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RESEARCH ARTICLE

Validating a Human Biotelemetry System for Use in Captive Blue Wildebeest (*Connochaetes taurinus*)

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We fitted two blue wildebeest (*Connochaetes taurinus*) with modified versions of the Equivital™ EQ02 wireless monitoring system to evaluate if the device could accurately measure heart rate and respiration rate in this species whilst anaesthetized as well as whilst fully conscious in captivity. Whilst under anaesthesia, we monitored each animal's heart rate and respiration rate using the Equivital™ biotelemetry belt, a Cardell® veterinary monitor and manual measurements. The animals were also administered doxapram hydrochloride (Dopram®) and adrenaline intravenously at different times to stimulate changes in respiration and heart rate, respectively. Once 30 minutes of monitoring was completed, we reversed the anaesthetic and left the animals in captivity for 24 hours whilst wearing the Equivital™ belts. After 24 hr, we repeated the anaesthesia and monitoring as well as the administration of the doxapram hydrochloride and adrenaline. Intraclass Correlation Coefficients (ICC) calculated between all three monitoring methods showed moderate to excellent agreements for heart rate on both days (ICC: 0.73–0.98). ICCs calculated between the three methods for respiration rate showed good to excellent agreement between the Equivital belt and the other two methods (0.82–0.92) with the exception of occasions when only poor to fair agreements were found between the Cardell® measurements and manual measurements. Heart rate and respiration rate were also found to increase with motion while animals were in captivity. The results indicate that a modified version of the Equivital™ EQ02 system can be used as a potential biotelemetry device for measuring heart and respiration rate in captive blue wildebeest. Zoo Biol. 34:321–327, 2015.

Keywords: biotelemetry; blue wildebeest; Equivital™; heart rate; respiration rate

INTRODUCTION

Telemetry systems used for recording cardiovascular variables such as heart rate, electrocardiogram (ECG) and blood pressure in animals were initially developed for pharmaceutical companies who used them for drug research and development [Samson et al., 2011]. In addition, numerous researchers and laboratories developed biotelemetry systems to measure physiological parameters in animals for other research purposes. As early as 1960, researchers built and used a device that transmitted the heart rate and wing beat rate of ducks [Eliassen, 1960; Ropert-Coudert and Wilson, 2005]. Thus, the term *biotelemetry* was born, being defined as the remote measurement of behavioural, physiological and energetic data from live subjects [Cooke et al., 2004; Ropert-Coudert and Wilson, 2005].

Today, modern biotelemetry systems either consist of external devices fitted to the bodies of animals or humans or implantable devices [Stabenow et al., 1996]. Both systems have advantages and disadvantages with external devices being more cost-effective and less invasive than implantable devices. External biotelemetry devices are typically used for short-term studies with a high throughput, involving a large number of animals. As there are no surgical procedures involved, they

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provide a non-invasive alternative to implantable devices and can be used with single or group-housed animals [Grenwis, 2010]. Implantable devices, however, are able to measure a larger number of variables more accurately, are less likely to be lost or removed and tend to cause little discomfort to animals once implanted [Wild et al., 1995; Grenwis, 2010].

Although biotelemetry is becoming more popular in animal research studies, it is still not as widely used in large terrestrial mammals as was anticipated when these types of systems were first developed. According to Cooke et al. [2004], the two most limiting factors to its use in species other than bird and marine species are firstly, the lack of commercial development for many applications and secondly, the cost of such systems. Eloranta et al. [2002] also stated that the reliability of the few existing cardiac telemeters for free-ranging terrestrial animals has not been adequately established and reported. This may be because cardiac biotelemetry currently requires double measurement by a secondary device, typically one that is implanted, to validate externally worn telemeters.

