this variation is the equations incorporated into the model to predict energy expenditure of exercise. Incorporation of more individualized estimators of exercise energy expenditure using HR, such as those proposed by Coenen (2008) and Eaton et al. (1995) could improve model accuracy for the exercising horse. However, further investigation into the efficiency of conversion from DE to NE for exercise would be necessary to make such equations applicable.

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