Turtle Shell Publications

Contactless Monitoring of Respiration Cycles and its impact to detect early signs of respiratory distress in multiple heath distress scenarios

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Introduction

The global population has increased seven folds in just four decades. While the healthcare infrastructure has also evolved and upgraded, it has not been able to keep pace with population growth. To add to this, the healthcare sector also has to deal with the excess burden of socioeconomic factors in developing and underdeveloped economies. There is a need for solutions to aid and optimize the efforts of our healthcare professionals.

Respiratory distress is a very common condition in subjects at risk who are either hospitalised or may need hospitalization. It can be caused by various underlying conditions like consumption of toxic substances, severe blood infections, severe lung infections, cardiovascular attack, a severe injury and more. A critical component here is easy access to vitals and other health indicators monitoring to indicate respiratory distress early. Among those who survive, a decreased quality of life is relatively common. Therefore it is essential to identify and take corrective measures as early as possible.

Studies have shown continuous monitoring has proven to be extremely effective over traditional (and sparse) periodic measurements [1]. Manual monitoring to replicate these results at scale is not feasible as it further burdens the already strained healthcare professionals. There is a projected deficit of 14 million healthcare workers globally by 2030 [2]. The other alternative is to use costly and cumbersome vital monitoring equipment traditionally used in the ICU. The cost involved along with the effort required to operate these makes this option not feasible as well. Further, these equipment become impractical outside the hospital setting.

We explore the feasibility of a novel health and vital parameter monitor, Dozee, based on contactless ballistocardiography (BCG). Ease of use, contactless operating and low cost make it a promising candidate. We explore the efficiency and accuracy in the later sections of this study.

Respiratory Rate as an indicator of serious illness

Although multiple vital sign changes take place as a patient deteriorates, some occur earlier and are more informative than others. Changes in respiratory rate are often the earliest warning of sepsis, systemic inflammatory response syndrome, shock, and respiratory insufficiency, among others. Normal adult respiratory rate is generally reported to be between 12 and 18 breaths per minute (bpm). Tachypnea (respiratory rate > 20 bpm) is often the first sign of systemic inflammatory response syndrome, sepsis, shock, and respiratory insufficiency, while bradypnea (respiratory rate < 8 bpm) is an early indicator of narcotic and sedative complications [3].

Several studies have highlighted the importance of respiratory rate to identify severe illness and health deterioration. In 1993, Fieselmann and colleagues reported that a respiratory rate higher than 27 breaths/minute was the most important predictor of cardiac arrest in hospital wards. Subbe and colleagues found that, in unstable patients, relative changes in respiratory rate were much greater than changes in heart rate or systolic blood pressure, and thus that the respiratory rate was likely to be a better means of discriminating between stable patients and patients at risk. Goldhill and colleagues reported that 21% of ward patients with a respiratory rate of 25–29 breaths/minute assessed by a critical care outreach service died in hospital. Those with a higher respiratory rate had an even higher mortality rate. In another study, just over half of all patients suffering a serious adverse event on the general wards (such as a cardiac arrest or ICU admission) had a respiratory rate greater than 24 breaths/minute. These patients could have been identified as high risk up to 24 hours before the event with a specificity of over 95% [4].

Thus, the importance of measuring the respiratory rate accurately and promptly, and then communicating and charting abnormalities, cannot be overemphasized. Respiratory rate is therefore the sentinel and arguably most important vital sign because its normal values are breached before those of other vital signs in nearly all states of clinical decline.

Significance of Respiratory Rate Monitoring in disorders that attack pulmonary functions like COVID-19

Even in the case of novel coronavirus COVID-19, in severe conditions, people suffer from acute respiratory distress with respiration rate greater than 30 per minute [5]. WHO interim guidelines identify respiratory rate greater than 30 breaths per minute as a strong indicator for severe pneumonia caused by COVID-19 [6]. Based on continuous monitoring of respiratory rate, severe cases are identified and shifted to intensive units for further treatment.