The aim of this study was to modify a biotelemetry device originally developed for use in humans to be suitable for use in captive wildlife species during short-term studies. The biotelemetry device chosen provides a far less invasive method of measuring heart rate and respiration rate simultaneously without the need for surgically implanted electrodes. Our goal was to illustrate the accuracy of the system without the necessity of a secondary biotelemetry device by showing that the Equivital™ EQ02 belt could measure heat rate and respiration rate accurately during immobilization, both before and after the animal was left fully awake in captivity for 24 hr. This approach not only reduces costs but also minimizes the behavioural and physiological disturbances from the monitoring protocol itself. In addition, we aimed to show that the Equivital belt was sensitive enough to detect changes in heart rate and respiration rate, induced by the administration of adrenaline and doxapram hydrochloride (Dopram®), respectively. Successful validation will enable researchers to perform more accurate, but less invasive, short-term continuous measurements of vital signs in wild mammals held in captivity for short periods of time.

METHODS

We received ethical approval for all aspects of the trial from the Research Ethics Committee: Animal Care and Use at the University of Stellenbosch, South Africa (Protocol Ethical Approval number SU-ACUM11-00005). Two qualified veterinarians handled and administered all the drugs used as well as consistently monitored the animals during anaesthesia.

Two male blue wildebeest (*Connochaetes taurinus*) were darted (3.5–4.5 mg of Thiafentanil oxalate; Thianil®, Wildlife Pharmaceuticals, RSA) and transported to an enclosure (6×8 m in size) constructed of gum poles and equipped with two infrared surveillance cameras (Nictec Radio Communications, Nelspruit, South Africa) for monitoring. Food and water was provided *ad libitum*. The study occurred in the Lowveld area of Mpumalanga, South Africa which forms part of the species' native range.

After 2 days, each animal was darted separately, spray painted with a number, weighed and shaved around the chest to accommodate the electrocardiogram (ECG) sensors. We used two Equivital™ (Hidalgo Limited, Unit F. Trinity Court, Buckingway Business Park, Cambridge, UK) EQ02 belts. For the purpose of this study, we were only interested in heart rate, respiration rate and motion although the system also has the capacity to measure other physiological parameters.

In animals, the design of the belt does not allow for the appropriate positioning of the data-logger and we therefore removed the shoulder straps on the Equivital belt, extended the chest bands with elastic material and reinforced the stretch inhibitor inside the belt to prevent over-stretching of the respiration sensor. Whilst immobilized, each wildebeest was fitted with a modified Equivital belt so that the data-logger was positioned above the heart. Electro-gel was applied to each ECG sensor and double-sided tape and Pattex Supergel® used to secure the belt to the skin. Opsite™ Flexigrip™ transparent film dressings from Smith & Nephew (Smith & Nephew (Pty) Ltd., Pinetown, South Africa) were placed over the data-logger to protect it from dirt or water (Fig. 1).

Once we fitted an animal with an Equivital belt, we moved it into a veterinary laboratory and began the study by recording heart rate and respiration rate every 15 sec for 30 min using the following three methods:

1. Equivital™ monitoring via Bluetooth™
2. Cardell® 9500 HD multi-parameter veterinary vital sign monitor (Kyron Laboratories (Pty) Ltd., Johannesburg, South Africa).
3. Manual monitoring of heart rate (via stethoscope) and respiration rate (by counting exhaled breaths)

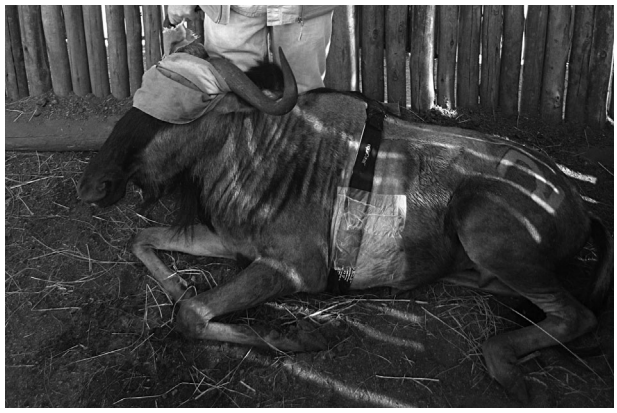

Fig. 1. A wildebeest fitted with a modified Equivital™ belt.

