DYSFUNCTIONAL BREATHING:
ITS PARAMETERS, MEASUREMENT AND RELEVANCE

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requirements for the degree of
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DECLARATION BY CANDIDATE

Except where due acknowledgment is made the work is that of the candidate alone.

The work has not been submitted previously, in whole or in part for any other academic award.

The content of the thesis is work that has been carried out since the official commencement date of the approved research project.

Any editorial work, paid or unpaid, carried out by a third party is acknowledged.

Rosalba Courtney

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LIST OF ABBREVIATIONS

BBT	Buteyko Breathing Technique
BHT	Breath holding time
BHT-DD	Breath holding time till first desire to breathe
BHT-IRM	Breath holding time till involuntary muscle motion
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CP	Control Pause
CSF	Cerebral spinal fluid
DB	Dysfunctional breathing
$ETCO_2$	End Tidal CO_2
FEV1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
HGYB	How Good is Your Breathing Test
HRV	Heart Rate Variability
HVPT	Hyperventilation Provocation Test
HVS	Hyperventilation Syndrome
LRCA	Lower Rib Cage Abdomen
MARM	Manual Assessment of Respiratory Motion
MARM%R	Manual Assessment of Respiratory Motion percentage of rib cage motion
M%RC	Mean % of rib cage contribution to tidal volume as measured by RIP.
MP	Maximum Pause
NQ	Nijmegen Questionnaire
OEP	Optoelectronic Plethysmography
$PaCO_2$	Partial pressure of arterial carbon dioxide
$PACO_2$	Partial pressure of alveolar carbon dioxide
PO_2	Partial pressure of oxygen
QCT	Quick Coherence Technique

RIP	Respiratory Induction Plethysmography
SEBQ	Self Evaluation of Breathing Questionnaire
SPO_2	Oxygen saturation of hemoglobin
T_E	Time taken for exhalation
T_I	Time taken for inhalation
$T_I/Ttot$	Fractional inspiratory time
T_{tot}	Duration of whole cycle of breath
URC	Upper rib cage
V_{min}	Minute volume
V_T	Tidal Volume
V_T/T_I	Mean inspiratory flow
WBB	Whole Body Breathing

THESIS ABSTRACT

Background- The commonly held idea that 'proper' breathing is important for health is generally accompanied by the view that incorrect or 'dysfunctional' breathing has adverse effects on health. It has been proposed that correction of dysfunctional breathing through breathing therapy reduces symptoms and improves the health of patients with conditions such as asthma, anxiety, speech disorders, chronic muscular skeletal dysfunction and medically unexplained physical symptoms. However, investigation of the impact of dysfunctional breathing and breathing therapies is hampered by the fact that dysfunctional breathing is not well defined and that there are few validated measures or standardized protocols to measure it.

Aims - The four main objectives of the experimental portion of thesis are:

- To further develop and validate some clinical tools for assessment of dysfunctional breathing;
- To explore and evaluate current methods for assessing dysfunctional breathing particularly those used by breathing therapists;
- To investigate the relationships between measures of dysfunctional breathing with a view to understanding the possible definitions and dimensions of dysfunctional breathing; and
- To explore possible mechanisms of breathing therapy.

Format- A series of seven studies were untaken. These papers, which are all published (or in press) manuscripts, form the experimental portion of this thesis. The seven studies presented in the empirical section of this thesis are grouped in four sub-sections- The first of these contains two studies on the topic of 'Measuring Breathing Pattern', the second contains one study on the topic 'Evaluating Dysfunctional Breathing Symptoms', the third include two studies that investigate 'Relationships between Measures of Breathing Functionality' and the final sub-section contains two studies that explores 'Measures of Dysfunctional Breathing and Breathing Therapy'.

Methods-Various non-experimental and quasi-experimental study designs were used. The studies reported in Chapters 6 and 7 tested inter-examiner reliability and accuracy of manual breathing assessment tools. Chaper 8 involved

administration of a survey with subsequent exploratory factor analysis of the survey items. Chapters 9, 10, 11 and were primarily correlational studies. Chaper 12 was a post-hoc analysis of clinical data. The participants in the study reported in Chapter 6 were 10 Yoga teachers or breathing therapists and 3 Osteopaths as examiners. The participants in the study reported in Chapter 7 were 56 Osteopaths and Osteopathic students. The 83 participants in the studies reported in Chapters 8,9,10 and 11 were either healthy or suffered from mild medical conditions. The 62 participants in the study reported in Chapter 12 were consecutive patients receiving treatment with a method of breathing and relaxation therapy called Whole Body Breathing.

Results/Discussion - Manual techniques for evaluating breathing pattern appear to be useful and reasonably accurate for evaluating thoracic dominant breathing and paradoxical breathing. The Self Evaluation of Breathing Questionnaire appears to have two dimensions that might be related to biochemical and biomechanical aspects of breathing dysfunction. Poor relationships between different categories of measures of dysfunctional breathing suggest that dysfunctional breathing has several dimensions. Breathing pattern appears to moderate dyspnea and altering breathing pattern may be one mechanism of breathing therapy.

Conclusion - While dysfunctional breathing cannot be strictly defined at present, for practical purposes dysfunctional breathing is probably best characterized as multi-dimensional. Dysfunctional breathing can occur in at least three dimensions: biochemical, breathing pattern and breathing related symptoms and these might not co-exist. Comprehensive measurement of dysfunctional breathing should include measures that evaluate all these dimensions. The therapeutic mechanisms of breathing theory are likely to be complex and include psychological, biomechanical and physiological parameters. However, dysfunctional patterns of breathing are one factor that influences patients' response to breathing therapy. Also correction of dysfunctional breathing patterns is one likely therapeutic pathway of breathing therapy, particularly for patients with dyspnea.

CHAPTER 1-INTRODUCTION

BACKGROUND

This thesis explores dysfunctional breathing, its measurement, possible definitions and its relationship to breathing therapy.

Many diverse groups, including respiratory psychophysiologists, physical therapists, somatic or mind/body therapists and practitioners of Yoga, Qi Gong or specialized breathing therapies like the Buteyko Breathing Technique share the belief that breathing can be salutogenic and therapeutic. To various degrees, they hold the view that the optimization of breathing is a means to improving health of the mind and body. A corollary to this view is that dysfunctional breathing is both a cause and consequence of poor health.

Various types of breathing therapy have been used, with apparent success, to treat conditions such as asthma, anxiety, speech disorders, chronic musculoskelatal dysfunction and medically unexplained physical symptoms. However, research into the use of breathing therapies in these conditions is hampered by the fact that their mode of action is not well understood.

One proposed mechanism of breathing therapies is that they correct dysfunctional breathing; yet dysfunctional breathing does not have a precise definition. The term can refer to hyperventilation, breathing pattern disorders or medically unexplained dyspnea but in a broad sense the term can also be taken to imply a disturbance of any function of breathing.

Dysfunctional breathing is evaluated using of a range of measures, such as levels of oxygen and carbon dioxide, breathing pattern, breath holding time and symptom questionnaires. These measures can be seen to be representative of biochemical, biomechanical, psychological and interoceptive parameters. The relationships between these various parameters are not well understood. It is not clear if these measures represent distinct or related aspects of breathing functionality, and it is also not clear which measures should be used in a comprehensive evaluation of dysfunctional breathing or in clinical assessments.

Improvements in dysfunctional breathing measures, such as breath holding time, breathing pattern, carbon dioxide measures and symptom questionnaires, have, at different times, been reported to be associated with positive therapeutic responses in patients practicing different types of breathing therapies. Therefore, a better understanding of these measures may be the key to developing understanding of the mechanisms of breathing therapies

Finally, some measures of dysfunctional breathing, including the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo breathing assessment, appear promising, but have not been adequately validated. Also, symptoms proposed to indicate the presence of dysfunctional breathing might provide the basis for a dysfunctional breathing questionnaire. This thesis begins by further developing and evaluating the MARM and the Hi Lo and then describes the development and factor analysis of a new questionnaire, the Self Evaluation of Breathing Questionnaire (SEBQ) for evaluating dysfunctional breathing symptoms.

THE OBJECTIVES OF THIS THESIS

The overall objectives of this thesis are to explore possible definitions of dysfunctional breathing and gain a better understanding of the role of dysfunctional breathing in the efficacy of breathing therapies. These objectives, which are the focus of the experimental portion of this thesis, are approached through an exploration of the measures of dysfunctional breathing, particularly those used by proponents of breathing therapies.

The main objectives of the experimental portion of thesis are:

- To further develop and validate some clinical tools for assessment of dysfunctional breathing;
- To explore and evaluate current methods for assessing dysfunctional breathing particularly those used by breathing therapists;
- To investigate the relationships between measures of dysfunctional breathing with a view to understanding the possible definitions and dimensions of dysfunctional breathing; and
- To explore possible mechanisms of breathing therapy.

EVOLUTION OF THE RESEARCH QUESTIONS IN THE EXPERIMENTAL PORTION OF THE THESIS

The specific research questions addressed in the individual studies that make up the experimental portion of this thesis evolved over the course of this research. All the papers in the experimental portion of the thesis have either been published or are in press. The order in which these studies are presented is not the same order in which they were performed or in the order that manuscripts were published. This section of the introduction describes the progression of the studies, and the evolution of the research questions addressed in this thesis to assist the reader in understanding how they are linked.

One of the initial objectives of this thesis was to investigate the assumption of a breathing therapy called the Buteyko Breathing Technique (BBT) that hypocapnia was the most important aspect of dysfunctional breathing and that the therapeutic mechanism of the BBT was dependent on reducing hyperventilation and normalising CO_2 levels in the blood and in the lungs.

Dr. Buteyko, originator of the BBT, developed a formula for assessing CO_2 levels from breathing holding time and assumed that improvements in patient's breath holding time indicated improved CO_2 status. The first study conducted in this thesis tested Dr. Buteyko's formula for calculating CO_2 from breath holding time. It also looked at how breath holding time and CO_2 levels correlated with other measures of dysfunctional breathing. This study resulted in a published study, presented in Chapter 10 titled "Investigating the claims of Dr. K.P. Buteyko: The relationship of breath holding time to end tidal CO_2 and other proposed measures of dysfunctional breathing".

Further analysis of the data gathered in this study was used in three other studies. The first of these, presented in Chapter 9, has been published and is titled "*Relationships between Measures of Dysfunctional Breathing in a Population with Concerns about Their Breathing*". Given that screening tools for dysfunctional breathing include measures that might represent distinct aspects of breathing functionality (e.g. biochemical, biomechanical, psychological or

physiological), a primary aim of this study was to further understand the dimensions of dysfunctional breathing and begin to explore what range of assessments might be necessary for a comprehensive evaluation of breathing.

The second study from this same data set, presented in Chapter 11, is in press and is titled "Relationship between dysfunctional breathing patterns and ability to achieve target heart rate variability with features of "coherence" during biofeedback". This study was based on the hypothesis that breathing patterns commonly associated with dysfunctional breathing (i.e. thoracic breathing and paradoxical breathing) would adversely affect cardiorespiratory interactions and the amplitude and frequency of heart rate variability.

The third study from this data set, presented in Chapter 8, describes the development and structural analysis of a questionnaire, the Self Evaluation of Breathing Questionnaire (SEBQ). This questionnaire was compiled from various sources and contains items proposed to identify individuals with dysfunctional breathing. The need for this type of questionnaire arose because the validated questionnaire that researchers used to identify dysfunctional breathing, the Nijmegen Questionnaire, was devised to measure hyperventilation syndrome rather than the broader definition of dysfunctional breathing sought in this thesis. Therefore a new questionnaire, the SEBQ, was developed and its structure analyzed. The published manuscript of this study is titled "Preliminary investigation of a measure of dysfunctional breathing symptoms: The Self Evaluation of Breathing Questionnaire (SEBQ)". The main aim of the structural (factor) analysis of the SEBQ was to explore whether the items of this questionnaire represented distinct and separate dimensions of dysfunctional breathing.

Results of these studies and the literature indicated that breathing pattern was an important aspect of dysfunctional breathing, yet much of the literature only seemed to define breathing pattern in vague terms. The manual palpation techniques used in the studies undertaken in this thesis, the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo appeared promising, but needed further validation studies to determine their rigour and

reproducibility. This led to the two studies that investigated the utility and validity of these manual techniques for measuring breathing pattern.

