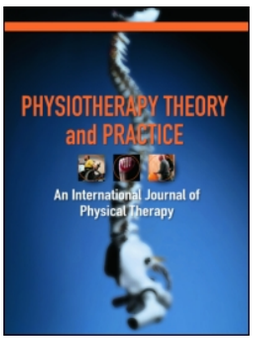

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Breathing pattern recordings using respiratory inductive plethysmography, before and after a physiotherapy breathing retraining program for asthma: A case report

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ABSTRACT

Breathing retraining (BR) improves symptoms, psychological well-being and quality of life in adults with asthma; but there remains uncertainty as to mechanism of effect. One of the intuitively logical theories is that BR works through altering breathing pattern. There is currently no evidence, however, that BR does result in measurable changes in breathing pattern. In this case report we describe the effects of physiotherapy BR on a 57-year-old female with a 10-year history of asthma. Data were collected before and after a physiotherapy BR program comprising three sessions over 18 weeks: breathing pattern (respiratory inductive plethysmography (RIP); physiology (end tidal carbon dioxide ($ETCO_2$), heart rate, oxygen saturations, spirometric lung function); questionnaires (Asthma Control Questionnaire (ACQ), Hospital Anxiety and Depression Score, Nijmegen Questionnaire); and medication usage. After BR, the patient's symptoms improved. Her physiology was largely unchanged, although her FEV_1 increased by 0.12L, peak flow by 21L/min. The patient reported using less Salbutamol, yet her asthma control improved (ACQ down 1.5). Her Nijmegen score dropped from positive to negative for hyperventilation (from 39 to 7). Her anxiety-depression levels both reduced into 'normal' ranges. The patient's expiratory time increased, with longer respiratory cycles and slower respiratory rate. No changes were seen in relative contributions of ribcage and abdomen. Controlled trials are now needed to determine the generalizability of these findings.

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Asthma; breathing pattern; breathing retraining; respiratory inductive plethysmography

Introduction

There is now a convincing body of evidence that breathing retraining (BR) for people with asthma is effective in improving patient-reported endpoints such as symptoms, health status, and psychological well-being, and may also be effective in reducing rescue bronchodilator medication usage. A systematic review of the effectiveness of BR in adult asthma was published in Thorax in 2009 (Bott et al., 2009). Their assessment of breathing exercises for asthma was: 'Breathing exercises, incorporating reducing respiratory rate and/or tidal volume and relaxation training, should be offered to patients to help control the symptoms of asthma and improve quality of life (Grade A)'.

However, studies related to the mechanisms underpinning BR have lagged behind the literature documenting their clinical effectiveness. One of the intuitively logical theories is that BR works through altering breathing pattern. The stated aims of BR for asthma are to 'normalize' breathing pattern by adopting a slower respiratory rate with longer expiration and reduction in overall ventilation (Ritz and Roth, 2003). The teaching also involves the use of nasal breathing and encouraging a predominantly abdominal (rather than upper chest) pattern, making more use of the diaphragm (Thomas and Bruton, 2014). However, it is still not known if BR significantly alters any of these parameters, because no published trial to date has recorded sufficiently detailed information on breathing pattern.

Physiotherapists are aware that patients often become more breathless when they are talking; this occurs because of the competition imposed between communicational needs and respiratory demand (Lee, Loudon, Jacobson, Stuebing, 1993). Compared to resting breathing, speech imposes additional stress on respiration, making it useful to highlight respiratory problems. The inability to speak in complete sentences is a clinical pointer to acute respiratory distress (Woollard and Greaves, 2004). Previous research has suggested that analysis of breathing during speech tasks can be useful for examining breathing patterns before

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and after a pulmonary rehabilitation program (Tehrany, Bruton, Barney, 2016).

This case report is the first to describe detailed objective measures of breathing pattern, at rest and during speech tasks, in a single patient before and after a clinical physiotherapy BR program for asthma. The work was approved by Southampton A Central Ethics Committee (Ethics number: 14/NI/0018). The patient was recruited via a respiratory medical consultant who routinely referred patients with asthma for physiotherapy BR. Written consent was obtained on the first day of physiotherapy BR.