This part of the study was referred to as Day 1 and all recordings were synchronised. For manual heart rate measurements, heart beats were counted as the number of heart beats/30 sec since it was difficult to manually count consecutive heart beats in a smaller interval. These values were then multiplied by 2 to get an estimated beats/minute. For manual counts of respiration rate, breaths/15 sec interval were counted and multiplied by 4 to get an estimated breaths/minute. The Equivital and Cardell monitors reported estimated heart rates and respiration rates per minute every 15 sec. The Cardell monitor records heart rate with electrode clips attached to the animal that detect signals caused by changes of electrical conduction in the heart during the cardiac cycle. The system measures respiration rate directly through a Capnostat® mainstream CO_2 probe.

Once enough stable recordings were made and the animal showed no negative reactions to the anaesthetic, we injected the animal intravenously (IV) via the ear vein with 100 mg of doxapram hydrochloride (Dopram®). Doxapram hydrochloride is a respiratory stimulant that increases respiration and is often used in patients with respiratory depression or apnoea. We administered the doxapram hydrochloride in order to determine if all three methods of respiratory monitoring could detect possible changes due to its administration.

After the effects of the doxapram hydrochloride had completely worn off, we injected the animal with 2,000 IU of adrenaline IV, again via the ear vein. Adrenaline is known to increase heart rate and has a short half-life so that its expected effect lasts for no longer than 1 min. Again, this was done to determine if the three heart rate monitoring methods could accurately detect changes in heart rate due to the administration of the adrenaline.

Once heart rate stabilised, we continued vital sign monitoring and recording until 30 min of data had been collected. It must be noted that during the monitoring of wildebeest 1, a problem occurred with the positioning of the Capnostat® probe that is used for the measurement of respiration rate with the Cardell monitor. As a result, measurements were only taken with the Cardell monitor for the first 7 min of the study period.

The Cardell monitor was then disconnected, the animal moved back to the enclosure and the anaesthetic reversed (35–45 mg naltrexone; Trexonil®, Wildlife Pharmaceuticals, RSA). Once awake, we left the animal in the enclosure for 24 hr. The process was repeated with the second wildebeest as well. It must be noted that battery life is a limiting factor when using the Bluetooth functionality of the system and thus it was decided to not exceed a 24-hr captivity period. External battery packs, however, are available for the system and could be used should the captivity period exceed 24 hr.

The next day, we darted the animals individually again and the previous days' protocol was repeated. This part of the study was referred to as Day 2.

Heart rate and respiration rate was continuously logged by the Equivital device whilst the animals were fully awake and in captivity. These data were also used for analysis. In addition, the Equivital data-logger also detects the motion status of the animal via tri-axis accelerometry in terms of a.) Stationary; b.) Moving slowly; and c.) Moving fast. This motion status is logged every 15 sec. Because the intent was to compare motion status with heart rate and respiration, the motion measured by the belt was not correlated to any continuous behavioural monitoring and wildebeest were observed only to note if any abnormal behaviours were present.

Statistical Analysis

We analysed the data using a restricted maximum likelihood estimation (REML) which included day and recording method as fixed effects. This was done using the Variance Estimation and Precision module of Statistica (version 12) statistical software (StatSoft, Inc., 2013). We accepted differences within the fixed effects as being significant if the probability of rejection of H_o was less than 5% ($P < 0.05$). We calculated Two-way Intraclass Correlation Coefficients (ICC) for Absolute Agreement between the different methods of vital sign monitoring on both study days for each animal. This was done for the total 30-min study period on each day as well as for the 2-min period after the administration of adrenaline or doxapram hydrochloride. We included the Cardell measurements for wildebeest 1 in the latter analysis as the doxapram hydrochloride was administered 4.5 min after the study period began and, thus, the Cardell monitor was still measuring for the 2-min interval after administration of the doxapram hydrochloride. ICCs are used for assessing agreement between two methods of measurement and we considered coefficients as significant at a confidence level of 5% ($P < 0.05$).

RESULTS

Day 1

Figures 2 and 3 show the heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 1 and wildebeest 2, respectively, as measured over the total 30-min study period on Day 1. Wildebeest 1 showed a slight increase in heart rate followed by a noticeable decrease in response to the adrenaline given (Fig. 1). The Cardell measurements did not show as marked an increase as the other two methods. In comparison, wildebeest 2 showed a noticeable increase in heart rate directly following the administration of adrenaline and this is clearly illustrated by all three methods (Fig. 2). None of the animals showed a marked increase in respiration rate in response to the doxapram hydrochloride, and all three monitoring methods showed varied respiration patterns.