The first of these published studies, validating the MARM, presented in Chapter 6, is titled "Evaluation of Breathing Pattern: Comparison of a Manual Assessment of Respiratory Motion (MARM) And Respiratory Induction Plethysmography". The main aims of this study were firstly to compare the MARM to a gold standard instrument for measuring breathing pattern, the Respiratory Induction Plethysmograph, and, secondly to determine the level of agreement achieved by different examiners.

The second study assessing the MARM and Hi Lo, presented in Chapter 7, is titled, "Comparison of the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo Breathing Assessment in determining a simulated breathing pattern". In the previous study, a high level of inter-examiner reliability was found for the MARM. Given that this previous study had used very experienced practitioners, it was not clear whether less experienced practitioners would be able to use these techniques with a similar degree of accuracy. Therefore, in this second study, the MARM and another technique called the Hi Lo were taught, in a short two hour training session, to two groups. One group was made up of experienced manual therapists (Osteopaths), the other group were students of Osteopathy. The main aim of this study was to gauge whether a two hour training period was sufficient to learn these techniques and whether accurate performance in the use of these techniques was affected by the general level of experience in manual therapy.

The final study, presented in Chapter 12, evaluated the therapeutic mechanism of an established breathing therapy, called "Whole Body Breathing". This study explored the relationships between breathing symptom and breathing pattern with the aim of determining whether breathing pattern moderated dysfunctional breathing symptoms. This study, titled "Medically unexplained dyspnea: partly moderated by dysfunctional (thoracic dominant) breathing pattern", has been accepted for publication and is in press.

The order in which the studies are presented in this thesis is described in the following section, which also outlines the content of the literature review chapters.

ORGANISATION OF CHAPTERS

THIS FIRST (CURRENT) CHAPTER IS THE INTRODUCTION

Chapter 1 - Introduction

CHAPTERS 2 - 5 ARE THE LITERATURE REVIEW CHAPTERS

Chapter 2 - The Functions of Breathing explores ideas about the functions of breathing as a means of understanding the possible parameters of dysfunctional breathing.

Chapter 3 - Hyperventilation Disorders provides an overview of the literature on hyperventilation disorders. It examines the changing perspectives on the role of hyperventilation in dysfunctional breathing.

Chapter 4 - The Functions and Dysfunctions of Breathing Pattern provides an overview of the functional anatomy of breathing. It also considers the role of breathing patterns disorders in dysfunctional breathing.

Chapter 5 - Dysfunctional Breathing discusses current usage of the term, dysfunctional breathing, and the various measures used to assess it. This chapter also identifies possible parameters of dysfunctional breathing based on proposed functions of breathing.

CHAPTERS 5 - 12 ARE THE EXPERIMENTAL PORTION OF THIS THESIS

SECTION ONE - CONTAINS TWO STUDIES EXAMINING MANUAL TECHNIQUES FOR EVALUATING BREATHING PATTERN

Chapter 6 - 'Evaluation of breathing pattern: Comparison of a manual assessment of respiratory motion (MARM) and respiratory induction plethysmography'.

Chapter 7 - 'Comparison of the manual assessment of respiratory motion (MARM) and the Hi Lo breathing assessment in determining a simulated breathing pattern'.

SECTION TWO- CONTAINS ONE STUDY WHICH DESCRIBES THE DEVELOPMENT AND STRUCTURAL ANALYSIS OF A DYSFUNCTIONAL BREATHING QUESTIONNAIRE

Chapter 8 - 'Preliminary investigation of a measure of dysfunctional breathing symptoms: The Self Evaluation of Breathing Questionnaire (SEBQ)'.

SECTION 3-CONTAINS TWO STUDIES, FROM THE SAME DATA SET, THAT EXPLORE THE RELATIONSHIPS BETWEEN MEASURES OF DYSFUNCTIONAL BREATHING

Chapter 9 - 'Relationships between measures of dysfunctional breathing in a population with concerns about their breathing'.

Chapter 10 - 'Investigating the claims of Dr. K.P. Buteyko: The relationship of breath holding time to end tidal CO_2 and other proposed measures of dysfunctional breathing'.

SECTION 4- CONTAINS TWO STUDIES THAT EXPLORE THE RELATIONSHIPS BETWEEN DYSFUNCTIONAL BREATHING AND BREATHING THERAPY

Chapter 11 - 'Relationship between dysfunctional breathing patterns and ability to achieve target heart rate variability with features of "coherence" during biofeedback'.

Chapter 12 - 'Medically unexplained dyspnea: partly moderated by dysfunctional (thoracic dominant) breathing pattern'.

THE FINAL CHAPTER CONTAINS THE THESIS DISCUSSION AND CONCLUSIONS

Chapter 13 - Discussion

CHAPTER 2- THE FUNCTIONS OF BREATHING

INTRODUCTION

To answer the question 'what is dysfunctional or abnormal breathing?' one can first enquire 'what is normal, functional or optimal breathing?' This section of the literature review explores these questions from the scientific literature and also from the perspective of some breathing therapies and various religious and healing traditions, some of which have not been scientifically evaluated but are of interest because they provide a broad context for later chapters.

Optimal breathing is often described as something that occurs in the perfectly healthy person who is in a state of physical rest and emotional ease. The following quote gives this description of the breathing pattern of such a person:

"During quiet rest a normal man breathes with effortless ease; he is not aware of his breathing or of a sensation of breathlessness (or dyspnea). His respiratory frequency is usually below 16 breaths per minute and if he is of average size, the tidal volume is less than 600ml" p 599 (Bass and Gardner 1985).

The Indian yoga literature describes optimal breathing in a person with peak physical health and emotional ease as slow, regular, even, diaphragmatic and nasal (Ramacharaka 1904; Swami Rama 1976; Sovik 2000). Taoist yoga adherents describe perfect breathing as inaudible and "so smooth that the fine hairs within the nostrils remain motionless" p136 (Blofeld 1978).

It has been argued that equating optimal or functional breathing with an ideal of breathing found in a healthy, calm and resting person has limitations, because the average person living in the 'real world' does not live in a state of continual physical rest or constant emotional calm. A person's breathing, to be functional, must adapt appropriately to changes in their external environment and their internal metabolic and emotional conditions. Particular breathing patterns that appear less than optimal may actually be an appropriate response to a particular circumstance and individuals may suffer from diseases or other

conditions that benefit from breathing adaptations that are in conflict with ideals of optimal breathing (Dixhoorn van 2007). Elsa Gindler, the originator of the Gymnastik movement of the early 1900's, from which many prominent European and American breathing therapies developed, says

"if we observe successful people we can often see that they display a wonderful flexibility in reacting, in constantly changing from activity to rest. They have flexible breathing or functional breathing" p9 (Johnson 1995).

Breathing functionality has often been characterized in terms of how well normal levels of CO_2 are maintained (McLaughlin 2009). One breathing therapy, the Buteyko Breathing Technique, equates optimal breathing and superior physical health and endurance with the presence of carbon dioxide levels well above established textbook norms (Buteyko 1990; Stark and Stark 2002).

Breathing functionality is also judged on the basis of the biomechanical functions of the muscular and skeletal components of the respiratory pump (De Troyer and Estenne 1988) and other aspects of breathing pattern and behaviour (Chaitow 2002). Breathing therapists often note breathing patterns and particular patterns are considered to be more optimal or functional than others based on their biomechanical efficiency although there is some argument about how to best characterise an ideal breathing pattern (Kaminoff 2006).

These various ways of viewing functional breathing provide some insight but do not give a complete picture. In the interests of having a more rounded view, this thesis starts with the premise that functional breathing is breathing that performs and adapts its various functions to quickly and appropriately meet the changing needs of the individual. These needs may be related to changes in physical, metabolic or psychophysiological conditions.

This leads to the next question explored in this literature review: 'What are the functions of breathing?'

The primary visible function of breathing involves the biomechanical action of the respiratory pump, which moves air into and out of the lungs. The other primary function, related to the first, is biochemical and involves

maintenance of correct arterial Oxygen (O_2) and Carbon Dioxide (CO_2) levels and the regulation of the body's pH. However, breathing has other functions, referred to here as secondary functions. For example, breathing affects motor control and postural stability and plays several roles in physiological and psychological regulation. Breathing can influence homeostatic functions in other systems including the autonomic nervous system, the circulatory system, the vestibular system, pH regulation and metabolism. Breathing is also thought to have important functions in self-regulation of stress and emotion. It is also worth taking note that most of the world's major religions believe that breathing has psycho-spiritual functions. These secondary functions are to a varying extent dependent on the efficiency and functionality of the primary biomechanical and biochemical functions of breathing, the ability to accurately perceive breathing sensations, and the efficiency and resilience of breathing control mechanisms.

PRIMARY FUNCTIONS OF BREATHING

THE RESPIRATORY PUMP

The biomechanical actions of the respiratory pump play a vital role in influencing the movement of air into and out of the lungs and also influence pressure and volume fluctuations within the circulatory and lymphatic systems. The approximate 21,000 breaths taken per day by the average person are dependent on the actions of the respiratory muscles on the chest wall. Changes in chest wall dimensions result in pressure changes within the intrapleural and alveolar spaces in relationship to atmospheric pressure and as a result, air moves either into or out of the lungs. Before inspiration, intrapleural pressure is −5 cm H_2O and alveolar pressure is 0 cm H_2O. During inspiration, alveolar pressure and intrapleural pressure fall becoming lower than atmospheric pressure. This establishes a driving pressure and air moves into the lungs inflating them. On expiration alveolar pressure becomes positive and intrapleural pressure rises creating movement of air out of the lungs (West 1985).

In addition to the movement of air, the actions of the respiratory pump affect other systems including the cardiovascular system, the lymphatic system and the muscular-skeletal system. A functional respiratory pump requires the properly co-ordinated action of the primary muscles of respiration such as the diaphragm, scalenes, intercostals and also the secondary muscles of respiration. An optimally functioning respiratory pump therefore requires normal length, strength, resting tone and responsiveness of respiratory muscles.

Functions and dysfunctions of the biomechanics of breathing are discussed in Chapter 4 of this thesis.

MAINTENANCE OF LEVELS OF O_2, CO_2 AND PH

Breathing is a key contributor to the biochemical state of the internal milieu. By exchanging CO_2 for O_2, breathing controls the fundamental gaseous fuels of life's energy which move between the arterial and venous blood to the alveoli through the process of diffusion. By altering ventilation to regulate CO_2, breathing also maintains pH in the narrow range needed for health (West 1985; Lumb 2000).

The health and integrity of the lung tissue and the circulatory system is fundamental to the maintenance of normal levels of the respiratory gases which are disturbed by disruptions in breathing or its regulation. This thesis concerns itself with functional breathing disturbances resulting primarily from disturbances in regulation of respiration rather than pathology of the heart and lungs.

Functions and dysfunctions of the biochemical aspects of breathing are discussed further in Chapter 3 of this thesis.

SPECIAL FUNCTIONS OF BREATHING

POSTURAL AND MOTOR CONTROL

Breathing impacts muscular and skeletal function because the habitual use of breathing muscles during respiration affects how these muscles are used for non-breathing movement and postural support.

There are close links between breathing and musculoskeletal function. Particular movements tend to be tied to specific phases of respiration. For example, during extension of the spine one tends to inhale and during flexion one tends to exhale, while lifting a heavy object often leads to the breath being held in, the Valsalva maneuver and standing on the toes leads to contraction of the diaphragm (Lewitt 1980).

Many muscles of respiration have key postural functions and are important for motor control and stability of the spine, neck and shoulder girdle. Even primary respiratory muscles are important for postural support and movement. The diaphragm is now known to have postural as well as respiratory functions (Lewitt 1980; Hodges, Butler et al. 1997; Hodges and Gandevia 2000). The intercostal muscles are involved in trunk rotation, in addition to their role in producing rib cage motion for ventilation (De Troyer, Kelly et al. 1985). In the lower body, the abdominal muscles are considered to be primarily postural muscles that also have a respiratory function (Lewitt 1980). In the upper body, muscles such as the trapezius, sternomastoid and pectoral muscles whose primary function is to move the neck and shoulder girdle, become involved in breathing when respiration or posture is faulty or when the ventilatory needs of the body increase (Lewitt 1980; Kapreli 2008).

