The Impact of Breathing Retraining and High Intensity Intermittent Training on Exercise Respiratory Symptoms.

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Abstract

Purpose The aim of this research was to determine the effect of breathing pattern retraining (BPR) and high intensity intermittent exercise (HIIT) on exercise respiratory symptoms during exercise. **Methods** Seven participants (age 36 ± 14 years (mean ± SD); body mass 69.5 ± 9.78 kg; stature 1.67 ± 10.11 m) were randomly assigned to either the HIIT and BPR group (2 female and 2 male), or just the BPR group (2 female and 1 male). Participants all reported exercise respiratory symptoms prior to their initial laboratory visit, and then continued to show signs of thoracic dominant breathing and/or thoracic/abdominal asynchrony during their initial testing. Initial testing included VO_2 max, basic spirometry, a Nijmegen questionnaire and modified Borg breathlessness scale in order to track the symptoms the participants' experienced over a six-week period. The HIIT group completed two laboratory-based cycling sessions per week, as well as the standardised BPR which both groups completed twice a day for at least 10 minutes. The BPR involved the participants practising a correct breathing pattern (which was described during the initial laboratory visit) and progressively introducing core-based exercises to increase the difficulty of maintaining the breathing pattern. **Results** A mixed model analysis of variance (ANOVA) showed that at the $p \leq 0.05$ significance level there was no statistical improvements in the participants' VO_2 max and lung function scores (VO_2 max, $p = 0.195$; FEV_1, $p = 0.881$; FVC, $p = 0.124$) at the end of the study. However, there was a significant improvement in both groups' Nijmegen questionnaire and modified Borg breathlessness results, although there was not a significant difference between the two interventions ($p = 0.365$; $p = 0.270$). **Conclusions** BPR may be an effective way of improving exercise respiratory symptoms for people with breathing pattern disorder, according to the perceived outcomes reported by participants in this study. However, this study does not show that the addition of HIIT further alleviated symptoms experienced.

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1.0 Introduction

1.1 Overview

According to the National Institute for Health and Care Excellence (NICE), there are currently over 8 million people who have been diagnosed with asthma in the UK, and while some of these people may have "grown out" of the condition, it is estimated that 5.4 million people are receiving asthma treatment (NICE, 2022; Asthma + Lung UK, 2022). NICE also claim that approximately 160,000 people are diagnosed with asthma in the UK each year. However, a significant number of these people may be misdiagnosed with asthma when attempting to find a cause for the respiratory symptoms (such as breathlessness, coughing and wheezing, shortness of breath and the inability to take a satisfying breath) that they have experienced whilst exercising or competing in their respective sports or disciplines. Thomas *et al* in 2001 reported that one third of women and one fifth of men treated for asthma had symptoms suggestive of a breathing pattern disorder (BPD).

These respiratory symptoms are often attributed to asthma, an airway disease that causes constriction of the airways, or exercise induced bronchoconstriction (EIB). However, GPs and other primary care providers often do not have the resources to provide objective testing such as fraction of exhaled nitric oxide (FeNO), spirometry, and bronchial provocation tests and because of this, though a number is hard to quantify, both under and over diagnosis of asthma is possible (Kavanagh *et al.,* 2019). Patients diagnosed with asthma will be offered inhaled salbutamol and corticosteroids to manage their symptoms in both the short and long term, such is the advice from the Global Initiative for Asthma (GINA) (2019). As well as the diagnoses of asthma, the symptoms experienced by the patients may also be due to a condition coined as breathing pattern disorder (BPD). This term is used when an individual has a BPD that results in either chronic or intermittent symptoms that may be respiratory and/or non-respiratory (Barker & Everard, 2015). This includes respiratory symptoms such as an inability to take a deep breath, and a sensation of not having enough air in the chest, and non-respiratory symptoms such as tightness around chest or throat, chest pain, dizziness, blurred vision, bloating feeling in the stomach, and tingling fingers (Barker & Everard, 2015).

A possible explanation for the common misdiagnosis of BPD is due to the lack of research undertaken to understand the pathophysiology and mechanisms, the symptoms that may develop and methods that can be used to help correct BPD. The difficulties in the diagnosis of both conditions are compounded by the similarities in the symptoms experienced by patients. Asthma patients are also likely to report a tightness around the chest and throat, chest pains and shortness of breath. This, along with a subsequent lack of resources for GPs to try and diagnose asthma, can result in misdiagnoses of either BPD or asthma and thus the incorrect method of treatment for the condition. Common methods of asthma care would be the either the prescription of inhaled corticosteroids (Thomas *et al.,* 2011), which is often used as in daily doses to reduce inflammation in airways of asthmatics (Barnes, 2010), and/or the prescription of salbutamol which is a short acting β-$_2$ agonist (SABA) which are prescribed for symptomatic relief (Marques & Vale, 2022). Misdiagnosing asthma for BPD or vice-versa could therefore lead to the mismanagement of either condition, which could in turn lead to the further impact upon the daily lives of either patient groups. BPD can have a large impact upon the daily lives of people who suffer from the condition and therefore further research into the diagnoses and therapeutic methods such as breathing pattern retraining (BPR) could be beneficial to what might be a large portion of the population (Barker & Everard, 2015).

1.2 Breathing Pattern Disorders

Although BPD has not been heavily researched, it has mechanisms, symptoms and definitions that vary across the studies and reviews that have been carried out. BPD has been described as an abnormal breathing pattern that occurs either in the absence of organic diseases, such as anxiety and stress (Han *et al.,* 1996), and in some cases because of the onset of conditions such as asthma and cardiovascular disease (Thomas *et al*., 2001). BPD is something that is not always easily defined, but a condition that can masquerade as asthma or other airway diseases (Morgan, 2002).

A common sign that one might be suffering from BPD is hyperventilation, and the idea that the patient’s breathing frequency will be higher than what is necessary for the level of exercise being performed (Brat *et al.,* 2019). However, one study noticed that patients hyperventilated prior to or at the onset of exercise, which they referred to as ‘anticipatory anxiety' which is causing the increase in ventilation. This means that often the treatment to this issue will be aiming to reduce anxiety prior to exercise (Jack *et al.,* 2003).

Because of a misdiagnosis of asthma, having an inefficient breathing pattern, and the consequent symptoms that one might develop, this may deter people from exercising due to fears of being uncomfortable or in pain due to the symptoms being experienced during exercise (Panagiotou *et al*., 2020; Avallone & McLeish, 2012). The avoidance of exercise, especially in the current climate where the rates of physical inactivity in the UK are at high (Public Health England, 2014), sedentary lifestyles are one of the most important risk factors in a range of diseases, not mentioning the detriments to quality of life (QoL) in specific populations (Biswas *et al.,* 2015). This increases the importance of further research into the area of BPD so that the correct care can be offered to those who are suffering from respiratory symptoms, as keeping people involved in physical activity is good for health and promotes a high QoL (Hagman *et al.,* 2008).

The general idea amongst the literature is that a breathing pattern can be retrained through specific breathing exercises that aim to teach the patient how to control their breathing through their diaphragm (Thomas *et al.,* 2003; Hagman *et al.,* 2011). This allows the patient to achieve a full expansion of the ribcage through efficient recruitment of intercostal muscles, which, in theory, should mean that patients should not have to over breathe when exercising. Over breathing commonly occurs during exercise where a BPD can lead to having a reduced inspiratory time and subsequently a reduced tidal volume. This then increases the demand for oxygen delivery, which eventually results in hyperventilation (Boulding *et al*., 2016).

1.3 Summary

It is well known that exercise and high intensity interval training (HIIT) is a good way of improving cardiorespiratory fitness (Skinner *et al.,* 2001), however further studies have shown that it is also useful in reducing risk factors for other health issues such as cardiovascular disease, COPD, hypertension and obesity (Lind *et al.,* 2021; Amundsen *et al.,* 2008; Beauchamp *et al.,* 2010; Boeselt *et al.,* 2017). Therefore, a further consideration when looking to correct a BPD would be a programme that includes HIIT, as it may be an efficient way of relieving respiratory symptoms during exercise, as participants will have the ability to practise their BPR as they experience these symptoms during the study.

With the lack of research currently being completed into the area of breathing pattern disorders and the methods which may be able to help patients reduce exercise respiratory symptoms that they are experiencing, this current study aims to add to existing research to try and discover how patients react to certain types of treatment. Studies have shown that BPR is able to help reduce exercise respiratory symptoms (Thomas *et al.,* 2003; Hagman *et al.,* 2011), however the aim of this study is to understand whether BPR in tandem with high intensity interval training (HIIT) is able to further improve these symptoms in an exercise capacity.

2.0 Literature Review

2.1 Breathing Pattern Disorders

A review of the literature set out to investigate BPD, its mechanisms, and treatments that have been used on current and past patients to understand what the next step is for the treatment of this population. Due to the potential of commonly misdiagnosing asthma and EIB in patients with disordered breathing patterns, scientists have set out in attempt to understand the mechanisms behind the condition and increase the awareness around it. BPD is often used as an umbrella term when an individual breathes in such a way that is different to a normal breathing pattern, where the ribcage and abdomen are contracting in synchrony, which has the potential to cause intermittent or chronic respiratory or non-respiratory symptoms (Depiazzi & Everard, 2016).