ICCs for Absolute Agreement calculated for the total 30-min study period for both animals on both days are given in Table 1. All ICCs were significant ($P < 0.05$).

Mean heart rates and respiration rates calculated for both animals on both days are given in Table 2.

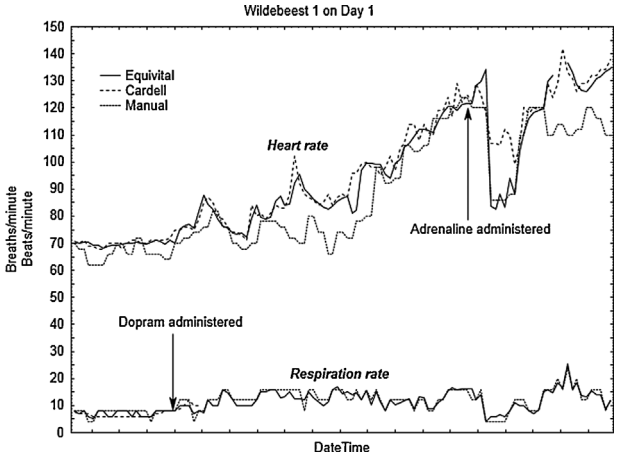

Fig. 2. The heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 1 on Day 1 over a 30-min period as measured with the Equivital system, a Cardell monitor and manually showing the response before and after the administration of adrenaline and doxapram hydrochloride.

ICCs for Absolute Agreement calculated for the 2-min period after the administration of adrenaline or doxapram hydrochloride for both animals on both days are given in Table 3. All ICCs were significant ($P < 0.05$) except for those ICCs indicated in Table 3.

No significant differences ($P > 0.05$) were found between mean heart rates and respiration rates measured with each of the three methods during this period on either of the two study days. Thus, all three methods measured similar heart rates and respiration rates during this period but measurements did not follow the same pattern (Figures 1–4).

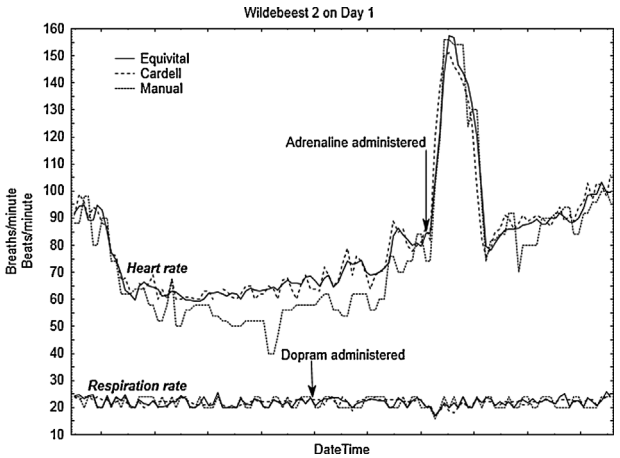

Fig. 3. The heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 2 on Day 1 over a 30-min period as measured with the Equivital system, a Cardell monitor and manually showing the response before and after the administration of adrenaline and doxapram hydrochloride.

TABLE 1. ICCs for absolute agreement calculated between heart rates as well as respiration rates measured with the Equivital belt, a Cardell monitor and manually for both wildebeest for the entire study period

	DAY 1			
	Wildebeest 1		Wildebeest 2	
	Heart rate	Respiration rate	Heart rate	Respiration rate
Equivital—Cardell	0.96	*	0.98	0.58
Equivital—Manual	0.88	0.92	0.93	0.60
Cardell—Manual	0.87	*	0.92	0.30
	DAY 2			
Equivital—Cardell	0.97	0.92	0.95	0.82
Equivital—Manual	0.76	0.89	0.78	0.55
Cardell—Manual	0.73	0.82	0.73	0.53

*The ICC was not calculated since only 7 min of data was recorded with the Cardell capnostat®.