Methods to measure and monitor respiration rate

There is no gold standard for respiratory rate measurement; in general wards the traditional method is to manually count the number of breaths for one minute, which is not as easy as it might seem, given the significant interobserver measurement variability among trained clinicians. Because respiratory rate is not always regular and is less frequent than, for example, heart rate, the use of shortcuts—such as the multiplication of breaths observed over a shorter time period magnifies any error in observation. In one study, nurses recorded nearly 72% of all respiratory rates as either 18 or 20 bpm, whereas only 13% measured by trained observers had these values, confirming a significant bias and/or multiplication artefact [3][7].

The intensive care units have nasal themistors to monitor the respiratory rate through airflow and Respiratory Inductive Plethysmography (RIP) belts to measure the chest and abdominal effort. These are cumbersome to use and require a trained professional to set up the data acquisition. This along with the high cost involved makes them impractical for usage outside intensive units and hospitals.

Ballistocardiography - A cost effective, unobtrusive and efficient alternative

Ballistocardiography (BCG) detects any physiological parameter that produces a motion -- including heart, breathing, snoring and limb movements [8][9]. BCG raw signal is a superimposition of respiratory effort, cardiac contractions and vibrations due to snoring;

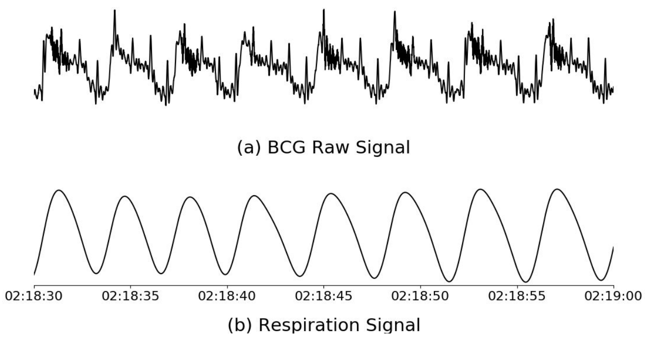

Figure 1: (a) Raw BCG signal, (b) Respiration signal

A normal respiration signal comprises alternate inhales and exhales, and is typically a sinusoidal waveform. The same is true for respiration effort as captured through BCG. Figure 1(a) shows raw BCG signal in comparison with airflow signal from the nasal thermistor acquired simultaneously.

Dozee - Contactless Patient Vitals Monitor

Placed under the mattress, Dozee monitors micro-vibrations produced by the body during sleep. Proprietary algorithms convert muscular, respiratory and cardiac movements into useful biomarkers to monitor heart, respiration, stress levels, restlessness, and sleep [8].

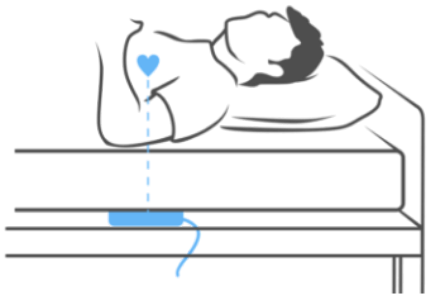

Figure 2: Dozee in use

Validation with golden standard

The algorithm was validated for 13 full-night PSG recordings on 10 subjects (96 hours) at NIMHANS. During each PSG recording, Dozee was also placed under the mattress. The raw BCG data was processed through our proposed algorithm to identify each respiration cycle and respiration rate for each 30s epoch. Respiration rate for each epoch as computed by the proposed algorithm was then compared against the same extracted from each of the nasal airflow signal, chest respiratory effort and abdomen respiratory effort.

Results

The average detection rate for the proposed algorithm was 72.8%. Figure 3 shows the respiration rate computed from the proposed algorithm for the whole night overlaid with each of the three validation sensors. We are able to achieve an average accuracy of 96.17% as compared to the respiration rate from nasal airflow, 95.68% compared to respiratory effort from the chest RIP and 95.63% in comparison to the respiratory effort from the abdomen RIP.

