Journal of Veterinary Behavior 9 (2014) 341–346

Contents lists available at ScienceDirect

Journal of Veterinary Behavior

journal homepage: www.journalvetbehavior.com

Research

Comparison of heart rate and heart rate variability obtained by heart rate monitors and simultaneously recorded electrocardiogram signals in nonexercising horses

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ARTICLE INFO

Article history:
Received 9 January 2014
Received in revised form
26 June 2014
Accepted 8 July 2014
Available online 29 July 2014

Keywords:
heart rate
heart rate variability
Polar system
electrocardiogram
horse

ABSTRACT

Heart rate (HR) and heart rate variability (HRV) are often determined with Polar heart rate monitors (HRMs; S810i; Polar, Kempele, Finland). The aims of this study were to compare data from horses obtained by Polar HRMs and a portable Televet electrocardiogram (ECG; 100 version 4.2.3; Kruuse, Marslev, Denmark) device and to determine appropriate recording times in horses (n = 14). Correlations were calculated and a Bland-Altman analysis was carried out to examine agreement between recording systems. For beat-to-beat (RR) interval, uncorrected and corrected data were highly correlated irrespective of the recording system and recording time ($r > 0.99$, $P < 0.001$). For HRV variables, standard deviation of RR interval and root mean square of successive RR intervals, correlations higher than 0.9 were obtained between uncorrected and corrected ECG but not Polar data. The RR interval, HR, and HRV from corrected Televet and Polar data at no time differed between the recording systems. However, with the increase in recording time, the RR interval decreased ($P < 0.001$). Thus, for comparisons, recording intervals of similar length should be chosen. Correlations among RR interval, HR, and HRV variables obtained by ECG and HRMs were highly significant at all recording times ($r > 0.9$, $P < 0.001$). Correlations increased with increasing recording time. Bland-Altman graphs showed a strong agreement between HRMs and ECG and mean RR intervals, HR, and HRV variables were close to identical. In conclusion, Polar HRMs are as adequate as ECG recordings in horses. Owing to a low HR in stationary horses, recording times below 2 minutes will underestimate changes in HR and HRV.

Introduction

The time intervals between successive heartbeats in animals are not of equal duration but are constantly shifting. These short-term changes are termed heart rate variability (HRV). Heart rate (HR) and HRV reflect the regulation of cardiac activity by the parasympathetic and the sympathetic branches of the autonomic nervous system. In animal behavior studies, the HRV is often determined as an additional parameter to assess the neurophysiological response of the sympathoadrenal system to stressful situations or challenges and to differentiate between parasympathetic and sympathetic activity. A decrease in HRV is interpreted as increased sympathetic activity, reduced parasympathetic activity, or a combination of both (Sayers, 1973; von Borell et al., 2007). In horses, changes in time domain HRV variables have been demonstrated in response to foaling (Nagel et al., 2010, 2012), equestrian activities (Ille et al., 2013; Schmidt et al., 2010a; von Lewinski et al., 2013), weaning (Erber et al., 2012b) and hot iron branding of foals (Erber et al., 2012a), road transport (Schmidt et al., 2010b, 2010c, 2010d) but not air transport (Munsters et al., 2012), or changing of the stabling system in adult horses (Erber et al., 2013). With the exception of foaling mares (Nagel et al., 2010, 2012) in which electrocardiograms were obtained, the HR was recorded with mobile Polar heart rate monitors (HRMs; S810i; Polar, Kempele, Finland) and HRV was calculated from the measured beat-to-beat (RR) intervals. Polar HRMs were initially developed for humans and adapted for use in horses. They are easier to use, more economical, and more comfortable for the animal than electrocardiogram (ECG) recording systems.

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http://dx.doi.org/10.1016/j.jveb.2014.07.006

Polar HRMs may give rise to measurement-related errors versus ECG recordings, which have to be corrected after visual identification. These errors have been characterized as Types 1-5 with Type 1-3 representing positive or negative single beat discrepancy between the Polar monitor and an ECG and Types 4 and 5 characterized by a very long RR interval in the Polar data or by 2 or more short RR intervals obtained by Polar but not ECG, respectively (Marchant-Forde et al., 2004). Because such errors may question the reliability of RR interval recordings, the HRMs should be validated against ECG recordings. Good correlations between HRV variables obtained by HRMs and ECG devices have been demonstrated in humans during increasing levels of exercise (Gamelin et al., 2006, 2008; Kingsley et al., 2005; Nunan et al., 2008), pigs (Marchant-Forde et al., 2004), stationary as well as freely moving cattle (Hopster and Blokhuis, 1994), and dogs under stationary conditions (Jonckheer-Sheehy et al., 2012). In horses, the HRMs have been shown to accurately and reliably record HR at rest and during exercise (Evans and Rose, 1986; Sloet van Oldruitenborgh-Oosterbaan et al., 1988), but with regard to HRV analysis, concerns have been raised (Parker et al., 2010). To the best of our knowledge, a validation of HRMs for HRV analysis in horses has not been published yet.

