ROYAL VETERINARY COLLEGE

Are you Breathing?

Non-Contact Respiratory Rate Monitoring of Resting Dogs

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Abstract

Introduction: This paper describes a novel method for non-contact respiratory rate monitoring of resting dogs tested in a clinical setting.

Methods: 15-30 second videos were recorded of dogs in kennels recovering from anaesthesia in a referral hospital setting resting in lateral or sternal recumbency. Videos were loaded on a laptop with custom software for analysis. The software tracked the movement of a manually selected square in the cranial abdomen throughout the video. Signal analysis was then performed on the coordinates of the squares' movement to obtain a respiration rate. Bland-Altman analysis was used to compare this respiration rate with one obtained visually from the video.

Results: The calculated respiration rates were within +/- 4 bpm of the reference method, the predefined interchangeable clinical limits. Bland-Altman analysis had a mean bias of -0.51 breaths per minute (95% CI -.19 to -.82 bpm) with limits of agreement (mean+/-2sd) of -3.5 to 2.5 bpm (95% CI:-2.9 to -4.1 and 3.0 to 1.91).

Discussion: These results show potential for a novel method for non-contact respiration monitoring of dogs, which is interchangeable with the reference method. Developments in non-contact monitoring will be of great benefit in veterinary practice. It provides a method to monitor stressed animals without falsely elevating the respirator rate or disturbing the patient, as well as providing an economical method for continuous monitoring, particularly for animals recovering from anaesthesia or in respiratory distress. To the authors' knowledge this is the first clinical study in the field of veterinary non-contact vital sign monitoring.

Abbreviations:

Bpm: breaths per minute

ROI: region of interest

RVC: Royal Veterinary College

Introduction

Regular assessment of vital signs is routine practice for hospitalized animals while recovering from anaesthesia, suffering from chronic diseases, and during assessment of response to treatment. Currently, measuring heart rate and temperature require physical contact with each animal, and respiration rate monitoring requires close visualization. All of this may increase stress in hospitalized animals, which has been shown to change resting physiological variables.[1] There is also an increased risk of spreading infection in a busy hospital setting using direct contact monitors. The ability to measure physiological values with a non-contact method could improve the accuracy of clinical information available to veterinarians by decreasing the stress of aggressive or nervous animals. Similarly there could be increased frequency of clinical data available without having to employ valuable personnel to constantly evaluate respiratory status. The use of contactless monitoring in a dyspnoeic patient case would allow clinicians to evaluate a more complete clinical picture without causing the patient to rapidly decompensate. In the case of anaesthesia monitoring it could provide valuable information, especially in charity and shelter situations where sophisticated equipment is not generally available. Additionally, these methods only require software and digital video recording, and could be run from a mobile phone or tablet, providing an inexpensive and inherently safe monitoring technique.

Non-contact vital sign monitoring is a major research focus in human medicine with recent studies showing the potential of providing an inexpensive and reliable monitoring method. To date, methods for analysing respiration rate have been complex, using technologies such as thermal imaging, microwave radar, and infrared, and requiring expensive technologies applied in the clinical setting. [2–4] Physiological monitoring from a video camera is also a major focus, with many of the methods working on heart rate estimation through light reflectance giving a photoplethymographic signal.[5–7] However most of these methods are tested only on healthy humans, in a controlled setting with only ambient sunlight.[5,8,9] To date the author found one paper that tested similar methodology on animals, a single mouse, fish and pig - however it only works with ambient sun light and not the florescent lights used in most clinical settings.[6]

In this study I implemented and tested a simple novel method of respiration monitoring by video analysis on resting dogs in a clinical setting. The method uses the location of a square on their abdomen, and programmatically tracks its movement over time, giving a signal that correlates well with respiration. We hypothesized that this would work as well as routine visual monitoring of resting dogs in a clinical setting.