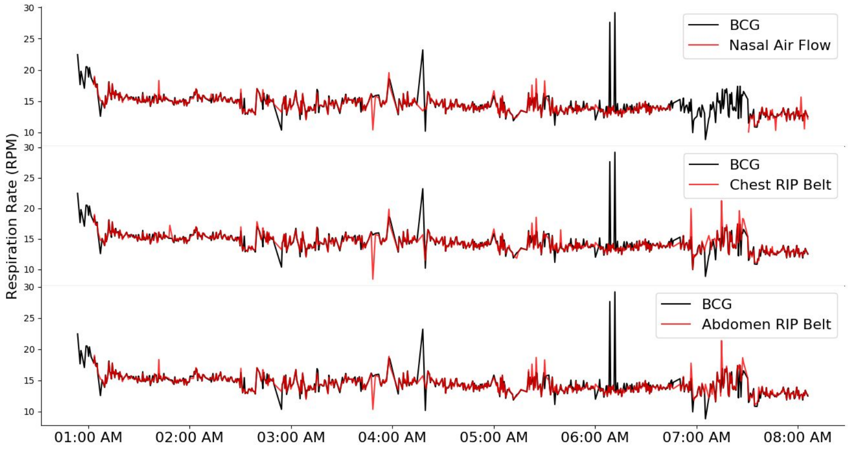

Figure 3: Whole night respiration rate comparison

Discussion and Outcomes

Ballistocardiography is an efficient method to monitor respiratory function in mass. It is ideal for usage in non-intensive units and home settings due ease of operation and low cost. It does not require trained professionals to set up and remote monitoring enables the accessibility of data without physical presence to the healthcare professionals as well as other caretakers. The high accuracy with respect to the gold standard medical equipment in the intensive units makes the data ideal and trustworthy for screening and taking preventive action before any adverse conditions occur. The system used and described in this study, Dozee, is already operational in the field. The preventive measures based on the data obtained from the system have not only saved cost and pain but have also proven life saving. In the concluding part of this study we also describe some of the cases where deviations in respiratory functions were identified correlated with significant health deterioration due to underlying conditions.

1. Respiratory Distress because of Pneumonia

Deviation in the respiratory rate and heart rate of a 45 year old male post traveled was captured through the vital parameter information recorded on Dozee. The early alert led to a diagnosis of pneumonia and hospitalization. The pneumonia worsened and the subject was shifted to the intensive unit. There was a significant reduction in lung capacity even after discharge. The recovery due to rehabilitation efforts at home was also captured on Dozee as the vitals signs including the respiratory rate slowly returned back towards the baseline before the health deterioration. Figure 4 shows his heart and respiration rate deviation of the person from healthy range to health deterioration to his recovery phase.