A study by Hagman *et al* (2008) showed how BPD and asthma differed as conditions based on the effect on an individual. They listed ten symptoms that had been agreed on by physiotherapists and practitioners for patients at rest, which was: (i) a sense of inspiratory heaviness; (ii) sense of not being able to take deep breaths; (iii) increased breathing frequency (>16/Min); (iv) frequent sighing or yawning; (v) frequent need to clear the throat; (vi) muscle and joint tenderness in upper part of the chest; (vii) hacking cough; (viii) chest tightness; (ix) sensation of lump in the throat; (x) previous or current effects of stress. A patient had to display at least five of these symptoms to be recognised as having a BPD. They discovered that patients with BPD recorded lower scores in the health-related quality of life questionnaire with lower scores in vitality, social functioning, and role emotion, and were also significantly more anxious, stressed, and depressed than asthma patients which had a more of an impact upon their daily lives. BPD patients recorded a significantly lower sense of coherence and a higher prevalence of hyperventilation, with 14 patients defined as having more severe symptoms than others, or hyperventilation syndrome, by the Nijmegen questionnaire (van Doorn, Folgering & Colla, 1982). BPD patients did however report shorter durations of their breathing problems compared to the asthma patients. They did report a higher proportion of emergency room visits, though this was not statistically significant. Both groups were limited due to their respiratory symptoms during exercise bouts, but there were no differences between them. For patients with a BPD suffering from these further psychological issues such as anxiety, stress and senses of lower coherence, breathing pattern retraining (BPR) could not only act as a method of reducing exercise respiratory symptoms, but a therapeutic method of reducing anxiety both prior, during and after exercise.

2.2 Mechanisms of breathing pattern disorders

A normal breathing pattern at rest is one where respiration is predominantly controlled using the lower intercostal muscles and abdominal ribcage movements, with the shoulders and upper chest remaining stationary without the recruitment of other accessory muscles such as the scalene, sternocleidomastoid, pectoralis major, trapezius and external intercostal muscles (Smyth *et al*., 2021). The pulmonary ribcage, abdominal ribcage and the abdomen must move in synchrony (Bradley & Esformes, 2014). During exercise, this changes to an increased expansion of the upper chest and subsequent accessory muscle use, whilst also transitioning from nose to mouth breathing at around 35 L/min (Sylvester, 2020). Ventilation symptoms can be induced for a patient with a BPD through a variety of different mechanisms. The literature on the topic has shown that there are different ways by which BPDs can be classified and how the mechanisms within different incorrect breathing patterns can be causes and triggers for symptoms that people may experience.

2.2.1 Thoracic Dominant Breathing

Thoracic dominant breathing is a term used to describe a breathing pattern that predominantly consists of use of the upper thorax, whilst also showing relative reduction of lower intercostal muscle use. This breathing pattern can occur at the onset of aerobic activity, because of respiratory or cardiac diseases (such as asthma or COPD, and in some cases morbid obesity) or in some cases even psychological stressors such as stress and anxiety (Courtney *et al.,* 2011; Boulding *et al.,* 2016; Depiazzi & Everard, 2016).

2.2.2 Thoracic-abdominal Asynchrony

This breathing pattern is one that shows a delay between upper abdominal movement, the diaphragm and the ribcage. This creates a bi-phasic inspiratory flow and therefore a reduced tidal volume (VT) and as a result the patient will have to increase their rate of respiration to meet the demands of their activity (Dickinson and Boniface, 2020). This breathing pattern has been claimed to be linked to upper airway obstructions, neuromuscular disorders and in patients with acute respiratory failures (Upton *et al.,* 2012). This type of BPD has also been known to decrease the level of carbon dioxide in the blood stream, which as a result can cause both the pH level of blood to increase (Garssen *et al.,* 1992), and also respiratory alkalosis (Gardner, 1996), which can trigger not only physiological but psychological changes within the body such as those mentioned in the Hagman study. This further shows the effect BPR may have for a patient with a BPD by helping them to feel more comfortable during and after exercise bouts.

2.2.3 Deep Sighing

Those who elicit symptoms of this type of breathing pattern will often experience a deep sigh in tandem with an irregular breathing pattern. It has been seen to affect asthmatics but is most observed in patients with BPDs. Increased tidal volumes three times as high as a normal reading has been said to show a crescendo type of increase on a lung volume trace before the sigh occurs (Boulding *et al.,* 2016).

2.2.4 Hyperventilation Syndrome (HVS)

Kerr *et al.* first reported HVS in 1937 where it was determined that anxiety was the initial cause for over breathing. However, further studies since the findings of Kerr *et al* have now accepted that anxiety may not occur at all or may even become induced by HVS (Lum, 1976; Bass & Gardner 1985). Breathing pattern often shows synchrony between the chest and abdomen, however over breathing and ventilation rates that exceed metabolic demands means that carbon dioxide (CO_2) elimination occurs faster than its production. Consequently, hypocapnia and respiratory alkalosis can occur which can lead to the development of symptoms such as tingling, dizziness, and cold hands and feet (Hornsveld & Garssen, 1997). However other studies have claimed that these symptoms could be caused by other factors since respiratory alkalosis and HVS are not mutually exclusive (Howell, 1997; Barker & Everard, 2015).

2.3 Symptoms of Breathing Pattern Disorder

The symptoms that may be elicited from a patient with BPD can be understood through looking at the Nijmegen questionnaire. This was a questionnaire composed by a group of scientists at the University of Nijmegen as a method of diagnosing HVS (van Doorn, Folgering & Colla, 1982). The list is comprised of a mix of respiratory, neurological, cardiovascular, and musculoskeletal symptoms (Table 1).

Table 1. *Symptoms caused by BPD based on the Nijmegen questionnaire.*

Respiratory Symptoms	Faster or deeper breathing, shortness of breath, tight feelings in chest, inability to breathe deeply
Neurological Symptoms	Blurred vision, dizzy spells, feelings of confusion, tingling fingers/pins and needles, cold hands and feet, headaches
Cardiovascular Symptoms	Palpitations, chest pain, reduced blood oxygen saturation (SaO_2)
Musculoskeletal Symptoms	Stiff fingers and arms, neck, shoulder and back tension, jaw tension

While the causes of these symptoms are not comprehensibly understood, it is known that each type of symptom does not simply fall under the whole bracket of BPD. Neurological symptoms such as dizziness, tingling, and cold hands and feet can be attributed to drops in alveolar CO_2 pressure and increases in blood Ph (Hornsveld & Garsson, 1997). Respiratory symptoms experienced are likely to be related to an incorrect breathing pattern, especially during exercise when there is an increase in VT (Han *et al.,* 2000).

2.3.1 BPD Prior to Exercise

Prior to the onset of exercise, exercise respiratory symptoms are often induced through different means to those during exercise. For example, patients have been seen to hyperventilate due to what is called “anticipatory anxiety” (Jack *et al.,* 2003). The emotional stress of exercise can also cause thoracic breathing which can cause muscular tension around the abdomen and inhibit diaphragm movement (Depiazzi & Everard, 2016). This can then result in further thoracic breathing and the recruitment of further accessory respiratory muscles which can induce dyspnoea, increased breathing rates, and muscle fatigue. This shows that the treatment of BPD may require more than just correction of the breathing pattern (Gilbert, 1998; Sieck *et al.,* 2013). Psychological factors are thought to be a large contributor to BPD and even can be the underlying cause (Dickinson and Boniface, 2020).

2.3.2 BPD During Exercise

A large proportion of those suffering from BPD will notice that their symptoms may be exaggerated during exercise. As the intensity of exercise increases, breathing rate will also increase which will place demand on the individual's breathing pattern to ensure that the required amount of oxygen is delivered to the working muscular systems. An important way of measuring the impact a dysfunctional breathing pattern can have on an individual is through the way VT changes at the onset of exercise (Figure 1).

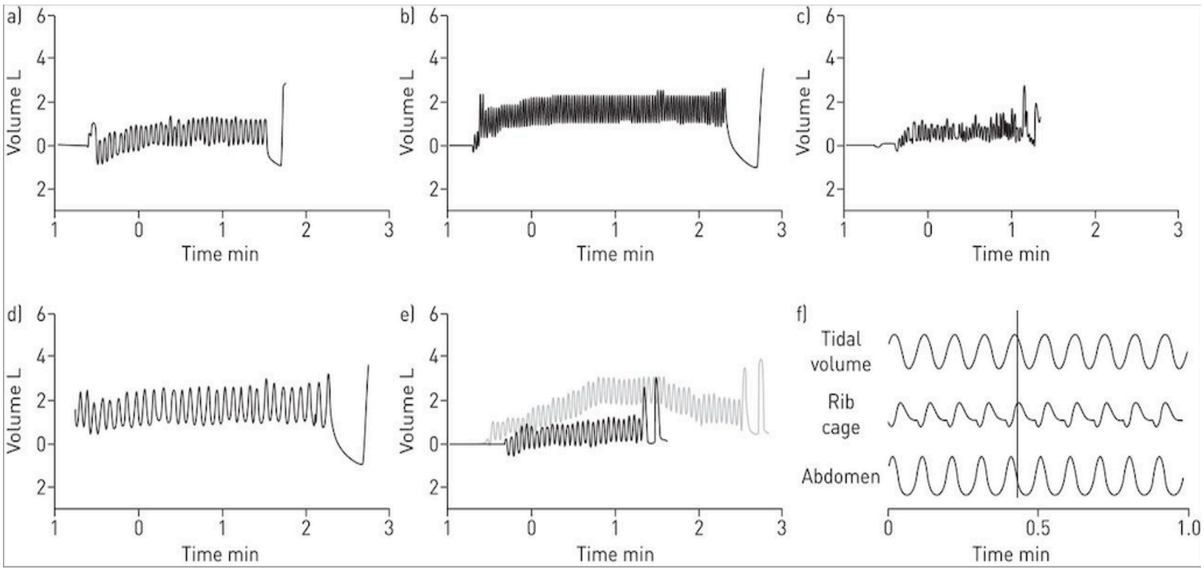

Figure 1. *Tidal volume and breathing frequency variations in people with breathing pattern disorder. The breathing patterns correspond to a) a healthy participant, b) hyperventilation syndrome, c) erratic breathing pattern, d) thoracic dominant breathing, e) forced expiratory pattern before (grey) and after (black) exercise, and f) thoraco-abdominal asynchrony. (Taken from Boulding et al., 2016).*

