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Proof of concept on energy expenditure assessment using heart rate monitoring and inertial platforms in show-jumping and riding school horses

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Abstract

Currently, the most accurate and non-invasive method used to assess energy expenditure (EE) in sport horses is based on heart rate (HR) monitoring. However EE assessment using inertial platforms has been lately discussed in human sports medicine. The objective of this study was to evaluate whether inertial platforms would be useful tools to assess EE in horses.

Six show-jumping and riding school horses (Thoroughbred and warmblood) were equipped with a HR monitoring system and a wireless inertial platform. Acceleration, HR and speed were measured during the exercise protocol that included walk, trot, canter and a sequence of 4 jumps. Stride maximum and minimum acceleration, and acceleration amplitude and root mean squares (RMS) were determined. Energy expenditure and oxygen uptake (VO_2) were calculated using HR and speed respectively. Bivariate correlations (non-parametric Spearman's ρ correlation) between EE, VO_2 and acceleration variables were tested.

Spearman's ρ correlation was positive between both EE and VO_2, and maximum acceleration, acceleration amplitude and RMS and negative for minimum acceleration. Acceleration variables of vertical and lateral movement were generally better correlated with EE and VO_2 ($p < 0.001$) than those of forward movement ($p < 0.01$).

The results of this innovative approach reveal that the determination of EE in horses could be assessed using inertial platforms. Moreover vertical and lateral movements appear to influence more EE than forward movement.

Keywords: acceleration; energy expenditure; heart rate; horse; inertial platform

Disclosure

Conflicts of interest: free loan inertial platforms were provided by BTS bioengineering, Garbagnate Milanese, Italy.

Contributors: JN participated in the conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article and final approval of the version to be submitted; FR design of the study, data analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the version to be submitted; EV participated in acquisition of data, data analysis, revising critically the manuscript for important intellectual content, and final approval of the version to be submitted; AA participated in data analysis, revising critically the manuscript for important intellectual content, and final approval of the version to be submitted; DB participated in the conception and design of the study, analysis and interpretation of data, drafting the article, and final approval of the version to be submitted.

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1. Introduction

Energy requirements of horses have been studied since many centuries, but the first scientific approaches that can be considered the basis of our present knowledge were developed mostly in the 90's [1]. However, there are some difficulties in the precise statement of the work required to horse today: this work in fact is deeply changing from one day to another, variable in intensity and duration, sustained by different cell energy sources. All these aspects are very difficult to study in field conditions without interfering with the normal activity, because measurements are "normally" based on invasive techniques (e.g. use of gas exchange measurement masks). Moreover, riders frequently don't understand exactly the importance of a precise definition of the energy requirements. The result is a generalized overestimation of these requirements and the possible onset of disturbances linked to energy excess, such as endocrine and metabolic disorders [2-4].

The development of non-invasive tools for the assessment of energy requirement during exercise, using new technologies understandable also for riders is one of the ways to safeguard and improve horse welfare, fitness and even consciousness of the rider in correct exploitation of the athletic potentiality of the horse, as already demonstrated in human field.

One of the new technologies that can be used to define energy requirements (both in humans and in animals) with non-invasive tools is the use of heart rate (HR) monitoring systems, on one hand, and accelerometers (or – more precisely – inertial platforms containing accelerometers) on the other. Such devices are widely accessible to a large part of riders (an accelerometer is present in the largest part of commercially available Smartphone), but no software is developed to study horse athletic activity at present.

Among all methods proposed in international literature for the calculation of energy expenditure (EE) for exercise in horses [5], in particular the German system is strictly linked with indirect measurements, through HR monitoring:

The German method, in fact, introduces an indirect evaluation of metabolizable energy (ME) based on the relationship between HR (beats per minute) and oxygen uptake (VO_2), allowing for estimation of anaerobic energy production at higher exercise level, based on the following equation:

$$EE\ (J\ kg\text{-}1\ BW\ min\text{-}1) = 0.0566 * HR^{1.9955}$$

where HR in beats*min^{-1}.

