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RESEARCH ARTICLE

A Comprehensive Analysis of Respiratory Patterns and Physiological Parameters in Asthma, Bronchitis, and Croup

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Abstract

Asthma is the most common misdiagnosed lung disease, especially for children aged 6 -15 years old. There was limited research done to isolate asthmatic symptoms from other common lung conditions, such as bronchitis and croup, as they often share very similar symptoms. This can cause the symptoms to worsen over time if the child is wrongly diagnosed. This study isolates asthma symptoms in children from other similar lung diseases and identifies a specific unique breathing pattern that isolates each other's lung disease. Within this study, asthma will be compared with bronchitis and croup. A series of different breathing types were tested to cover all the situations. A subject with lung disease, like asthma, bronchitis, and croup, may experience normal breathing with a cough, short breath with a cough, or long breath with a cough. It measured the displacement at various anatomical locations, such as the ribs and the abdomen, to find the most optimal and maximum displacement area. The average oxygen saturation (SPO2) and heart rate data were also collected. These parameters were measured against the varied altitudes of 3000 ft,6000ft, 9000ft, 12000ft, 15000ft, and 18000ft to represent the severity of the condition. Overall, the results are only used to predict and distinguish breathing patterns and determine how the average displacement, SPO2, and heart rate are affected as the severity of the condition increases. The raw data shows slightly different patterns for each breathing condition at different altitudes. However, the average taken for each altitude against displacement, SPO2, and heart rate shows a more distinct pattern for each condition.

Keywords: Asthma; pediatrics; elevation training mask; sensors; pulse oximeter; bronchitis; croup.

1. Introduction

Pediatric Asthma is one of the most common chronic illnesses in childhood, with a prevalence of 10% to 30%, and carries significant morbidity [1-4]. Asthma is the most activity-limiting condition in children, which accounts for more school days lost than any other chronic condition. Poor control can cause significant function impacts like loss of school and exercise, indirect costs, including parent time off work, and direct health care costs as Emergency department admissions [5, 6]. Asthma is a chronic inflammatory condition associated with the respiratory system, specifically affecting the lung exhalation and inhalation process directly linked to the respiratory system, particularly inhalation and the lung's exhalation. The breathing (inhale/exhale) is controlled by the diaphragm's movement and the intercostal muscles located between the ribs. The lungs are affected by the surroundings; this includes the rib cage and diaphragm, protected by the thoracic cavity. The asthmatic subject will experience breathing problems such as shortness of breath, coughing, and wheezing; adults will have additional chest tightness [7]. Other lung diseases mainly affect children through either genes or infections, such as bronchitis and croup. These lung diseases have similar symptoms of asthma. However, there is limited research to isolate asthma symptoms from similar conditions. Thus, many children are misdiagnosed as having asthma or other lung diseases due to the similar symptoms between them; this can cause the symptoms to worsen over time if the child is wrongly diagnosed [8].

Despite the similar symptoms of asthma, bronchitis, and croup, there are still differences among the three. Asthma in the mild and moderate form is affected by dyspnea expiratory; this affects the breathing by elongating the exhalation while breathing. Severe asthma may also affect inhalation [9]. Bronchiectasis is when the bronchi in the lower airway widen to an abnormal diameter (larger than 2mm), leading to increased infections [10]. Bronchitis is a respiratory disease that directly affects oxygen concentration levels and is caused by the loss of elasticity of the alveoli. Due to the loss of elasticity of the alveoli, the carbon dioxide cannot be fully exhaled, leading to difficulties in breathing in new oxygen, resulting in breathlessness and wet-sounding cough. Children with bronchitis are prone to asthma, and many will have both. Bronchitis is heavily affected by the oxygen level's saturation, as 97% - 100% is normal; results that are <92% from a child would be considered a severe disease, and >92% would suggest a less severe condition [9,11]. Croup is a viral infection that mostly affects children, more boys than girls in the ratio of 1.4:1, respectively, and most commonly age 1-3 years old but can occur between age 1 to 15 years old [12]. Croup rarely occurs in adults, while asthma and bronchitis can also affect adults. Croup causes the child to have difficulty breathing during inhalation; this can cause inspiratory stridor, resulting in a prolonged inhale compared to a prolonged exhale for an asthmatic child. Children with croup will have a distant bark-like cough and hoarseness, which are unique symptoms compared to asthma and bronchitis [9,12,13]. As the disease is affected by children, it is common for their parents to describe the symptoms. It is often misdiagnosed because the parents cannot differentiate the specific symptoms, such as stridor, which can often be misidentified as wheezing. To avoid this, producing a breathing pattern for each condition would be able to avoid this situation. Further, the diagnosis of asthma is particularly challenging in the pediatric population. Computed Tomography imagery (CT) is a common way to detect lung diseases through a simple scan. However, this is usually suitable for severe asthma patients, as this can be represented by increased bronchial wall thickness and air trapping. The degree of thickness and air trapping can be associated with the severity of the patient's asthmatic condition. Mild asthmatic patients may not benefit as much as a severe asthmatic patient would as the CT scan would likely show a normal thoracic tomography of the lungs for a mild asthmatic patient [8]. Similar to asthmatic, bronchiectasis also shows bronchial wall thickening and air trapping. The results for asthma and bronchiectasis are very similar. Although, with further analysis, it is possible to differentiate between asthma and bronchiectasis. CT scans, however, lack information/ patterns for patients with croup. This can be a major concern as croup is very common among children. Without a clear expected result for croup, it may be a concern to diagnose a child with this method [8] confidently. The pulmonary function test is the most common lung disease diagnosis method. In particular, spirometry measures lung function by comparing lung volume against time [10]. Young children usually cannot be cooperative enough to undergo formal pulmonary function testing, which is the gold standard in diagnosing asthma. Thus, they often must be diagnosed clinically [14-19].

This study would assist in the differential diagnosis of asthma and identify a specific unique breathing pattern that isolates asthma from similar lung diseases. By finding out how each lung condition behaves against the increase of lung severity by experiencing different breathing testing types, these include normal breathing with a cough, short breath with a cough, and long breath with a cough. The breathing pattern will be obtained by (1) measuring the average and maximum of three clinical parameters: displacement, oxygen saturation (SPO2), and heart pulse rate. (2) These parameters were measured against the varied altitudes of 3000 ft,6000ft, 9000ft, 12000ft, 15000ft, and 18000ft to represent the severity of the lung condition and compared with normal range values of these parameters.

Nomenclature & Symbols			
CT	Computed Tomography	Min	Minimum
DAU	Data Acquisition	SpO2	Oxygen saturation
ft	feet	**Symbols**	
LED	Light Emitting Diode	a	Initial acceleration of the accelerometer
Max	Maximum	x	Initial position of the accelerometer

2. Materials and Methods

2.1. Measurement Systems

The schematic diagram of the proposed measuring systems showing data transfer protocol from sensors and oximeter to computer is depicted in Figure 1. The variables (displacement, SPO2, and heart rate) were measured and transferred to the LabVIEW visualization and MATLAB analysis computer. MATLAB will be used to analyze the raw data stored via Labview.

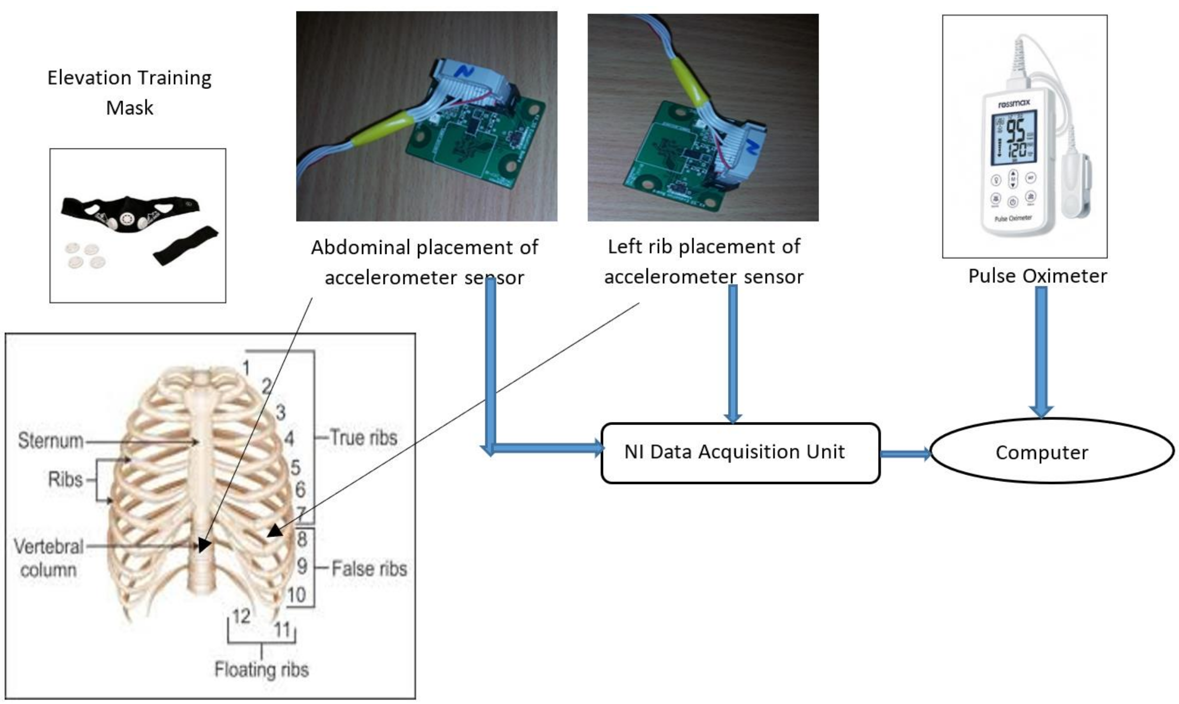


Fig. 1. The schematic diagram of the proposed measuring system.