The graphs in Figure 1 show how different types of breathing patterns can impact on VT. Figure 1a shows a healthy participant and Figure 1b shows a participant with HVS, where the respiratory rate is significantly higher and faster compared to the healthy participant. This patient's tidal breathing is also closer to their respiratory capacity than the healthy participant. Figure 1c and 1d show an erratic and a thoracic dominant breather respectively. The erratic breather shows a VT that is not maintained throughout the exercise, and they also could not perform a maximal expiratory or inspiratory movement at the end of the recording. This could explain why a patient may experience symptom such as a deep sigh or an inability to perform a deep breath. This is also the case in Figure 1d, which shows the thoracic dominant breather, where the volume of each breath is higher, however the inspiratory reserve capacity is reduced which will lead to the next breath being smaller. Figure 1e shows a grey line which is a forced expiratory pattern before exercise and a black line after exercise, whereas Figure 1f depicts a panel showing recordings from motion sensors which show a thoraco-abdominal asynchronous breathing pattern.

2.4 Diagnosis of BPD

While there is no gold standard way of defining or diagnosing BPD, measures such as forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) are used to determine the patient's lung function which can often be affected in cases of asthma, EIB and BPD. BPD patients often have normal lung function according to these tests; however, studies have shown that FEV_1 and FVC can fall below predicted values by 10-15% (Courtney & Cohen, 2008; Courtney & Greenwood, 2009). The former of the Courtney studies recognised that patients with abnormal lung function had lower blood CO_2 levels, shorter breath holding times, and lower SaO_2 readings, which is indicative of an incorrect breathing pattern. Therefore, although spirometry is not universally accepted as a diagnosis tool, it could be that abnormal lung function is an indication of a dysfunctional breather.

Optoelectronic plethysmography (OEP) has also been used in some cases to analyse breathing pattern. It is a non-invasive, motion analysis system which can measure the way in which the pulmonary ribcage, abdominal ribcage and abdomen all move in relation to each other throughout the breathing process (Massaroni *et al.,* 2017). OEP may not be the most prominent method of diagnosing BPD as the motion analysis system is quite often only accessible through educational or research institutions. The equipment is also very expensive and therefore OEP as a method of BPR is not very accessible to patients. It can still be an important assessment to use in research settings to better understand people's breathing patterns. In a recent study by Smyth *et al*. (2021) OEP was used to aid BPR by providing real time feedback to those with BPD, which was effective in showing participants their live breathing pattern whilst taking part in a cycling test.

Another tool used by researchers to help diagnose BPD is through the completion of the Nijmegen Questionnaire (NQ). This is a list of different symptoms one might encounter devised by a research group at the University of Nijmegen in 1982 (van Doorn, Folgering & Colla, 1982). For the 16 symptoms listed, patients will give a score based on how often they experience them from 0 (never) to 4 (very often). BPD is signified when the sum of these scores is higher than 23. Though used as a method for diagnosis, the NQ can also be used to track how a patient's symptoms may be progressing after treatment or during an exercise programme. However, due to the subjective nature of questionnaires and the psychological factors associated with thinking about your breathing may lead to inaccurate results reported by patients.

The Breathing Pattern Assessment Tool (BPAT) is a newly validated method for diagnosing BPD in patients with asthma (Todd *et al*., 2018). BPAT involves a respiratory physiotherapy assessment, where a score of ≥4 indicates a positive BPD diagnosis (Todd *et al*., 2018). Interestingly, a recent study showed that BPAT and NQ did not diagnose the same patients with BPD when used simultaneously to screen patients with asthma (Sedeh *et al*., 2018). Although proven to be a useful tool in diagnosing BPD in asthma patients, its utility in other respiratory conditions is yet to be fully shown (Hylton *et al*., 2019). Although, a recent study did show a high level of sensitivity and specificity for diagnosing BPD in post-COVID patients (Hylton *et al*., 2022).

Often the most effective way of diagnosing a breathing BPD can boil down to an observation from a researcher or practitioner. There are no standardised methods to help diagnose the condition however observations of the patient's breathing pattern, respiratory rate, movements of abdomen and chest, and the recruitment of accessory muscles can be observed at rest and during exercise (Dickinson and Boniface, 2020). These observations are better performed when the patient is unaware that they are being observed, such as during a cardiopulmonary exercise test (CPET) so that there is no conscious effort to breathe well under observation.

2.5 Treatment of BPD

2.5.1 Breathing Pattern Retraining

The nature of BPD is based around the idea that patients suffer with respiratory symptoms due to over breathing because of an incorrect breathing pattern (Brat *et al,* 2019). Therefore, treatment has developed which aims to focus on slow and controlled diaphragmatic breathing efforts, which can be completed in different and more challenging postures and positions to further train the respiratory muscles to correct either an unsynchronised thoracoabdominal or thoracic dominant breathing pattern. This is done by reducing the rate and depth of breathing (Bott *et al.,* 2009), and over time patients will use breathing retraining to modify their breathing pattern and then attempt to maintain a normal diaphragmatic breathing pattern (Han *et al.,* 1996). Breathing pattern retraining sessions will most commonly be structured in a similar fashion to other training programmes, where patients will perform correct breathing techniques, either with or without visual or physical aids, for 1-2 minutes at a time with short periods of rest between repetitions. Much like any other training programme aiming to strengthen skeletal muscle, the more frequently the muscle is exercised, the more it will adapt (Warburton *et al*., 2006), therefore it is important patients are constantly attempting to engage in breathing retraining.

Studies have shown that breathing retraining is effective in correcting dysfunctional breathing patterns and helping patients to minimise their symptoms. A randomised control trial devised by Thomas *et al* in 2003 showed that over half of the patients involved in the trial showed a clinically relevant improvement in QoL following a breathing retraining intervention that involved patients practising diaphragm based breathing efforts, which was maintained in 25% of the cohort after 6 months of completing the trial. Hagman *et al* in 2011 also found that physio-led breathing retraining sessions also led to patients having improved QoL and experiencing fewer respiratory symptoms in their daily lives and whilst exercising.

Though these studies show that breathing pattern retraining can improve exercise respiratory symptoms experienced by patients suffering from BPD, the effectiveness of the methodology behind the trials could be questioned in order to decipher the most efficient way of correcting breathing pattern. For example, Thomas *et al* (2003) had a cohort of 33 people whose respiratory symptoms were only reported through self-assessment tools such as the Nijmegen and Asthma Quality of Life questionnaires, which places a lot of the onus on the perceptual side of diagnosis, rather than using quantitative physiological tests such as a VO_2 max test and spirometry. The study also took place over a 6-month period, and with perceptual symptoms being the only barometer of change, this opens the possibility of whether the breathing retraining in this instance was placebo. Since only 25% of participants maintained the improvement in exercise respiratory symptoms over a further 6-month period after the intervention, this further suggests the idea of placebo as breathing pattern disorder can be affected by psychological and emotional factors. However, even 5-years after the breathing pattern retraining intervention by Hagman *et al* (2011) patients were still benefiting from improved QoL scores, fewer hospital visits, and significantly reduced exercise respiratory symptoms during exercise, suggesting that the breathing retraining programme had a lasting positive impact on those patients' lives. Both studies had physiotherapists leading the intervention so the delivery of breathing retraining may not be important in the longevity of the intervention.

The previously mentioned Smyth study in 2021 used OEP to investigate real time feedback on breathing pattern given to participants during an incremental cycling test. Participants were also given breathing retraining exercises to complete between their two cycling tests. The results showed that the live feedback in conjunction with breathing retraining acutely improved dysfunctional breathing patterns, as participants were able to see live feedback on their breathing pattern and focus on using correct breathing techniques (Smyth *et al.,* 2021). This shows that increasing the awareness people have of their own breathing pattern is a further aid for helping to correct a dysfunctional breathing pattern. Future research could use a similar method to determine whether BPR in conjunction with OEP would be able to reduce some of the psychological issues illuded to in the Hagman study in 2008 where patients were suffering from anxiety, stress and a lack of cohesion during exercise.