Heart rate monitoring is based on the application of two electrodes on the horse's skin, with some discomfort for the adjustment of the brides and saddle, and some problems for the accuracy of measurements. For this reason, the use of inertial platform has been considered for the studies of horse's EE. These devices have been used for several purposes in humans, to study physical activity in older men [6], bodyweight and EE [7-9]. Unfortunately, very few papers are on the contrary available in international literature about accelerometric measurements applied to animal science. One of the first was about cormorants migration [10].

As to horses, pressure based accelerometer were used for the definition of horse biomechanics at the end of 19th century [11], while modern devices have been used, in recent years, to study hoof acceleration in the exercising horse [12], biomechanical and energetic determinants of the walk–trot transition in horses [13], and in particular horse's biomechanics, symmetry, lameness and gait analysis [14-16].

Very few papers and data are available on the use of accelerometers for the estimation of EE in horses. Two of the latest were proposed by Kubus et al. [17,18], the more recent investigating the relationships between HR monitoring and accelerometry.

Today, triaxial devices working at 100Hz and more are the bases for modern studies. Our group developed, in the recent years, some competences in this area based on previous experiences [19-21].

In this paper, we started from field measurements of indirect EE, coupled with accelerometric measurements, in riding school horses; the preliminary relationship between the two methods are discussed.

2. Material and Methods

This study was carried out in accordance with the EU Directive 2010/63/EU for animal experiments. Only non-invasive methods were used to determine EE; in particular equine belt for HR sensor was used to monitor HR, and inertial platforms were attached to the saddle pad. This article complies with the Uniform Requirements for manuscripts submitted to Biomedical journals [22].

2.1. Animals

Three warmblood competing in show-jumping (Selle Français, Sella Italiano, and Holsteiner; 2 females and 1 gelding) and three riding school (Thoroughbred and Lippizan crossbreed, and warmblood; 1 female and 2 geldings) horses (12.7 ± 1.6 years old) were equipped with Polar Equine RS800 G3 heart rate monitoring system (Polar Electro Inc., Lake Success, NY) and BTS Bioengineering wireless inertial platform (BTS Bioengineering Corp., Brooklyn, NY).

2.2. Exercise program

Horses were ridden by different experienced riders. Each exercise was monitored for 1 minute. The exercise program included linear, right and left walk and trot and right and left canter and canter with a sequence of 4 jumps (height 40 cm). Each horse was monitored once for each exercise. Horses were ridden in sand indoor arena.

2.3. Heart rate and speed monitoring

Heart rate and speed were recorded every 5 seconds for the entire duration of the exercise program. Mean and minimum HR and mean speed during each exercise (walk, trot, canter and jump) were calculated using Polar Equine Software.

2.4. Acceleration measurement

Inertial platform wireless sensors (BTS Bioengineering, Garbagnate Milanese, Italy) were placed at withers level, attached to the saddle pad under the saddle pommel. Acceleration was measured at 100 Hz during each exercise. Collected data included acceleration in forward (x), lateral (y) and vertical (z) directions.

2.5. Determination of energy expenditure (EE) and oxygen uptake (VO_2)

Minimum and mean EE were calculated using HR (bps) during each gait (walk, trot, canter and jump) using the method proposed by Coenen [23], EE ($J*kg\ BW^{-1}*minute^{-1}$) = $0.0566*HR^{1.9955}$.

Mean oxygen uptake was determined using speed (S; m/s) during each exercise according to Coenen [24], VO_2 ($ml\ O_2*kg\ BW^{-1}*minute^{-1}$) = $4.515 + 9.14S+0.726S^2-0.00452S^3$ during each exercise.