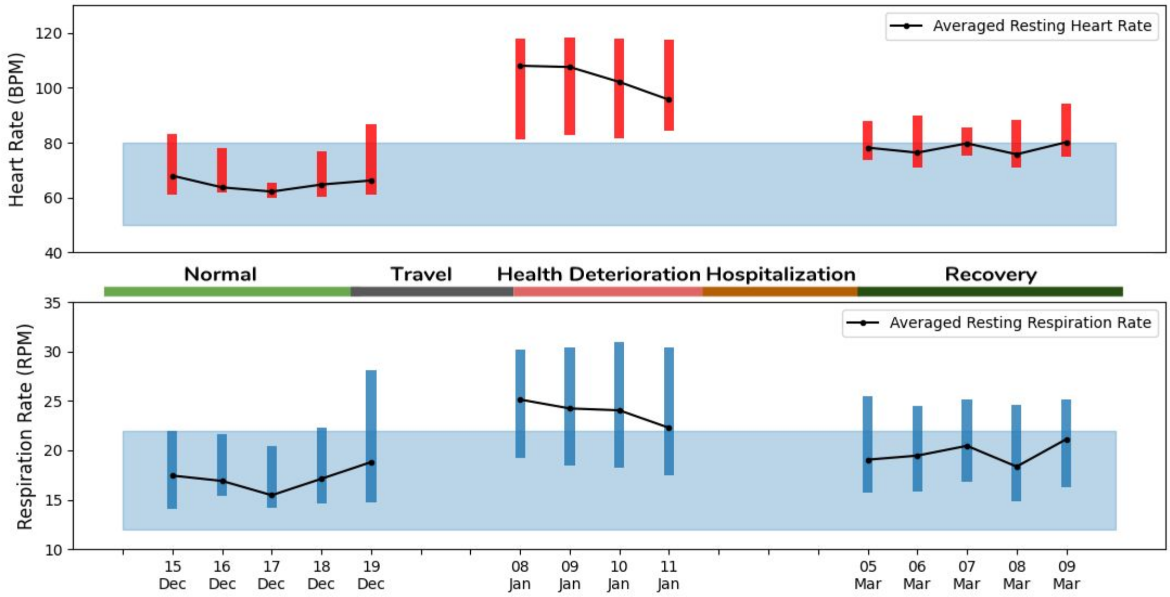

Figure 4: Deviation in heart and respiration rate of the diagnosed pneumonia patient from healthy range to health deterioration to his recovery phase

2. Respiratory distress arising from Pneumonia & Pulmonary Fibrosis due to Tuberculosis

A 21 year old female was recorded with severe persistent nocturnal tachypnea for 2 days in a row as shown in Figure 5. Post consulting medical professionals and blood tests, it was identified as an early asymptomatic case of Tuberculosis.

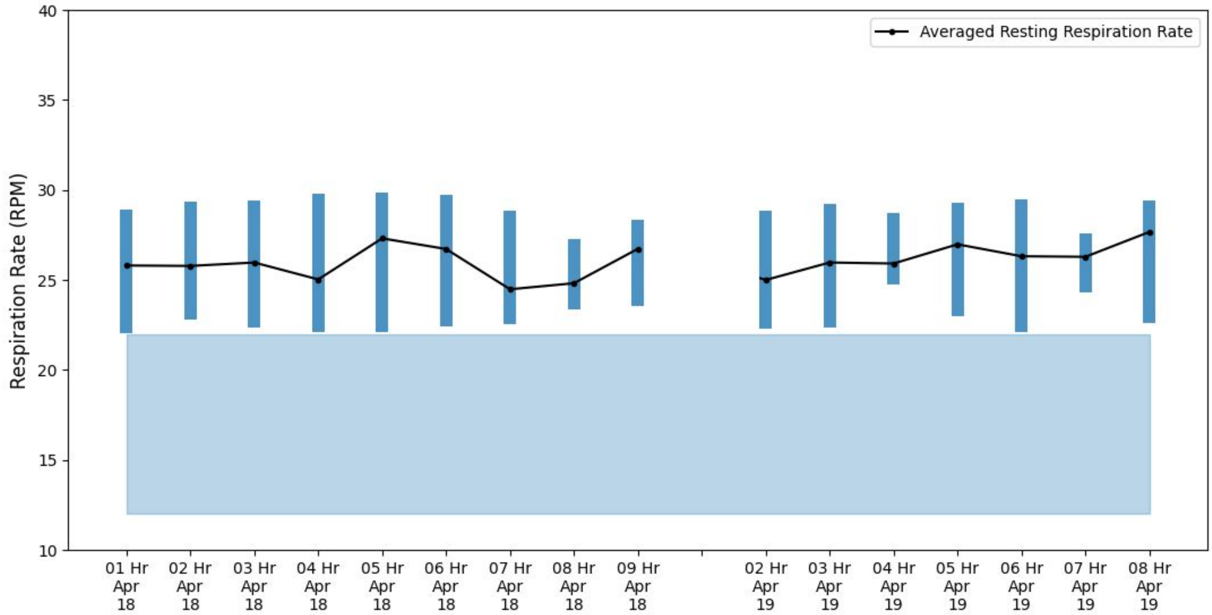

Figure 5: Respiration rate of a 21 year old female with persistent nocturnal tachypnea

3. Severe tachypnea as an indicator of mortality

Severe persistent tachypnea has been observed to be an indicator of an adverse health deterioration event and even mortality in some cases. Two such cases were recorded on Dozee where severe persistent tachypnea (BR>30 RPM for more than 5 hours) was followed by death.