2.5.2 Relaxation Therapy

Relaxation therapy is another technique that has been used for patients with BPD as a way of attempting to reduce the impact and severity of HVS. This can often be done through activities such as yoga, Pilates, or other activities that do not require increased heart and breathing rates. A study in 2007 investigated the impact of relaxation therapy and breathing retraining on three different groups' frequency and severity of HVS symptoms (Holloway and West, 2007). There was a control group and an intervention group which was delivered by a respiratory physiotherapist. The Papworth method, first developed in the 1960s, was used during the relaxation therapy sessions, and involves a mixture of both relaxation and breathing retraining techniques. The findings were that the intervention group's respiratory symptoms were improved due to the Papworth method with patients recording significantly lower scores on the Hospital Anxiety Depression Scale and on the Nijmegen questionnaire (with scores reduced from 17.8 – 15 – 14.2 for the control group, and from 19.2 – 11 – 11.9 in the intervention group). This method of therapy for BPD would most effectively be used in a setting for patients and athletes who are more likely to suffer with respiratory issues prior to exercise bouts such as the previously mentioned "anticipatory anxiety." Patients who can learn to correct their breathing pattern prior to exercise will be more efficient in their breathing patterns in the early stages of their exercise bouts.

Relaxation therapy and breathing retraining together may be an interesting pairing in the literature studied, however previous pieces of literature that have investigated whether they both could be placebo treatments for people with BPD. In 1992, Dr. Bret Garssen from the University of Amsterdam dubbed Breathing retraining as a “rational placebo” (Garssen *et al.,* 1992). He claimed that although the treatments used for BPD seemed logical, they did not work on closer inspection. Despite this, he claimed that breathing pattern retraining could have a therapeutic effect on patients as “senses of control, even if based on illusion, can be effective in reducing anxiety”.

2.5.3 High Intensity Interval Training

Maximal oxygen uptake, otherwise known as VO_2 max, is well known to be an accurate indicator of aerobic fitness, and therefore also of potential cardiovascular risks that could arise (DeFina *et al.,* 2015; Myers *et al.,* 2015). A cardiopulmonary exercise test (CPET) is normally used to determine VO_2 max, and these tests have also been used to diagnose BPD or HVS (Warburton & Jack, 2006; Jack *et al.,* 2004). Though the recovery period is prolonged, HVS patients would usually reach a high level of work rate, though it was lower in comparison to healthy patients without a diagnosis of HVS (Jack *et al.,* 2000). There is currently no standardized way of identifying HVS during a CPET, however they are useful to use in conjunction with situations where patients do not show any symptoms at rest (Vidotto *et al.,* 2019), as breathing rates and breath volumes will be higher, which makes it easier to analyse breathing patterns.

High intensity interval training (HIIT) is a frequently used method of exercise which is popular for several reasons, such as the effect it can have on exercise capacity, and due to the short time scale that a HIIT session can be performed in (Foster *et al.,* 2015). HIIT consists of alternating periods of high intensity exercise, alongside periods of either passive or active recovery (Ito, 2019). It has been shown through research that HIIT is more effective in improving VO_2 max as opposed to a longer, continuous, and more moderate intensity of exercise (Daussin *et al.,* 2007; Helgerud *et al.,* 2007). At the time of writing, the effect of HIIT on patients with BPD has not been investigated, but it has proved to be an effective method of increasing cardiorespiratory fitness (Skinner *et al.,* 2001), during which patients will be able to practise a correct breathing pattern during high intensity exercise, which is often when patients experience exercise respiratory symptoms.

Studies have shown that HIIT has improved heart rate response to exercise and myocardial function (Conraads *et al.,* 2015; Molmen-Hansen *et al.,* 2012). A study published in 2009 investigated the impact HIIT had on left ventricular function in patients with coronary heart disease (Amundsen *et al.,* 2007). Patients were assigned to either a HIIT exercise group (80-90% VO_2 max) or a moderate exercise group (50-60% VO_2 max) for a ten-week exercise programme. The results showed a significantly higher increase in VO_2 max for the HIIT group, of 17% compared to 8% in the moderate exercise group, as well as an increase in the filling speed and subsequent relaxation of the left ventricle which was only observed in the HIIT group. These improvements in cardiac output and VO_2 max due to the HIIT training may help to reduce risk factors for cardiovascular disease such as obesity, high blood pressure, and diabetes (Lind *et al.,* 2021).

HIIT is also advised for those who suffer from chronic obstructive pulmonary disease (COPD), as it has been shown to improve exercise capacity and QoL (Beauchamp *et al.,* 2010). As with the previously mentioned study investigating the impact of HIIT on cardiovascular disease, the benefits of HIIT outweighed those of more moderate and continuous training programmes in COPD patients too (Casaburi *et al.,* 1997). Although often COPD patients are limited to the level of intensity of exercise that they can reach due to the severity of their symptoms (Maltais *et al.,* 1997). A study from 2017 was able to conclude that two 90-minute HIIT sessions per week over a three-month period was able to increase the exercise capacity of the patients, measured through the distance travelled during a 6-minute walk test which increased from 407.9 ± 152.09 m at the start of the study to 459.3 ± 126.6 m after three months, and they also showed the HIIT sessions led to improvement of their QoL as reported by clinically relevant improvements in the St George's Respiratory Questionnaire scores (Boeselt *et al.,* 2017). Though this training study is one of a long duration, it does demonstrate the crucial role exercise, and in particular HIIT, can play in improvements of quality of life and symptom relief for those with chronic health conditions.

2.6 Research Aims

The primary aim of this research was to determine the effect of breathing pattern retraining (BPR) and high intensity intermittent exercise (HIIT) on exercise respiratory symptoms experienced by a population of people with disordered breathing patterns. With HIIT being an important method of rehabilitation for patients with other chronic health conditions, such as COPD and cardiovascular disease, this study will help to determine whether it has the same effect on the population of people with a dysfunctional breathing pattern. The participants' VO_2 max and lung function were compared at the beginning and end of the study to determine whether the 6-week BPR and HIIT protocols had improved these parameters. A review of literature explored the previous effects BPR had on these symptoms, but none so far had yet examined the effect this has when in tandem with HIIT. It was hypothesised that the BPR and HIIT, with the participants' new awareness of their breathing pattern (Smyth *et al.,* 2021), would more effectively improve the respiratory symptoms suffered by the participants (Thomas *et al.,* 2003; Hagman *et al.,* 2011), whilst also improving their VO_2 max and lung function results.

3.0 Methods

3.1 Participants

The participants in this study were recruited from the University of Kent and from the local community. They had an average age of 36 (±14) years, an average body mass of 69.50 ±9.78kg and height of 1.67 ±10.11m, respectively. They were all physically active, and regularly took part in either team sport training or recreational fitness. The participants filled out a health questionnaire to declare that they had no current injuries or medical conditions and all signed a consent form for participation once the purpose and protocol of the study had been fully explained to them. The participants who had a previous medical history of asthma were screened for asthma using an EVH challenge (see 3.3.2 EVH Challenge Protocol), where one participant was excluded from the study due to a positive diagnosis.

3.2 Experimental Design

Participants could only take part if they had no prior history of asthma, or tested negative on the EVH challenge (see Eucapnic Voluntary Hyperpnoea ((EVH)) Challenge Protocol, and had reported respiratory symptoms during exercise that are suggestive of disordered breathing prior to the study, such as tight chest, difficulty breathing in, wheezing while breathing in, and difficulty taking a satisfying breath. Symptoms each participant experienced were reported during their initial visit to the laboratory. The participants with a previous medical history of asthma, as diagnosed by their GP, were required to visit the laboratory for an initial asthma screening, followed by spirometry and a maximal oxygen uptake (VO_2 max) test, if the result of their EVH was negative. A negative EVH challenge was determined by their FEV_1 falling by less than 10% from baseline at two consecutive points during the test (Hull *et al.,* 2016).

If the participants had no prior history of asthma, they began the preliminary testing by completing spirometry and a VO_2 max assessment (see 3.3.3 VO_2 max Protocol). They were then randomly assigned, using a random number generator, to either the breathing pattern retraining (BPR) group or the BPR and HIIT group. The BPR group (n=3, 167cm ±5, 71kg ±12, 33 years old ±19 (means ±standard deviation)) completed a breathing retraining programme (BRP), and the HIIT group (n=4, 171cm ±7, 71kg ±10, 32 years old ±12) completed the BPR but also participated in a HIIT cycling programme which would be completed in a laboratory on (RacerMate) CompuTrainers, using the PerfPRO studio software. The training programme consisted of 2 sessions of HIIT per week (protocols 1 and 2), for a total duration of 6 weeks (total of 12 sessions).

At the start, middle (3 weeks) and end (6 weeks) of the training programmes, the participants completed the Nijmegen questionnaire on breathlessness (van Doorn, Folgering & Colla, 1982) to help understand their baseline and how the interventions were affecting the symptoms experienced by participants. At the end of the 6-week training programme, the participants completed spirometry and VO_2 max testing to measure the effect of the breathing retraining on VO_2 max and lung function.