SPEECH AND VOCALISATION

The ability to regulate the motor control of breathing muscles for speech and vocalization is linked to the efficiency of the biomechanics of breathing and integration of neuronal control mechanisms of speech and breathing (Gandevia, Butler et al. 2002). Human speech and emotional expression, requires fine control of the muscles of breathing beyond that required for normal ventilation

(Bunn and Mead 1971). This fine motor control, integrated with cognitive factors, is needed to vary normal quiet breathing and enable the production of long phrases punctuated with quick inspirations placed appropriately to give proper linguistic meaning and to control pitch and intonation (MacLarnon and Hewitt 1999).

Stress, emotion and cognitive process can simultaneously affect breathing and speech mechanisms producing dysfunctional muscle tension in these two related systems (Chapell 1994). Paradoxical vocal cord dysfunction, a condition often misdiagnosed as asthma, which often results from severe psychosocial and intense emotion stress, is associated with respiratory difficulty and tense patterns of breathing (Leo and Konakanchi 1999). In conditions such as muscle tension dysphonia, speech muscles contract inappropriately and are incorrectly coupled with inspiration rather than expiration (Vertigan, Gibson et al. 2006). In muscle tension dystonia, breathing is generally inadequate to support proper voice production and most patients show signs of tension in the neck muscles which also function as accessory muscles of respiration (Altman, Atkinson et al. 2005). Attention to correct breathing and relaxation can greatly assist these speech dysfunctions (Lee and Son 2005).

PSYCHOPHYSIOLOGICAL FUNCTIONS OF BREATHING

From the large number of popular media references to the use of breathing for relaxation and stress reduction, it seems widely accepted that attention to, and modification of, breathing produces relaxation and a sense of control in times of stress. Some popular book titles about this subject include "Breathe for Life; De-stress and Enhance Your Fitness" (Gabriel 2000), "Natural Stress and Anxiety Relief; How to Use the Johnson Breathing Technique" (Johnson 2008), "The Breath Connection; How to Reduce Psychosomatic Stress-Related Disorders with Easy-To-Do Breathing Exercises" (Fried 1990). In fact, Umezawa (2001) found that breathing modification is the most common self-regulation strategy for relaxation and stress management (Umezawa 2001).

Research indicates that breathing regulation is effective in changing one's emotional state and response to stress. It has been reported that voluntary

breath modulation accounts for 40% of the variance in positive feelings such as joy and negative feelings such as fear, sadness and anger (Philippot, Gaëtane et al. 2002). Breathing has been shown to calm both mind and body, increase resilience in stressful situations and dampen levels of psychological and physiological arousal (McCaul, Solomons et al. 1979). Numerous studies have also shown that conscious control of breathing improves anxiety, depression and panic disorder (Ley 1999; Ley and Timmons 1999; Brown and Gerbarg 2005).

The routes whereby breathing regulates physiological, cognitive and emotional states associated with stress are not entirely understood, but several psychological and physiological mechanisms have been suggested. It has been proposed that attention to the breath absorbs the mind, distracting it from negative self talk (Chapell 1994). Another reason proposed for the tension reducing effects of breath modulation is that it increases the sense of control or indirectly decreases tension by influencing complex whole body systems (Dixhoorn van 2007). Focused attention to breathing, particularly when combined with its modulation, is proposed to quieten the regions in the cortex involved with anticipation, planning and worry, synchronize brain wave activity in ways similar to meditation, and regulate dysfunctions in the limbic system brought about by chronic stress (Brown and Gerbarg 2005). Pleasurable somatic sensations such as those that can be experienced through slow relaxed breathing are proposed to signal to the brain that homeostasis is being well maintained. These pleasurable sensations activate pleasure networks in the cortex, limbic system and autonomic nervous system that are stress reducing and generally salutogenic (Esch 2004).

Many studies attribute the psychophysiological effects of breathing modification to the fact that it regulates the functions of the autonomic nervous system. Breathing influences sympatho-vagal balance and can produce short-term amplification of parasympathetic activity during a stressful task (Nogawa, Yamakoshi et al. 2007). Regular practice of slow controlled breathing has also been shown to increase basal parasympathetic activity and reduce sympathetic activity (Pal, Velkumary et al. 2004). The increased activity of the

parasympathetic nervous system encouraged by certain types of controlled breathing promotes homeostasis and assists recovery and restoration of function in body systems disturbed by stress (Recordati and Bellini 2004). The sympathetic dampening and parasympathetic promoting effects of breathing on autonomic nervous system function have been seen in patients with chronic obstructive pulmonary diseases (Raupach, Bahr et al. 2008), essential hypertension (Kaushik, Kaushik et al. 2006) and other diseases (Brown and Gerbarg 2005). Dynamic breathing practices, which actually stimulate the activity of the sympathetic nervous system, by increasing respiratory rate, and alternating changing rhythms, may also be useful in re-setting neuro-endocrine components of the stress response when they are used in combination with calming practices (Telles 1992; Brown and Gerbarg 2005).

BREATHING, OSCILLATIONS AND HOMEOSTASIS

Oscillations or fluctuations of activity within systems are vital to homeostasis and regulation because they increase adaptability and coordinated interaction of systems to changes in environmental conditions (Giardino, Lehrer et al. 2000). Breathing functions as an oscillating system that also interacts with, and is a key influence on, other oscillating systems. It influences the feedback mechanisms that maintain homeostasis in systems such as the baroreflex system and the cardiovascular system through its ability to affect the fluctuations in pressure and autonomic nervous function that drive these feedback mechanisms (Daly 1986; Bernardi 2001).

Breathing can be consciously manipulated to entrain other oscillations and increase physiological regulation. When breathing frequency is slowed to between 4 and 6 breaths per minute (0.06-0.1Hz), oscillations in blood pressure, heart rate and autonomic nervous system tend to synchronize at this frequency and be amplified due to resonance effects between these systems (Lehrer, Vaschillo et al. 2000; Vaschillo and Lehrer 2002; Song and Lehrer 2003). Specific frequencies of breathing can improve coupling between body systems and result in improved physiological efficiency (Yasuma and Hyano 2004). These resonance effects between cardio respiratory oscillations and autonomic function, produced by breathing rates of around 0.1 Hz, have

implications for health as evidenced by the fact that regular practice assists people with a range of conditions including asthma, COPD, depression, hypertension and irritable bowel syndrome (Gevirtz 1999; Giardino, Chan et al. 2004; Lehrer, Vaschillo et al. 2004; Karavidas, Lehrer et al. 2007).

Similar to the oscillations in other systems, breathing rhythms can become disturbed in disease or as a result of psychological stress (Wilhelm 2001) yet, unlike other oscillations, breathing can be brought under conscious control and thus provides an avenue for physiological self-regulation.

A BRIDGE BETWEEN MIND AND BODY: THE SOMATIC PERSPECTIVE

Breathing is highly responsive to, and reflects levels of, physiological and psychological arousal and metabolic activity (Dixhoorn van 2007). The breath is also often referred to as a bridge, connector or channel between the body and mind because of the inter-relationship between emotions, mental processes, patterns of body tension and breathing (Johnson 1995; Ley 1999; Mijares 2009). Van Dixhoorn (2007) considers that the breath functions as an indicator of psychological states, presumably in ways that may not always be realised. There is a tradition of breathing therapy, which has as an underlying tenant that increased self-awareness allows better self-regulation with awareness of breathing being considered particularly important. Western modern somatic psychotherapies such as Reichian Therapy and Middendorf Breathing Therapy describe the breath as being a conduit to an expanded self-awareness which is beyond normal day-to-day awareness and which allows a person to access suppressed feelings, the body's innate wisdom and the subconscious mind (Middendorf 1990; Johnson 1995; Mijares 2009). It is also believed that becoming aware of, and fully sensing, the natural breath connects a person with the deeper levels of their psyche and thus supports physical and psychological integration. Middendorf describes the process as holding on the "guide rope of the breath until the clarity of consciousness can develop out of the unconscious" p 78 (Johnson 1995).

ESOTERIC AND PSYCHOSPIRITUAL FUNCTIONS OF BREATHING

Many of the world's major religions include practices that utilise the breath for spiritual purposes. They claim that the breath is a means to control the mind and body, and a pathway to spiritual attainment. This section reviews some of the views about the psychospiritual functions of breathing. No attempt is made to evaluate these from a scientific perspective, as little research exists. However these esoteric views on the functions of breathing are of interest because they illustrate long held beliefs that presumably reflect human experience over many cultures over a long period of time.

In Middle Eastern religions, including Sufism and the mystical branches of the Jewish religion, breathing practices are combined with movement, intonation of sacred syllables and phrases and particular types of visualization (Mijares 2009). The Sufis claim that the supreme value of breath is its ability to connect one with divine consciousness.

Sufi master Hazrat Inayat Khan has been quoted as saying:

"Once a man has touched the depths of his own being by the help of the breath, then it becomes easy for him to become at one with all that exists on heaven and earth" p .151(Mijares 2009).

The Upanishads, ancient Hindu scriptures that constitute the core teachings of Vedanta and form the basis of modern Yoga, refer to the use of breath control and breath attention as means to refine consciousness and achieve states of bliss and transcendence (Feuerstein 2008). In Yoga, breath control is claimed to be the key to gaining the mental control needed for spiritual development. Patanjali, who is often credited with originating much of what has now become modern Yoga, states that:

"the restriction of the fluctuations of consciousness is achieved through expulsion and retention of the breath, according to the yogic rules" Yoga sutras of Patanjali , p219. (Feuerstein 2008)

One of the most enduring books on yoga breathing practices "Science of Breath" by Yogi Ramacharaka (1904) says that:

"Man's mental power, happiness, self-control, clear-sightedness, morals and even his spiritual growth may be increased by an understanding of the science of breath" p 9(Ramacharaka 1904).

In Buddhism, regular and extensive practice of mindful attention to the breath is a core practice for spiritual development. The Annapanasati, Buddha's teachings on the mindfulness of breathing, describes the importance of breathing practices for the development of the mindful states needed for the attainment of self-knowledge, wisdom and ultimately enlightenment:

"When mindfulness of breathing is developed and cultivated, it is of great fruit and great benefit. It fulfills the four foundations of mindfulness. When the four foundations of mindfulness are developed and cultivated, they fulfill the seven enlightenment factors. When the seven enlightenment factors are developed and cultivated, they fulfill true knowledge and deliverance" p.943 (Nanamoli 2001)

In a number of cultures, the breath is equated to spirit or vital energy and breathing practices are credited with the ability to enhance and control the movement of this vital energy or life force. This is proposed to be made evident by the fact that the word for breath and the word for life force or vitality are one and the same in many languages, e.g. in India the term prana is used, in China the equivalent term Qi is used, in Tibet the term is *lung* , in Islam it is *baraka* and in Hebrew, *ruach*. Kalahari Bushmen use the term *num* and the Lakota Sioux use the term *neyatoneyah* (Lewis 1997). The ancient Greeks also appear to have made connection between the function of the diaphragm and thus the breath, with the mind. The Greek word *phren* means mind and we still refer to the nerve which innervates the diaphragm as the phrenic nerve.

SALUTONGENIC AND THERAPEUTIC BREATHING

There is a long tradition of using breathing as a salutogenic tool to enhance wellbeing and as a therapeutic tool to treat disease. In Indian and Chinese Taoist yoga, the salutogenic and therapeutic potency of breath control, are explained in terms of its ability to influence life force (Prana and Qi) and also to calm the nervous system and reduce stress (Ramacharaka 1904; Swami Rama 1976; Nagendra 1999; Sovik 2000; Janke 2002). In Chinese Taoist yoga it is believed that a person who practices breathing control is able to prevent disease and prolong life (Blofeld 1978; Zi 1994; Lewis 1997). In a classic text

of Chinese Medicine from the Han Dynasty (200 BCE-220BCE),′ The Yellow Emperors Classic Book of Medicine′, it is stated:

" Health, well-being, and long life can only be achieved by remaining centered with one's spirit, guarding against squandering one's Qi, using breath and movement to maintain the free flow of Qi and blood, aligning with the natural forces of the seasons, and cultivating the tranquil heart and mind" P 75, Janke (2002).