2.6. Determination of acceleration variables

Data analysis was done using a tailored program developed in Scilab platform (Scilab 6.0, Scilab enterprises, Versailles, France). Fast Fourier transform was used to define frequency spectrum from 3-D acceleration data during 40 seconds of regular exercise. The first 3 spectrum harmonics were used for bandpass filtering. Filtered acceleration signal was then determined using inverse FFT. Stride frequency was determined using the filtered signal. Maximum and minimum acceleration, acceleration amplitude and RMS (m/s^2) were calculated for each stride. Thirty strides were considered for statistical analysis concerning each gait. Mean maximum and minimum acceleration, acceleration amplitude and RMS were considered for statistical purposes.

2.7. Statistical analysis

Statistical analysis was done using SPSS 17.0 (IBM, Armonk, NY). Each horse was considered as experimental unit. Data distribution was assessed using Shapiro-Wilk test. Correlation between EE (mean and minimum) and acceleration variables (maximum, minimum, amplitude and RMS) was assessed using Spearman's ρ correlation. Differences were defined for $P < 0.050$ and statistical tendency for $P < 0.100$.

3. Results

All horses were healthy during this study. One school riding horse did not perform left gallop for behavioral problems, therefore in this case only right gallop was considered for statistical analysis. Two riding school horses did not jump because were not trained for this exercise. Therefore the number of observations for correlation analysis was 22. The number of strides considered to calculate acceleration variables was below 30 in 4 horses during walk because acceleration spectra were irregular. In these cases, the mean number of strides used for acceleration variables calculation was 22 ± 6 strides.

Spearman's ρ correlation was positive between EE and maximum acceleration, acceleration amplitude and RMS and negative for minimum acceleration. The same was observed for VO_2 (table 1).

Absolute value of Spearman's ρ correlation between EE and acceleration variables varied between 0.645 (minimum EE and minimum forward acceleration; $p = 0.001$) and 0.830 (minimum EE and vertical acceleration amplitude; $p < 0.001$)(table 1). Absolute value of Spearman's correlation between VO_2 and acceleration variables varied between 0.604 (maximum forward acceleration; $p = 0.003$) and 0.782 (lateral minimum acceleration; $p < 0.001$).

Acceleration variables of vertical and lateral movement were generally better correlated with EE (range between 0.697 and 0.830; $p < 0.001$) than those of forward movement (range between 0.645 and 0.750; $p = 0.001$ and $p < 0.001$). The same was observed for VO_2, which correlation with vertical and lateral acceleration variables ranged between 0.623 and 0.782 ($p = 0.002$ and $p < 0.001$) compared with those in forward direction, ranging from 0.604 to 0.656 ($p = 0.003$ and $p = 0.001$ respectively).

Spearman's ρ absolute value was generally higher for correlation between acceleration variables and minimum EE (range between 0.645 and 0.830; $p = 0.001$ and $p < 0.001$ respectively) than mean EE (range between 0.659 and 0.769; $p = 0.001$ and $p < 0.001$). Minimum EE and lateral and vertical acceleration variables are presented in figures 1 and 2 respectively.

4. Discussion

The objective of this study was to evaluate whether inertial platforms would be useful tools to assess EE in horses. Energy requirements in sport horses are related with maintenance and exercise EE. Exercise-related EE can be currently defined using different methods. The first methods available, based on intensity and duration of workload, were reviewed by Ellis [1]. Over the last decade, efforts to assess accurate EE in sport horses were made. Currently, the most easy and accurate method, which is suitable to field conditions, to assess energy requirements in sport horses is based on HR monitoring [24]. This method was previously used to calculate the EE in sport horses even during high demanding competition [25]. This method is founded on the relationship between HR and VO_2, being the last directly related with EE. Oxygen uptake measurement is difficult to apply in field conditions due to expensive and technically complex equipment. Heart rate correlation with VO_2 is high (R^2=0.911; [24]). Yet HR monitoring for EE assessment presents some disadvantages: 1) HR varies also with stress and excitement, 2) HR decline during recovery periods following exercise is not imputable to EE, 3) discomfort for the adjustment of the brides and saddle, 4) accuracy issues. Inertial platforms could be used in field conditions to assess EE in sport horses because it is widely available in commercial electronic devices, such as smartphones, and it retrieves data that are exclusively related with biomechanical effort. Therefore we have analyzed the suitability of inertial platforms to assess EE during exercise through correlation with HR-based monitoring system.