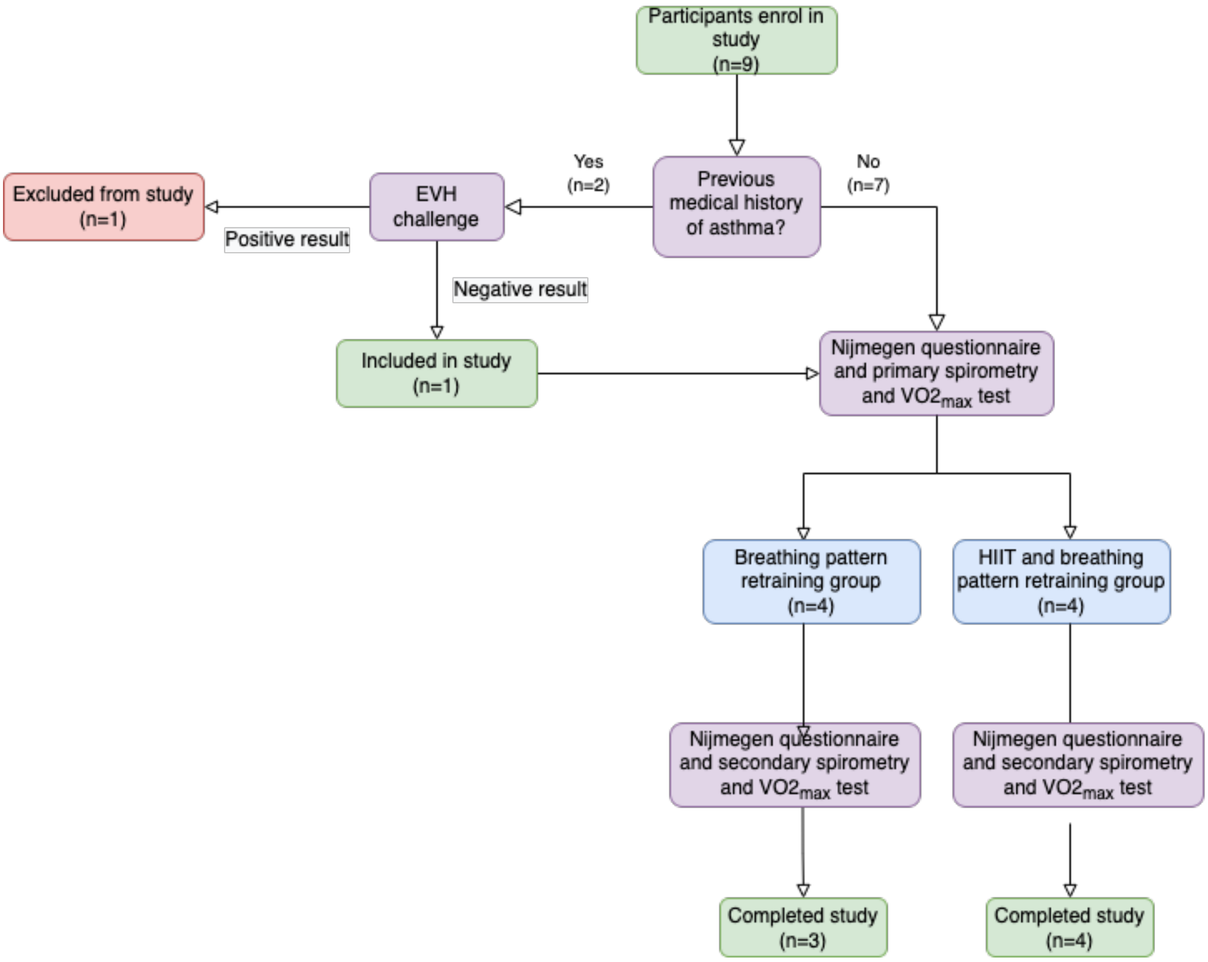

Figure 2. Flow chart of the study design. EVH; Eucapnic Voluntary Hyperpnea. HIIT: High Intensity Interval Training. VO_2 Max: Maximum Oxygen Uptake.

3.3 Testing Protocol

3.3.1 Spirometry to determine Lung Function

Prior to spirometry testing, a test to measure fraction of expired nitric oxide (FeNO) to give an indication of airway inflammation was completed. A FeNO score of > 50 ppb is an indication of high eosinophilic inflammation (Dweik *et al.,* 2011).

Baseline tests were then taken to measure forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1). The test was completed three times in succession, with the highest measurement of the three being recorded. This measure was then multiplied by 30 to determine how much gas the participant would require to breathe in order to perform a successful EVH challenge. Assessments were carried out following European Respiratory Society (ERS) and American Thoracic Society (ATS) guidelines (Graham *et al*., 2019).

3.3.2 EVH Challenge Protocol

Participants were challenged to breathe heavily for a total of 6 minutes whilst inhaling air consisting of 21% oxygen, 5% carbon dioxide, and 74% nitrogen. The participants received the gas through a gas cylinder, reservoir, and two-way valve. Maximal voluntary flow-volume loops were measured at 3, 5, 10 and 15 minutes after the challenge had been completed, with two flow-volume loops being collected at each time point. The maximal flow-volume loop with the highest FEV_1 was recorded at each time point. A test is deemed positive for EIB/Asthma if the FEV_1 falls by at least 10% from baseline at two consecutive points following the EVH challenge (Anderson *et al.,* 2001). If a participant recorded a positive EVH challenge result, they were excluded from the study as this test was undertaken to determine whether a participant was asthmatic or not.

3.3.3 VO_2 max Protocol

The VO_2 max test was completed on a Lode cycle egometer, with the respiratory gas exchange data being assessed using a Metalyzer 3B Cortex, online breath by breath gas analyser (Metalyzer 3B; CORTEX Biophysik GmbH, Leipzig, Germany). Prior to all testing the Cortex analyser was calibrated with ambient air and known concentrations of O_2 (17%) and carbon dioxide (5%). The bidirectional turbine (flow meter) was calibrated with a 3-litre calibration syringe. The test began after a 10-minute warm up at a power output of 50 W, where the power output was increased by 25 W every minute until voluntary exhaustion was reached. The test would also be ceased by the researcher when the participant could not sustain a cadence above 60 rpm. Once the test had ceased, the participants were allowed to remain on the bike to pedal as a cool down for as long as requested. Participants wore heart rate monitors and provided a score for overall feelings of breathlessness (0-10) (Borg, 1982) and rating of perceived exertion (RPE) (6-20) during the final 15 seconds each stage using the Borg breathlessness scale (appendix 2). The results of each outcome measure was taken at four different time points throughout the VO_2 max test; the start and end of the test, and also at ventilatory thresholds one and two (VT1 and VT2). VT1 was determined using the criteria of an increase in both ventilatory equivalent of oxygen (VE/VO_2) and end-tidal pressure of oxygen ($PETO_2$) with no concomitant increase in ventilatory equivalent of carbon dioxide (VE/VCO_2) (Pallares *et al.,* 2016). VT2 was determined using the criteria of an increase in both the VE/VO_2 and VE/VCO_2 and a decrease in $PETCO_2$ (Lucía *et al.,* 1999).

3.3.4 HIIT Cycling Protocol 1

The total time of this protocol was approximately 28 minutes. The participants began with a 5-minute warm up at a steady cadence of 60 rpm. They would then perform three sets of high intensity cycling exercise. The first set being at maximal intensity (>80% HRmax, RPE >15), 30 seconds at a time with a 45 second recovery. This was performed six times to complete the first set. The participants would then cycle for two minutes to recover, before completing the same set again twice more but with 30 and then 10 seconds recovery instead of 45. The Borg breathlessness scale was used at the start of the two-minute recovery period to determine whether the participant experienced any breathing difficulty. At the end of the three sets, the participants were able to remain on the bikes and pedal for a cool down for as long as required and were encouraged to engage in static stretching of the lower body.

3.3.5 HIIT Cycling Protocol 2

The total time of this protocol was approximately 30 minutes. It was completed using the '10-20-30' protocol. After a 5-minute warm up at a steady cadence of 60 rpm, the participants performed four sets of five minutes cycling. Each minute would follow the same structure. The first 30 seconds would be of a low intensity (45-60% HRmax, RPE <11), the next 20 seconds of a moderate intensity (60-75% HRmax, RPE 12-15), and the final 10 seconds at maximum intensity. There would then be two minutes recovery cycling before completing the same structured five minutes again. Similarly, the Borg breathlessness scale would be used at the beginning of the recovery period to monitor respiratory symptoms.

3.3.6 Breathing Retraining Protocol

Before beginning the BRP, the participants were instructed on the correct method of breathing with correct posture. They started by breathing in from empty lung to completely full lungs, where the rate of inhalation should be steady and smooth. When breathing in, the participant was instructed to focus on using lower breathing muscles to move the ribs side-ways, out and up in a smooth motion, instead of initiating the breath with their shoulders, or with their lower ribs before their upper ribs. Physical aids, such as hands on the side of the ribcage or a theraband, were provided while the participant breathed like this for two minutes. The participants then performed the two minutes again but without the physical aid. This was completed twice daily for ten minutes each time. Once the participant felt they could perform this adequately, they could progress their training with these added stressors.

Progression 1 occurred during the first two weeks of the BRP and involved the participant breathing as described above whilst holding a superman pose (a simple core exercise shown in Figure 3). They then performed the breathing pattern exercise whilst swinging arms as if they were running. The final progression was a march and swinging arms together whilst performing the breathing pattern described above. The participants were not progressed until they felt they performed the previous stage adequately.

3.3.6.1 Core Exercise

Exercises such as the plank, bird dog, and dead bug were performed whilst performing the breathing exercises (Figure 3). The participant used the hands on the ribcage or a theraband to start with before progressing. After performing the breathing exercises statically, movements were added in through exercises such as the dead bug and bird dog, whereby the participant would perform each exercise for one minute, repeating five times with one minute rest between each exercise.