Day 2

Figures 4 and 5 show the heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 1 and wildebeest 2, respectively, as measured over the 30-min study period on Day 2. Again, Figure 4 shows that all three methods indicate a slight increase in wildebeest 1's heart rate followed by a noticeable decrease after the administration of adrenaline. Wildebeest 2, on the other hand, showed a slight decrease in heart rate followed by a marked increase following the administration of adrenaline with all three methods indicating the same pattern. After the administration of doxapram hydrochloride, wildebeest 1 showed an increased respiration rate measured with all three methods although the Cardell monitor measured the most marked increase. Wildebeest 2's respiration rate showed varied patterns between the three monitoring methods after the administration of doxapram hydrochloride with the Equivital and Cardell measurements showing the most similar pattern while the manual measurements showed noticeable fluctuations.

ICCs for Absolute Agreement for Day 2 are given in Table 1. All ICCs were found to be significant ($P < 0.05$). Mean heart rates and respiration rates are given in Table 2. ICCs calculated for the 2-min period after the administration of adrenaline or doxapram hydrochloride on Day 2 are given in Table 3.

Heart Rate and Respiration Rate Whilst in the Enclosure

The mean heart rate and respiration rate of wildebeest 1 while in the enclosure was calculated as 65.39 ± 0.21 beats/

TABLE 2. Mean heart rates (beats/minute) and respiration rates (breaths/minute) ± standard error of the mean (S.E.M.) as measured by the three different methods on Day 1 and Day 2

	DAY 1					
	Mean heart rate			Mean respiration rates		
	Equivital	Cardell	Manual	Equivital	Cardell	Manual
Wildebeest 1	$91.24^{a} \pm 1.61$	$92.26^{a} \pm 1.61$	$84.55^{b} \pm 1.61$	$10.90^{a} \pm 0.33$	*	$11.15^{a} \pm 0.33$
Wildebeest 2	$83.40^{a} \pm 1.74$	$83.79^{a} \pm 1.75$	$80.24^{a} \pm 2.22$	$22.12^{a} \pm 0.17$	$22.06^{a} \pm 0.18$	$21.19^{a} \pm 0.17$
	DAY 2					
Wildebeest 1	$80.73^{a} \pm 2.10$	$81.94^{a} \pm 2.10$	$78.81^{a} \pm 2.10$	$12.47^{a} \pm 0.44$	$13.27^{a} \pm 0.44$	$13.38^{a} \pm 0.44$
Wildebeest 2	$69.76^{a} \pm 1.65$	$70.79^{a} \pm 1.65$	$62.18^{b} \pm 1.65$	$23.81^{ab} \pm 0.19$	$23.64^{b} \pm 0.19$	$23.19^{bc} \pm 0.19$

[abc] Means with the same letter between methods for a specific animal do not differ significantly ($P > 0.05$). *The Cardell measurements for respiration were excluded from this analysis as measurements were only taken for 7 min of the total study period.

min and 10.67 ± 0.12 breaths/min, respectively. The mean heart rate and respiration rate of wildebeest 2 while in the enclosure was calculated as 70.80 ± 0.36 beats/min and 13.30 ± 0.09 breaths/min, respectively.

We also calculated mean heart rates and respiration rates per animal for each motion category as measured by the Equivital belt. Both heart rate and respiration rate increased significantly ($P < 0.05$) with motion (Table 4).

The results showed that wildebeest 1 spent 68.79% of its time being stationary, 27.62% of its time moving slowly and 3.59% of its time moving fast. In comparison, wildebeest 2 spent 76.62% of its time being stationary, 18.86% of its time moving slowly and 4.52% of its time moving fast.

TABLE 3. ICCs for absolute agreement calculated between heart rates as well as respiration rates measured with the Equivital belt, a Cardell monitor and manually for both wildebeest for the 2-min period after the administration of adrenaline or doxapram hydrochloride

	DAY 1			
	Wildebeest 1		Wildebeest 2	
	Heart rate	Respiration rate	Heart rate	Respiration rate
Equivital—Cardell	0.42	0.45*	0.95	0.07*
Equivital—Manual	0.93	0.72	0.97	0.89
Cardell—Manual	0.36	0.30*	0.92	0.04*
	DAY 2			
Equivital—Cardell	0.96	0.90	0.87	0.74
Equivital—Manual	0.69	0.71	0.71	0.39*
Cardell—Manual	0.67	0.61	0.63	0.32*

*ICC is not significant ($P > 0.05$).

