TECHNICAL CONTRIBUTION

A NON-INVASIVE SYSTEM FOR REMOTELY MONITORING HEART RATE IN FREE-RANGING UNGULATES

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A new, external non-invasive telemetric heart rate (HR) monitoring system was evaluated on eight wapiti, Cervus elaphus canadensis, *yearlings in July and August 1996. The assembly consisted of a leather girth strap, onto which a HR transmitter and a customized carriage bolt electrode system were fixed. To prevent the girth strap from rotating on the animal, it was secured with adjustable nylon straps extending anteriorly between the forelegs up to an adjustable neck collar. In preliminary testing, audible tones were received during 99 per cent (n = 902) of the 15s intervals when the animals were active, but only during 33 per cent (n = 156) when they were bedded. After 2 weeks, the equipment remained functional (and was removed); the effective signal range was consistently beyond 500m. This HR monitoring system is easy to attach externally, obviates complications from surgery, and provides coverage over an extended range.*

The monitoring system offers a reliable, humane and inexpensive method for short-term measurement of HR in captive or wild ungulates. Further tests may reveal a potential for long-term application. The ability to measure physiological responses under different management regimes can aid ungulate farmers in selecting optimal herd sizes and social structures for their animals; and in developing superior housing, enclosure designs, handling and transport methods. This improves the animals' welfare, and ultimately leads to an increase in animal growth and herd productivity. In addition, information about heart rates can help wildlife managers to improve their management strategies, by gaining an understanding of the energy expenditure associated with various activities and environmental influences.

Keywords: *animal welfare,* Cervus elaphus canadensis, *heart rate, ungulate, wapiti, wildlife management*

Introduction

Quantifying energy expenditure is essential to developing a better understanding of the biological requirements of ungulates (Freddy 1984). Furthermore, as farmers become increasingly aware of the relationship between animal welfare and productivity, the value of comprehending how physiological changes can reveal physical or psychological stress has been emphasized. Despite the difficulties that sometimes arise when attempting to distinguish physiological changes resulting from disturbance from those attributable to physical activity, heart rate (HR) is a useful indicator of energy expenditure and acute stress in animals.

Heart rate measurements have been widely incorporated into studies investigating the bioenergetics of non-domestic ungulates (mule deer, *Odocoileus hemionus*, [Kautz *et al* 1981]; white-tailed deer, *O. virginianus*, [Holter *et al* 1976; Moen 1978]; wapiti [Lieb 1981; Chabot *et al* 1990; Chabot 1991]; moose, *Alces alces*, [Renecker & Hudson 1983; 1985]; and reindeer, *Rangifer tarandus*, [Nilssen *et al* 1984; Fancy & White 1986; Sokolov 1990]). As an indicator of stress, HR has been used extensively to detect discrete physiological changes when an animal is disturbed, particularly when overt behavioural responses are not manifested (eg wapiti [Chabot 1991; Chabot *et al* 1990; 1996]; red deer, *Cervus elaphus*, [Espmark & Langvatn 1979; Pollard *et al* 1992; Price *et al* 1993]; white-tailed deer [Moen *et al* 1978; Jacobsen 1979]; moose and reindeer [Roshchevskii *et al* 1976]; bighorn sheep, *Ovis canadensis*, [MacArthur *et al* 1979; 1982a; Stemp 1983; Geist *et al* 1985]). Measurement of HR has also been used to predict blood parameter (eg plasma cortisol) levels in sheep (Harlow *et al* 1987).

Heart rate research has contributed to considerable animal welfare improvements, ranging from predicting optimal herd size and social structure (eg MacArthur *et al* [1982b]; Syme & Elphick [1982]), to enhancing animal housing and enclosure designs (Price *et al* 1993), and to more humane handling techniques and transport methods (eg Baldock & Sibly [1990]; Hargreaves & Hutson [1990a, b]; Pollard *et al* [1992]; Price *et al* [1993]). However, the performance of HR monitoring systems has had varying degrees of success. Hence, there exists a need for a reliable, non-invasive system for remotely obtaining HR information in ungulates, which facilitates both short- and long-term monitoring.

Surgically implanted physiological monitoring systems offer long-term use with a minimal threat of tampering with the equipment by the animal. However, their disadvantages include, threat of infection or other adverse effects of surgery, difficulty in repairing or replacing faulty equipment, and impracticality for short-term use. These all severely limit their application. Furthermore, the long turnaround times associated with retrieving equipment for attachment to alternative individuals, add to their impracticality and raise animal welfare concerns.