A complete list of diseases that Indian and Taoists yogis claim to be improved with regular breathing practices (often combined with movement) would be very long and is not attempted here. However, some common examples include; bronchial asthma, diabetes mellitus, hypertension, ischemic heart disease, ophthalmic disorders, irritable bowel syndrome, colitis, anxiety neurosis, depression, tension headache, migraine, arthritis, back pain and epilepsy (Foundation 1996; Sancier 1996; Nagendra 1999). Research studies on Indian yoga breath control or pranayama have indicated that pranayama may be of benefit in the following conditions, insomnia (Khalsa 2004), heart disease(Spicuzza 2000; Shannahoff-Khalsa, Sramek et al. 2004), asthma (Murthy 1983; Nagarathna 1985; Singh 1990; Vedanthan 1998), non insulin dependent diabetes (Monro R 1992), epilepsy, obsessive compulsive disorder and depression(Janakiramaiah 1998; Murthy 1998; Janakiramaiah 1999; Vedamurthachar, Janakiramaiah et al. 2006).

There are also a number of more recently developed western breathing therapies, which are used to treat a wide range of disorders. There is a growing body of scientific evidence for the effectiveness of some of these breathing therapies in a range of diseases including asthma, heart disease, anxiety and depression(Brown and Gerbarg 2005; Dixhoorn van 2007; Karavidas, Lehrer et al. 2007; Meuret, Wilhelm et al. 2008; Bruton and Thomas 2011).

In a systematic review of breathing techniques for asthma, Ernst reported that at least 30% of the 3837 respondents interviewed used breathing techniques to relieve their asthma symptoms (Ernst 2000). The most recent Cochrane review on breathing therapies for asthma identified a number of possibly helpful therapies including the Buteyko Breathing Technique (BBT) (Holloway 2003). There have been at least five published clinical trials on BBT

asthma (Bowler 1998; Opat, Cohen et al. 2000; Cooper, Oborne et al. 2003; McHugh, Aicheson et al. 2003; Abramson, Borg et al. 2004; Slader, Reddel et al. 2006; Cowie, Underwood et al. 2008). These clinical trials indicate that people learning the Buteyko Method are able to substantially reduce medication with no deterioration in their lung function or asthma control, although no studies have demonstrated objective changes in lung function. The quality of evidence for the Buteyko Method according to an Australian Department of Health report is stronger than that for any other complementary medicine treatment of asthma (Marks, Kotsirilos et al. 2005). Recent studies indicate that several other types of breathing therapies also help asthma symptoms and lung function, for example, resonant frequency breathing biofeedback (Lehrer, Vaschillo et al. 2004), capnometry biofeedback (Ritz, Meuret et al. 2009) and breathing rehabilitation(Holloway and West 2007; Thomas, McKinley et al. 2009).

Breathing therapy has also been found to be very helpful for cardiovascular disease. In a study comparing patients who received standard cardiac rehabilitation with those receiving additional training in breathing therapy after myocardial infarction (MI), it was found that the breathing therapy group had about a 30% decrease in cardiac events at 5 year follow-up (van Dixhoorn and Duivenvooden 1999). Another study showed that exercise training in patients with MI was not always successful in preventing future cardiac events, however the risk of treatment failure was reduced by half when relaxation and breathing training was added to exercise training (Dixhoorn, Duivenvoorden et al. 1989). Other breathing therapy based on yoga breathing was also found to improve hemodynamics and various cardiorespiratory risk factors in cardiac patients (Murthy 1998; Shannahoff-Khalsa, Sramek et al. 2004).

The effectiveness of breathing therapies in psychological conditions and chronic stress has also been shown in several studies. In major depression, both resonant frequency biofeedback and modern yoga derived breathing techniques appear to be effective (Janakiramaiah 1998; Murthy 1998; Karavidas, Lehrer et al. 2007). People with anxiety and panic disorder also

show beneficial response to capnometry and other breathing therapy protocols (Tweedale, Rowbottom et al. 1994; Abu-Hijleh, Habbal et al. 1995; Meuret, Wilhelm et al. 2008).

This sampling of the literature on breathing therapies, while not exhaustive, strongly suggests that breathing may be able to function as a therapeutic or salutogenic aid, yet despite many positive research findings, breathing therapies are not widely utilised. One reason for this may be that there is insufficient understanding of the mechanisms underlying breathing therapies. Certain theories about the mechanisms of breathing therapies propose that they helpful because they correct some aspect of dysfunctional breathing.

CONCLUSION

One of the aims of this thesis is to elucidate the nature of dysfunctional breathing. The task has been approached by broadly and inclusively examining the functions of breathing. It can be concluded that the functions of breathing are proposed to go beyond moving air into and out to the lungs for the purposes of maintaining blood gas levels. Breathing is proposed to interact with, and influence, other physiological systems. It is also proposed to have therapeutic, homeostatic, regulatory, psychophysiological and spiritual functions. Understanding the broad functions of breathing and the nature of dysfunctional breathing may help to elucidate the mechanisms of breathing therapies.

CHAPTER 3: HYPERVENTILATION DISORDERS

INTRODUCTION

One of the most important functions of breathing is the maintenance of normal blood levels of oxygen (O_2) and carbon dioxide (CO_2). It is well known that depletion of oxygen (hypoxia) and accumulation of CO_2 (hypercapnia) can occur when the lungs are diseased or circulation is impaired. However, in the absence of severe pathology of the lungs and/or circulatory system, CO_2 depletion is more common than its accumulation (Fried 1987; Lumb 2000). Low CO_2 levels can develop quickly because of the very high solubility of CO_2, and lack of feedback mechanisms for its retention (Levitsky 1995). The ease with which CO_2 is excreted means that sustained increases in ventilatory drive resulting from stress, disease or disorders of respiratory control can result in significant depletion of CO_2 (Heistad, Wheeler et al. 1972; Fried 1987; Fried 1993).

The breathing dysfunction that results in CO2 depletion or hypocapnia is called hyperventilation. Hyperventilation disorders discussed in this chapter include chronic hyperventilation, intermittent hyperventilation and hyperventilation syndrome.

DEFINITIONS

HYPERVENTILATION

Hyperventilation is defined as breathing in excess of metabolic demands, which results in alveolar and arterial hypocapnia (Comroe 1974; Mines 1986; Hlasta and Berger 1996). The relationship between alveolar ventilation and arterial CO_2 levels is shown in the alveolar ventilation equation. This equation shows an inverse relationship between $PaCO_2$ and ventilation so that as ventilation increases $PaCO_2$ decreases (Berne and Levy 1996).

VA (L/min) X $PaCO_2$ (mm Hg) = VCO_2 (ml/min x K).

(VA)=alveolar ventilation
($PaCO_2$)= arterial PCO_2
(VCO_2) = carbon dioxide production.
The unit conversion constant K, is 0.863 mmHg X L/ml.)

Transient increases in minute ventilation that produce hypocapnia are normal responses to increased psychological or physiological arousal and, in the majority of cases, the increased ventilation is adequately compensated by subsequent decreases in respiratory drive so that homeostasis is maintained. However, a hyperventilation disorder exists when this response is exaggerated or persistently results in sustained hypocapnia or frequent intermittent hypocapnia.

CHRONIC HYPERVENTILATION

Individuals with chronic hyperventilation appear to have a low set point for CO_2 resulting in persistently low CO_2 levels. While CO_2 levels may normalize during sleep, they return to low levels soon after waking and supplemental CO_2 inhalation does not return their CO_2 levels to normal (Gardner 1986; Jack, Rossiter et al. 2003).

INTERMITTENT HYPERVENTILATION

In some individuals there may be normal, or only slightly reduced, levels of CO_2 at rest and the exaggerated tendency to hyperventilate is only demonstrated in response to, or in anticipation of, psychological or physiological challenge such as stress or physical exercise (Gardner 1986; Jack, Rossiter et al. 2003). These individuals have some similarities to the sub-category of panic disorder patients with hyperventilation tendencies (Ley 1992). However, it has been proposed that they differ from panic disorder patients in that they are able to tolerate supplemental CO_2 (Jack, Rossiter et al. 2003).

HYPERVENTILATION SYNDROME

The definition of Hyperventilation Syndrome (HVS) has changed in the last 20 years as a result of controversy about the relationship of hypocapnia with the large number of symptoms that had over time come to be associated with this

syndrome. The definition agreed upon by attendees of the 4th International Symposium on Psychophysiology in Southampton in 1984 is as follows:

"Hyperventilation syndrome is a syndrome characterized by a variety of somatic symptoms induced by a physiologically inappropriate hyperventilation and usually produced in whole or in part by voluntary hyperventilation" p287, (Howell 1990).

The definition of the HVS, the role of hypocapnia in producing symptoms historically associated with the HVS and the very existence of the HVS itself came to be questioned over the next decade (Gardner 1995). By 1997, it became clear that the definition proposed in Southampton in 1984 was insufficient. A new definition was proposed at the 3rd International Conference of Respiratory Psychophysiology in Nijmegen, The Netherlands. This definition continues to link medically unexplained physical symptoms with dysregulated breathing but decreases the emphasis on the importance of hypocapnia as an etiological factor:

Hyperventilation Syndrome is " a dysregulation of ventilation, causing hypocapnia, in the absence of somatic causes for hyperventilation, with symptoms not necessarily linked to hypocapnia" p73 (Molema and Folgering 1997).

Despite this more flexible definition, HVS remains a controversial diagnosis. The following brief review of the history of the Hyperventilation Syndrome is presented to provide a context to understanding the controversies surrounding the Hyperventilation Syndrome.

HISTORY OF HYPERVENTILATION SYNDROME

Before the 1980s, Hyperventilation Syndrome (HVS) was a generally accepted diagnosis for patients with anxiety, disturbed breathing and unexplained "psychosomatic" symptoms and was argued to be common, yet infrequently recognized (Lum 1975; Lum 1976; Magarian 1982). Since that time the existence of a defined HVS has been increasingly questioned. After the late 1980's scientists began to increasingly voice doubts about the specific role of CO_2 in the symptoms of HVS and the gold standard diagnostic test for HVS, the

Hyperventilation Provocation Test (HVPT) (Garssen 1992; Hornsveld and Garssen 1996).

While some researchers tried to develop new models that did not entirely dismiss hypocapnia in the pathophysiology of HVS (Hornsveld and Garssen 1996; Howell 1997; Folgering 1999; Wilhelm, Gertivz et al. 2001) others argued that HVS probably did not exist (Hornsveld 1997). In subsequent years, HVS became a controversial diagnosis; researchers tended to avoid it and clinicians struggled to find new names to describe patients with the combination of breathing abnormalities and unexplained symptoms (Hornsveld 1997). In recent years, researchers have begun to reconsider the importance of hyperventilation (Warburton and Jack 2006), and in the field of respiratory psychophysiology there has been a renewal of research interest in the role of hypocapnia in symptom production. This recent work tends to support a moderating role for CO_2 in asthma and panic disorder (Howell 1990; Meuret and Ritz 2010).

Since the beginning of the nineteenth century it has been known that central and peripheral neurovascular symptoms such as numbness, dizziness, muscle hypertonicity and tingling sensations could be brought on by voluntary forced ventilation (Bass 1989) which produces hypocapnia and respiratory alkalosis (Haldane 1908). The idea of a hyperventilation syndrome, which included these classic symptoms of hypocapnia and additional symptoms such as chest pain, palpitations, breathlessness, disorientation and anxiety, began after Kerr reported his use of the hyperventilation challenge to elicit these complaints in 35 patients whose symptoms were otherwise unexplained (Kerr 1937) (Chaitow 2002). The symptoms of one of the main diagnostic labels which preceded HVS, the "effort syndrome", were subsequently attributed to hypocapnia and respiratory alkalosis (Soley and Shock 1938). The range of symptoms attributed to HVS eventually came to encompass a large number of symptoms of central and peripheral neurovascular, muscular, respiratory, cardiac, gastrointestinal origin (Soley 1938; Lewis 1953; Magarian 1982). Typical symptoms of HVS are shown in Table 1.