Over the last decade, several studies reported the potential use of inertial platforms to assess EE in daily life activities [7,26] and sport [27] in humans, in horses [17] as well as in other animals [10]. Several studies were also performed to validate methods using inertial platforms to assess EE in human (among others, [28-31]).

In this study, correlation of EE estimation using the HR method and the biomechanical method were similar for all variables. Maximum acceleration, acceleration amplitude and RMS per stride increased and minimum acceleration decreased with EE estimation using HR monitoring method. Therefore, the four acceleration variables (maximum, minimum, amplitude and RMS) could be suitable to assess EE in horses. Vertical and lateral acceleration correlated better with EE estimation using HR monitoring method. The methods previously described to assess EE in horses, which are based on speed during exercise [1], do not take in consideration EE related with lateral and vertical movement. From a functional point of view, vertical and lateral movement can be either useful (e.g. dressage competing horses) or deleterious (e.g. racing horses) depending on horse performance and discipline. Therefore, from a biomechanical point of view, it can greatly influence sport performance, and it seems to influence particularly EE. Therefore both lateral and vertical movement should be considered in future studies aiming to develop new methods to determine EE in horses.

Future studies comparing HR monitoring and acceleration measurement to assess EE should focus on minimum HR during exercise rather than mean HR, because EE results using minimum HR were better correlated with biomechanical parameters than those using mean HR.

Limitations of this study include the limited number of animals, the variability of individual performance and the fact that horses were ridden by different riders. Further studies to assess EE related to exercise in unridden horses, and in horses competing in specific disciplines would be needed.

Practical applications of biomechanical methods to assess EE in horses would include real time accurate monitoring of EE in field conditions, considering different subject and environmental conditions, such as rider experience and body weight, horse sport performance and equestrian discipline.

5. Conclusions

The results of this innovative approach reveal that the determination of EE in horses could be assessed using inertial platforms. Indeed correlation between EE estimation using HR monitoring systems was correlated with EE estimation using acceleration variables. Moreover vertical and lateral movements appear to influence more EE than forward movement. Advantages of EE determination using inertial platforms include, among others, the fact that these systems are non-invasive and easy to use in field conditions. Further studies including more animals, less individual variability (breed, age, sport performance, discipline), different conditions (ridden vs. unridden horses, experienced vs. amateurish riders) should be done to validate the assessment of EE using inertial platforms in horses.

6. Tables

Table 1. Spearman's ρ correlation between acceleration variables in 3-D axes (x, y e z) and mean and minimum energy expenditure (respectively EE_avg and EE_min, J*kg BW^{-1} *$minute^{-1}$) and oxygen uptake (VO_2, ml O_2*kg BW^{-1} *$minute^{-1}$) at walk, trot, canter and jump (N = 22).

Axial component	Acceleration variable	EE_avg[#] (J*kg BW^{-1} *$minute^{-1}$)	EE_min[#] (J*kg BW^{-1} *$minute^{-1}$)	VO_2[##] (ml O_2*kg BW^{-1} *$minute^{-1}$)
Forward (x)	Maximum	0.659*	0.680*	0.604*
	Minimum	-0.750**	-0.645*	-0.656*
	Amplitude	0.699**	0.646*	0.634*
	RMS	0.734**	0.674*	0.611*
Lateral (y)	Maximum	0.697**	0.828**	0.623*
	Minimum	-0.769**	-0.705**	-0.782**
	Amplitude	0.754**	0.803**	0.684**
	RMS	0.720**	0.777**	0.692**
Vertical (z)	Maximum	0.757**	0.817**	0.698**
	Minimum	-0.718**	-0.818**	-0.653*
	Amplitude	0.745**	0.830**	0.697**
	RMS	0.747**	0.822**	0.722**

[#] $EE = 0.0566 \cdot HR^{1.9955}$ **[23]**; [##] $VO_2 = 4.515 + 9.14S + 0.726S^2 - 0.00452S^3$ **[24]** with HR as heart rate (bps), and S as speed (m/s) during each exercise; * $P < 0.01$; ** $P < 0.001$.