External monitoring assemblies, although generally reliable when directly attached to recording equipment, can experience inconsistent signal reception when used remotely. They are traditionally limited to captive animals and are generally only practical for short-term use. For example, in research conducted on swine by Friend *et al* (1991), only 30 per cent of the electrodes did not require replacement before completion of the 5-day trial (ie the electrodes usually needed replacement every 2–3 days). This translates into increased animal handling, which can be stressful for the animals.

My objective was to devise a reliable, humane system for remotely monitoring HR in captive or wild ungulates, and which would be suitable for either short- or long-term use.

Materials and methods

The study was conducted at Ministik Wildlife Research Station, a University of Alberta wapiti facility in central Alberta, Canada. The equipment was developed on eight, yearling female wapiti during July and August 1996. These animals were raised in a free-ranging, pasture-based system with minimal handling and weighed 167–190 kg. Assembly attachment and periodic signal reception were tested on five animals, while HR monitor performance was evaluated intensively on three individuals.

Apparatus design

The telemetric HR monitors consisted of a VHF-C-1 (Very High Frequency) HR transmitter with a lithium battery (10-month life, 50g), all encased in sterilized wax (Mini-Mitter, Sunriver, Oregon, USA). These units transmit at a frequency of 150MHz, measure approximately 8x3.5x4 cm, and weigh less than 150g. Lithium batteries are an appropriate power source, as they have high energy density, a very stable output voltage over their entire working life, store quite well when not in use, and are relatively cold-tolerant (R Rushton personal communication 1996). The antenna was internal (ie within the wax) and two, 1m insulated metal electrode leads extended from one end of the unit. These units are intended primarily for internal use (ie for either subcutaneous or body cavity implantation); however, for the purposes of this study, they were fitted into a specially designed assembly for external use (Figure 1).

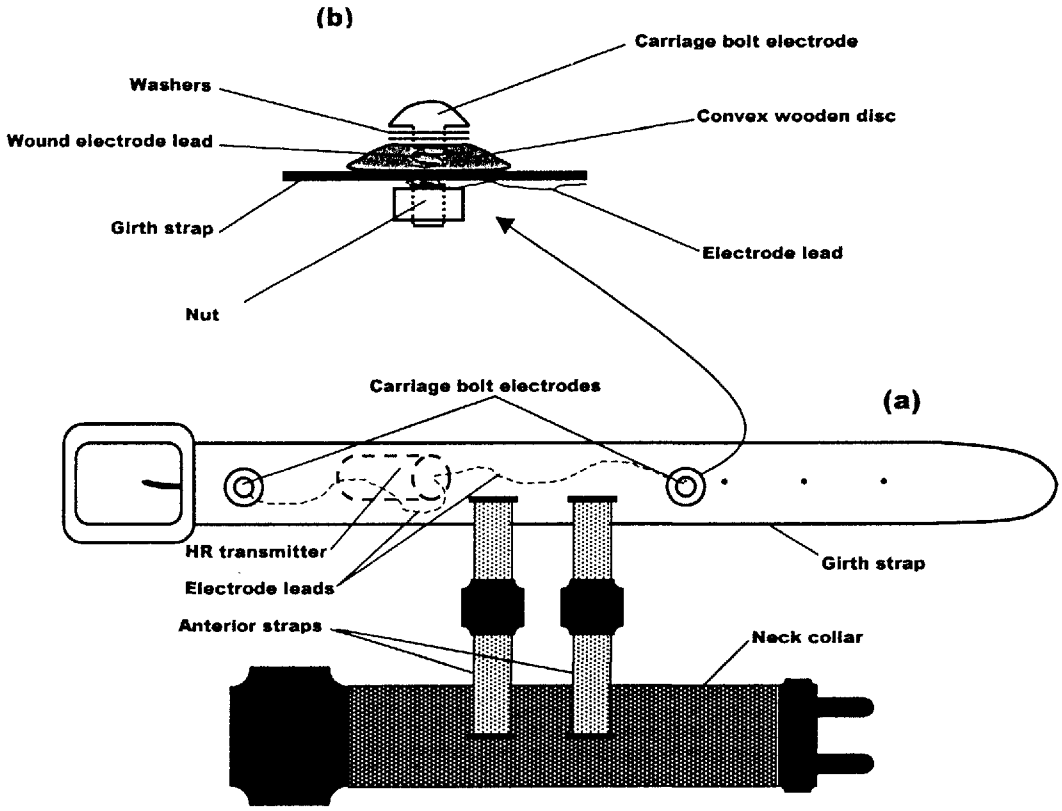

Figure 1 **(a) Schematic diagram (not to scale) of the ventral view of a non-invasive external assembly for measuring the heart rate (HR) of ungulates; (b) side view of the carriage bolt electrode system.**