2.1.1. The Pulse Oximeter

Pulse oximetry is a non-invasive method that measures blood hemoglobin's percentage carrying oxygen (SPO2) and heart pulse rate. This device's work principle is based on a red beam of light passed through a fingertip to determine the oxygen level (SpO2) by measuring how much light is absorbed as it passes through the fingertip. The light source and detector are used to evaluate oxygen transportation in the body by measuring changes of red and infrared light absorption in the blood. The oxygenated blood absorbs a more significant amount of infrared light and lower amounts of red light than deoxygenated blood [20, 21]. The average levels of SPO2 are generally at least 95%. However, the levels range between 80–90%, and those decreasing over time frequently indicate severe disease and the potential for a rapid drop. Heart rate can also be obtained due to volume changes within capillaries during heartbeats, as this will also affect light absorption [22, 23]. The pulse oximeter CMS60D measures the bloodstream's oxygen concentration levels for each altitude and breathing type. A record of the heartbeat will also be measured throughout the experiment. The adult attachment (LED pulse reading) will be attached to the index finger to provide the most accurate reading; the finger is then rested at the subject's side. Any nail polish or excess movement can disturb the reading [24, 25]. The pulse oximeter will be connected to the computer to measure the average heart rate and SPO2 level.

2.1.2. The Accelerometer Sensors

The sensors (Kionix KXPB5-2050 accelerometers) [26] will be attached to parts of the ribs/abdominal to produce a displacement when breathing, see Figure 1. A National Instruments data acquisition (DAQ) unit was used to acquire and transfer the sensors' signals to the computer. Data acquisition is a powerful, cost-effective, and flexible process for acquiring and transferring sensor output voltages to a computer. Labview (National Instruments, TX, USA) software was used to write the program that converted the voltage into respective measurements [27]. The sound and vibration suite function of the Labview was used to convert acceleration to displacement.

$$x(t) = \iint_0^t a(t)\ dtdt \tag{1}$$

where x is the initial position of the accelerometer, and a is the initial acceleration of the accelerometer. The sensors can measure in x, y, and z-axis. However, to measure the ribs/ abdominal displacement, the z-axis will be considered. As this equipment measures displacement in 3D, it was required for the subject to be as still as possible.

2.2. Subjects and Experimental Setup

The experimental work involved using the elevation training mask [28-30] (see Figure 1), which is designed to reduce airflow for the wearer. This mask, therefore, causes the person to feel resistance when breathing. The elevation training mask was used to increase the severity of each lung condition; the mask consists of different altitudes as labeled: 3000ft, 60000ft, 9000ft, 12000ft, and 18000ft, where altitude can be altered [28-30]. It provided resistance to breathing, which closely resembles what a subject with a lung condition will experience. It was concluded that it should be used to mimic the difficulties in breathing. For this particular experiment, 3000ft was used to represent a mild lung condition's resistance, 9000ft was used to mimic a moderate lung condition, and 18000ft was used for a severe lung condition, in this case, asthma, bronchitis, and croup.

Experimental evaluation was carried out in the lab environment for a volunteer male subject who was not trained in respiratory exercise. All tests were done in a flat laying position. The sensors will be used to measure the displacement of the left rib and the abdomen. The left rib location is placed directly on the subject between ribs seven and eight; this is placed 45°clockwise from the side (as the rib bends), see Figure 1. The abdominal is placed just beneath the Xiphoid process to prevent any movement restrictions. Once the subject is attached to the sensors, the subject will be required to rest for about 20 minutes at the start to stabilize the heart rate from any previous activities, such as walking. The subject will lay down flat with the attachment of the oximeter attached to the index finger, and the arms should be rested on the side of the body. The subject will breathe for one minute as the Labview software and the pulse oximeter records the displacement, SPO2, and heart rate levels, respectively. Imitating asthma, bronchitis, and croup for normal, short, and long breathing, all accompanied by coughs, each repeated with different altitudes: 3000ft, 9000ft, and 18000ft. The outcome of each experiment will consist of the displacement against time from the output of Labview. A summary report from the pulse oximeter consisting of the average SPO2 and heart rate plus the minimum SPO2 and heart rate. These results will be recorded and compared to find how each lung condition behaves against the increase in lung severity. A comparison of the average displacement will be made with the increasing altitude. To further explain, three lung conditions, asthma, bronchitis, and croup, are categorized by breathing, normal breathing, short breathing, and long breathing (all accompanied by coughs). These will provide raw data where the output is the displacement against time per millisecond for one minute. Each output displacement will be averaged and rearranged to displacement against altitude. For example, asthmatic displacement will be plotted against the altitude (3000ft, 9000ft, 18000ft) to reveal any behavioral patterns in the left rib and the abdominal area. The maximum inhalation and exhalation will also be attempted to imitate.

2.3. Study Protocol

The first set of experiments was conducted to get an accurate output of maximum displacement. This set was separated into two test groups: (a) the position of the sensors and (b) the positions of the subjects. Firstly, from the (a) position of the sensor test, it was concluded that the displacement patterns for the left and the right rib would be similar, as seen in Figure 2 (a). Therefore, observation of the abdomen against the left rib see Figure 2 (a) would provide more meaningful information regarding the breathing patterns. Related to the (b) positions of the subject test, which consisted of three positions: (a) sitting down, (b) standing up, and (c) lying flat. As appeared from the position of the sensors test, the left rib and the abdominal displacement were also required from the position of the subject test, and it appeared the best position was to allow the subject to lay flat horizontally to observe the displacement behavior of the abdominal as the abdominal is very unlikely to expand as it holds the pelvis in a straight position while the subject is standing or sitting [31, 32]. Therefore, all the second experiments were done lying flat with sensors on the left rib and the abdomen.

During the second set of experiments, the three types of lung diseases will be modeled: asthma, bronchitis, and croup. Imitating these children's breathing patterns will be based on the following reported patterns, as referenced: asthma [33], bronchitis [34], and croup [35]. Combining this with the previously analyzed breathing patterns produced by physiological and pathological breath sounds [36]. This study has a beneficial effect on the healthcare system [37-40] and valuable data to support the applications of biomechanical investigations [41-43]. Rough guidance for asthma, expiratory dyspnea, and extending exhalation will be used. Bronchitis: Inhale and exhale will be extended. Croup: extended inhalation while exhalation is normal. Each type of these three lung diseases will be used throughout the experiment in three different forms: (1) normal breathing and cough, (2) short breathing and cough, and (3) long breathing and cough. They will also be used for different altitudes by the assistant of the elevation training mask. As guidance, 3000ft represents mild, 9000ft represents moderate, and 18000ft represents severe lung conditions.

3. Experimental Results

3.1. Test 1: Subject and sensor positions during breathing

For the normal breathing of a healthy lung function, the sensors are placed on the left and right rib while standing up, as illustrated in Table 1.

Table 1. Comparison of the displacement, SPO2, and heart rate through different testing positions.