The accuracy of HR and HRV data is influenced by the recording time, and only data obtained for recording intervals of similar length should be compared. Recording intervals of at least 1 minute have been recommended for large animal studies (von Borell et al., 2007). Because horses have a lower HR than most other species, irrespective of the recording system, a longer recording time might be appropriate for HR analysis and HRV calculations in the equine species. Effects of recording times on HRV calculations in horses have not been studied systematically so far. With prolonged recording intervals potentially increasing the accuracy of HRV data, this may also affect the correlation between measurements with different diagnostic systems, that is, the HRMs and portable ECG devices.

The aims of this study were to collect HR and HRV data from healthy adult horses allowed to move freely in loose boxes by simultaneous recording with Polar HRMs and a standard ECG, to compare the data obtained with both systems and to determine appropriate recording time in horses. We hypothesized that a strong correlation exists between HR and HRV data obtained by HRMs and ECG. The HRM thus can be used reliably in horses. In addition, we tested the hypothesis that for HRV analysis in horses, longer recording times are required compared with recommendations for other domestic animal species.

Materials and methods

Animals

A total of 14 Haflinger mares were available for the study. Age of the mares was 8.4 ± 2.8 years (±standard deviation; range, 5-14 years). Mares were kept in adjacent individual loose boxes (3.0×3.5 m) on straw and were fed hay twice daily. Water and mineral supplements were always available. All mares were healthy before and throughout the experiment and had neither any history nor current evidence of cardiovascular disease.

Experimental procedures

Data were recorded simultaneously from the horses with 2 different recording systems, namely a Polar HRM and a portable ECG device (Televet 100 version 4.2.3; Kruuse, Marslev, Denmark). Electrodes for both systems were attached to the thorax of the horse with an elastic girth and were fixed with a second girth, which also contained pockets for the Polar recording watch and the Televet transmitter. Water and ultrasound gel were used to optimize the contact between electrodes and skin. Recordings were always done in 2 horses at the same time. Recordings started in the morning at 08:30 hours and lasted for 60 minutes.

Recordings with the Polar HRMs were made as described (Schmidt et al., 2010a, 2010b). The positive electrode was located at the right shoulder and the negative electrode at the mid of the left thorax. Ultrasound transmission gel was applied liberally to the Polar electrode sites. Data were transmitted at the end of each recording session to a laptop computer via infrared transmission. No data correction was made with the Polar software.

Televet recordings followed the procedures described by Nagel et al. (2010) for fetomaternal electrocardiography with the modification that no fetal ECG was obtained and localization of the electrodes thus differed. The ECG-settings were 25 mm/second feed and 40 mm/mV gain. For ECG recordings, 4 electrodes were attached to the horses' shaved skin with self-adhesive pads. For all measurements, the green electrode was placed 3 cm right from the sternum. The red and black electrodes were fixed 20 and 30 cm below the withers on the left side of the thorax. The yellow electrode was positioned similar to the red electrode on the opposite side of the thorax. All electrodes were connected to the Televet 100 recording device, which was fixed by an elastic girth around the thorax of the mares. During the recording period, ECG data were sent to a computer via Bluetooth for instant watching and data storage.

Polar and Televet recordings were synchronized by starting the Polar monitor and at the same time marking the ECG. The 2 curves were also visually compared following data collection. Recordings lasted for 60 minutes, and comparisons between the 2 recording systems were made for intervals of 1, 2, 5, and 30 minutes each.

The Televet 100 software places a vertical mark at the point of each R-wave of the ECG curve, thus allowing verification of the correct operation of the built-in algorithms. Incorrect R-wave detections were manually corrected as described (Jonckheer-Sheehy et al., 2012) before any further analysis. For HRV analysis, the Kubios HRV software (Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland) was applied in the same way for data obtained with both recording systems. To remove trend components, data were detrended and in addition an artifact correction was made. Detrending with the Kubios software follows the procedure described (Tarvainen and Niskanen, 2008; Tarvainen et al., 2002) using a smoothness priors approach. The smoothness parameter was set at 500 milliseconds. For artifact correction, the custom filter of the program was set at 0.3, identifying RR intervals differing from the previous RR interval by more than 30% as artifacts. After abnormal interval removal, the program's algorithm substitutes detected errors with interpolated intervals calculated from differences between previous and next accepted RR intervals. In our study, the RR intervals were recorded; and from these, HR and the time domain HRV variables, namely standard deviations of the RR interval (SDRR) and root mean square of successive RR differences (RMSSD) were calculated.

Statistical analysis

Statistical analyses were made with the SPSS statistics package (version 17.0; SPPS, Chicago, IL). All data were normally distributed (Kolmogorov-Smirnov test). Differences between recording times (i.e., 1, 2, 5, and 30 minutes) in the same animals were made by analysis of variance using a general linear model for repeated measures with type of recording device (Televet ECG or Polar HRM) as between-subject factor. Correlations between data obtained by Televet ECG and Polar HRM were calculated using Pearson's