The assembly consisted of a thick leather belt (5cm wide x 173cm long) onto which the transmitter was affixed with strong reinforced tape. The terminals of the electrode leads, which were also attached to the outer surface of the belt, were wound around 3cm-long carriage bolts. This effectively converted the carriage bolts into electrodes, as they were made of highly conductive galvanized steel. The rounded head of each bolt served as the contact between the transmitter and the animal's skin. Between each carriage bolt head and the leather strap, there was a 4cm-diameter x 1.2cm-thick convex wooden disc and two metal washers (spacers) to increase the space between the belt and the skin surface, thereby improving electrode contact. This design provided a completely self-contained system, whereby the transmitter, leads and electrodes were not exposed, protecting them from environmental (eg weather, sunlight or snagging) and animal (eg grooming or chewing) damage.

Two, adjustable reinforced nylon straps (with plastic buckles) were attached to a nylon neck collar (also with a plastic buckle) located in front of the girth strap. This assembly served to stop the girth strap from rotating and shifting electrode placement, as well as preventing the animal from removing the HR monitoring assembly.

The features of this system would allow it to be utilized on ungulates of a wide range of sizes. This could be accomplished via a combination of belt buckle hole selection and the addition of a series of holes for the carriage bolts, to vary electrode placement. The anterior straps and neck collar could also be adjusted accordingly. The girth straps tested, were prepared specifically for use on yearling female wapiti (ie for a girth range of 124–163 cm).

Apparatus attachment

The positioning of the equipment on the animal is illustrated in Figure 2. Three yearling wapiti were physically immobilized and fitted with HR monitors. Two areas (c 20cm in diameter) were closely clipped to remove hair for placement of the electrodes. The ventral (positive) electrode was placed on the chest just behind the olecranon (elbow), and the dorsal (negative) electrode immediately behind the shoulder blade, on the opposite side of the thoracic vertebrae to the ventral electrode. Electrode positioning was chosen to approximately transect the heart. (Initial calibration may be required, as there can be marked intra- and interspecific variation in optimal electrode placement.) Neither skin penetration nor electrode gel were necessary to obtain a reliable signal, with minimal noise from musculoskeletal movement. The two nylon straps were extended between the forelegs up to the neck collar and tightened sufficiently to secure the girth strap, preventing rotation. The plastic buckles should be wrapped with reinforced tape as they can be easily broken (eg by animal chewing).

Observations and habituation trials

Following equipment attachment, each wapiti was released into a large holding pen for observation. If suitable HR signals were received throughout the observation period, the wapiti were eventually released into large pastures for periodic monitoring. They remained on pasture for up to 5 days, to ascertain whether the equipment remained properly fitted and functional. Signals from the transmitter were detected with a TR-2 receiver (Telonics; Mesa, Arizona, USA) with a 15cm coil monopole two-way radio antenna.

More extensive equipment testing, involving three wapiti, took place over a 3-day period. This was part of other research on evaluating habituation rates in farmed wapiti. During these habituation trials, two yearlings (one of the yearlings fitted with a HR monitor, and one not) were confined in a 12x7 m pen, with 3m-high fencing and hessian attached to create a visual barrier. The animals were kept in pairs to reduce stress, as wapiti are naturally gregarious. Each of three pairs was, in turn, exposed to a novel alarm stimulus at various frequencies for 1h in the morning and afternoon, for 3 consecutive days. In this case, the novel stimulus was the observer wearing a bright yellow raincoat on top of the fence, frantically waving his arms in the air for 15s. The frequencies of disturbance were every 5, 10, or 20 min (ie 12, 6, and 3 times h^{-1}). Following the stimulus, instantaneous HR was measured over consecutive 15s intervals for a total of 4min, by manually counting audible pulses. We also recorded whether animals were active or bedded during these habituation trials.