Measurements	Standing up position	Sitting down position	Laying down position
Average displacement of left rib	2.22mm	1.57mm	2.39mm
Max displacement of left rib	5.67mm	6.10mm	6.17mm
Average displacement of right rib	1.90mm	1.54mm	1.48mm
Max displacement of right rib	5.70mm	5.00mm	5.10mm
Average SPO2	99.0%	98.30%	98.70%
Min SPO2	98.0%	98.0%	98.0%
Average heart rate	81.60 bpm	69.80 bpm	64.80 bpm
Min heart rate	74.0 bpm	67.00bpm	60.0 bpm

Standing up shows a maximum displacement of 5.70 mm for the right rib and 5.67 mm for the left rib. The average displacement for the right rib is 1.90 mm and 2.22 mm for the left rib. The SPO2 is within the normal range of 99.0%; however, the heart appears to be on the high end of 81.6 bpm. This is for normal breathing and healthy lung function while sitting down. It shows a maximum displacement of 5.0 mm for the right rib and 6.1 mm for the left rib. The average displacement for the right rib is 1.54 mm and 1.57 mm for the left rib. The SPO2 level is within range, and the average SPO2 (98.30%) is slightly lower than standing up by 0.7%, but the minimum SPO2 (98.0%) is the same. The heart rate (69.80 bpm) is lower than standing up by 11.8 bpm. This is for normal breathing and healthy lung function while lying down. It shows a maximum displacement of 5.10 mm for the right rib and 6.17 mm for the left rib. The average displacement for the right rib is 1.48 mm and 2.39 mm for the left rib. The SPO2 (98.70%) is within range and the same minimum SPO2 level (98.0%) as standing and sitting. However, the average heart rate is the lowest at 64.80 bpm, and the minimum heart rate is 60.0 bpm. Figure 2-a illustrates the average displacement for the left and right ribs compared to the altitude as the left, and right ribs will have very similar movement since they are moved with both the internal and external intercostal rib muscles; the only difference would be the ratio between the left rib and the right. However, the pattern should remain the same.

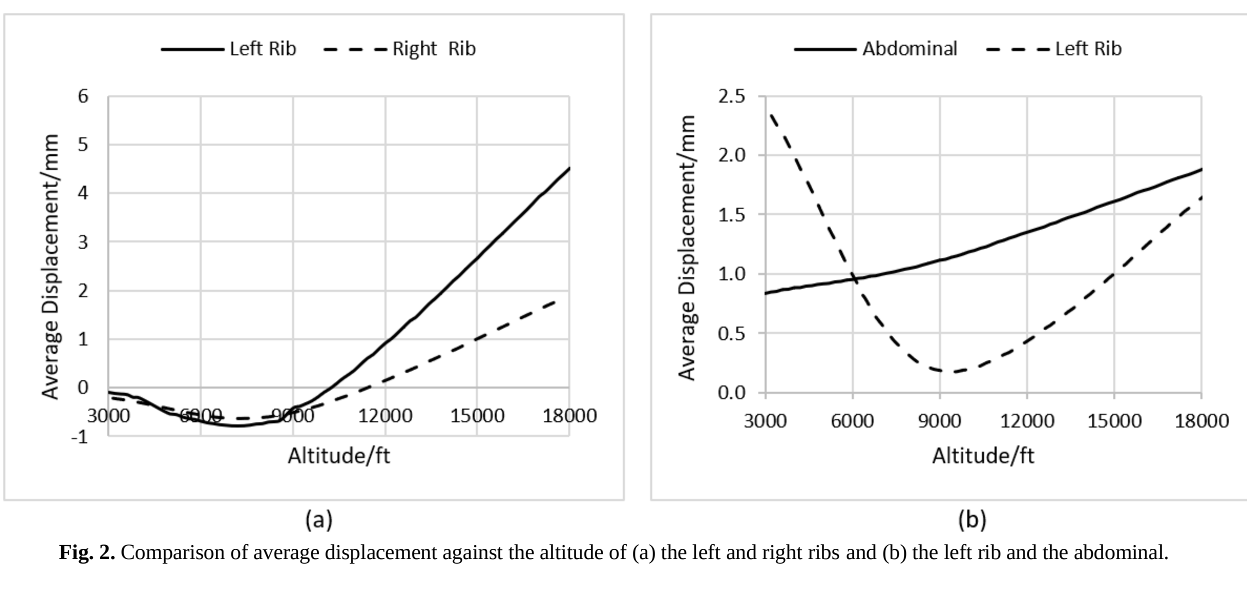


Fig. 2. Comparison of average displacement against the altitude of (a) the left and right ribs and (b) the left rib and the abdominal.

The abdominal muscles were not tested when the subject was sitting or standing; the abdominal muscles' displacement is unlikely to increase as the abdominal muscles must hold the pelvis in a straight position. Due to this, the abdomen is very unlikely to expand [31, 32]. Figure 2 (b) illustrates the average displacement for the left rib and the abdomen compared to the altitude. The abdominal has an increased average displacement as the altitude also increases. The graph in Figure 2 (b) shows two different curves, the abdominal and left rib. However, the graph in Figure 2 (a) shows two similar curves, left and right ribs, as they have similar behavior, and the left rib appeared as the most dominant with the maximum displacement (4.52 mm). This study used the left rib and abdomen to learn their behavior.

3.2. Test 2: Asthma

Related to normal breathing and cough, as shown in Figure 3 (a), asthmatics' breathing consists of one intersection at 6000ft. The abdomen shows an increase throughout the increasing altitude, while the left rib shows a dramatic decrease until 9000ft, where the average displacement increases. From Figure 3 (b), the SPO2 stayed consistent between 97%-99% at 3000ft; however, the consistency decreased as the minimum SPO2 decreased exponentially and steadied around 11000ft. From Figure 3 (c), the average and minimum heart rates increased as the severity increased. However, the heart rate seems to have remained constant after 9000ft for both the average and minimum heart rates.

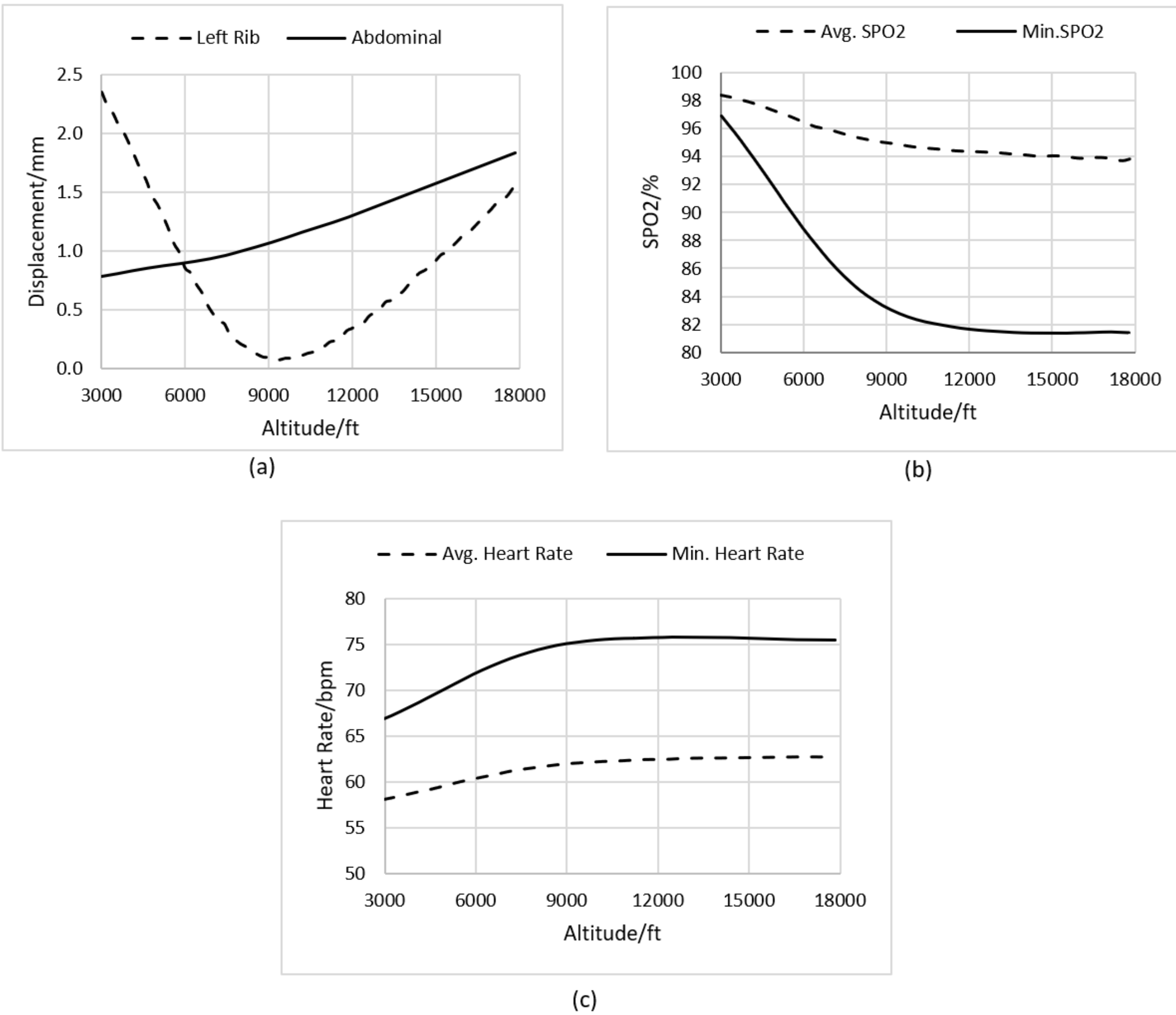


Fig. 3. Asthma normal (a) displacement against altitude, (b) SPO2 against altitude, and (c) heart rate against altitude.