Materials and methods

All dogs recovering from general anaesthesia for elective clinical procedures at the Queen Mother Hospital for Animals, Royal Veterinary College (RVC) during a 3 week period were included in the study. The study was approved by the RVC ethical committee ref number 2014-S334. Client consent was deemed unnecessary as monitoring did not deviate from normal clinical practice. Data was collected in a hospital setting, with multiple fluorescent lights and no ambient sunlight. Videos were taken of the dogs in individual kennels in the recovery room of the hospital following anaesthesia for a various procedures (8 surgery, 5 MRI/CT, 1 CSF tap). Videos were recorded in colour on a Sony RX 100 mounted on a gorilla tripod for 15 to 30 seconds, about 1 metre from the dog, with a sampling rate of 25 or 29 frames per second, and a pixel resolution of 1440x1080, saved in mp4 format, encoded as H264, and copied onto a Sony Vaio Z laptop for analysis. The dogs' coat colour and hair length were recorded, since previous computer vision algorithms were affected by variations in skin complexion. Human visual observation was used as a method of validation: a final year veterinary student counted the breaths visible in each video and calculated the breaths per minute for each dog. The length of video recorded was selected to simulate the visual method usually performed.

Post processing and analysis were performed using custom software written in Python 2.7.5, that was dependent on the following libraries: OpenCV 2, numpy, scipy, and matplotlib.pyplot. The user (a veterinary student) selected a rectangle in the cranial abdomen/caudal thorax from the first frame, where respiration was noticeable. This rectangle was then used as a template, and the xy coordinates of the top left of the template

Figure 1: Image from video analysis of respiration rate. Inner green rectangle is the template, and outer blue rectangle the ROI.

recorded. A region of interest (ROI) was then chosen by going out 10 pixels in each direction from the template (Figure 1). The algorithm then proceeded to the next frame in the video and using openCV matchTemplate, with the CV_TM_CCOEFF_NORMED comparison method, searched in the ROI for the location that best matched the template. Three signals were created and appended to, for each frame: the x coordinates, the y coordinates, and the distance from the original point to the current point. A new ROI was then selected, again 10 pixels in each direction of the new location of the template. The loop continued in this manner, advancing through the video frame by frame, and building up the three signals with the new coordinates.

Various methods of signal processing were applied to ascertain which one yielded accurate results. Comparison of all three signals recorded (the x coordinates, y coordinates, and x/y distance change) found that the x coordinates contained the most plethysmographic signal, so that was used for all analysis. In order to detect change in velocity of the movement further processing of the x/y signal with differentiation was trialed, but it did not yield a reliably plethysmographic signal. Due to subtle camera movements and inaccuracies in template matching, it was determined that applying a linear Gaussian smoothing function to the signal with 10 degrees yielded the best results across all the dogs. To determine the respiration rate, both peak to peak distance, and fast Fourier transform were applied. When monitoring heart rates, peak to peak distance evaluation has the advantage of being able to detect arrhythmias; however breathing in a conscious animal is normally rhythmical. Peak to peak evaluation led to more inaccuracies due to difficulty in peak detection. Applying a fast Fourier transform to the signal yielded the most reliably accurate results, hence it was used to obtain a power spectrum. The largest peak in the power spectrum in the range of 16-2.5 Hz (10-150 breaths per minute) represented the respiration frequency of the dog.

Statistics:

Bland-Altman plots created in Microsoft Excel 2010 were used to evaluate the raw data against the reference method of human visual monitoring. The differences of the two rates were plotted against the mean, and limits of agreement were defined as the mean +/- 2 SD.[10] The methods would be deemed interchangeable with a variation of +/- 4 breaths per minute (bpm), based on the reference method including some variability in assessment of incomplete breaths at the start and end, and the fact that a multiplication of 2 or 4 is included in each assessment. This difference in respiration rate would be deemed to be clinically acceptable.