DISCUSSION

The results showed that the Equivital system could accurately measure heart rate, both before and after being worn by a fully conscious wildebeest in captivity for 24 hr. The Equivital belt also measured heart rates ranging from 69.76–91.24 beats/min (bpm), which is similar to results reported by Dittberner [2011]. This author reported mean heart rates ranging from 70.5 to 102.9 bpm for blue wildebeest immobilized with different variations of etorphine with hyaluronidase.

All three monitoring methods indicated that the heart rates of both animals responded differently to the administration of the adrenaline on both study days. These responses cannot be explained in this study but may be related to unknown underlying physiological mechanisms. Both the Cardell monitor and those measurements taken manually showed a lack of sensitivity to heart rate changes in response to adrenaline on at least one of the study days,

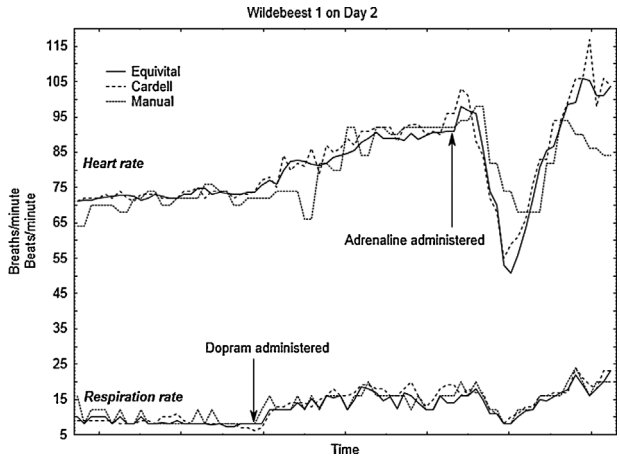

Fig. 4. The heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 1 on Day 2 over a 30-min period as measured with the Equivital system, a Cardell monitor and manually showing the response before and after the administration of adrenaline and doxapram hydrochloride.

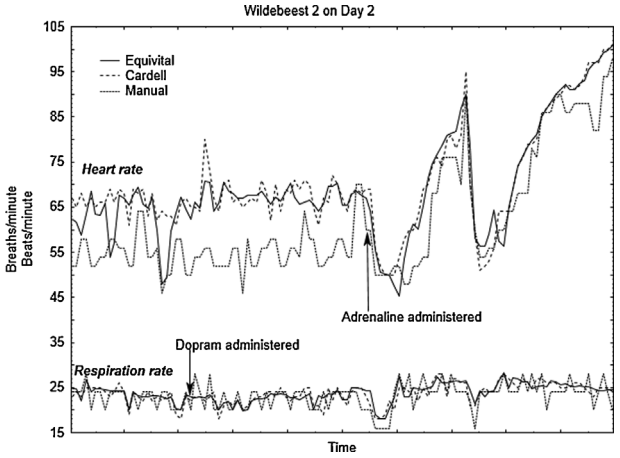

Fig. 5. The heart rate (beats/minute) and respiration rate (breaths/minute) of wildebeest 2 on Day 2 over a 30-min period as measured with the Equivital system, a Cardell monitor and manually showing the response before and after the administration of adrenaline and doxapram hydrochloride.

indicating that erroneous measurements may have been taken using these two methods. However, in both animals on both study days, the Equivital belt measurements had a good to excellent agreement with at least one of the other monitoring methods if not with both.