Related to long breathing and cough, the graph in Figure 4 (a) also shows an intersection; however, this occurs at a higher altitude (severe condition), around 16000ft. The left rib increases steadily while the abdominal where maximum displacement occurs increases to 8000ft before decreasing. From Figure 4 (b), the SPO2 for long breathing shows a constant level of SPO2 around 98% to 98.7% from 3000ft to 9000ft before decreasing to around 97.4% at 18000ft. The fluctuation also seems to have a decrease as the severity increases. From Figure 4 (c), the heart rates do not increase as much as normal breathing. The fluctuation between the maximum heart rate and the minimum heart rate is also very low throughout the increasing altitude.

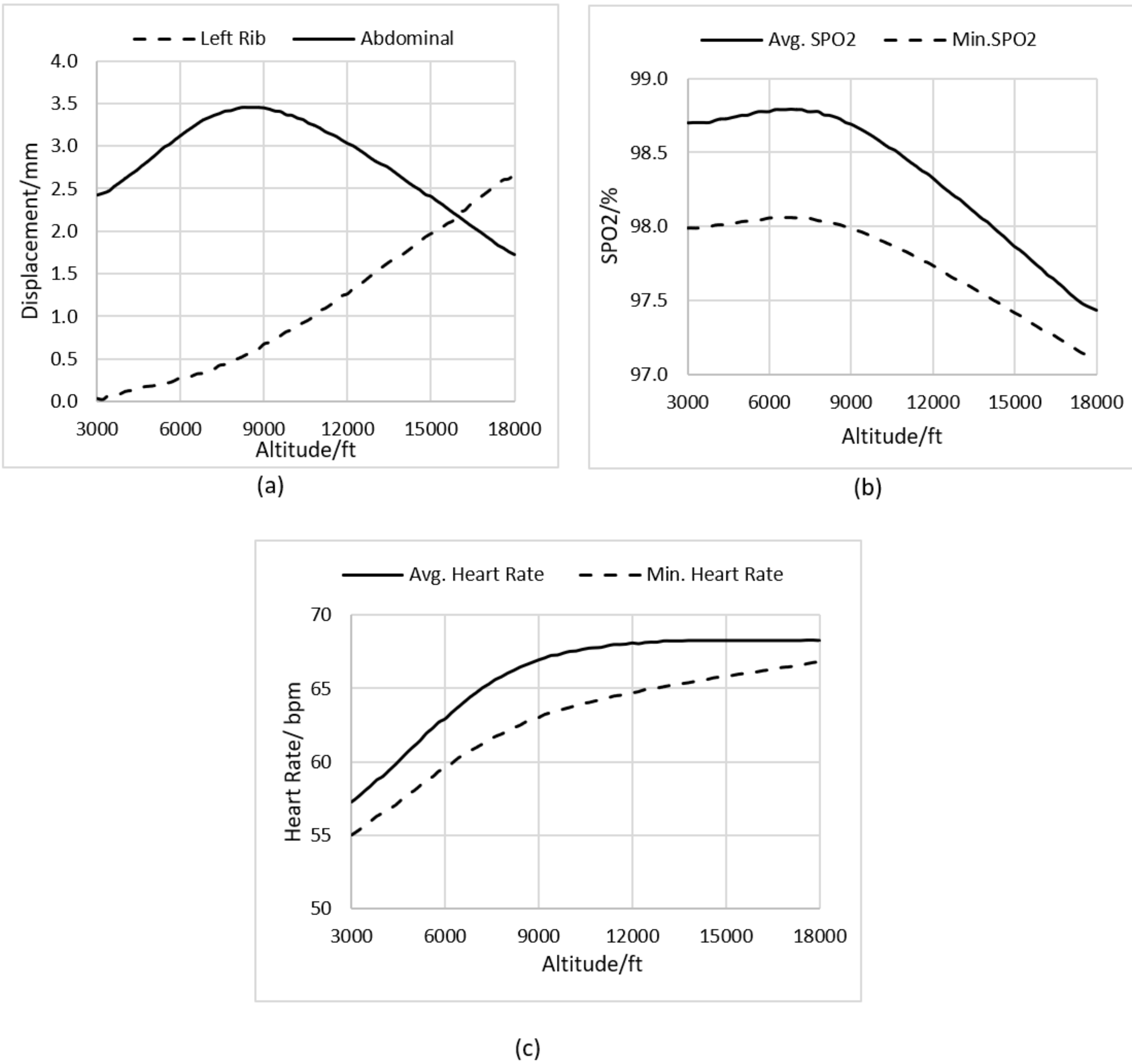


Fig. 4. Asthma long (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

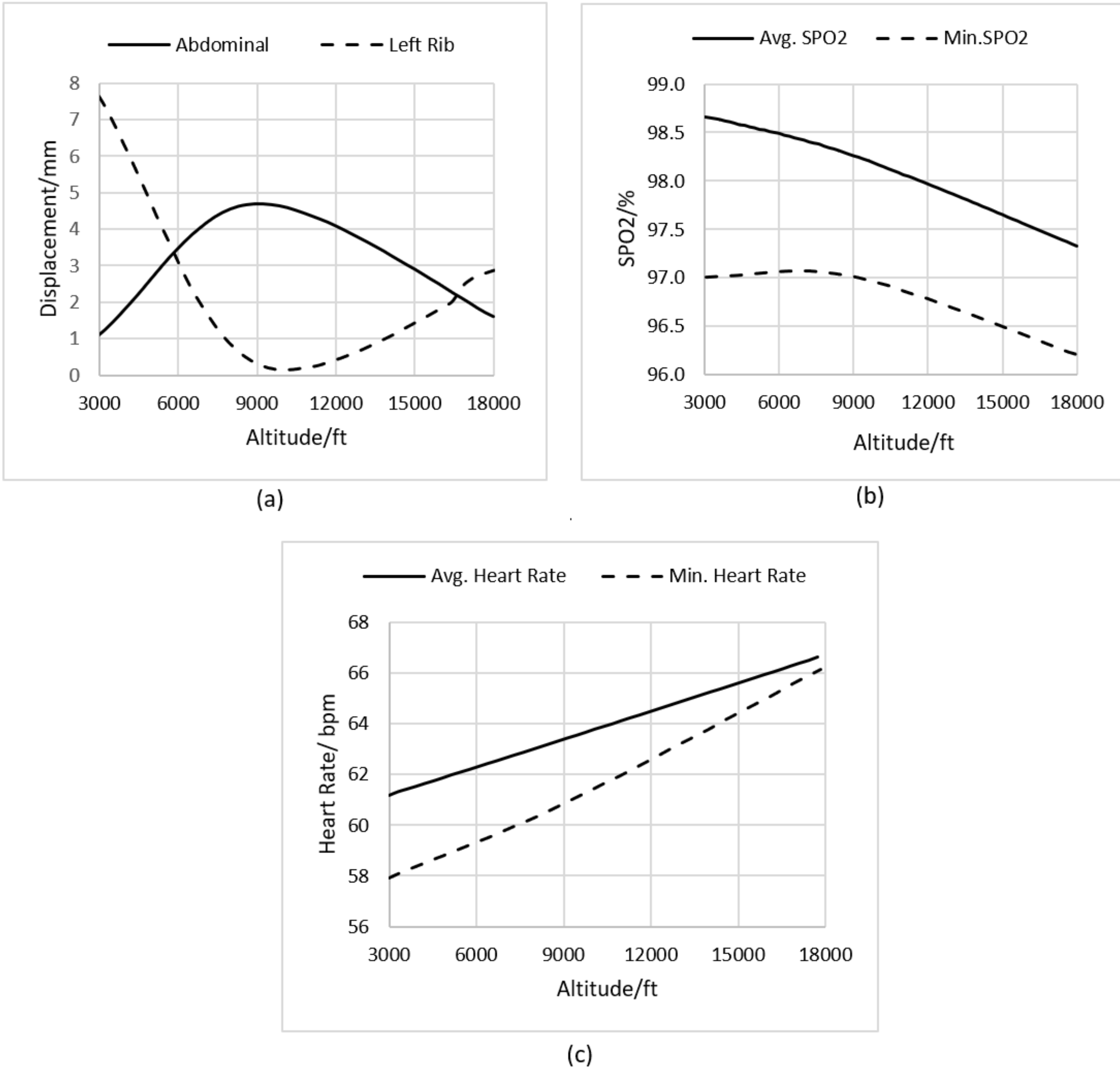
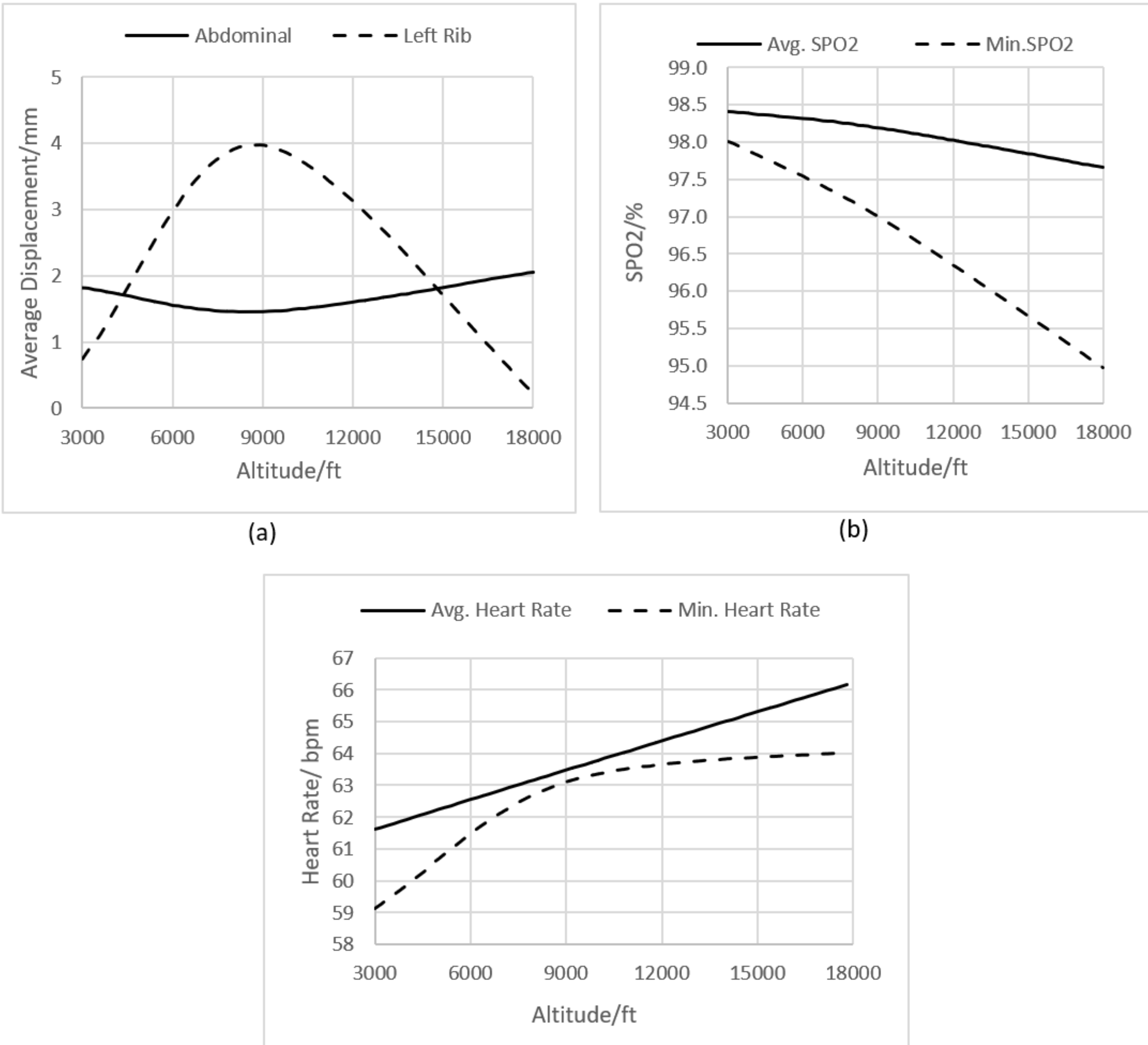