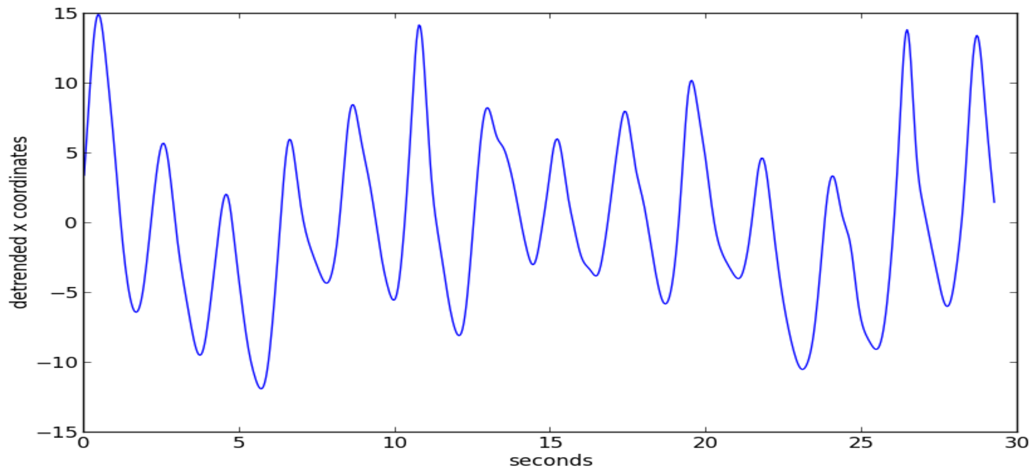

Figure 2: Smoothed and detrended respiration signal from x coordinates of a resting dog.

Results

Fourteen dogs were included in the study. The average age of the dogs included was 5.8 years (min: 6 months, max: 13.9), 9 of the dogs were female and 5 male, and a variety of breeds were represented (See Appendix A for further details on the dogs included). Across the dogs there were variations in coat colour (white = 6; tan/brown=4; black = 3; brindle = 1; grey = 1) and coat length (short haired = 7; long haired = 4; shaved area of interest = 4). The dogs underwent various advanced imaging, medical or surgical procedures before they were filmed resting in the recovery room (lateral recumbency = 11; sternal recumbency = 4). The signals from each dog showed a clear respiration signal (figure 2).

Bland-Altman analysis had a mean bias of -0.51 breaths per minute (95% CI -.19 to -.82 bpm) with limits of agreement (mean+/-2sd) of -3.5 to 2.5 bpm (95% CI:-2.9 to -4.1 and 3.0 to 1.91) (figure 3). All of the calculated respiration rates were within +/- 4 bpm of the reference method, the predefined interchangeable clinical limits.