The first subject, a 34 year old male, was suffering from late stage melanoma in comatose condition for over 3 days. 24 hours previous to death the respiratory rate increased from a baseline value of 24 RPM to more than 36 RPM as shown in Figure 6.

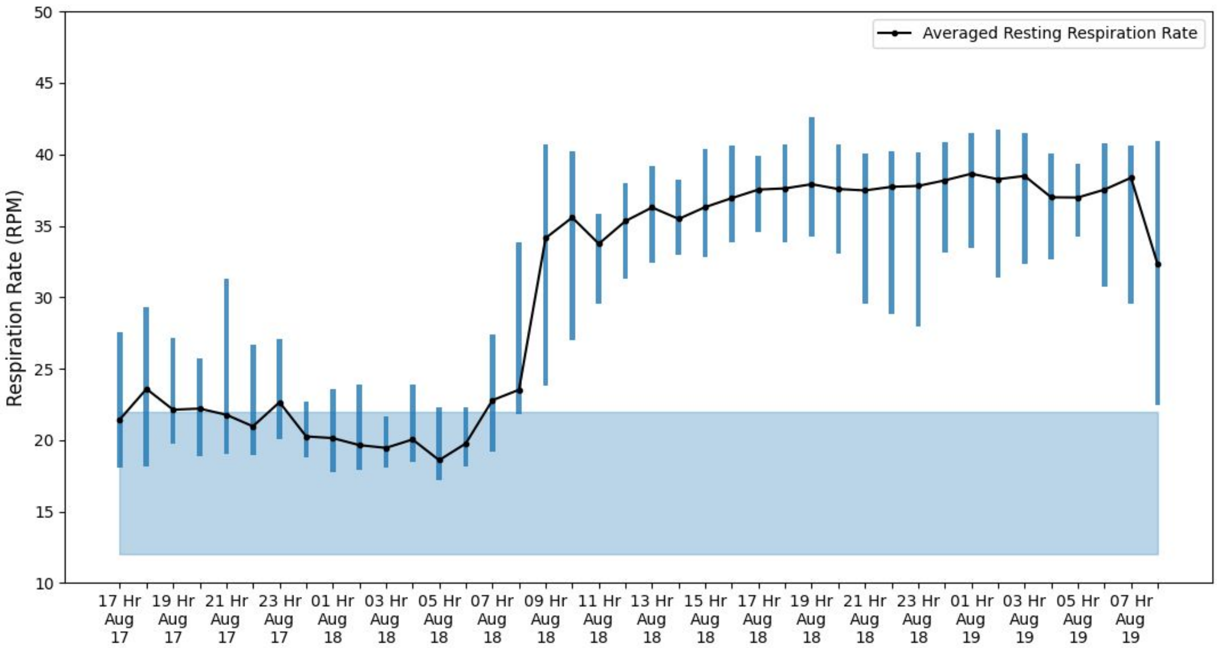

Figure 6: Increase in respiration rate of the melanoma patient

In another case, it was observed that the heart and breathing rate of a 72 year old was constantly high with an average of 88 heart beats and 28 breaths per minute respectively. Based on this information, the subject consulted a medical professional and was admitted subsequently. However, the subject could not survive the severe health deterioration.

Respiratory rate had the most significant deviation as compared to any other vital sign 4 days prior to the death of the subject. Figure 7 shows the change in his vitals throughout the month.