Fig. 5. Asthma short (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

Related to short breathing and cough, as shown in Figure 5 (a), there are two intersections for asthmatic during rapid breathing. The left rib also decreases drastically until 10000ft before slowing increasing. The abdominal, on the other hand, increases until 9000ft before decreasing. From Figure 3 (b), The SPO2 shows a decrease in both the average and the minimum. The amount of fluctuation is also constant throughout the range of severity. The overall decrease is very little, similar to long breathing. From Figure 3 (c), the average and minimum heart rates increase linearly. The fluctuation between the minimum and maximum heart rate decreases as the severity increases, as shown at 18000ft.

3.3. Test 3: Bronchitis

Normal breathing and cough: Similar to short breathing for asthma, normal breathing for bronchitis also has two intersections, as in Figure 6 (a). However, the abdomen has a constant average displacement while the left rib increases to 9000ft, followed by a decrease. Subjects with bronchitis do not show a large effect on the SPO2 average. In Figure 6 (b), the fluctuation between the minimum and the maximum of the SPO2 increases as the condition's severity increases. From Figure 6 (c), the average heart rate increases linearly as the severity increases. The minimum and maximum heart rate fluctuation appears at 9000ft. At 3000ft and 18000ft shows the maximum fluctuation.



(c)

Fig. 6. Bronchitis normal (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

Related to long breathing and cough, long breathing for bronchitis shows little to no displacement for the left rib, as in Figure 7 (a). All displacement is done by the abdomen. The abdomen shows a steady increase until 9000ft before decreasing. There is also no intersection. There is no fluctuation for long breathing for bronchitis. The minimum and average SPO2 were consistent at 99% throughout the experiment, as shown in Figure 7 (b). The average heart rate was constant at 58.2 bpm from 3000ft to 9000ft before increasing to 61.5 bpm at 18000ft. The minimum heart rate increased linearly throughout the severity. The fluctuation was also larger at 3000ft and 18000ft, with 9000ft having the smallest fluctuation.

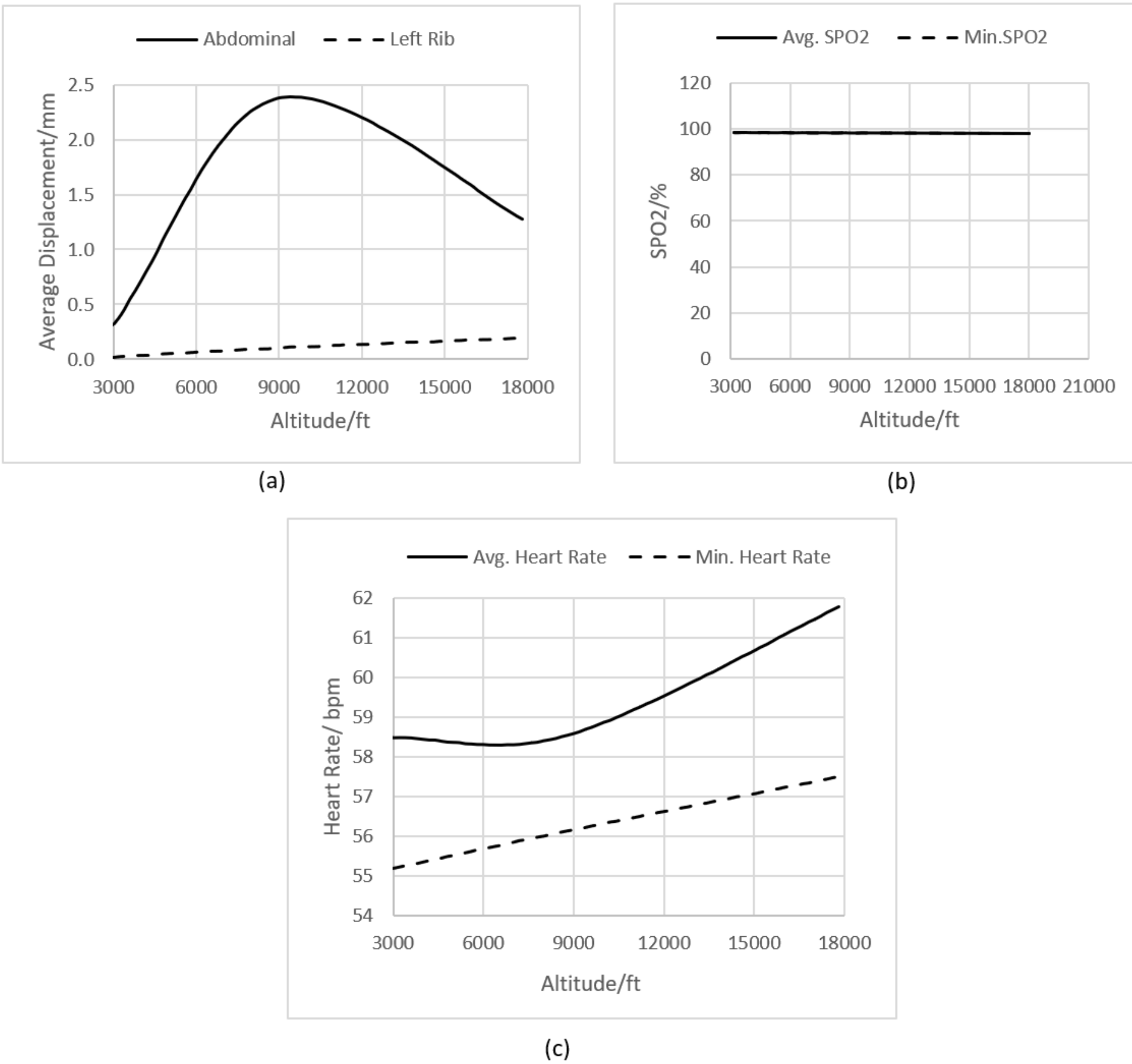


Fig. 7. Bronchitis long (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude