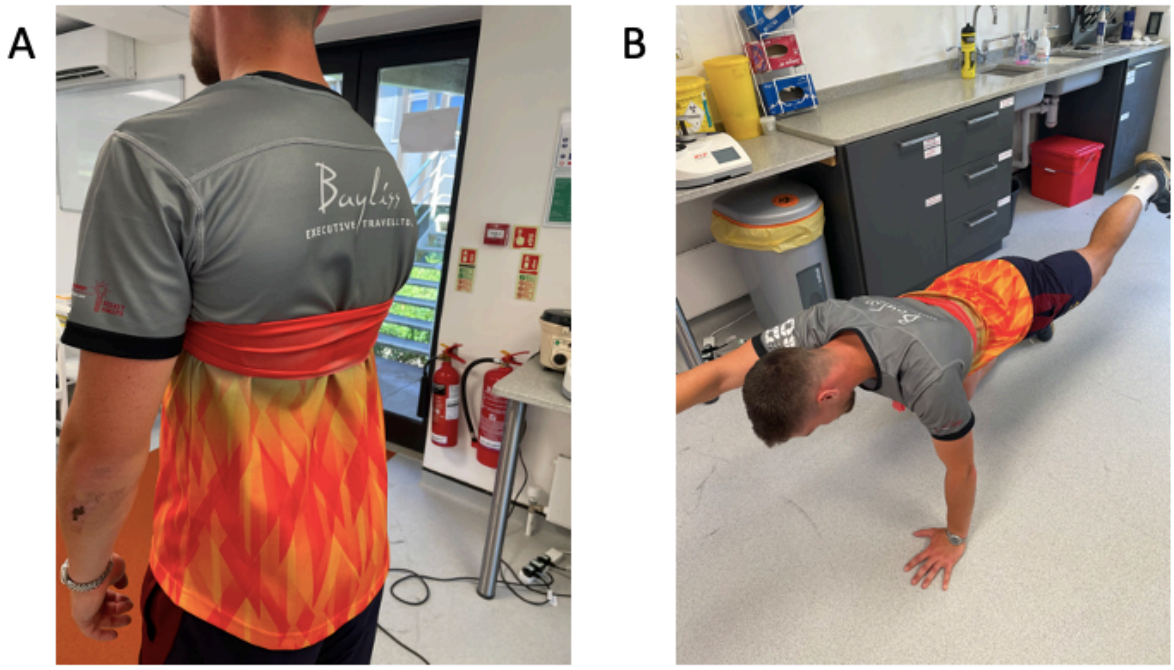

Figure 3. Participant completing breathing pattern retraining with a theraband. Participant is in a) upright standing position and b) bird dog (superman pose).

3.3.6.2 Stretch Exercise

The participants also completed the breathing exercises whilst performing stretches of their choice (static or dynamic, however it was recommended they start with static) for a total 10 minutes twice a day. This helped to ensure the participants were not using respiratory muscles to brace during the stretch and help to improve breathing pattern in various postures.

3.4 Statistical Analysis

Statistical testing was completed using the SSPS software (IBM, New York, USA), where testing for normal distribution was completed using a Shaprio-wilk test. A mixed model repeated measures analysis of variance (ANOVA) was conducted to help to assess the change in respiratory symptoms from the beginning and end of the programme. Post hoc analysis was also then used to show changes in certain physiological and perceptual parameters such as oxygen uptake (VO_2), breathing frequency (BF), respiratory exchange ratio (RER), minute ventilation (V_E), Modified Borg scale, spirometry, and NQ at four different timepoints throughout the VO_2 max test.

4.0 Results

4.1 Statistical Analysis

Before the difference between the groups were investigated, a Shapiro-Wilk test checked that the data was normally distributed. The significance values from the Shapiro-wilk test are shown in appendix 1, and with the significance level being set 0.05, it was not possible to reject the null hypothesis that the data were normally distributed for each protocol.

4.2 Analysis of Variance

A mixed model analysis of variance (ANOVA) was performed on the results of the participants' VO_2 max and lung function results both before and after the 6-week programme. Again, at the 0.05 significance level, it was deemed that there was no statistical improvement in the participants' VO_2 max and lung function scores (VO_2 max, $p = 0.195$; FEV_1, $p = 0.881$; FVC, $p = 0.124$).

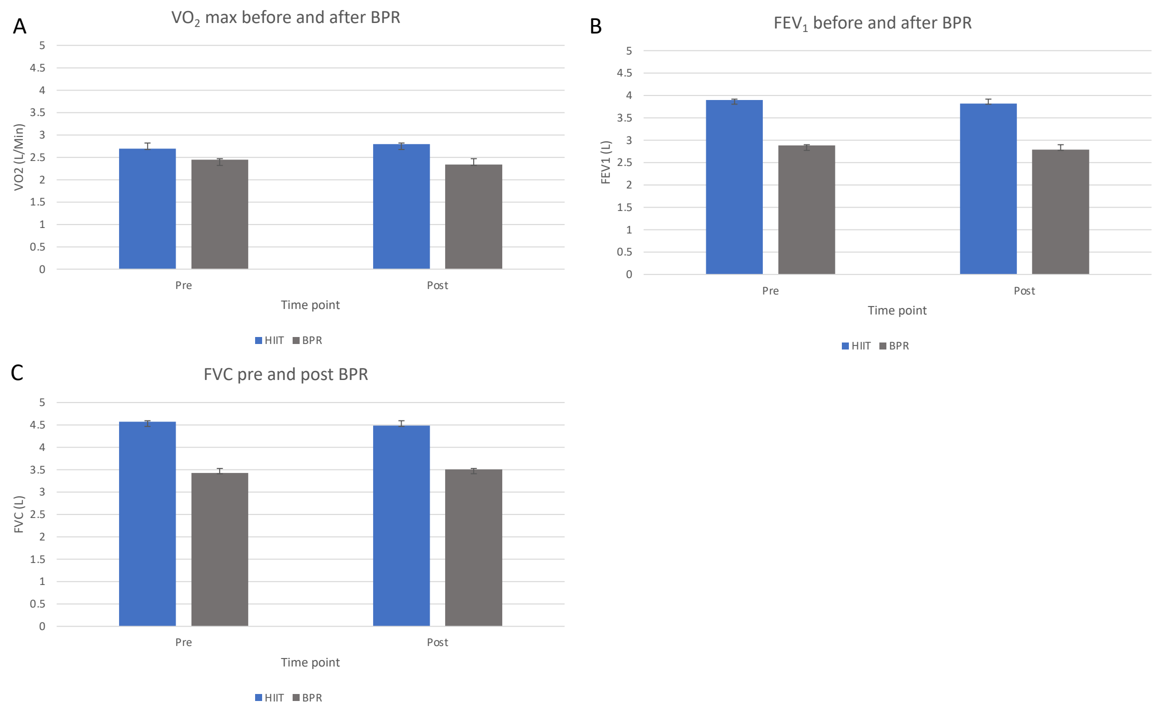

Figure 4. Mean changes in breathing parameters and lung function for HIIT and BPR groups: a) VO_2 max, b) FEV_1, and c) FVC before and after the breathing pattern retraining (BPR) intervention. Error bars represent the standard deviation.

4.3 Physiological Outcomes

Other physiological parameters, such as VO_2, RER, V_E and BF, which were recorded during the VO_2 max test can be analysed to show if they have been affected by the different training programmes. The ANOVA was also performed on both groups' physiological data across the different time points (start of the VO_2 max test, ventilatory threshold 1 (VT1), ventilatory threshold 2 (VT2), and at VO_2 max) throughout the VO_2 max test at both visits and were deemed to be normally distributed by the Shapiro-Wilk test. It was apparent that there had been no statistically significant changes or differences in the participants' VO_2 max, RER, V_E and BF ($p = 0.56, 0.46, 0.76, 0.88$, respectively). The mean and standard deviation of the physiological values for the HIIT and BPR groups are shown in Figure 5.