Case description

The patient was a 57-year old female who lived with her husband and pet dog. She was 1.65 m tall and weighed 58 kg, giving her a 'healthy' BMI of 21.3. She had a 10-year history of asthma managed pharmacologically on a combination of Symbicort 200/6 turbohaler two puffs twice a day, Spiriva 18mcg handihaler one puff once a day, montelukast 10mg at night, and a salbutamol inhaler to be taken as needed. She was also taking 10mg of omeprazole for reflux and Avamys nasal spray for chronic rhinosinusitis. She was referred for a respiratory physiotherapy outpatient appointment for assessment of a possible breathing pattern disorder, after it was noted at a routine asthma clinic appointment, that she was experiencing both oral and digital paraesthesia whilst performing spirometry.

The patient received three face-to-face sessions of assessment and physiotherapy BR over a period of 16 weeks. The content of this program was similar to that described in a previous publication (Thomas and Bruton, 2014).

Outcome data collection

The following data were collected on the first and last day of her BR sessions with the physiotherapist: breathing pattern data; physiology data (i.e. end tidal carbon dioxide ($ETCO_2$), heart rate, oxygen saturations, spirometric lung function, and controlled breath hold time [breath hold at functional residual capacity, held to the point of initial discomfort]); questionnaire data (i.e. Asthma Control Questionnaire (ACQ), Hospital Anxiety and Depression Score (HADS), and a hyperventilation screening tool - Nijmegen Questionnaire); and medication usage.

At the first physiotherapy session, after giving informed consent, the patient's demographic data and medication usage were recorded. She was then instrumented with the $ETCO_2$ nasal cannulae, and an oxygen saturation sensor (finger probe). Oxygen and carbon dioxide data were recorded over a period of four minutes while she sat quietly, completing the questionnaires. The sensors were removed and she was then asked to do a timed controlled breath hold, after which she performed spirometric lung function tests: forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC), adhering to guidelines set out by the American Thoracic Society (Miller et al., 2005). This was followed by breathing pattern data collection.

Breathing pattern recording procedure

An Inductotrace® (Ambulatory Monitoring Inc., Ardsley, NY) device, which is a respiratory inductive plethysmograph, was used to measure the patient's breathing pattern from the displacements of her ribcage (RC) and abdomen (AB) during inspiration and expiration. Respiratory inductive plethysmography (RIP) is considered to be the best available non-invasive method for measuring breathing pattern. The principle of operation is based on frequency changes in coils around the body. These frequency changes are proportional to changes in the cross-sectional area within the coils, which are much closer to changes in actual volume than other methods (Penzel and Canisius, 2006). The patient was fitted with two elasticized belts (Inductobands) embedded with Teflon insulated wire coils. One band was secured around her chest at the level of the ribcage (below the axilla) and one round the abdomen (below the lowest vertebral rib). A custom-built analogue-to-digital converter was used to convert the signals acquired by the RIP to digital form. Calibration of breathing parameters was performed off-line using Qualitative Diagnostic Calibration (QDC) previously described by Sackner (1996).

The patient's breathing and speech breathing patterns were recorded during three two minute periods of: 1) quiet breathing; 2) reading; and 3) conversational speech. The same task order was used for both data collection sessions. The RIP Inductobands were removed after each recording period. The same data recording procedure was followed on the last day of the BR program.

Extraction of breathing parameters from recordings

All breathing parameters were extracted using a customized peak detection algorithm written in Matlab® (2009). Breathing parameters were calculated through the detection of the local minima and maxima (defined as the lowest and highest points respectively) of each individual displacement signal recorded from the RIP, and from their sum. Eight breathing parameters were directly extracted from the recorded signals: 1) inspiration time (TI) and 2) expiration time (TE) in seconds,

defined as the time from a minimum to the next maximum signal, and time from a maximum to the next minimum respectively; 3) inspiration volume (IV) and 4) expiration volume (EV) expressed in arbitrary units and defined as the signal amplitude change from minimum to maximum and from maximum to minimum respectively; regional percentage contributions of the ribcage (RC) during 5) inspiration and 6) expiration (%RCinsp and %RCexp); and regional percentage contributions of the abdomen (AB) during 7) inspiration and 8) expiration (%ABinsp and %RCexp)–these were defined as the amplitude change during inspiration or expiration in the RC or AB signal relative to the amplitude of the sum of the two, and expressed as a percentage. The mean of each of the eight parameters over each 2-minute recording was then calculated. One further parameter, respiratory rate (RR) in breaths per minute was then calculated by summing the TI and TE for each cycle, to get the total breathing cycle duration, and taking the reciprocal of the mean of this measure over the 2-minute recording period to give RR.