Related to short breathing and cough, similar to bronchitis long breathing, short breathing also shows no intersection, as shown in Figure 8 (a). However, both the left rib and the abdomen increase as the severity increases. The left rib was shown to be the dominant movement and increasing linearly. The average and minimum SPO2 both decrease as the severity increases, as shown in Figure 8 (b). The minimum SPO2 decreases linearly with a larger gradient compared to the average SPO2. As the severity increases, the fluctuation also increases. Similar to normal breathing in bronchitis. The average heart rate has a steeper gradient of increase compared to the minimum heart rate, as shown in Figure 8 (c). Both remain constant after 9000ft. The fluctuation also increases until 9000ft, and the fluctuation remains constant.

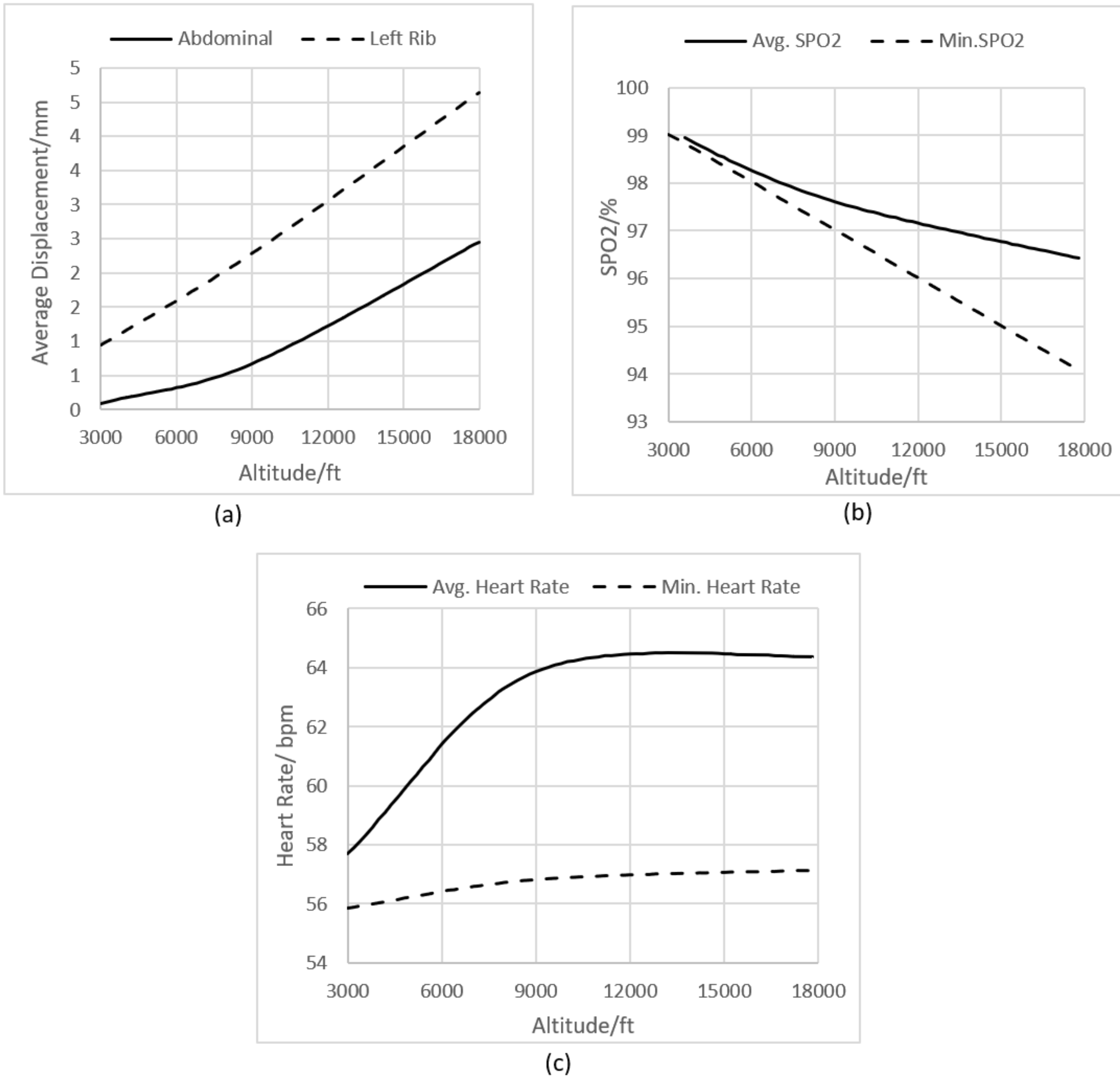
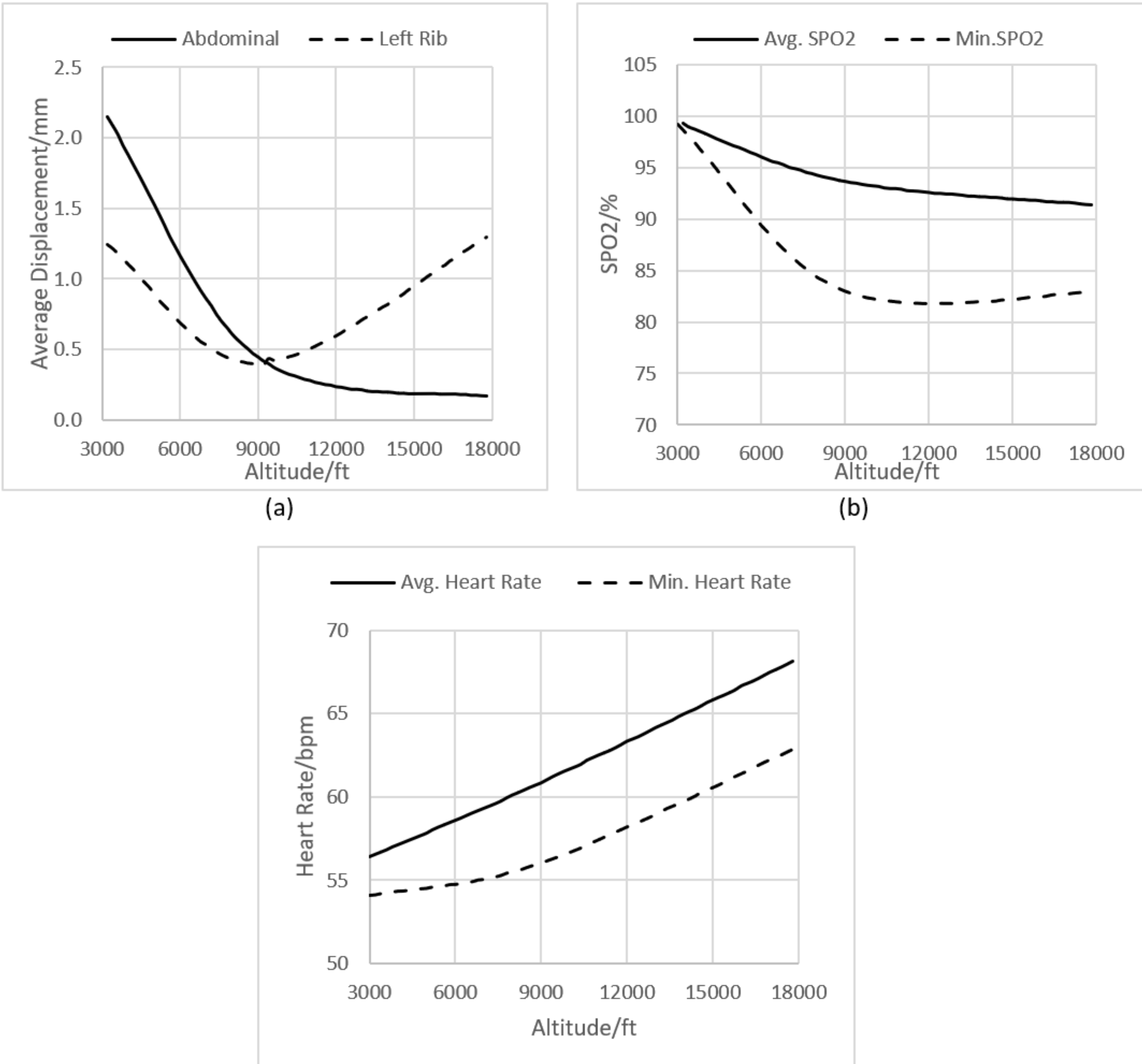


Fig. 8. Bronchitis short (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

3.4. Test 4: Croup

Normal breathing and cough, subject with croup show an intersection at 9500ft, as shown in Figure 9 (a). The abdominal area decreases as the severity increases; this contrasts with the left rib, where it decreases to an increase of 9000ft. From Figure 9 (b), the average and minimum SPO2 decrease as the severity increases. The fluctuation also increases until 9000ft, where the fluctuation remains constant: the average and the minimum heart rates in Figure 9 (c) increase with the average heart rate increasing linearly. The fluctuation is also reasonably constant throughout the graph. This also consists of the most massive increase in the average heart rate.