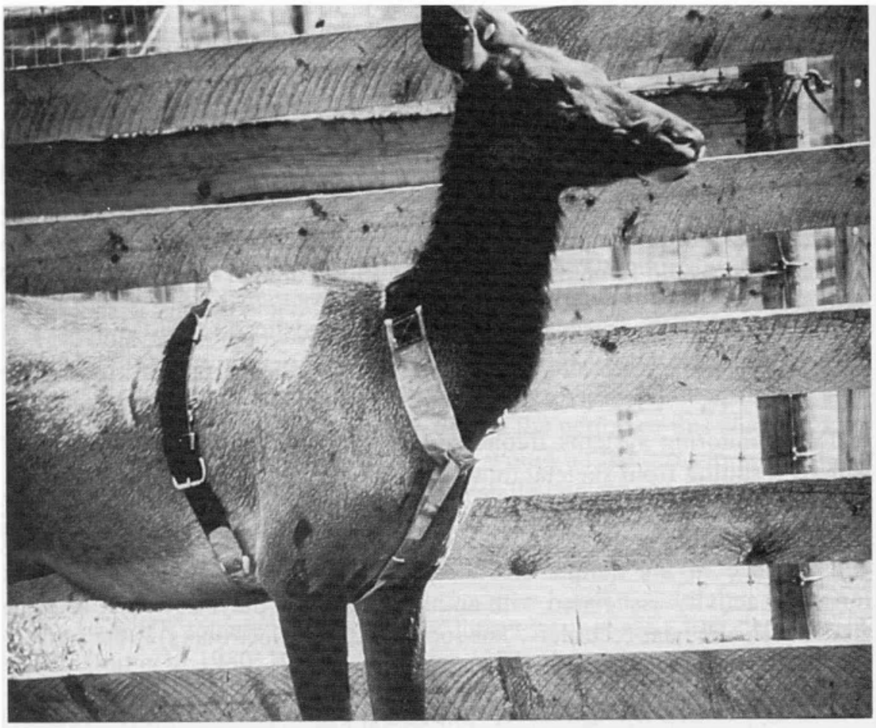

Figure 2 **A non-invasive external heart rate monitoring assembly fitted on a female wapiti yearling.**

Results

Immediately following HR monitor attachment, the wapiti were adversely affected by the equipment, running erratically and 'bucking'. After 10–20 min they relaxed, and the only apparent notice they took of the apparatus were attempts to groom areas around the girth strap. By 40–60 min, they generally ignored the equipment, except for occasional comfort movements. Although the wapiti had been able to remove earlier versions of the system, with the current design, the equipment remained in position and functional for 2 weeks (on the yearlings involved in the habituation trials), before we removed it. One of these yearlings developed a skin irritation beneath the girth strap on the crest of her thoracic vertebrae during this period. Among the other five wapiti tested (ie those not involved in the habituation trials), the HR monitors functioned for up to 5 days, before they were removed for installation on alternative individuals.

In the habituation trials, a strong signal was received during 99 per cent of the 15s intervals (n = 902) while wapiti were active; however, tones were audible only 33 per cent of the time when the animals were bedded (n = 156). With audio signal monitoring, artefacts from muscle activity associated with animal movement were not noticeable; however, problems might be encountered when using an automatic beat-recorder. During these tests, an audible signal could be received at distances in excess of 500m, using a coil monopole antenna. For the monitoring range required in the habituation trials, a sufficiently strong signal could be detected without an antenna.

Discussion

Preliminary results suggest that the current design of the HR monitoring system described in this study, provides consistent, reliable transmission of HR in wapiti yearlings. Stable function, however, appears to be limited to active animals, as electrode-skin contact becomes poor when they are in a laterally recumbent position (ie bedded). Although this is a limitation, most HR measurements that are required do tend to be from active animals.

A possible solution to this limitation, would be to incorporate sections of reinforced elasticized material on the girth strap. This would allow the belt to be tightened to such an extent that it would remain relatively taut during animal recumbency, maintaining electrode-skin contact. If employed for an extended period (eg several seasons), this would also ensure strap tension during weight fluctuations (eg winter weight loss). However, the elasticized belt might weaken the girth strap, thereby increasing the chance of breakage or removal by the animal.

HR monitoring systems frequently encounter problems with interference from spurious signals resulting from skeletal muscle activity (eg Johnston *et al* [1980]; Kautz *et al* [1981]). The assembly used in this study, appeared to be unaffected by muscular artefacts, as demonstrated by the clean traces and consistent interbeat intervals recorded. This may be a consequence of the unique electrode-skin interface devised for this system. Noise from muscular activity associated with animal movement may, however, affect readings collected from automatic beat-recorders. The location of the electrode(s) is the most important factor in minimizing ambiguous electronic emissions.

Being completely external, this system offers the convenience of rapid attachment, without the host of deleterious effects associated with internal units. Lieb (1981) implanted HR monitors in wapiti, and 8 of 16 implants resulted in death. When Wild *et al* (1998) surgically implanted transmitters in bighorn sheep, they encountered problems with lameness, seromas, and transmitter migration, including one which was passively expelled. Although, most of these disorders can be easily dealt with in captive ungulates, failure to treat them in the wild could compromise an animal's welfare. Equipment failure due to body fluid seepage into the transmitter package has also been recorded (Wallace *et al* 1992; Wild *et al* 1998).