Physiotherapy Intervention

Physiotherapy session 1

When the patient first presented for physiotherapy, her main symptom was exertional dyspnoea, only being able to manage about five minutes playing with the grandchildren before having to stop through breathlessness. She also complained of central chest pain, tight feelings in her chest and tingling in her fingers, both on exertion and at rest.

On initial examination by the physiotherapist, the patient's breathing pattern was noted to be predominantly apical with reduced abdominal movement. Her respiratory rate was 16 breaths per minute, and she had no end-expiratory pause. She was a habitual mouth breather despite good bilateral nasal airflow. Her Nijmegen score was measured at 39/64 and her controlled breath hold timed at 13 seconds. During this initial physiotherapy session, time was spent explaining the relationship between a dysfunctional breathing pattern and asthma. The first session of physiotherapy was aimed at re-educating the patient's dysfunctional breathing pattern by switching the focus of apical movement to lower abdominal movement and make use of breathing control. This was taught with the patient in the sitting position. A demonstration of good abdominal movement was given by the physiotherapist, and then the patient was encouraged to mimic this movement. Nose breathing was also encouraged to filter and warm inspired air. The patient was asked to carry out these breathing control exercises at home for 10 breaths up to 10 times a day. There are currently no guidelines for the frequency of exercise repetition. We believe the repetition frequency needs to be high enough for the improved pattern to become more natural, but not so high that it becomes burdensome, or unachievable.

Interim medical review

Four weeks after her initial physiotherapy session, the patient was reviewed by a specialist respiratory registrar in a hospital out-patient clinic. It was reported that she remained symptomatic with her asthma symptoms and was using up to 10 puffs of her salbutamol daily, which was causing her to experience palpitations. An ECG was recorded and normal sinus rhythm reported. Her forced exhaled nitric oxide (FeNO) level was measured at 33 ppb and her asthma control questionnaire (ACQ) was 3.85, both of which reflect uncontrolled asthma symptoms. The patient's medication was changed from Symbicort to Fostair 100/6 three puffs twice daily. Fostair is a small particle inhaler with improved lower airway deposition, which was prescribed in an attempt to control her uncontrolled symptoms. The doctor also encouraged the patient to continue with her BR program.

Physiotherapy session 2

This second physiotherapy appointment was four weeks after her medical review (eight weeks after her first respiratory physiotherapy session). The patient reported an improvement in her asthma symptoms. Her Nijmegen score had reduced to 30/64 and although the score was still high (a score over 23/64 being positive indicative for hyperventilation symptoms), it suggested an improvement in her hyperventilation-related symptoms. The patient reported carrying out her breathing control exercises between 4–6 times a day, and was finding nose breathing becoming more natural. Her breathing pattern was observed and she was noted to have greater use of her abdomen and less apical movement. The patient was encouraged to continue with regular home practice of the breathing control exercises, using the now-improved breathing pattern, at the same number of repetitions. The aim was to ensure she mastered the correct breathing pattern and would be able to embed it into her daily life.

The patient's controlled breath hold was measured and found to have increased marginally to 15 seconds. It is believed that a longer end-expiratory breath hold is associated with better control of breathing, which reflects improved asthma control. During this session the controlled breath hold was therefore introduced as an exercise to be practiced

three times in succession, three times a day, in addition to the 10 breathing control breaths up to 10 times per day. The patient was given the target of increasing her breath hold time to over 20 seconds over the next few weeks. Our clinical experience is that greater asthma control is gained with a minimum breath hold of 20 seconds. Respiratory physiotherapy follow-up was arranged for 8 weeks later to allow for an extended period of time to practice and master these techniques.

Physiotherapy session 3

The third (final) physiotherapy session was eight weeks after the second (16 weeks after her first physiotherapy session). The patient reported that she had been continuing to practice the breathing control exercises regularly, that they now felt natural and automatic to her and that she was feeling much more in control of her breathing. This was reflected in a reduction in her Nijmegen score to 10/34 and an increase in her controlled breath hold time to 26 seconds. Her breathing pattern was observed and she was noted to have predominance of movement in her lower abdomen with little apical movement. It was also noted that the patient breathed through her nose throughout the session.