DOUBTS ABOUT THE ROLE OF HYPOCAPNIA IN HVS

CHRONIC HYPOCAPNIA IN HVS

One reason that the existence of HVS as a distinct syndrome began to be questioned is that patients diagnosed with HVS did not consistently show chronic CO_2 deficit. Researchers found evidence of chronic hypocapnia in a proportion of individuals with HVS but this finding was not universal (Gardner 1995). By the mid 1990's Gardner, in a review of HVS, described the uncertainty about the boundaries of HVS and doubts about its existence largely because of the lack of correlation between symptoms and pCO_2. He reported that patients could have low CO_2 but no symptoms, while other people could have relatively normal CO_2 levels but still exhibit the symptoms of HVS (Gardner 1995). Howell measured PCO_2 levels in 31 patients with disproportionate breathlessness and other symptoms of hyperventilation and found that they had mostly normal levels of CO_2 (Howell 1990). Han, in comparing 399 symptomatic hyperventilators with 347 normals, found no difference in End Tidal CO_2 ($ETCO_2$) (Han, Stegen et al. 1996). In a major review of hyperventilation, Hardonk and Beumer reported that $ETCO_2$ levels were not significantly different in symptomatic or normal controls when measured in the laboratory (Hardonk and Beumer 1979).

THE HYPERVENTILATION PROVOCATION TEST AND ACUTE HYPOCAPNIA IN HVS

The production of symptoms during voluntary hyperventilation sometimes known as the Hyperventilation Provocation Test (HVPT) has been a cornerstone of the diagnosis of HVS and its validity was assumed, but not rigorously tested (Magarian 1982) (Vansteenkiste 1991). Some studies found a relationship between hyperventilation and the onset of recognized HVS symptoms (Soley 1938; Hardonk and Beumer 1979; Huey and West 1983). However, other studies showed a poor relationship or showed that that factors such as mental stress were equally capable of producing the same symptoms (Garssen 1992; Spinhoven, Onstein et al. 1993; Hornsveld and Garssen 1996).

The validity of the HVPT was challenged most strongly by the studies of Hornsveld and Garssen (1996) who showed that a positive response to the

HVPT was not dependant on CO_2, because their research participants also experienced symptoms when breathing a placebo isocapnic gas mixture (Hornsveld, Garsson et al. 1996). In one study 115 patients believed to have HVS were given the HVPT, 74% of their subjects were positive on the test and reported the onset of their symptoms after hyperventilation (Hornsveld, Garsson et al. 1996). However, 65% of these responders were also positive on the placebo test, during which CO_2 levels were kept stable through manual titration. A second stage of this study, involving transcutaneous monitoring of CO_2 levels of patients in their daily lives, showed that patients suffering from attacks of the HVS symptoms suffered only a very slight drop in CO_2 levels at the onset of their symptoms and this usually followed rather than preceded the onset of symptoms (Hornsveld 1997). As this study, and others (Hornsveld 1997), found that neither chronic nor acute deficiency of CO_2 could be experimentally linked to HVS these authors recommended that the term hyperventilation syndrome be discontinued (Hornsveld 1997). In recognition of the fact that causes of breathing-related symptoms are unclear and often associated with psychological disturbance, researchers proposed that the term hyperventilation syndrome be replaced with behavioral breathlessness (Howell 1990) or unexplained breathing disorder (UBD) or chronic symptomatic hyperventilation (Gardner 1995; Howell 1997). Since this research, the term hyperventilation syndrome is used infrequently and the terms dysfunctional breathing (Thomas, McKinley et al. 2001) and breathing pattern disorder (Chaitow 2002) have become more common (Dixhoorn 1997; Chaitow 2002; Stanton, Vaughn et al. 2008).

PREVALENCE OF HYPERVENTILATION DISORDERS

Reports on the prevalence of HVS, in times before this syndrome became questioned, estimated that between 5-10% of the general population suffer with this condition (Brown 1953; Folgering 1999). These estimations were often made on the basis of symptom checklists and on patients' recognition of these symptoms during the Hyperventilation Provocation Test (HVPT) rather than on CO_2 measurement. Given the current doubt about specificity of the characteristic HVS symptoms to hypocapnia and the questionable validity of the

HVPT, the reported prevalence estimates need to be interpreted with caution (Hornsveld 1997).

However, there is reported increased prevalence of hyperventilation and corresponding hypocapnia in individuals with specific medical and psychological conditions including panic disorder and anxiety (Cowley 1987; Wilhelm, Gerlach et al. 2001), depression (Damas Mora, Grant et al. 1976), chronic pain (Wilhelm, Gertivz et al. 2001), functional cardiac disorders (Wilhelm, Gertivz et al. 2001), chronic fatigue syndrome (Bazelmans, Bleijenberg et al. 1997; Bogaerts, Hubin et al. 2007), fibromyalgia (Naschitz, Mussafia-Priselac et al. 2006), asthma (McFadden Jr 1968; Demeter and Cordasco 1986; Tobin 1989; Osbourne 2000; Bruton and Holgate 2005) and autism (Galletti, Brinciotti et al. 1989).

ETIOLOGY OF HYPERVENTILATION DISORDERS

Hyperventilation has been attributed to psychological, physiological and organic causes. In a review of 150 cases of individuals with hyperventilation, Lewis attributed 98 to psychological causes, 47 to mixed psychogenic and organic origin and 5 to purely organic origin (Lewis 1953).

BEHAVIORAL AND PSYCHOLOGICAL CAUSES

Hyperventilation disorders are linked to psychological states such as anxiety, which tend to produce physiological hyperarousal, but not necessarily to any formal psychiatric diagnosis with the possible exception of panic disorder (Gardner 1995). It is well known that strong emotions, particularly when they result in sustained increases in sympathetic nervous system tone, increase respiratory drive and promote hyperventilation (Heistad, Wheeler et al. 1972; Wientjes 1992). Specific emotions and behavioural traits that have been linked at various times to hyperventilation disorders include fear, insecurity, anxiety, resentment, anger, repressed guilt, perfectionism, frustration, and grief (Kerr 1937; Friedman 1944; Lum 1976; Magarian 1982; Bass and Gardner 1985; Howell 1990).

Panic disorder, a condition with complex psychophysiological causes, increases the predisposition to hyperventilation in many suffers (Hegel and Ferguson 1997; Wilhelm, Gertivz et al. 2001). Some studies have shown that panic disorder patients generally have more respiratory symptoms and more hypocapnia than other types of anxiety disorder patients (Hegel and Ferguson 1997). Results of other studies suggest that this is not always the case (Garssen 1992). This may be due to the fact that relationships between hyperventilation and aggravation of panic disorder symptoms exist only in the "hyperventilation subtype" of panic disorder where respiratory symptoms predominate (Ley 1992; Hegel and Ferguson 1997).

There are a number of theories that attempt to explain how the mechanisms underlying panic disorder cause hyperventilation. One of these theories, Klein's Suffocation False Alarm Theory proposes that individuals with panic disorder have abnormal sensitivity to CO_2 and are unable to tolerate even slight elevations in CO_2, which trigger feelings of dyspnea and hyperventilation (Klein 1993). A more recent theory suggests that the disturbances in respiratory control which exist in many panic disorder patients are just one manifestation of a more general homeostatic dysregulation trigged by abnormal sensitivity and imbalances in neurotransmitters in the brain's fear network, which is proposed to be composed of the hippocampus, the medial prefrontal cortex, the amgydala and its brain stem projections (Nardi, Friere et al. 2009).

ORGANIC CAUSES

A large number of organic diseases have been observed to predispose individuals to hyperventilate (Lewis 1953; Lum 1976; Magarian 1982; Fried 1987). A summary is given by Hardonk and Beumer (Hardonk and Beumer 1979) and by Folgering (Folgering 1999). Some of the main organic causes of hyperventilation are discussed below.

RESPIRATORY DISEASE

It has often been observed that hyperventilation occurs as a consequence of chronic respiratory diseases, for example, asthma (Herxheimer 1946; McFadden Jr 1968; Clark and Gibson 1980; Tobin 1989; Osbourne 2000; Bruton and Holgate 2005), COPD, chronic bronchitis and fibrosing alveolitis (Gardner 1995; Laffey and Kavanagh 2002).

The tendency to hyperventilation in asthmatics and in some individuals with COPD, so called pink puffers, can be a direct consequence of broncho-constriction. Acute increases in flow resistive loads, due to broncho-constriction, stimulate sensory receptors in the airway and appear to be the cause of increased ventilatory drive in asthma (Kelsen, Fleeger et al. 1979). In more chronic airway obstruction, as seen in long term suffers of COPD, endogenous opioids appear to play a part in moderating this response (Scardella, Parisi et al. 1986).

Individuals with COPD differ in their response to the chronic stress of dyspnea and airway obstruction, with some individuals adapting more than others to the chronic airway obstruction and chronic dyspnea. Endogenous opioids inhibit the response of ventilatory drive and dsypnea perception to a range of nociceptive respiratory stimuli (Santiago and Edelman 1985). In patients with COPD blocking of endogenous opioids by the opioid inhibiting drug Naloxone results in increased ventilatory drive(Santiago, Sheft et al. 1984). In chronic airway obstruction, some individuals become habituated to the these loads and ventilatory response becomes blunted because of the increased activity of the opioid pathways in these individuals(Santiago, Remolina et al. 1981).

Undiagnosed, mild asthma is thought to be the main cause of some cases of chronic hyperventilation, resulting in classic hyperventilation symptoms of paraesthesiae and tetany which resolve when the lung inflammation is treated (Gardner 1992; Osbourne 2000). Buteyko (1990), in a unique twist, proposed the reverse etiology, that hyperventilation causes asthma and that the bronchoconstriction of asthma is a useful defense mechanism produced by the body to correct hyperventilation. In Buteyko's view, correction of

hyperventilation and restoration of normocapnia is not only a means for improving the symptoms of asthma, but also removes the cause of asthma (Stalmatski 1999). This theory has not been adequately tested and while having some truth is probably overly simplistic.

CARDIOVASCULAR DISEASE

Hyperventilation has been found to have a strong relationship to functional cardiac disorders (Grossman 1983; Gilbert 1999; Wilhelm, Gertivz et al. 2001). However, organic heart disease can also increase some patient's predisposition to hyperventilation. Heart failure, pulmonary hypertension and aortic valve disease can all produce hyperventilation (Gardner 1995).

Individuals with functional cardiac disorders and symptoms such as chest pain and sinus tachycardia have been found to have significantly higher levels of hypocapnia than normal controls (Wilhelm 2001) with improvement occurring after breathing therapy (DeGuire, Gervitz et al. 1996).

OTHER DISEASES

Increased hyperventilation tendencies have been observed in patients with chronic fatigue syndrome (Saish, Deale et al. 1984; Rosen, King et al. 1990; Naschitz, Mussafia-Priselac et al. 2006), chronic pain (Wilhelm, Gertivz et al. 2001), fibromyalgia (Naschitz, Mussafia-Priselac et al. 2006), epilepsy (Fried 1993), depression (Damas Mora, Grant et al. 1976) and migraine (Fried 1993).

PERPETUATING FACTORS IN THE ETIOLOGY OF HV

It has been proposed that, once HV is triggered due to psychological, physiological or organic causes, another set of cognitive, conditioning and physiological factors and breathing behaviors perpetuate it (Clark and Gibson 1980; Margraf 1993; Gardner 1995).

FEAR AND MISATTRIBUTION OF SYMPTOMS

Apprehension of the symptoms arising from hyperventilation is thought to be one of the factors that perpetuate hyperventilation (Lewis 1953; Ley 1989). This model proposes that people interpret symptoms such as dizziness, chest pain or dyspnea as indications of serious disease and therefore increase their

hyperventilation as a result of their fear and feelings of impending doom. This model might not be valid for all symptoms or in all cases of hyperventilation, but does appear to apply to sensations of dyspnea in asthmatics (Carr, Lehrer et al. 1992).

CONDITIONING AND HABIT

The tendency to hyperventilation, like other abnormal breathing behaviours, can become conditioned (Gallego and Perruchet 1991; Jack, Rossiter et al. 2003). Conditioning has been proposed to be one of the more important factors that perpetuates hyperventilation (Ley 1999; Jack, Rossiter et al. 2003). Hyperventilatory respiratory responses to stressful stimuli which are anticipatory to physical threat or metabolic needs, rather than responsive to present metabolic needs, are to some extent normal (Suess 1980; Homma and Masaoka 2008). However, they are stronger in anxious individuals (Masaoka and Homma 1997) and also subject to conditioning, thus increasing the tendency for susceptible individuals, such as those with anxiety, to hyperventilate in response to a widening number of situations (Gallego and Perruchet 1991).

It has also been proposed that particular breathing habits such as frequent sighing and rapid speech patterns, which involve gasping intake of breathing and thoracic breathing, may all perpetuate hyperventilation tendencies in susceptible individuals (Lum 1976; Magarian 1982; Gardner 1995).