Respiration rate results were more confounding with all three methods showing varied agreements with each other. In wildebeest 1 on both days, it appeared that all three methods recorded accurate readings, showing excellent agreements with each other. However, in wildebeest 2, the three methods showed at best a moderate agreement with each other except for the Equivital belt measurements which were in good agreement with the Cardell measurements on Day 2. This lack of consistency may be attributable to the sensitivity of the Cardell capnostat® probe in picking up subtle changes in respiration such as an increase in shallow breaths induced by anaesthesia. These shallow breaths may not have been picked up by the Equivital respiration sensor or manual respiration counts. In addition, manual measurements of respiration rate were calculated from the counting of exhaled breaths with no fractional component (unlike the Equivital system) so that there was a lack of sensitivity in picking up changes in respiration.

This inconsistency between the three methods in measuring respiration was evident as well after the administration of doxapram hydrochloride. However, the Equivital belt showed at least a moderate to good agreement with one of the other two methods in each of the animals on both study days. Weaker agreements were found between the Cardell and manual measurements during this time indicating again that erroneous readings were likely taken with one of these methods.

We found that mean respiration rates measured with the Equivital belt while the animals were in the enclosure ranged from 7.92–19.10 breaths/min. which is comparable to those reported by Mortola and Lanthier [2005] for blue wildebeest (17 breaths/min). In agreement with our findings where the Equivital belt respiration rates for the anaesthetised animals ranged from 10.90 to 23.81 breaths/min, Dittberner [2011] reported respiration rates for immobilised blue wildebeest to range from 19 to 26 breaths/min.

The analysis of belt-measured motion served to further substantiate its measures of heart and respiration rates. We expected that moving fast would result in the highest mean heart rates and mean respiration rates since increased motor activity can result in increased respiratory and cardiovascular output [Price and Sibly, 1993].

Overall, the study found that the modified version of the Equivital belt can measure heart rate, respiration rate and motion in this species with a good degree of accuracy. The inconsistencies, found in respiration rate using all three monitoring methods, require further investigation in order to fully explain them. The successful use of such a biotelemetry system can greatly improve the understanding of factors that may cause changes in these parameters whilst animals are conscious and in captivity.

CONCLUSIONS

1. The Equivital belt reliably measured heart rate in blue wildebeest when compared to heart rate measured with a Cardell monitor and measured manually, even after being worn for 24 hr in captivity
2. The Equivital belt could also accurately detect changes in heart rate due to the administration of adrenaline.
3. On both study days, respiration measured with the Equivital system was accurate when compared to respiration measured manually and with a Cardell monitor in the first wildebeest. It was less accurate in the second wildebeest; however, manual and Cardell respiration rates also showed only a moderate agreement with each other in this animal.

TABLE 4. Mean heart rates (beats/minute) and respiration rates (breaths/minute) ± standard error of the means (S.E.M.) as measured by the Equivital belt for both wildebeest per motion category

	Wildebeest 1		Wildebeest 2	
Motion	Heart rate	Respiration rate	Heart rate	Respiration rate
Stationary	61.96 ± 0.24	7.92 ± 0.12	64.20 ± 0.36	12.03 ± 0.10
Moving slowly	71.69 ± 0.37	16.62 ± 0.19	89.71 ± 0.73	17.11 ± 0.20
Moving fast	82.53 ± 1.04	17.75 ± 0.53	103.74 ± 1.50	19.10 ± 0.41

4. Changes in respiration due to the administration of doxapram hydrochloride were inconsistent between the three monitoring methods, although the Equivital measurements were in moderate to excellent agreement with at least one of the other two methods after the administration of doxapram hydrochloride
5. In addition, the Equivital biotelemetry belts measured corresponding increases in heart and respiration rates with increased physical activity while being worn in captivity.
6. All mean heart rates and mean respiration rates measured with the Equivital system fell within acceptable ranges as reported for this species.
7. The Equivital respiration sensor may not be sensitive enough to detect subtle changes in respiration due to the administration of certain drugs and, thus, further investigation is required to evaluate factors that may influence its accuracy in measuring respiration rate.
8. The short battery-life of the Equivital data logger limits its use in long-term studies and additional investigations need to be performed on its use with an external battery pack.
9. Overall, the Equivital system shows promise as a suitable biotelemetry device for use in short-term studies involving captive wildlife species, specifically those investigating activity and heart rate responses. The biotelemetry belts are easily modified, require no surgery to be fitted and show potential for use in zoo and captive environments.

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