The improvement in her symptoms was discussed with the patient and she was made aware of the importance of maintaining this correct breathing pattern during her activities of daily life. The patient was advised to continue to check her controlled breath hold once weekly as a way of monitoring her overall breath control. She was advised that if were to drop below 20 seconds, she should increase the frequency of her breathing control exercises again to 10 breaths up to 10 times a day as advised in the first physiotherapy session. Our clinical experience suggests that this is a good way to help patients maintain breath control as it is unlikely that patients will continue with a high frequency of exercise repetition in perpetuity. The patient expressed that she now felt able to manage her breathing independently and she was discharged back to the care of her General Practitioner.

Outcomes

At the end of the physiotherapy BR program, the patient's exertional dyspnoea was much reduced and she reported that she was able to walk the dog for half a mile without becoming breathless. Her symptoms of paraesthesia, chest pain and chest tightness had all gone.

The patient's heart rate, $ETCO_2$ and oxygen saturations were essentially unchanged after the BR program (Table 1). There were small increases in her lung volumes and flows. The average minimal patient perceivable improvement for FEV_1 is reported as 0.23 L and for Peak Expiratory Flow Rate (PEFR) it is 18.79 L/min (Santanello et al., 1999). The patient's increase in FEV_1 was 0.12 L (below the threshold for perceivable improvement) and her PEFR increase was 21L/min (above the threshold for perceivable improvement).

Table 1. The patient's physiological data.

	Before breathing retraining	After breathing retraining
FEV_1 (litres)	1.20	1.32
FVC (litres)	1.66	1.74
FEV1% (%)	72	79
PEFR (litres/minute)	249	270
$ETCO_2$ (kPa)	5.1	4.1
HR (beats per minute)	91	89
SpO_2 (%)	97	97
BHT (seconds)	13	26

FEV_1 – forced expiratory volume in one second; FVC – forced vital capacity; PEFR – peak expiratory flow rate, $ETCO_2$ – end-tidal carbon dioxide; HR – heart rate; SpO_2 – oxygen saturation; BHT – breath hold time

The questionnaire data revealed the following changes. The patient's Nijmegen score reduced to below the threshold for hyperventilation (> 23), her anxiety and depression levels (HADS scores) reduced below the accepted threshold for 'normality' (normal range = 0–7), and her asthma control (ACQ) improved by 1.5 (Table 4). A difference in score of 0.5 in the ACQ is the smallest that can be considered clinically important (American Thoracic Society, 2016; Qoltech, 2016). Her controlled breath hold time had also increased from 13 to 26 seconds.

Table 2 gives details of the patient's breathing pattern during two minutes of quiet breathing, reading and conversational speech before and after the BR. Although the data for the quiet breathing recordings at the first session were unfortunately corrupted, data from both the reading and conversational speech tasks showed that the patient's expiration times were increased, with longer breathing cycles, and a reduced respiratory rate after the BR program. Her inspired and expired volumes increased during the conversation task, but not the reading task. No changes were seen in the average contributions of her ribcage and abdominal movement to respiration. Before the BR the patient was predominantly using her ribcage, and this remained the same after the BR. There were some differences in these parameters between reading and conversational speech tasks, but ribcage movement was consistently dominant.

After the BR, the patient reported reducing the number of puffs of Salbutamol that she took from between 9 and 12 a day, to around 6 a day (Table 3).

Table 2. The patient's breathing pattern parameters before and after the breathing re-training programme during quiet breathing (QB), reading (R) and conversational (C) speech tasks (2 minute periods for each).