ABNORMALITIES OF RESPIRATORY CONTROL

Individuals with hyperventilation disorders have demonstrable abnormalities of breathing control that tend to produce and sustain abnormally elevated ventilatory drive (Hardonk and Beumer 1979; Gardner 1986; Jack, Rossiter et al. 2003). One peculiarity that has been noted is the tendency for ventilation to increase in response to hypocapnia rather than the normal decrease (Folgering and Colla 1978). Folgering and Colla (1978) propose that these abnormalities of CO_2 regulation are evidence of normal negative feedback responses being turned into abnormal positive feedback responses. In chronic hyperventilation, the set point of CO_2 appears to be fixed at abnormally low levels so that

restoration of CO_2 levels to normal, through breathing supplemental CO_2 or during sleep, is not sustained on waking or on return to breathing ambient air (Gardner 1986; Jack, Rossiter et al. 2003).

This increased ventilatory drive in hyperventilation disorders have been proposed to be due to change in sensitivity of chemoreceptors (Heistad, Wheeler et al. 1972) but there is evidence to suggest that behavioural mechanisms originating in the central nervous system have a stronger impact on determining ventilation in hyperventilation disorders than abnormalities in chemoreflex control (Hormbrey, Jacobi et al. 1988; Jack, Rossiter et al. 2003).

SIGNS AND SYMPTOMS

A large number of symptoms have been associated with hyperventilation. A typical list is shown in Table 1:

TABLE 1-SYMPTOMS OF HYPERVENTILATION SYNDROME[1]

Central Neurovascular	Faintness, dizziness, unsteadiness, impairment of concentration and memory, feelings of unreality and, infrequently, complete loss of consciousness.
Peripheral Neurovascular	Numbness, tingling and coldness of the distal extremities, especially the hands, and often involving the face and perioral regions.
Muscular	Variable, usually diffuse, muscular spasm and myalgia, coarse tremors, twitching movements and, uncommonly, carpopedal spasm with generalized tetany.
Respiratory	Shortness of breath, tightness in or about the chest and, less impressive, but equally significant, sighing respirations and excessive yawning.
Cardiac	Palpitations, tachycardia, "skipped beats" and atypical chest pain. The chest pain is usually described as momentary, sharp twinges about or lateral to the nipple, or as a more persistent, dull, aching pressure over the lower anterior thorax.
Gastrointestinal	Marked mouth dryness, dysphagia (often suggestive of globus hystericus) and distressing abdominal bloating, belching and flatulence.
Psychic	Variable degrees of overt anxiety, tension and apprehension except in certain hysterical subjects, who display inappropriate pseudo calmness.
General	Easy fatigability, diffuse weakness, insomnia and chronic exhaustion.

1 From Lewis (1953, p.918)

BREATHING PATTERN

A number of abnormal breathing patterns have been observed in association with hyperventilation disorders. Most commonly described are thoracic breathing, increased sighing, irregular and unstable breathing, altered ratios between inhalation and exhalation, and gasping (Lum 1975; Magarian 1982; Carr, Lehrer et al. 1992; Fried 1993).

PATHOPHYSIOLOGY

PHYSIOLOGICAL EFFECTS OF HYPOCAPNIA

The systemic effects of hyperventilation and CO_2 depletion (hypocapnia) are described in many textbooks and review articles (Brown 1953; Levitsky 1995; Abelow 1998; Lumb 2000). A summary of the main physiological effects of hypocapnia is included in Table 2. Some of the documented, but less well-known, systemic effects are then discussed.

TABLE 2--PHYSIOLOGICAL EFFECTS OF HYPOCAPNIA

	Primary Effect	**Related Effect**
pH	Respiratory alkalosis.	Cellular - movement of chloride from intracellular to extra cellular environment. Decrease in cellular bicarbonate. Hypophosphatemia. Renal Compensation Excretion of bicarbonate and magnesium, calcium, sodium and potassium. Metabolic Effects resulting from cellular and renal compensation Decreased ATP and 23 DGP production. Loss of buffering capacity.
Bohr Effect	Increased affinity of hemoglobin for oxygen. Decreased desaturation of hemoglobin.	Tissue hypoxia. Metabolic Effects: Inhibition of aerobic glycolysis. Increased anaerobic glycolysis. Increased pyruvate production and inhibition of pyruvate oxidation. Accumulation of lactic acid.

NERVOUS SYSTEM EFFECTS

Hypocapnia, induced by hyperventilation, has powerful effects on neuronal excitability and synaptic transmission (Macefield and Burke 1991; Sparing, Dafotakis et al. 2007). It also has direct effects on the neuronal membrane

(Balestrino and Somjen 1988) and on production of neurotransmitters. Glutamine, a precursor of the neurotransmitters glutamic acid and gamma amino butyric acid, varies linearly with cerebral spinal fluid bicarbonate and hydrogen ion concentration (Hoop, Shih et al. 1983). Hypocapnia stimulates glutamate secretion into the synaptic cleft and activates the N-methyl-D-aspartate receptor (Vannucci, Brucklacher et al. 1997). Gamma activity increases during hypocapnia as a result of enhanced GABAergic transmission (Jensen, Hari et al. 2002).

THE RESPIRATORY SYSTEM

In the lungs hypocapnia can contribute to bronchoconstriction, decreased lung compliance and lung damage (Sterling 1968; McFadden Jr, Stearns et al. 1977; O'Cain, Hensley et al. 1979; Kolbe, Kleeherger et al. 1987; Van Den Elshout 1991; Lindeman, Croxton et al. 1998; Laffey 2003; Bruton and Holgate 2005). The mechanisms of lung injury by hypocapnia, which are ameliorated by supplemental CO_2, include increased pulmonary capillary permeability, parenchymal injury and decreased surfactant (Laffey 2003).

CARDIOVASCULAR EFFECTS

Blood pressure, myocardial contractility and cardiac blood flow can also be adversely affected by hypocapnia (Laffey and Kavanagh 1999; Ahrens, Schallom et al. 2001; Laffey and Kavanagh 2002). Cardiac output and stroke volume fall in response to hypocapnic alkalosis (Zwillich, Pierson et al. 1976). Coronary artery spasm is a well known response to hyperventilation (Magarian and Mazur 1991). These effects on the heart can contribute to clinically relevant coronary pathology and to functional cardiac syndrome(Grossman 1983; DeGuire, Gertvitz et al. 1992; Wilhelm, Gertivz et al. 2001)

HYPERVENTILATION IN THE CRITICALLY ILL

Hypocapnia, hyperventilation and respiratory alkalosis are common findings in intensive care patients. A systematic analysis of $PaCO_2$ levels and mortality indicated a direct and linear correlation between $PaCO_2$ levels and mortality.(Mazzara, Ayres et al. 1974) The authors of this study found that when 114 patients in an intensive care unit were categorized into four groups on the basis of carbon dioxide, the patients with the lowest $PaCO_2$ had the

highest mortality. Patients (n=25) with $PaCO_2$ of 15mm Hg or less had a greater than 88% mortality rate, patients (n=35) with a $PaCO_2$ of 20 to 25mmHg had a 77% mortality rate, patients (n=33) with a $PaCO_2$ of 25 to 30mmHg had a 73% mortality rate, patients (n=21) with a $PaCO_2$ of 35 to 45 mm Hg had a mortality of 29% (Mazzara, Ayres et al. 1974).

SPECIFICITY OF HYPERVENTILATION SYMPTOMS TO HYPOCAPNIA

Many symptoms attributed to hyperventilation disorders are not easily explained by hypocapnia alone. There is often the interplay of psychological factors and perceptual-cognitive processes (Saltzman 1963; Folgering 1999; Ley 1999). Several studies have shown that, while the tendency to hyperventilate in response to stress occurs in most people, the development of symptoms in association with hypocapnia is variable and tends to occur in individuals who are predisposed in some way (Saltzman 1963; Suess 1980; Bass and Gardner 1985). The symptoms of hyperventilation disorders seem to be strongly influenced by psychological factors and conditions such as increased adrenergic tone (Folgering 1999). Fear and catastrophic interpretation of the symptoms of hyperventilation is proposed to be an important factor in amplifying symptoms (Lewis 1953; Bass and Gardner 1985; Folgering 1999). Also, catastrophic interpretation of symptoms, in addition to increasing the person's anxiety and the distress associated with the symptom, further disturbs breathing creating a vicious cycle (Lum 1976).

Some symptoms attributed to hyperventilation disorders have a stronger relationship to CO_2 levels than others. Somatic symptoms, particularly symptoms such as dizziness, numbness and tingling of extremities and tetany, have a clearer relationship to hypocapnia, while psychological symptoms such as tension and anxiety are more strongly related to psychological factors (Wientjes and Grossman 1994). Uncomfortable respiratory sensations related to dyspnea, such as feeling unable to breathe deeply, suffocation and air hunger, do not appear to be strongly related to hypocapnia (Hormbrey, Jacobi et al. 1988; Gardner 1992; Hornsveld and Garssen 1996). Howell proposes that dyspnea symptoms may be more related to neuromuscular influences than to biochemical factors (Howell 1997).

SENSITISATION AND CONDITIONING IN BREATHING AND SYMPTOM PERCEPTION

In a review of HVS, Folgering (1999) argues that the poor relationship between symptoms of hyperventilation and hypocapnia may be a result of classical conditioning (Folgering 1999). In this model, which accounts for the persistence of symptoms in the absence of hypocapnia, it is proposed that symptoms are initially triggered by hypocapnia, but become learned over time and are subsequently triggered by situations, behaviours and emotions that were previously related to hypocapnia. Recent research has shown that this is the case with dizziness, a common reaction to hyperventilation, which can be initially produced in response to hypocapnia and then conditioned to arise in response to particular odours in the absence of hypocapnia (Bresseleers, Van Diest et al. 2010).

The inconsistent relationship between hypocapnia and symptoms of hyperventilation syndrome may also be due to sensitisation to hypocapnia, which leads to an exaggerated response to fluctuations in CO_2. Howell (1990) found that individuals vary widely in their reactions to the effects of hypocapnia and that individuals with rapid onset of symptoms in response to hypocapnia had the largest numbers of classic hyperventilation symptoms (Howell 1990). More recent studies have shown that sensitisation to CO_2 happens more readily in anxious individuals and that sensations of air hunger occur at lower CO_2 levels in these cases (Wan, Van Diest et al. 2008).

BREATHING PATTERN AS A PATHOPHYSIOLOGICAL FACTOR

The abnormalities in breathing pattern that have been observed in individuals with hyperventilation disorders have been proposed to be a source of some symptoms traditionally associated with hyperventilation, but which do not appear to correlate with hypocapnia (Hornsveld 1997). Air hunger, or inability to take a satisfying breath, is a common symptom in hyperventilation disorders (Magarian 1982; Gardner 1995). This symptom can occur as a result of hyperinflation of the lungs (O'Donnell 2006) and is associated with poor respiratory muscle co-ordination and other dysfunctions related to the biomechanics of breathing. This is discussed in greater detail in Chapter 4.

Thoracic breathing is one breathing pattern that has been found to correlate with hyperventilation symptoms in asthmatics and individuals with panic disorder that may contribute to at least some of these symptoms (Carr, Lehrer et al. 1992).

INVESTIGATION AND DIFFERENTIAL DIAGNOSIS

MEASURING CO_2 LEVELS

CAPNOGRAPHY

Carbon dioxide levels can be effectively assessed in most cases with capnography, a process of continuously recording the level of CO_2 in expired air by infrared spectroscopy. The percentage of CO_2 at the end of expiration, called End Tidal CO_2 ($ETCO_2$), gives a close approximation of the alveolar ($PACO_2$) concentration which in turn reflect arterial levels of CO_2 ($PaCO_2$)(Corbo, Bijur et al. 2005; Donald and Paterson 2006; Nagler and Krauss 2008).

TRANSCUTANEOUS MONITORING OF CO_2

Another method for continuous noninvasive measurement of $PaCO_2$ is via transcutaneous monitoring, which is done via application of an infrared transducer applied to the skin. Transcutaneous CO_2 pressure has been reported to accurately reflect arterial CO_2 pressure ($PaCO_2$) (Greenspan, Block et al. 1981). However, this method of CO_2 assessment for hyperventilation disorders has been criticised because rapid changes in CO_2, which tend to occur in these disorders, are not accurately reflected in this measurement technique due to the time delay inherent in this technology (Meuret and Ritz 2010).