(c)

Fig. 9. Croup normal (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

Related to long breathing and cough, the graph in Figure 10 (a) for croup shows two intersections, first at 3000ft and second at 12500ft. The left rib increases linearly after 9000ft with the largest displacement. SPO2 levels in Figure 10 (b) decrease as the severity increases. The average SPO2 and the minimum SPO2 are constant until 9000ft, where the fluctuation increases as the severity increases. The heart rate in Figure 10 (c) shows a very little increase in the average heart rate. The minimum heart rate, however, decreases after 9000ft. It appears the fluctuation is the largest at 18000ft, followed by 3000ft, and finally the smallest at 7000ft.

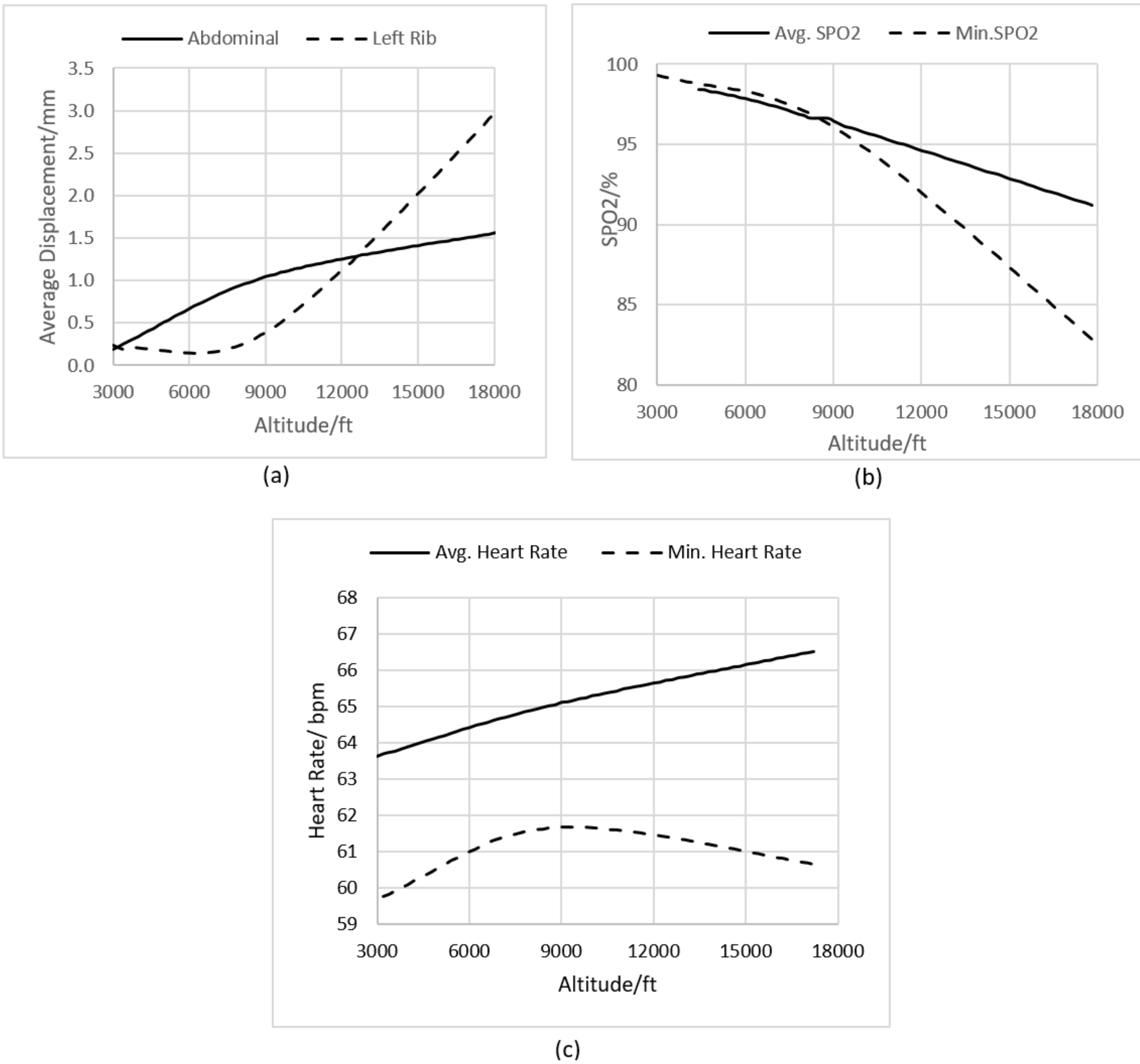


Fig. 10. Croup long (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

Related to short breathing and cough, similar to the long breathing for croup, there are also two intersections, as shown in Figure 11 (a). However, the displacement of the left rib remains constant throughout the severity increase. On the other hand, the abdominal area has an increase in displacement until 9000ft, when it starts to decrease. The SPO2 levels in Figure 11 (b) are incredibly similar to long breathing for croup. Both decrease as the severity increases. However, short breathing shows the curve as a linear decrease and an increase of fluctuation from 3000ft. Figure 11 (c) shows that the heart rate increases with severity. The fluctuation is the same at 3000ft and 18000ft; however, the fluctuation is halved at 9000ft. The minimum heart rate stays constant from 9000ft to 18000ft.