A further complication that can arise from surgical implantation, is infection. It is nearly impossible to produce sterile conditions in the field, and transport to an aseptic facility for surgery can be stressful for the animals and/or expensive (Wallace *et al* 1992). This highlights the safeness of the external assembly described in this study, in that incision is not necessary for electrode placement. The dorsal skin abrasion found on one yearling was probably caused by increased friction under the girth strap at the site of the thoracic crest, and could be alleviated by the addition of some padding. Wapiti have rather pronounced thoracic crests, so this may not be a problem when the assembly is applied to other ungulate species. Modifications of this assembly are, however, necessary to ensure its safe use and to prevent injury to the animal.

As the daily movements of wild ungulates can be extensive, the effective range of the transmitter-receiver system is of critical importance (Johnston *et al* 1980). The transmitter manufacturers suggest that when the HR monitors are used internally, they provide reliable signals at distances in excess of 100m (R Rushton personal communication 1996).

Transmitter function in this study was enhanced, probably due to its dorsal location. Achieving a range of > 500 m, using a small-coil monopole antenna, is encouraging for use with wild ungulates. Moreover, the functional range could be substantially extended through the deployment of a 3-point directional antenna, or even a larger fixed-tower antenna.

Another alternative to increase functional range would be to replace the internal transmitter antenna with an external whip antenna. Increased range, however, would be compromised by exposing the antenna to environmental rigours and by animal tampering. Maximizing the distance at which HR may be measured, decreases the risk of animal harassment and eliciting behavioural or physiological responses. For example, if visual contact is required during HR monitoring, one can employ binoculars or a spotting scope to maintain an appreciable distance between observer and animal.

The superior performance that these HR monitors demonstrated in habituation trials over 2 weeks, suggests that further testing may reveal a system that can be used for extended periods. Although a layer of dirt and oil had collected on the surface of the carriage bolt (electrode) after 2 weeks, this did not seem to impede electro-conductance. However, further accumulation over time, could pose a problem. In addition, regrowth of hair in the clipped patches might eventually lead to signal loss. Regrowth during the period of this study had no affect on signal strength. One stipulation for extended use, would be the need to account for animal growth. For instance, the assembly should not be installed on animals which have not achieved their mature weight, unless proper precautions are taken (eg using expandable girth strips). Neck growth during the rut should also be considered when fitting neck collars on males.

A frequent problem with HR telemetry (particularly long-term), is electrode detachment and lead breakage (Johnston *et al* 1980; Brown & Taylor 1984; Baldock *et al* 1988; Wallace *et al* 1992; Price *et al* 1993). This assembly offers the advantage of having completely self-contained leads, protecting them from wear and tampering. Moreover, the unique and robust design of the carriage bolt electrodes eliminates the problem of electrode disconnection. However, as is common with external assemblies, there is a risk of entanglement with branches, which could put the animal's welfare at risk in the absence of constant monitoring. Hence, this system could be better suited for open-habitat species, as opposed to those that inhabit thicker brush.

Conclusions and animal welfare implications

The ability to reliably measure HR is important, as the knowledge gained is vital to developing an understanding of animal bioenergetics and acute stress. In captive animals, this information may assist farmers in improving animal welfare and, consequently, animal growth and herd productivity. For example, employing this assembly in HR research could provide insights into ungulate physiological responses to new handling and transport methods, housing and enclosure designs, and social configurations – leading to animal welfare improvements. One drawback to the use of HR as a measure of acute stress, is the inability to distinguish HR augmentation due to stress from that arising from physical activity. However, it could still help wildlife managers who need to assess energy expenditure resulting from activity and environmental influences (eg climate, weather or human disturbance), thereby leading to improved management strategies.

One advantage of the current design of this HR monitoring assembly is its effective short-term use (further research may reveal its potential for long-term application). As an external, non-invasive system, it obviates many of the complications that can arise when using surgically implanted transmitters. The range over which a strong signal can be received would also allow its use on wild ungulates without harassing the animals or eliciting behavioural or physiological responses.

The simplicity of attachment (and removal) of the HR monitors enables rapid replacement or translocation, thereby minimizing stress to the subject(s). It also offers the option of conducting several short-term experiments on a variety of captive animals in a short period. The monitor is, therefore, suitable for a wide range of applications and, depending on research objectives, could greatly reduce research costs by decreasing the number of transmitters required. Further research should be conducted on this system to establish whether function can be sustained and animal health maintained over longer periods.

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