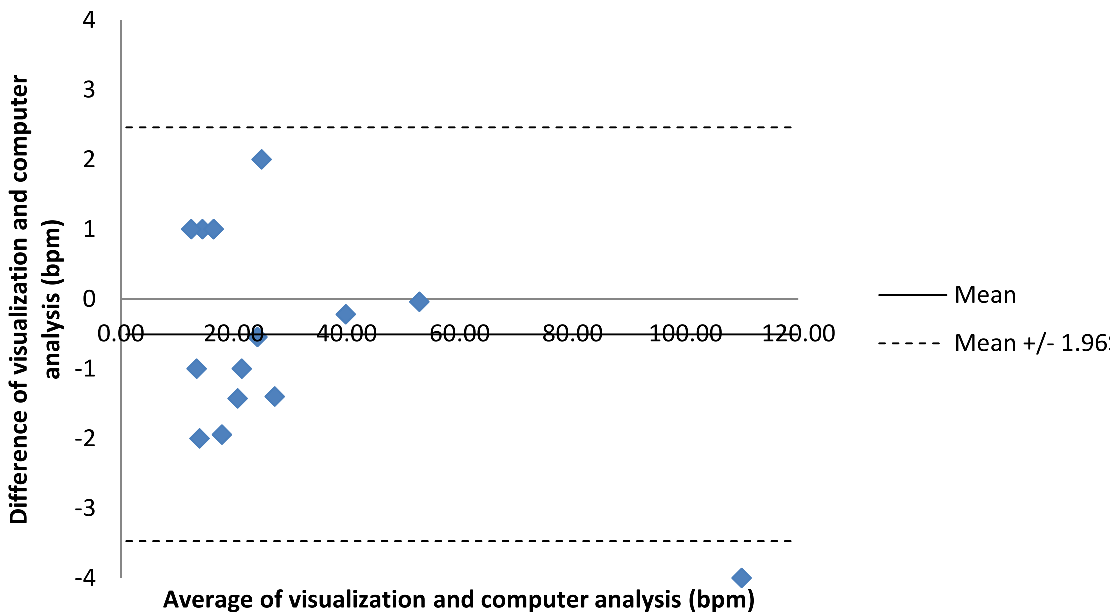

Figure 3 Bland-Altman plot of non-contact respiration monitoring vs human visual observation of 15 resting dogs.

Discussion

The results show a novel method of non-contact respiration monitoring in a clinical setting, which is interchangeable with human visual monitoring and accurate to within +/- 4 bpm. From our literature review, this is the first paper showing non-contact respiration monitoring in dogs in a clinical setting. Since the respiration rate is calculated using fast Fourier transform, this detects the rhythmical rate of breathing accurately, without having to round up or down based on incomplete breaths. When used to analyse an animal over an increased time period, (using a sliding window), this method should be able to detect changes in respiration rate, effort, and any departure from rhythmical breathing with the possibility of setting up alerts should parameters change. With future development, the software could be programmed to give alerts when certain parameters change, for example if the respiration rate stays over 60 breaths per minute for an extended time period, or becomes non-rhythmical, and could retrospectively save video of these instances for later viewing.

Non-contact respiratory rate monitoring may provide improvements in many areas of the veterinary field. Once fully developed, this method will only require a tablet or a video camera connected to a computer, to provide continuous respiratory rate monitoring of resting animals, and thus is more economical than most monitoring systems. In some non-referral settings, animals may be left in the hospital overnight with infrequent or no monitoring, and even in busy ICU settings that are well staffed, animals cannot be visually monitored 100% of the time. If each kennel is fixed with a mounted tablet, upon the staff arrival in the morning they could see the amount of time the animal spent resting, and how their respiratory rate varied. It could also be set up to send alerts to an on call nurse or veterinarian if parameters exceed set limits. This would provide added information and alerts to catch changes in respiratory rate earlier, which could be vital especially for animals in respiratory distress. Additionally, animals with appropriate mentation may not tolerate being connected to other forms of monitoring. As the patient begins to improve and move around the cage more, wires often get tangled and monitoring systems end up providing little information. However with a non-contact method it is still possible to have added information with alerts should patients begin to relapse back into respiratory distress. Additionally it will be of great benefit in a research setting, allowing respiration monitoring without the added variable of human presence.

Studies of peri-operative small animal fatalities have shown that the majority of deaths during procedures occur in the post-op period, with one study finding 47% of deaths in dogs and 61% in cats occurring during recovery.[11] A later study also found that respiratory or cardiovascular causes of death accounted for 74% and 72% of deaths in dogs and cats, peri-operatively.[12] Mounted monitors over animals recovering from general anaesthesia would provide additional monitoring of respiratory rate, especially in small hospitals without dedicated, manned, recovery rooms, potentially lowering the risk of peri-operative fatalities. Pulse-oximeter usage during anaesthesia has also been shown to decrease the risk of death during procedures, which implies that monitoring of respiratory function may decrease peri-operative risk.[12] However, pulse-oximeters require contact with the animal, so non-contact monitoring may provide a more useful alternative, especially during recovery. Additionally brachycephalic breeds are more prone to upper airway obstruction and a stress free recovery with careful monitoring is especially critical,[13,14] thus a monitoring method without attachments would be of particular use.