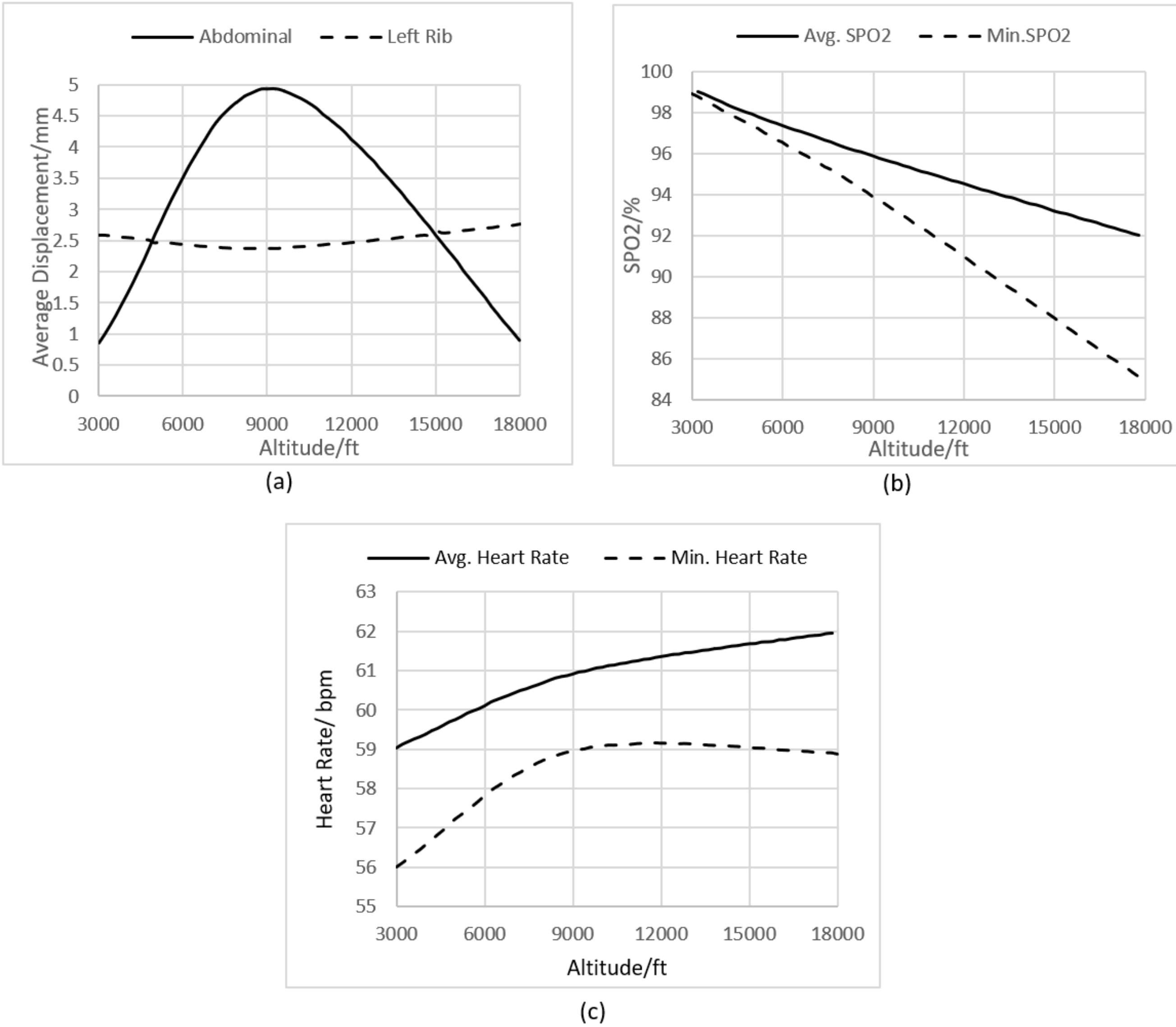


Fig. 11. Croup short (a) displacement against altitude, (b) SPO2 against altitude and (c) heart rate against altitude.

4. Discussion

To get an accurate output, a series of position tests were conducted to determine the most suitable position for this study. No training mask was used as it was purely to identify the best position to find the maximum displacement for the result considering SPO2 levels and heart rate levels, as shown in Table 1 and Figure 2. From the three subject positions, standing, sitting and lying flat, consider the same patterns for the left and right ribs. It was decided that the laying-down position would provide the most accurate left rib and abdominal measurement method. There are many factors involved; firstly, the sensor is 3D. Therefore, it must be perfectly still during the experiment for the sensors only to measure the rib displacement. This study investigated the pattern of the abdominal and the left rib (in this case, the left rib displacement was larger than the right). Due to this, a standing position would not be ideal. It would be challenging for the subject to stand perfectly still for one minute, especially considering it targets children.

Furthermore, the standing position also consists of the highest average heart rate at 81.60 bpm with a minimum heart rate of 74.0 bpm; see Table 1; this large difference of 7.60 bpm may suggest a lack of accuracy. For the left rib displacement, the sitting down position had the least average displacement (1.57 mm) compared to the average displacement of standing (2.22 mm) and laying down (2.39 mm) positions, respectively. One of the main concerns was the lack of direct contact of the sensor to the rib bone; the sitting position allows the ribs to be 'hidden/padded', which could cause the results to be less reliable. Despite the fact standing up consists of the largest average displacement (2.22 mm), the maximum displacement (5.67mm) is slightly different from sitting down (6.10 mm) and laying down (6.17 mm). Sitting down and lying down have a similar maximum displacement, and lying down has a slightly higher average displacement (2.39 mm). The heart rate was also at the ideal measurement. In the laying position, it is easy for the volunteer to relax without too much movement. The volunteers are also not conscious of breathing as they cannot see their recorded breathing, SPO2, and heartbeat. This allows for more natural breathing and, therefore, a more accurate reading. Thus, the laying down position would afford the most precise means for left rib and abdominal measurements.

4.1. Average Displacement Comparison

From the outline of the displacement parameter related to normal breathing in asthma conditions, see Figure 3 –a. The displacement increased as the severity of the subject condition increased. The abdominal and the left rib share equal displacement represented by (0.91 mm), even though the left rib is appreciably the dominant displacement. In the bronchitis condition, see Figure 6 (a), the displacement decreased as the severity of the subject condition increased, and the abdominal appeared to be the dominant one. The croup subject, see Figure 9 (a), shows equal dominance in the left rib and abdomen. At the lower croup severity, the abdomen appeared to be the dominant one. However, at higher croup severity, the left rib increases its displacement while the abdominal displacement decreases. For long breathing, in asthma conditions, see Figure 4 (a), the displacement increased by increasing the severity of the asthma condition. The left rib has the dominant displacement compared to the bronchi, as shown in Figure 7 (a). The displacement decreased by increasing the severity of the condition, and the dominant displacement appeared in the abdominal wall rather than the left rib compared to asthma. However, the croup shows a different displacement pattern from asthma and bronchi; see Figure 10 (a). Firstly, the abdominal area seems to have the dominant displacement, followed by an intersection where the left rib becomes the dominant one. Like asthma, the displacement increased by increasing the severity of the conditions. For short breathing, in asthma condition, see Figure 5 (a), the abdominal displacement appeared as the more dominant one in a more severe asthma situation (1800 ft) and had the maximum displacement (1.62 mm), while the left rib was more dominant at a milder condition (3000 ft). For subjects with bronchi, see Figure 8 (a), the displacement increased as the severity of the condition increased. The left rib appeared to be the dominant one. Subjects with croup condition, see Figure 11 (a), like asthma, have the same displacement pattern except that the left rib displacement appeared roughly persistent as the severity of the croup condition increased compared to the abdominal shows its maximum displacement (4.9 mm) at moderate condition (9000 ft).

4.2. Average and Minimum SPO2 Comparison

From the pattern of the SPO2 parameter, for normal breathing, it appeared the pattern of difference between the average and minimum SPO2 might not be the most reliable way to distinguish between croup and asthmatic conditions see Figs.3-b & 9-b. Since the croup subject's pattern shows a similarity to an asthmatic subject, bronchitis (see Figure 6 (a)) has a different apparent pattern. Therefore, it may be a reliable way to distinguish between bronchitis with croup and asthma. With long breathing, subjects with croup, as shown in Figure 10 (b) have the largest drop of 15% from average to minimum SPO2. Bronchitis does not affect the SPO2 with relation to the level of severity, as seen in Figure 7 (b). While asthma, seen in Figure 4 (b), only starts to react to the SPO2 after 9000ft, before 9000ft, the SPO2 level is constant. Short breathing shows a very similar pattern with asthmatics with very similar SPO2 drops, as seen in Figure 5 (b). For Bronchitis and croup, see Figure 8 (b) and Figure 11 (b), respectively, both have an increase in fluctuation, while the asthmatic subject has a decrease in fluctuation, as shown in Figure 5 (b).

4.3. Average and Minimum Heart Rate Comparison

From the heart rate parameters pattern, all lung breathing conditions showed increased heart rate. For normal and long breathing, as seen in Figure 3 (c) and Figure 4 (c), asthma showed the largest heart rate increment with 24.50% and 17.90%. For normal breathing, asthmatic subjects consist of constant fluctuation after 9000ft; the heart rate reached 75 bpm at 9000ft and stayed constant. Bronchitis see Figure 6 (c), however, has a minimum fluctuation at 9000ft and increases as the altitude increases; the heart rate increased linearly with a 10.7% increase from the minimum heart rate and the maximum average heart rate. Croup had a linear increase in the average heart rate see Figure 9 (c). There was also an increase of 20.6% from the minimum heart rate to the maximum average rate. With long breathing, the subject with asthmatics has a decrease in fluctuation after 9000ft, showing the heart rate becoming more steady, and the maximum average heart rate reached 68.10 bpm at 12000ft, see Figure 4 (c). Bronchitis consists of a minimum fluctuation at 7000ft, with the minimum heart rate increasing linearly, see Figure 7 (c). The average heart rate stays constant until 9000ft. Croup shows a similar pattern with bronchitis except for a non-linear increase in the minimum heart rate, see Figure 10 (c). Short breathing for asthmatics consists of two linear lines for both average and minimum heart rates, as seen in Figure 5 (c). The fluctuation also decreases steadily as the severity increases. Asthmatics also consists of the largest heart rate increase of 12.8%. Bronchitis consists of a constant minimum heart rate with a 2.6% increase, while the maximum average heart rate of 64.5 bpm is reached at 12000ft, see Figure 8 (c). There is also a constant large fluctuation after 12000ft. Subjects with croup, as seen in Figure 11 (c), show a constant minimum heart rate from 9000ft to 18000ft; minimum fluctuation also occurs at 9000ft.

5. Conclusion

Due to the comparable signs, there is difficulty distinguishing asthmatic breathing patterns from other common lung diseases in children. There is a need for a guideline that will help the asthma physician detect these symptoms sooner, thus decreasing the possibility of the child being wrongly diagnosed and the likelihood of emergency medical procedures. This study presents a raw breathing pattern obtained to produce the average displacement, SPO2, and heart rate values; these were measured against the varied altitudes to represent the severity of the lung condition. These results are only used to predict the breathing patterns and determine how the average displacement, SPO2, and heart rate are affected as the severity of the lung condition increases.

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