RESTING CO_2

Reported levels of alveolar CO_2 considered to indicate hyperventilation vary according to the source. Respiratory physiology texts have stated that levels of $PaCO_2$ less than 37 mmHg indicate physiological hyperventilation (Comroe 1974). Many individuals can be found to have CO_2 below this level, but are not obviously symptomatic. Gardner found that mean resting levels of CO_2 in normal subjects was 36.4 mmHg with 2 standard deviations below this being 32.2mm Hg. He states that 30 is the lower limit of normal (Gardner 1986). At

the other extreme, Buteyko (1990) claimed that levels below 38.5 mmHg should be considered to indicate hyperventilation. The basis on which Buteyko made this claim is not clear due to difficulty in accessing studies published in the former Soviet Union. Buteyko believed that ideal ventilation levels as found in optimally healthy people would result in levels around 45 mmHg and that this was associated with a breath holding time of 60 seconds (Buteyko 1990).

STRESS TESTING OF CO_2

In many patients with signs and symptoms suggestive of hyperventilation disorders, there is no evidence of decreased baseline end-tidal CO_2 levels, and abnormalities of CO_2 are only uncovered with some type of stress provocation or in response to exercise. There may be a fall of CO_2 in anticipation of measurement (Vansteenkiste, Rochette et al. 1991) or in anticipation of exercise (Jack, Rossiter et al. 2004). Sustained decreases of CO_2 levels in response to exercise can unmask hyperventilation tendencies in individuals who at rest may have only slightly reduced CO_2 levels (Jack, Rossiter et al. 2004). Recollection of stressful events or emotionally charged memories, "the think test", has also in the past been used at part of a clinical protocol to unmask hyperventilation tendencies (Nixon and Freeman 1988).

HYPERVENTILATION PROVOCATION TEST

The Hyperventilation Provocation Test (HVPT) has, until recent years, been a cornerstone of the diagnostic criteria for Hyperventilation Syndrome. During the HVPT the patient hyperventilates for a period of time that can vary from as little as 20 deep breaths (Howell 1990), to a more often recommended 3 minutes (Hardonk and Beumer 1979) (Vansteenkiste 1991). HVPT has been used as a diagnostic tool with and without confirmation of its effects on alveolar CO_2 levels (Han, Stegen et al. 1996; Howell 1997).

When the HVPT is used without concurrent measurement of CO_2, the examiner relies on the patient's reporting of symptom recognition. As discussed previously, this has been found to be invalid as a means of diagnosing hyperventilation disorders and is thought to give false positive results (Hornsveld, Garsson et al. 1996). The HVPT can also give false negative results

when patients reassured by the presence of the experimenter and the relative safety and predictability of experimental conditions when compared to real life do not experience their usual breathing related symptoms (Bass and Gardner 1985).

One use of the HVPT that is still considered valid is to measure the rate of recovery of CO_2 after voluntary hyperventilation (Warburton and Jack 2006). Slow recovery of CO_2 after the HVPT can also identify individuals with abnormalities of respiratory control that sustain hyperventilation tendencies. Recovery of CO_2 to pretest levels in normal individuals occurs within 1 to 3 minutes (Hardonk and Beumer 1979), but in hyperventilation disorders recovery is delayed. It is suggested that this delayed recovery due to impairment of the normal negative feedback mechanisms which generally inhibit ventilation as hypocapnia increases (Hardonk and Beumer 1979; Folgering 1999; Warburton and Jack 2006).

BREATH HOLDING TIME IN HYPERVENTILATION DISORDERS

Breath holding time has often been observed to be abnormally short in hyperventilation disorders (Gardner 1995; Eke and McNally 1996; Jack, Darke et al. 1998; Warburton and Jack 2006). In one study by Jack and colleagues, breath holding time in individuals with idiopathic hyperventilation was significantly reduced to a mean of 20 seconds versus controls who had a mean of over 60 seconds (Jack, Rossiter et al. 2003).

BUTEYKO'S FORMULA

Extensive studies were reported to be undertaken in the former Soviet Union by Dr. K. P Buteyko on the correlation between breathing holding time and CO_2. He patented a formula in the former Soviet Union for using breath holding time as a measure of $PaCO_2$. Practitioners of the Buteyko Breathing Technique (BBT) use breath-holding time as an indirect measure of arterial CO_2 levels and consider the Control Pause (CP= time of post expiratory breath hold) as a measure of alveolar CO_2 concentration according to the formula:

$$\mathbf{PaCO_2\ \% = 3.5\% + .05\ MP}$$

(This formula was described in Buteyko KP, "Method of defining CO_2 content in alveolar air (In Russian)", Soviet Patent No. 1593627, 17 October 1986).

The relationships predicted by Buteyko to exist between breathing rate, breath holding time and alveolar $PaCO_2$ are shown in Table 3, however the accuracy of these relationships has never been independently confirmed.

TABLE 3- RELATIONSHIP BETWEEN $PACO_2$, BREATH RATE AND POST EXPIRATORY APNOEA (BUTEYKO'S)

Breath Rate	**Post Expiratory Apnea**	**Alveolar PCO_2**
6-8	60	45.5
9-11	50	42
12-15	40	38.5
16-20	30	35
21-25	20	31.5
>26	10	28

(K.P. Buteyko 1968, unpublished.)

SYMPTOM QUESTIONNAIRES

NIJMEGEN QUESTIONNAIRE

The 16 items of Nijmegen Questionnaire (NQ), the most well known symptom questionnaire for hyperventilation disorders, evolved from the very large number of complaints ascribed to Hyperventilation Syndrome. The NQ is often used to diagnose Hyperventilation Syndrome, but it is argued this may not be a valid use of this questionnaire as no studies have established that the NQ is specifically diagnostic of chronic or intermittent hypocapnic states (Warburton and Jack 2006). The NQ was developed at a time when Hyperventilation Syndrome was still an acceptable diagnosis (van Doorn, Folgering et al. 1982). The key validation study on the NQ showed that this questionnaire was able to differentiate patients with Hyperventilation Syndrome from those without, and that its sensitivity was 91% and its specificity 95% (Dixhoorn and Duivenvoorden 1985). However, this validation study categorised individuals as having HVS on the basis of clinical diagnostic protocols that included previous

diagnosis by practitioner (partly on the basis of presence of HVS symptoms), presence of disordered breathing (rapid, thoracic, irregular, frequent sighing), and reproduction of symptoms during the HVPT, a test which is no longer considered a valid tool for confirmation of hyperventilation disorders (Hornsveld and Garssen 1996). Another validation study by Vansteenkist and colleagues, found an 86% correlation between high scores on the NQ (> 24) and recognition of unexplained symptoms of daily life during the HVPT (Vansteenkiste 1991). However, in this study the symptoms that were most commonly reported during the HVPT were breathlessness, breathing restriction, tension, palpitations and chest pain. These symptoms are not strongly associated with hypocapnia and could be due to other factors including disturbances of the biomechanical breathing dysfunction (Hormbrey, Jacobi et al. 1988; Gardner 1992; Hornsveld 1996; Howell 1997).

INTERVENTIONS FOR HYPERVENTILATION DISORDERS

Successful approaches to correcting hyperventilation include various combinations of psychotherapy, relaxation training, breathing re-education and biofeedback (Lum 1975; van Doorn, Folgering et al. 1982; Grossman 1984; Ley and Timmons 1999). There has been vigorous debate as to whether the successful outcomes from these therapies are due to improved CO_2 levels or to relaxation effects and psychological factors (Garssen 1992; Garssen, de Ruiter et al. 1993; Ley 1993; Wilhelm, Gertivz et al. 2001). While a number of studies have shown improvements in CO_2 regulation after therapy (van Doorn, Folgering et al. 1982; Grossman 1984) and provided evidence for a moderation of symptoms by CO_2 (Meuret, Wilhelm et al. 2008; Ritz, Meuret et al. 2009), other studies indicate that symptom improvement is not necessarily correlated with improved CO_2 status (Garssen 1992)

BUTEYKO BREATHING TECHNIQUE

The Buteyko Breathing Technique (BBT) specifically aims to raise CO_2 levels through breathing retraining with very little focus on psychological factors. BBT is most well known as a treatment for asthma, but has been used to treat a large number of conditions believed by Buteyko to be related to hyperventilation. The BBT has been tested in a number of clinical trials, which have all tended to show therapeutic benefit (Bowler 1998; Opat, Cohen et al. 2000; Cooper, Oborne et al. 2003; McGowan 2003; McHugh, Aicheson et al. 2003; Abramson, Borg et al. 2004; McHugh, Duncan et al. 2006; Slader, Reddel et al. 2006; Cowie, Underwood et al. 2008). As with other therapies for hyperventilation, it is not clear if BBT treatment effects are due to changes in CO_2 status (Al-Delaimy 2001). It is argued that effects of the BBT are due to non-specific effects, for example sense of control over asthma symptoms but this has not been rigorously tested (Slader, Reddel et al. 2006).

CONCLUSIONS

Hyperventilation is an important aspect of dysfunctional breathing that has established physiological effects and negative health consequences. Individuals are predisposed to hyperventilate for psychological and physiological reasons and in response to diseases of the respiratory, cardiovascular and nervous systems.

Hyperventilation Syndrome is no longer considered a valid diagnosis because of the complex relationship between symptoms and acute and chronic hypocapnia. The previous gold standard for diagnosis of hyperventilation disorders, symptom recognition during the Hyperventilation Provocation Test may not be a valid way of establishing the relationship of symptoms to CO_2 levels although it is a useful test for uncovering abnormalities of CO_2 control. Assessment of CO_2 through measurement of end tidal or transdermal CO_2 are valid and well established ways of directly establishing presence of hypocapnia.

In the clinical setting, presence of hyperventilation is sometimes inferred indirectly. Symptoms questionnaires, such as the Nijmegen Questionnaire, Breath Holding Time and presence of breathing pattern abnormalities such as rapid breathing, thoracic breathing and irregular breathing are sometimes

assumed to indicate presence of hyperventilation. However, a clear relationship between CO_2 and these measures has not been established. The question of the relationship of these measures to chronic hypocapnia is addressed in this thesis in two separate chapters. Chapter 10 looks specifically at Buteyko's claims about the relationship of breath holding time to CO_2 and Chapter 9 examines the relationships between various measures of dysfunctional breathing, including CO_2 measures derived from capnography, the Nijmegen Questionnaire, breathing pattern and breath holding time.

CHAPTER 4 - THE FUNCTIONS AND DYSFUNCTIONS OF BREATHING PATTERN

INTRODUCTION

The efficiency with which the mechanical act of breathing is performed is an important aspect of breathing functionality. Efficient breathing patterns depend on the co-ordination of many breathing muscles, appropriate timing and volume adjustments and a balance between stability and responsiveness in order to respond to changes in the internal and external environment and to maintain homeostasis.

Prior to the 1940's, the literature on functional breathing disorders paid greater attention to describing breathing pattern abnormalities than on measuring and reporting on a patient's carbon dioxide status (Maytum 1934; Christie 1935). In more recent times breathing pattern disturbances do not appear to have been studied as closely as hyperventilation disorders. However, dysfunctional or 'tense' breathing patterns have often been observed in patients believed to have Hyperventilation Syndrome and it has been proposed that dysfunctions of respiratory muscles and the respiratory pump might be the source of some symptoms, such as dyspnea and chest wall pain. These symptoms have been incorrectly thought to arise from hypocapnia (Hormbrey, Jacobi et al. 1988; Wolf 1994; Hornsveld 1997), and it is suggested that inefficient breathing patterns which become habitual might play a role in perpetuating hyperventilation disorders (Lum 1976; Gardner 1995).

NORMAL BREATHING

Components of breathing pattern that have been studied in normal individuals include relative timing and volumes of inspiration and expiration, breathing movement and co-ordination patterns (Tobin, Tejvir et al. 1983; De Troyer and Estenne 1988), also the role of sighing and irregularity in regulation of normal breathing (Vlemincx, Taelman et al. 2010).

The following section is a brief review of some key aspects of the functional anatomy of breathing to introduce terminology and concepts that are used in later discussions in this chapter and subsequent chapters.