	TI (sec)		TE (sec)		IV (a.u)		EV (a.u)		Ttot (sec)		RR (bpm)		%RCexp		%ABexp	
ID	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
QB	- *	1.58	- *	2.50	- *	0.38	- *	0.38	- *	4.08	- *	14.68	- *	82.23	- *	15.25
R	0.57	0.79	2.38	3.46	0.50	0.48	0.49	0.48	2.98	4.24	20.31	14.09	84.98	76.78	14.83	22.65
C	0.49	0.76	2.82	3.97	0.40	0.76	0.40	0.77	3.29	4.71	18.08	12.64	83.15	94.95	17.40	4.12

TI (sec) = Inspiration time (seconds); **TE (sec)** = expiration time (sec); **IV (a.u)** = inspiration volume (arbitrary units); **EV (a.u)** = Expiration volume (arbitrary units); **Ttot (sec)** = breathing cycle time (sec); **RR (bpm)** = respiratory rate (breaths per minute)**;%RC Insp =** Ribcage percentage contribution to inspiration**; %AB Insp** = Abdominal percentage contribution to inspiration; %**RC Exp** = Ribcage percentage contribution to expiration; %**AB Exp** = Abdominal percentage contribution to expiration. *Unfortunately, there was some equipment failure during the quiet breathing recording session on the patient's first day, which meant that these data were corrupted and therefore unusable.

Table 3. The patient's self-reported medication usage.

Before breathing retraining	After breathing retraining
Symbicort inhaler (once a day)	Fostair inhaler (twice a day)
Salbutamol (9–12 puffs per day)	Salbutamol (6 puffs per day)
Montelukast (once a day)	Montelukast (Once a day)

Table 4. The patient's questionnaire data.

	Before breathing retraining	After breathing retraining
NQ	39	7
HADS	A = 10, D = 15	A = 1, D = 1
ACQ	3.83	2.33

NQ – Nijmegen hyperventilation questionnaire; HADS – Hospital Anxiety and Depression Scale; ACQ = asthma control questionnaire

The average minimal patient perceivable improvement for inhaled beta-agonist use is said to be −0.81 puffs a day (Santanello et al., 1999). However, the patient's GP changed her medication from Symbicort to Fostair 6 weeks after starting her BR. Symbicort and Fostair are both combination inhalers. They contain a long-acting beta-agonist to relieve ongoing symptoms, such as breathlessness and a tight chest, plus a corticosteroid to prevent inflammation in the airways over the long term. Symbicort is combined budenoside and formoterol, while Fostair is combined beclomethasone and formoterol. These inhalers are said to be similar in efficacy, but no trials have made direct comparisons between them. A reliever inhaler (such as Salbutamol) is usually prescribed as well, as in the patient's case, to give immediate on-the-spot relief from asthma symptoms (Asthma UK, 2016)

Discussion

BR for asthma has been associated with improvements in several patient centered endpoints, such as symptoms, health status and psychological well-being (Bruton and Thomas, 2011), but studies related to the mechanisms of the intervention have lagged behind those documenting clinical effectiveness. Although one of the intuitively logical theories is that BR works through altering breathing pattern, no published trials of asthma BR have included detailed objective measures of breathing pattern in their outcome measures. Some previous studies have reported $ETCO_2$ (Ritz et al., 2014; Thomas et al., 2009) and some have reported minute ventilation (Bowler, Green, Mitchell, 1998; Thomas et al., 2009), but this was the first opportunity to record detailed objective measurements of breathing pattern and movement before and after a BR program for a patient with asthma.

There were changes and improvements reported by the patient herself for patient centered outcomes such as medication usage, hyperventilation (Nijmegen questionnaire), asthma control (ACQ), and anxiety and depression (HADS). There is also some evidence from the patient's case report that her objective breathing parameters and lung function (PEFR increase) also altered following the intervention.

Breathing pattern changes

The conversational speech task was associated with larger changes in breathing pattern following the BR program than the reading task. A conversational speech task provides individuals with the ventilatory freedom to make adjustments to their speech within a comfortable range to avoid breathlessness, because conversational speech does not impose any pre-scripted grammatical boundaries (Winkworth, Davis, Adams, Ellis, 1995). In contrast, a reading task cues individuals to breathe and pause in response to the pre-written grammatical boundaries in the text, resulting in less flexible breathing patterns (Winkworth, Davis, Ellis, Adams, 1994), which imposes more stress on the respiratory system.