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8. Figure captions

Figure 1. Dot plot of minimum energy expenditure (EE_min) and lateral acceleration variables (maximum: up left; minimum: up right; amplitude: down left; RMS: down right). Note: confidence interval 75%

Figure 2. Dot plot of minimum energy expenditure (EE_min) and vertical acceleration variables (maximum: up left; minimum: up right; amplitude: down left; RMS: down right). Note: confidence interval 75%

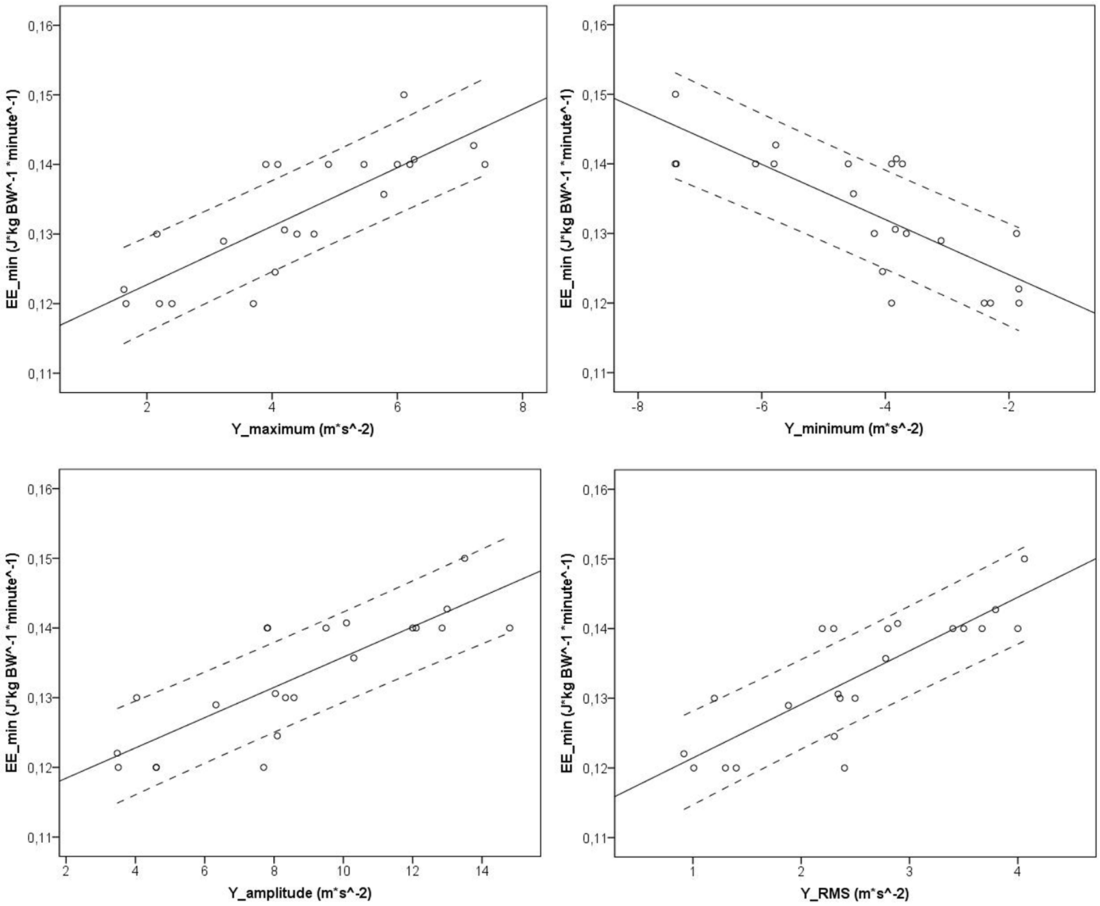
EE_min (J*kg BW^-1 *minute^-1)
Y_maximum (m*s^-2)
Y_minimum (m*s^-2)
Y_amplitude (m*s^-2)
Y_RMS (m*s^-2)