Management of respiratory emergencies require monitoring of respiratory rate while using minimal handling and restraint to reduce stress [15,16]. Non-contact respiratory rate monitoring will provide a method of continuous monitoring without requiring constant supervision and human intervention, which is ideal in this situation. When a patient presents with left sided heart failure, this method may also provide valuable quantitative analysis of how they cope with diuretics over the course of their treatment. It may also help quantify the amount of effort and abdominal involvement, alerting staff to increases in either. During administration of other therapies, like blood transfusions or chemotherapy, continuous monitoring would also be beneficial. Animals recovering from surgical cervical myelopathies are more prone to respiratory compromise and require close monitoring for 24 hours post-operatively, so this method would be of particular use.[17] Other neurological disorders, especially neuromuscular diseases, put animals respiratory system at risk and require close respiratory monitoring, for example polyradiculoneuritis[18].

While this study only included dogs, further testing is likely to show that it will work on other animals like cats and horses, as their abdominal movements during breathing are similar to dogs. Cats often become stressed in a hospital environment, especially if they present in respiratory distress.[1] When a dyspnoeic cat presents as an emergency, they are often put in a covered oxygen chamber or kennel to rest. With our novel method of monitoring, a small camera or tablet mounted in the oxygen chamber would allow the staff to monitor the cat's behaviour and respiratory rate, without having to interact with the cat until they have settled down. In equine general anaesthesia, respiratory-related problems account for 4-25% of deaths.[19] However, when horses are recovering from general anaesthesia, it is usually too dangerous to be present in the recovery box, making adequate physiological monitoring difficult. Equipping recovery boxes with a video camera with this software will allow the recovery team to appreciate changes in respiration rate, and intervene if there are complications. Further research into non-contact heart rate monitoring in the horse has the potential to be useful during the recovery period.

However there are several limitations of the current study that must be considered before this method could be used. Currently this method depends on user input to select the template in the frame for analysis, and it requires the dog to be lying still. Further work will allow automated detection and tracking of the dog, stopping and starting monitoring as the dogs move around and resettle over time, and then automated selection of the template so it could be left to run without user input. Real time analysis with a sliding window should be possible; however it will have a latency of the length of the window.

This study shows a novel method for non-contact respiration monitoring in the dog. This is one of the first studies to show accurate non-contact vital sign monitoring in a clinical setting in animals. While non-contact vital sign monitoring is currently a hot topic for research in the human computing and medical world, the veterinary field is lagging behind. This study is hopefully the first in an exciting, promising, new veterinary field, and should motivate more development and validation of non-contact monitoring in animals in a clinical setting.

Word Count: 2519

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Appendix A:

Details of dogs included in the study.

	Breed	Age (years)	Gender	Procedure	Problems
1	Cross breed	0.7	MN	Surgery	FHNO
2	Labrador Retriever	9.3	MN	CT	PSS/HE
3	Whippet	12.2	MN	MRI	IVDD, thalamic infarct, PLN
4	Boxer	3.6	FS	Surgery	Infected implant removal
5	Pointer	9.6	FS	MRI	IVDD + lytic bone lesions
6	Cross breed	0.7	FE	CT	Rectal prolapse
7	Sealyham Terrier	1.6	Male	CSF tap and cystocentesis	SRMA
8	Pug	0.5	FE	Surgery	FHNE
9	Cocker Spaniel	12.5	FS	Surgery	IVDD - Hemilaminectomy
10	Cocker Spaniel	9.2	FS	CT and Surgery	Otitis externa - TECA LBO
11	Miniature Schnauzer	6.7	MN	Surgery	CCL
12	Yorkshire Terrier	1.0	FE	Surgery	TECA
13	French Bulldog	0.4	FE	surgery	Implant removal
14	Cross breed	13.9	FS	MRI	IVDD