As well as teaching control of respiration in terms of timing and volume, asthma BR also encourages the use of a predominantly abdominal (rather than upper chest/apical) pattern of breathing, making more use of the diaphragm (Thomas and Bruton, 2014). We examined the patient's chest and abdominal movements from the RIP data, anticipating a change towards

more abdominal breathing, in line with the physiotherapy teaching and with the physiotherapist's direct observations. No such change was recorded. We are uncertain, however, about the validity of RIP data for measuring these parameters. Although RIP is reported to be the 'gold standard' for non-invasive breathing pattern recordings, the validity studies have been based on timing and volume measures, not on compartment contributions (Chadha and Sackner, 1983; Tobin et al., 1983a, 1983b). In our experience the recommended placement for the lower RIP band (umbilicus level) may not capture the area of the abdomen most likely to move during respiration.

Patient centered factors

A previous randomized controlled trial of (RCT) BR for asthma reported some reductions in anxiety and depression, but only after six-months post intervention (Thomas et al., 2009). Another RCT by Holloway and West (2007) showed no changes, but involved patients with levels of anxiety and depression within the normal range at baseline, giving no room for improvement. In the patient's case there were reductions in levels of both anxiety and depression, which went from being high enough to be clinically relevant to being 'normal'. There were also improvements in the patient's perception of her asthma control. These changes exceeded the Minimal Clinically Important Difference that has been reported for the ACQ (Qoltech, 2016).

Reductions in use of reliever medication have been reported in several trials of BR for asthma (O'Connor et al., 2012). The patient's medication usage also changed. She was able to reduce her Salbutamol (reliever) intake, suggesting the occurrence of fewer episodes of acute bronchoconstriction. Reduced periods of bronchoconstriction may permit longer, more sustained expirations and longer breathing cycles, with a slower respiratory rate, as observed in this case. During the retraining period the patient switched from using Symbicort to Fostair (both are combination inhalers). It is not possible to know, therefore, if the patient's reduction in reliever use was related to her BR, or her altered combination medication, or to some other factor.

Previous trials of asthma BR have not reported any significant changes in Nijmegen scores (Holloway and West, 2007; Thomas et al., 2009), but in these studies baseline mean group scores were below the threshold for hyperventilation, leaving little room for improvement. The patient's subjective hyperventilation score started high (39) and reduced to well below the threshold for hyperventilation syndrome after the program. In contrast, one of the objective physiological parameters that might be associated with hyperventilation ($ETCO_2$) was largely unchanged and remained within normal ranges. However, one of the limitations associated with using capnography to record carbon dioxide levels in awake individuals is the need for nasal cannulae, which will not capture the outgoing breaths in a habitual mouth breather. The patient's controlled breath hold time increased (doubled) which suggests she had gained better control over her breathing, and may indicate an improved tolerance to carbon dioxide, but this is speculation.

Future research

The objective measurement of respiratory movements is not straightforward, and all of the available clinical tools present problems. Although RIP is a valid portable instrument for non-invasive recording of respiratory timing and volume, it has limitations with regard to compartmentalising ribcage and abdominal contributions to respiration. Advancing technology and miniaturisation is already resulting in the production of new tools that need to be evaluated in both research and clinical settings. During BR for asthma, clinicians aim to alter respiratory movements and encourage nasal breathing; so we need technologies that can record these simply, but objectively, in the clinical setting. BR for asthma is effective, but we still do not know how the effect is produced, or whether it is related to real changes in breathing pattern, or route of breathing.

Conclusion

This case report has demonstrated that it is possible to collect detailed breathing pattern data in a clinical environment and that changes in breathing pattern can be identified within an individual before and after a physiotherapy BR program. The patient showed improvements in patient centered outcomes, such as medication usage, respiratory symptoms and psychological well-being; and she also showed changes in the objective measurements of her breathing pattern. In particular, her respiratory timing parameters were found to alter in line with the teaching to produce longer expirations and longer breathing cycles, and a slower respiratory rate. It is unfortunate that her medication was changed during her breathing retraining program, as this has made it more difficult to identify the cause of her improvements. The lack of measurable objective change in her use of ribcage and abdomen was unexpected, and this area requires further research with other tools. There is also a need to assess the route of breathing before and after BR. Controlled studies

with a cohort of patients are now needed to establish if the detailed analysis of objective measurements of breathing pattern have value as an outcome measure of BR, or can be used to shed light onto the mechanisms behind the acknowledged effectiveness of BR. Until then clinicians are encouraged to continue to make use of BR techniques to modify breathing patterns in those with symptoms of dysfunctional breathing.

Declaration of Interest

The authors report no declarations of interest.

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