Figure 1

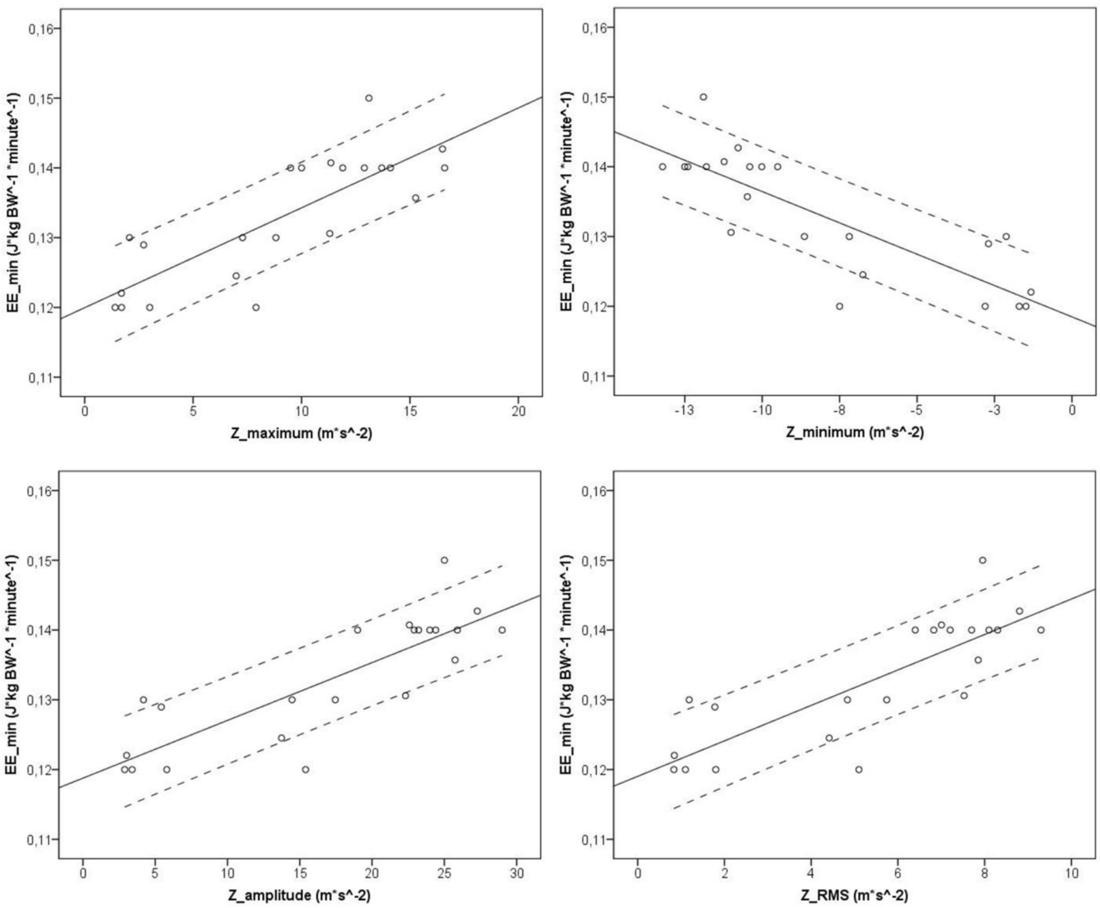
EE_min (J*kg BW^-1 *minute^-1)
0,16
0,15
0,14
0,13
0,12
0,11
Z_maximum (m*s^-2)
0
5
10
15
20
Z_minimum (m*s^-2)
-13
-10
-8
-5
-3
0
Z_amplitude (m*s^-2)
0
5
10
15
20
25
30
Z_RMS (m*s^-2)
0
2
4
6
8
10

Figure 2