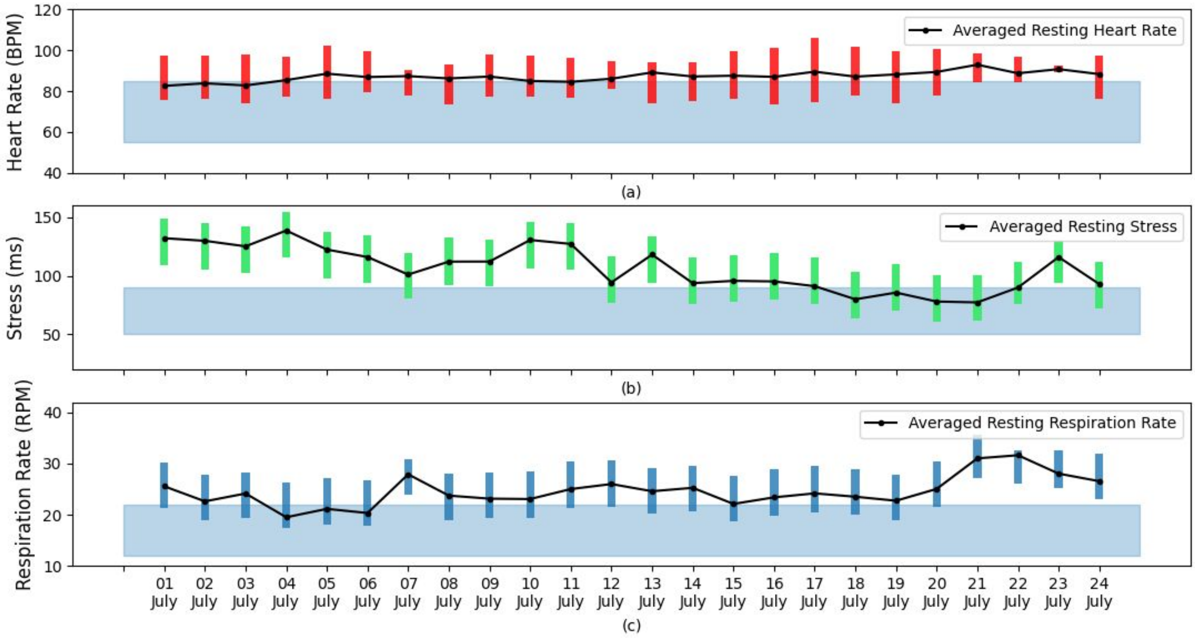

Figure 7: (a) Heart Rate (b) Stress Levels (c) Breathing Rate of the 72 year old.

4. Respiratory distress caused by heavy dosage of medication

A 55 year old male with a diagnosis of Atherosclerosis was prescribed a heavy dose of medication for the same. Following this the respiratory rate elevated for the next 2 days as shown in Figure 8 along with a feeling of discomfort. Based on this data the prescription was changed to a lower dosage of another drug and the respiratory rate returned to the normal baseline.