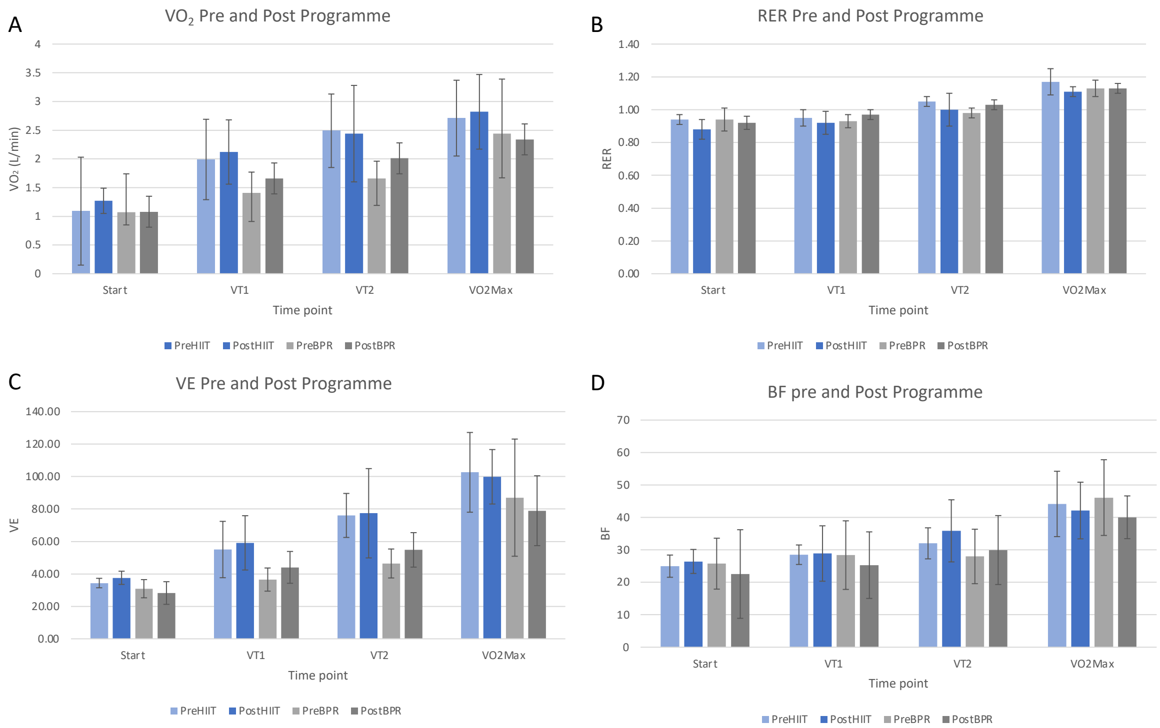

Figure 5. Mean of participants' changes in physiological parameters analysed during VO_2 max test: a) VO_2 , b) RER, c) V_E and d) BF before and after the breathing pattern retraining (BPR) intervention. Error bars represent standard deviation.

4.4 Perceptual Symptoms

While there were no significant differences in the physiological outcomes of the VO_2 max tests, it was possible to investigate whether the training programmes had any impact on the way the participants perceived how their symptoms had affected them during the study. The participants filled out Nijmegen questionnaires at the start, middle, and end of the programmes, and recorded a rating of perceived breathlessness throughout their VO_2 max tests which indicated whether they had any symptoms at the start, VT1, VT2, and VO_2 max time points (Figure 6). The ANOVA showed that there was a statistically significant improvement in the two groups' scores for the Nijmegen questionnaire at the start versus the end of the study ($p = 0.003$), which tells us that participants recorded lower scores as the study progressed indicating reduced severity of their respiratory symptoms. Despite this, there was no statistical difference between the HIIT and BPR groups' improvements (p = 0.365). This improvement in score in the Nijmegen questionnaire was seen at both a group (Figure 6a) and individual level (Figure 6b).

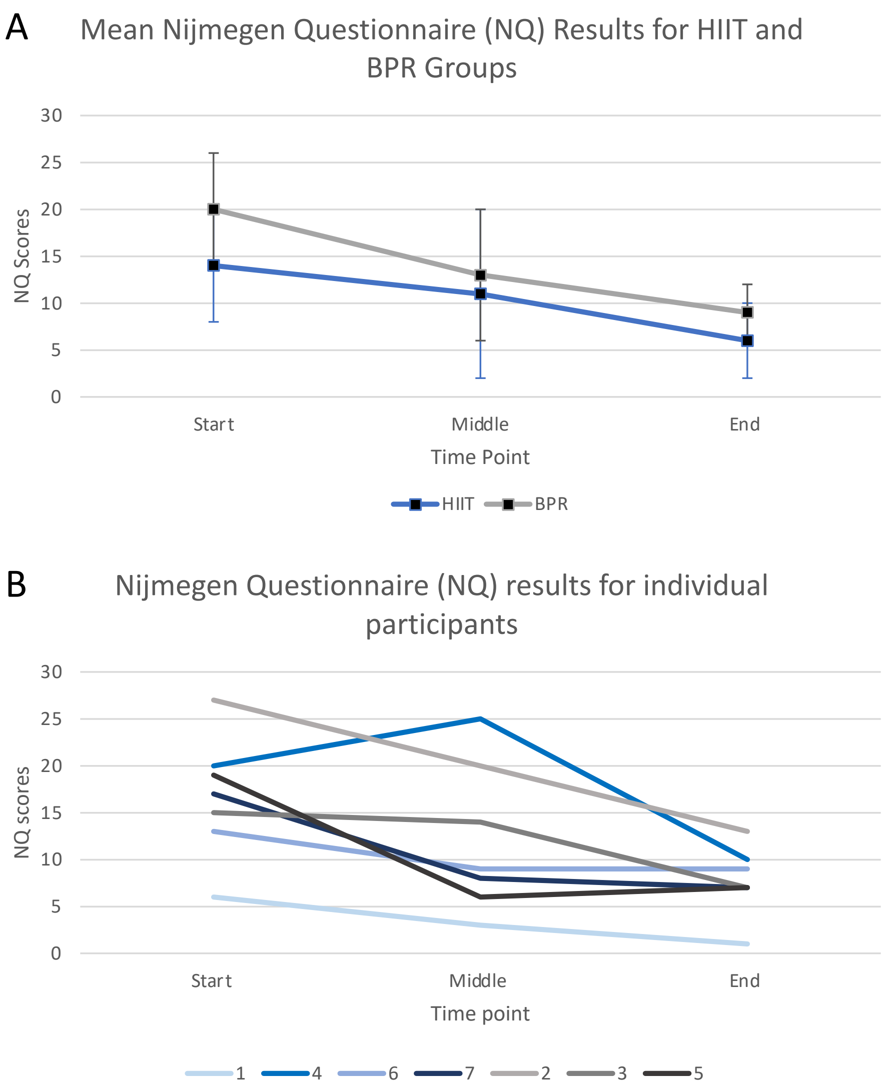

Figure 6. Nijmegen Questionnaire scores for the HIIT and BPR groups at the beginning, middle (3 weeks) and end of the training programme showing the a) mean and b) individual participants scores.

Furthermore, the ANOVA showed that there was a significant difference in the groups' mean scores on the Borg Breathlessness Scale at the start versus the end of the study (p = <0.001), however there was no statistical difference between the groups' improvements (p = 0.270) (Figure 7).

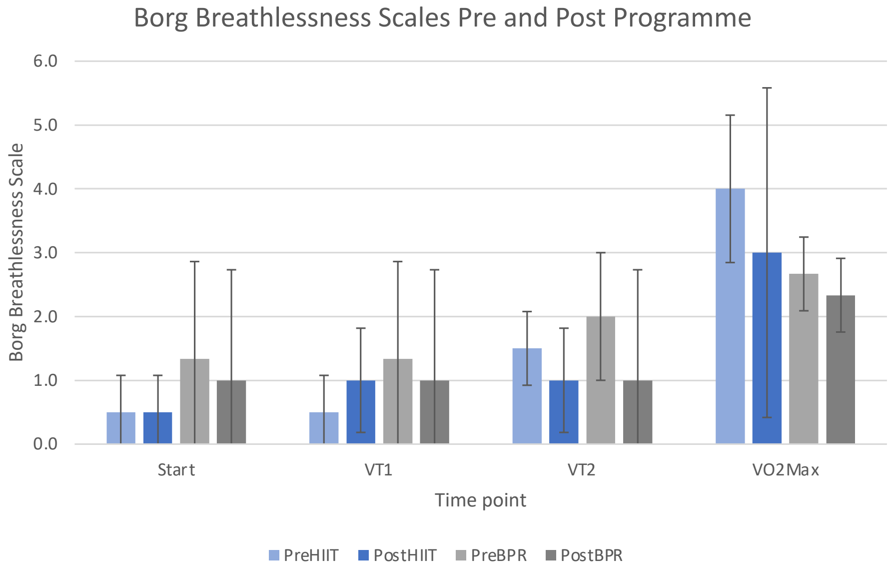

Figure 7. Mean scores (± standard deviation) of perceived breathlessness based on the Borg Breathlessness scale, report by participants at each time point for both the HIIT and BPR group.

5.0 Discussion

5.1 Effects of the Training Programmes

In this study, there were no statistically significant differences in the improvements in the VO_2 max and lung function between the different programmes ($p > 0.05$). Although the participants from both groups' ratings of perceived breathlessness during the VO_2 max test (Figure 7), and Nijmegen questionnaire results (Figure 6) were significantly improved ($p = <0.001$ and 0.003 respectively), there were no significant difference between the improvements between the two groups. This was consistent with the results from Thomas *et al.,* 2003 and Hagman *et al.,* 2011 which showed that breathing retraining impacted patients' respiratory symptoms at rest and during exercise, although these studies did not compare the added effect of HIIT. However, the addition of the HIIT programme did not further improve the symptoms experienced by the participants in the training group, which is contrary to the effects of HIIT training in other studies that have been investigating COPD, cardiovascular disease, or other respiratory conditions (Conraads *et al.,* 2015; Molmen-Hansen *et al.,* 2012; Amundsen *et al.,* 2007; Lind *et al.,* 2021; Beauchamp *et al.,* 2010). These studies however are differing to the present study due to conditions such as sample size of the groups, slightly longer training studies, and the nature and differences in the diseases being investigated.

Some explanations for the differing outcomes of this study and those investigating the effect of HIIT in other respiratory diseases may be due to an aspect of this programme such as programme length or programme intensity. For example, the Thomas *et al.* study from 2003 had fewer visits to the laboratory with one group session and a further two individual sessions over the first three weeks, but as the sessions were led by a physiotherapist, with asthma education sessions, and explanations and practice of breathing retraining exercise, this may have improved the participants' adherence to the exercises. The analysis of the differences between the control group and the intervention group took place over one- and six-month periods, which allowed for further time for the participants to retrain their breathing pattern.