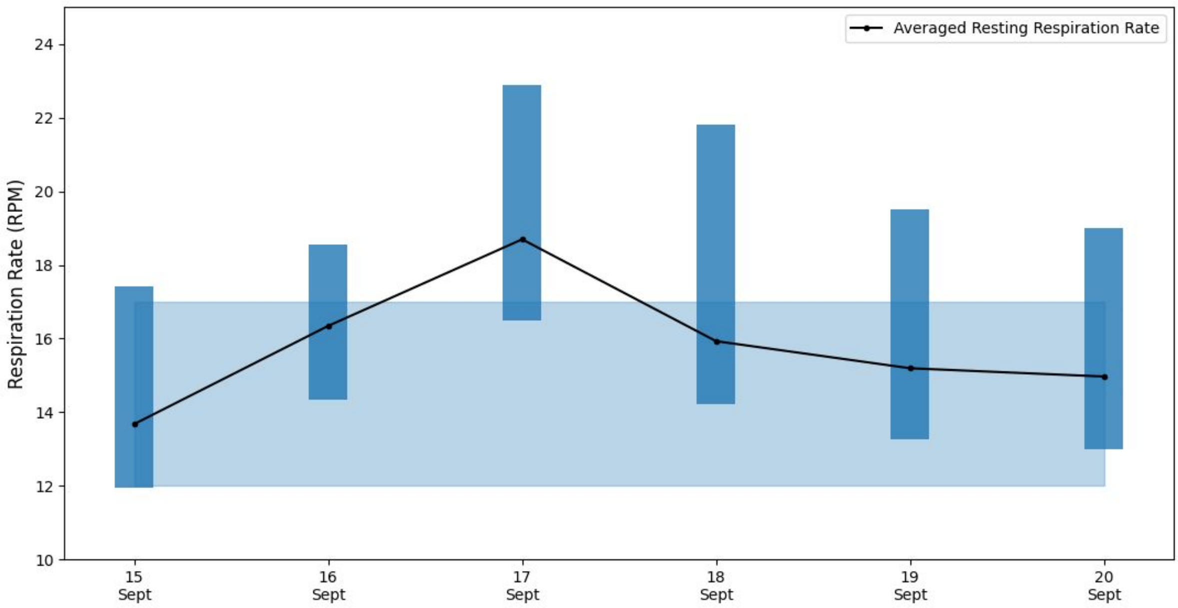

Figure 8: Breathing Rate of a 55 year old with diagnosed Atherosclerosis

5. Irregular respiratory rates and patterns as an indicator for sleep apnea and other respiratory disorders

Sleep apnea and other nocturnal respiratory disorders are associated with abrupt changes in respiratory rate during sleep. Further analysis of the respiratory signal obtained from the BCG signal gives the information of specific conditions. Figure 9 show an apnea event captured during a full night PSG along with BCG data acquisition.

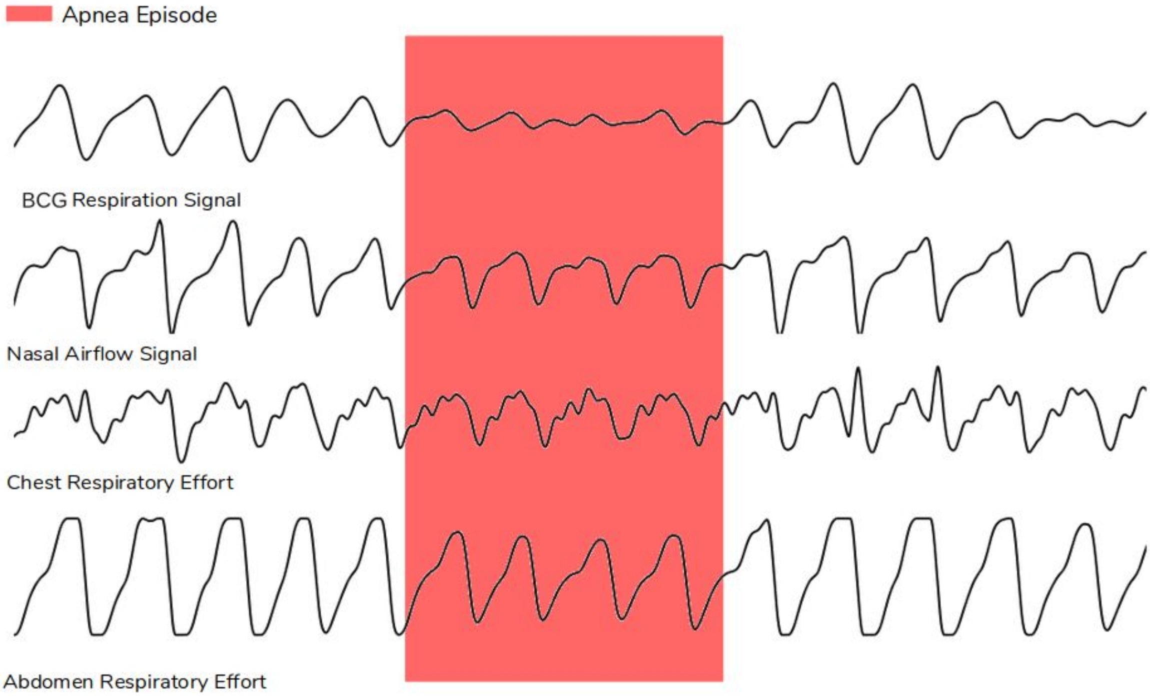

Figure 9: Breathing signal with apnea episode in BCG, nasal thermistor and chest and abdomen respiratory bands

Other respiratory patterns like Cheyne-Stokes, Biot's, etc. also can be identified in the respiratory signal obtained from BCG. Further, Dozee has also detected apnea events for subjects using a CPAP machine as a corrective measure. Based on this, it was identified that the masks needed adjustment for proper functioning of the CPAP machine. Post tuning and readjustments, no apnea events were recorded as expected.

Acknowledgement

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