Aspects of the participant inclusion criteria could also affect the outcomes of the study. For example, the current level of exercise prior to the induction of the programme for each participant could result in a different level of response to the training. Bradley & Esformes in 2014 for instance required their patients to exercise at least three times per week to be included in the study. This could be due to the differing levels of exercise efficiency that can change in participants of older ages (Woo *et al.,* 2006). The varied age and sex of the participants could also lead to further discrepancies, as women in older age going through the menopause experience decreases in metabolism and weight gain (Mishra & Devanshi*,* 2011). Though there was one participant who this applies to at the completion of the study, a study this small could have the results affected by such discrepancies.

Analysis of each participant's VO_2, RER, V_E, and BF at four different time points from their VO_2 max tests also showed no significant improvements after the exercise programme differences (Figure 5). Despite the lack of statistical significance in the changes in the physiological values from the VO_2 max test, it does show small increases in VO_2 at the end of the test (Figure 4a). Likewise, Figure 5d shows small decreases in BF after the second ventilatory threshold which may be due to small corrections in breathing pattern achieved over the six-week training programme helping the participants to not over breathe during the VO_2 max test. These differences could however simply be due to the participants becoming more familiar with the testing environments, such as the facial equipment being used, and being generally more accustomed to the laboratory environment. This is substantiated in the data for rating of perceived breathlessness in Figure 7, which also shows decreases in scores given throughout the test.

Despite no statistically significant changes in physiological parameters after the interventions, the results of parameters such as the previously mentioned breathlessness scale and the Nijmegen questionnaire in this study shows that the training programmes may have a positive effect on the participants' perceptions of their own symptoms, such as what occurred during the Hagman (2011) and Thomas (2003) studies. Although these parameters are subjective as they rely on the perceptions of the participants, they are nonetheless an important method of understanding how the participants are feeling and the levels of comfort that they are experiencing. It is an important outcome of this study to know that after completing the BPR, participants felt more comfortable during exercise they completed in the laboratory through their Borg breathlessness results (Figure 7) and during their own leisure reported through the Nijmegen Questionnaire (Figure 6).

The addition of physiotherapist led sessions, a longer study length, and the use of visual aids such as OEP (Smyth *et al*., 2021), may have enhanced the differences seen between the interventions. Figure 6 shows the decrease in NQ scores, which was deemed a significant (p

= 0.003), however the differences between the two groups' decreases were not (p = 0.365). With BPD having a large effect on the population of people who suffer with the condition (Barker & Everard, 2015), any research that can aim to reduce the intensity of the symptoms that people experience may go a long way in breaking down barriers for participation in recreational exercise.

5.2 Limitations

One obvious limitation to these results is the size of the population that was tested at part of the study. A small sample size can often lead to difficulty when completing statistical testing as the lack of participants can reduce the power of the results generated where having a larger sample size enables more trends and differences to be seen between participants. The lack of enrolment in this study meant that the groups were not sufficiently large enough to observe whether there was a true difference between the HIIT intervention and the BPR.

It should be noted that this study was conducted in 2021-2022, following the COVID-19 pandemic, which may have impacted the recruitment of participants for the study due to the nature of the study involving breathing symptoms. Anxiety surrounding COVID-19 or the misattribution of symptoms to long COVID may have meant people excluded themselves from the study. The study largely recruited in and around the university campus, and with the introduction of home learning, the requirements of students and staff to be present on campus decreased which could have been a potential barrier to participation. Furthermore, the varied age range and fitness levels of the participants means that each participant will react to the interventions in very different ways, with older age being associated with a decrease in exercise efficiency (Woo *et al.,* 2006).

Another limitation to this study is that it is there was no method of knowing whether the participants were adhering to the instructions given on the breathing retraining, such as the techniques and prescription of the training across the course of the week. It was not reasonable to expect participants to attend the laboratory twice daily to have observed sessions, with some participants engaged in either full time work or commuting from distance to participate in the study. Studies such as the Hagman *et al* study in 2011 and the Holloway & West study in 2007 delivered the breathing pattern retraining through physiotherapist led sessions each week that meant participants could be actively coached on their breathing pattern across the course of the study. Without this, participants in the present study may have been reinforcing incorrect parts of their breathing pattern without knowing which could offset the validity of the study. Similarly, participants completing the breathing pattern retraining exercise in different volumes according to the prescribed programme could bring about differences in results, however this would have been difficult to prevent even with physiotherapy led sessions, unless the participants agreed to undertake no other exercise during the six-week study at the start of the programme. A study that required the participants to complete their BPR in the laboratory alongside their HIIT training may result in better adherence to their programme. Checking in with participants' progress weekly instead of fortnightly could also lead to better adherence to the BPR. Finally, an interesting addition to the present study, had there been a larger recruitment of participants, would have been the addition of a control group who did not undergo HIIT or BPR, which would have been able to show the impact BPR was having. For example, the Thomas *et al.,* study from 2003 had an intervention group which included the BPR, but also a control group, which involved only asthma education sessions, so was able to draw out the differences made by the BPR.

5.3 Future Research

At the time of writing, this is the first study to have looked at using HIIT in tandem with BPR as a method of rehabilitation for BPD. Though it is a small study, the results show that there are small improvements, albeit not statistically significant, in the participants' VO_2 max scores and the physiological parameters that can be analysed within them. There were also significant improvements in the participants' Nijmegen Questionnaire scores, although the HIIT group did not show any significant differences to the BPR group. This shows that this present study can potentially be used as a pilot study for further testing with a larger sample size which may demonstrate that HIIT could have a role to play in rehabilitation for this population of dysfunctional breathers.

The original hypothesis was composed with ideas from the Smyth *et al.,* study in 2021 which showed that, using OEP for live feedback, participants' can have a conscious awareness of their breathing pattern during exercise which can help them with correcting it during an exercise bout. Though the present study did not have access to that technology, future research that would be able to use this technology, whilst also applying a HIIT programme may help to increase the participants' awareness of their breathing pattern during their training. Participants in the present study often neglected using their new knowledge on breathing pattern during their HIIT sessions, as observed by incorrect breathing pattern by the researcher, but once reminded about applying their new breathing pattern exercises during sessions, it helped to alleviate their symptoms. Having technology such as OEP during a HIIT session may not only act as a further visual aid to help the participants control their breathing pattern, but also help in diagnosing in which way their breathing pattern is dysfunctional (for example thoracic dominant or thoracic-abdominal asynchrony) which may result in curtailing the BPR to be more specific to each participant's needs.

6.0 Conclusions

This study indicates that BPR with, or without, HIIT can decrease the intensity of exercise respiratory symptoms for a population of dysfunctional breathers according to scores taken from both the participants' ratings of perceived breathlessness during a VO_2 max test, and the Nijmegen questionnaire. An added HIIT training programme showed not to have any further effects on the participants' symptoms neither did it significantly improve VO_2 max results after the programme was completed. Analysis on physiological parameters during the test showed that the HIIT training can illicit small changes on breath frequency and minute ventilation, however these changes were also not statistically significant. Future research on this intervention should recruit a larger sample size to determine whether breathing retraining in tandem with HIIT could further decrease people's exercise respiratory symptoms. This future research should also consider using visual aids such as OEP in order to provide more accurate live feedback on breathing pattern during exercise for more accelerated rehabilitation.

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Appendices

Appendix 1. Normality table showing significance levels for main variables.

Variable	P Value
VO_2 Max	Pre-Programme - 0.11 Post-Programme - 0.70
FEV_1	Pre-Programme - 0.71 Post Programme - 0.86
FVC	Pre-Programme - 0.73 Post-Programme - 0.69
NQ	Pre-Programme – 0.67 Post-Programme – 0.36

Appendix 2. Borg breathlessness scale (Borg, 1982).

Borg Score/ Breathlessness scale:

This is a scale that asks you to rate the difficulty of your breathing. It starts at number0 where your breathing is causing you no difficulty at all and progresses through to number 10 where your breathing difficulty is maximal.

How much difficulty is your breathing causing you right now?

During exercise you should try to work at number 3-4. This is where you are feeling moderately breathless on exercise**.**

Stop exercising if you experience chest pain or symptoms of angina, if you **are too** breathless to continue, experience increased wheeze or any other symptoms; such as calf pain, dizziness or nausea.

0	**Nothing at all**
0.5	**Very, very slight (just noticeable)**
1	**Very slight**
2	**Slight**
3	**Moderate**
4	**Somewhat severe**
5	**Severe**
6	
7	**Very severe**
8	
9	**Very, very severe (almost maximal)**
10	**Maximal**

Appendix 3. Nijmegen Questionnaire

Nijmegen Questionnaire

A score of over 23 out of 64 suggest a positive diagnosis of hyperventilation syndrome.

	Never 0	Rarely 1	Sometimes 2	Often 3	Very Often 4
Chest pain					
Feeling tense					
Blurred vision					
Dizzy spells					
Feeling confused					
Faster or deeper breathing					
Short of breath					
Tight feelings in chest					
Bloated feeling in stomach					
Tingling fingers					
Unable to breathe deeply					
Stiff fingers or arms					
Tight feelings round mouth					
Cold hands or feet					
Palpitations					
Feeling of anxiety					