THE CHEST WALL

The chest wall is comprised of two distinct compartments, separated by the diaphragm. The upper compartment is often referred to as the rib cage and the lower as the abdomen (Konno and Mead 1966). Because the lower compartment includes the lower six ribs, the terms rib cage and abdomen are potentially confusing, and these two compartments are more accurately referred to as upper rib cage (URC) and lower rib cage/abdomen (LRCA). The term thoracic breathing generally refers to breathing that is evidenced by greater upper rib cage motion and the terms abdominal breathing and diaphragmatic breathing refers to breathing that involves motion of the lower rib cage and abdomen (Lewis 1997; Kaminoff 2006). These two rib cage compartments both move in three planes: vertical, lateral and anterior/posterior; however their movements differ because of differences in their bony and muscular articulations (De Troyer and Estenne 1988).

UPPER RIB CAGE (URC)

The upper ribs tend to move with the sternum, as a unit, rather than displaying individual movement. The predominant motion of the upper ribs, described as being like a pump handle, is in the anterior/posterior and in the vertical plane. There is little lateral expansion of the upper ribs during respiration. During quiet breathing the primary muscle action is from the intercostal muscles with some contribution from the scalenes (De Troyer and Estenne 1988). When ventilatory needs increase, accessory muscle use increases. Accessory muscles of respiration which move the upper rib cage have other movement functions, on the neck and upper limb, which must be integrated with respiration (Kapandji 1974).

LOWER RIB CAGE/ ABDOMEN (LRCA)

The lower six ribs have a greater ability to move independently when compared to the upper six ribs. The motion of the lower ribs is often described as bucket handle motion, moving cephalad and widening during inspiration and moving caudad and narrowing during exhalation. The intercostals, the diaphragm and abdominal muscles all attach to the lower ribs and produce the characteristic respiratory motion of the LRCA (De Troyer and Estenne 1988).

BALANCE OF CHEST WALL MOTION DURING NORMAL RESPIRATION

In normal breathing the contribution of URC and LRCA motion is relatively equal and the compartments move synchronously, increasing their dimensions during inspiration and decreasing their dimensions during exhalation (Tobin, Tejvir et al. 1983).

There is some normal variability in the balance of URC to LRC motion, influenced by age and gender. Older people tend to use more LRCA motion during breathing (also called abdominal breathing) than younger people (Sharp, Goldberg et al. 1975; Faithfull, Jones et al. 1979; Verschakelen and Demedts 1995) and females use more URC motion during breathing (also called thoracic breathing) than males (Sharp 1983; Verschakelen and Demedts 1995).

There is also variability in the balance and synchrony of chest wall motion in response to changes in posture, ventilatory drive, activity levels, and rate and volume of respiration. Upright posture, large volume of inspiratory effort, rapid respiration and increased activity tend to produce greater URC motion (Sharp, Goldberg et al. 1975; De Troyer and Estenne 1988).

Despite the findings that particular diseases (Tobin, Tejvir et al. 1983), increased ventilatory drive and activity levels are associated with functional imbalances in rib cage motion(Sharp, Goldberg et al. 1975; De Troyer and Estenne 1988) , it is generally observed that the breathing of normal healthy individuals at rest is characterized by balanced motion of the upper and lower compartments of breathing (Chaitow 2002, Pryor and Prasad 2002).

THE MUSCLES OF RESPIRATION

The primary muscles of respiration are the diaphragm and the intercostals with a small contribution from the *scalenes* (De Troyer and Estenne 1984). In healthy individuals, additional muscles knows as accessory muscles of respiration are recruited when ventilatory needs increase beyond those required for quiet breathing and these muscles are used to increase the speed, volume or forcefulness of either inhalation or exhalation. The accessory muscles of respiration change the pattern of ventilation - in the URC they increasing vertical motion during inspiration and in the LRCA they decrease the anterior/posterior dimensions and move the ribs caudad during exhalation. The accessory muscles of inspiration and expiration are listed in Table 4:

TABLE 4 - ACCESSORY MUSCLES OF RESPIRATION

Inspiration	**Expiration**
Sternocleidomastoid	*Abdominal Obliques- Internal and External*
Scalenes (increased use*)*	*Rectus Abdominus*
Pectoralis Major and Minor	*Transverse Abdominus*
Serratus Anterior	*Lower Illiocostalis*
Serratus Posterior Inferior	*Lower Longissimus*
Upper illiocostalis	*Serratus Posterior Inferior*

THE DIAPHRAGM

The diaphragm has two parts, costal and crural, which differ in their embryological origins and functions. The costal diaphragm is the primary force generator of the respiratory pump. Its actions influence the actions of other respiratory muscles. It is a large dome shaped muscle whose fibers originate from a central tendinous structure and then insert into several peripheral attachments, including the inner and upper portion of the lower six ribs and the xiphoid process of the sternum. When the diaphragm is relaxed it lies alongside (and is apposed to) the inside of the lower ribs with its fibers orientated in a vertical direction. The area of the lower rib cage, which has direct contact with the vertically orientated diaphragm fibers, is called the zone of apposition. The

curvature of the diaphragm, its length and the size of the zone of apposition are maximised when the diaphragm is relaxed at the end of exhalation. This zone of apposition represents about 30% of the total surface area of the rib cage at the end of a normal exhalation (at functional residual capacity) (De Troyer and Estenne 1988). The size of the zone of apposition, the length and curvature of the diaphragm influence its power and efficiency.

ACTIONS OF THE COSTAL DIAPHRAGM ON THE RIB CAGE AND ABDOMEN

During an effective exhalation the diaphragm relaxes and lengthens and the zone of apposition is maximized. During inspiration the diaphragm shortens and descends towards the abdominal cavity, increasing intra-abdominal pressure. It lifts and widens the lower rib cage and also displaces the abdominal wall anteriorly. The actions of diaphragm are summarized in table 5:

TABLE 5 - ACTIONS OF THE DIAPHRAGM DURING INSPIRATION AND EXPIRATION

	Length	**Shape**	**Zone of Apposition**	**Actions on Rib Cage**	**Effects on intra-abdominal pressure**
Inspiration	Shortens (contracts)	flattens	decreases	Lift and widen lower 6 ribs (to horizontal orientation)	increases
Expiration	Lengthens (relaxes)	domes	increases	Depress and narrow lower 6 ribs (to vertical orientation)	decreases

ABDOMINAL MUSCLES

The muscles that form the anterior and lateral abdominal wall (rectus abdominus, external oblique, internal oblique and transverse abdominus) play several important roles in respiration.

ACTIONS OF ABDOMINAL MUSCLES

The abdominal muscles are accessory muscles of expiration, which become activated during forced expiration; however, they also play a role in inhalation

because of their interaction with the diaphragm. Weakness of the abdominal muscles affects both inspiratory and expiratory power.

Their contraction during exhalation decreases the dimensions of the chest wall by pulling the sternum and ribs downward and decreasing the anterior and posterior diameter of the rib cage. It also increases abdominal pressure, helping to push the diaphragm upwards maximizing its curvature and resting length in preparation for inspiration.

Abdominal contraction during inspiration creates a mechanical and energy advantage for the diaphragm and rib cage motion. It increases the curvature and length of the diaphragm maximizing its power and efficiency because of the well known length/tension rule of muscles to increase power with increased length (De Troyer and Estenne 1988; Society 2002; Finucane, Panizza et al. 2005). Abdominal contraction during inspiration causes the end-expiratory position of the diaphragm and the end-expiratory volume of the abdomen to be smaller than during relaxation. This action of the diaphragm promotes lengthening and prevents excessive shortening of the diaphragm, increasing its ability to generate pressure throughout the inspiratory phase. It also helps the lower rib cage to expand laterally during inspiration.

CO-ORDINATION OF THE DIAPHRAGM AND ABDOMINAL MUSCLES DURING RESPIRATION

Abdominal displacements are often used as approximations of diaphragm displacements; however this is an oversimplification as diaphragm contraction can produce motion that is localized at the lateral rib cage as well as at the abdomen (Konno and Mead 1966; Loring, Mead et al. 1985). Individuals with normal respiratory muscle control are capable of voluntarily modifying their breathing to emphasise either abdominal protrusion or lateral rib cage expansion during inspiration. If abdominal tone is maintained during inhalation, the increase in abdominal pressure resulting from diaphragm descent is directed towards lifting and widening the lower six ribs in an inspiratory direction. During inspiration, if abdominal tone is relaxed, or if abdominal protrusion is exaggerated, lateral rib cage motion will be inhibited (Konno and Mead 1966; Loring, Mead et al. 1985; De Troyer and Estenne 1988).

There is substantial argument about whether 'diaphragmatic breathing' is most efficiently performed by holding the abdomen firm and emphasizing lateral rib cage motion or by fully protruding the abdomen during inspiration (Kaminoff 2006). There is no absolute answer to this question because the relationship between lateral rib cage and abdominal motion to efficiency of diaphragm action is dependent on a range of circumstances. In most healthy individuals, the relative amount of rib cage to abdominal motion resulting from diaphragm contraction naturally varies on a continuum in response to changes in posture, muscle tone, activity level, respiratory drive, volume and timing (De Troyer 1983).

During relaxation, and in the supine position, there is a natural tendency to increased forward displacement of the abdomen during inspiration (De Troyer 1983; Verschakelen and Demedts 1995). This relaxed configuration of thoraco-abdominal motion is also evident in sitting and standing if the person has low abdominal tone or if they voluntarily relax the abdomen (Verschakelen and Demedts 1995). On standing and upright sitting posture and during physical activity, there is a natural tendency for the resting muscle tone of the abdominal muscles to increase with localisation of breathing motion to the lateral rib cage in the lower rib cage. This is referred to as the active thoraco-abdominal configuration of respiratory muscle activity (Sharp, Goldberg et al. 1975; De Troyer 1983; Verschakelen and Demedts 1995). In the active configuration, there is less forward abdominal displacement and greater lateral rib cage motion (produced by the diaphragm) and vertical motion of the rib cage (produced by the accessory muscles of respiration)(De Troyer 1983; De Troyer 1997).

The decreased amount of abdominal motion during sitting and standing is proposed to be a normal and functional response that increases the efficiency of the diaphragm by preventing the diaphragm from shortening (descending) excessively during inspiration (Sharp, Goldberg et al. 1975; De Troyer 1983). Preservation of diaphragm length and curvature enables stronger contraction and greater pressure from the diaphragm to be exerted during inspiration (De Troyer 1983). It may also increase postural support from the diaphragm and

the abdominal muscles during activity (Hodges and Gandevia 2000; Gandevia, Butler et al. 2002). It also serves to minimize the increase in end-expiratory lung volume that normally occurs in the standing position (De Troyer 1983).

TIMING AND VOLUME COMPONENTS OF NORMAL BREATHING

The fundamental timing and volume components of the breath are respiratory rate (f), tidal volume (VT) and minute volume (Vmin), which is a product of respiratory rate and tidal volume, expressed mathematically as Vmin = f x VT (West 1985; Levitsky 1995). These fundamental timing and volume components only give limited information and can be further broken down to fractional inspiratory and expiratory components of the respiratory cycle which give additional information about ventilatory drive and central nervous system respiratory control. The duration of one whole cycle of breath (Ttot) is made up of time taken for inspiration (TI) and time taken for expiration (TE).

When respiratory drive is increased, air is taken in more quickly. Respiratory drive can be expressed mathematically as V_T/T_I, or the proportion between tidal volume and time taken for inspiration and is termed mean inspiratory flow (Clark and von Euler 1972; Milic-Emili and Grunstein 1976).

Fractional respiratory time is expressed mathematically as T_I/T_{TOT}. This ratio is a reflection of central timing control mechanisms (Clark and von Euler 1972).

Normal values for timing and volume components of the breathing cycle have been established (Table 6) and these enable comparison with diseased individuals and those with functional breathing disorders (Tobin, Tejvir et al. 1983).

TABLE 6 - TIMING AND VOLUME COMPONENTS OF NORMAL BREATHING

	M	***SD***
Respiratory Rate (f)	16.7	2.7
Tidal Volume(VT)	383 *mls*	85 *mls*
Minute Volume(Vmin)	6.02 *(L/min*)	1.32 *(L/min*)

Time taken for inspiration (T_I)	1.60 *s*	.30 *s*
Mean inspiratory flow (V_T/T_I)	.424 *mls/sec*	.032 *mls/sec*
Fractional inspiratory time (T_I/T_{TOT})	.249	.54

From Tobin (1983), (values for young people, mean age 29)

RELATIONSHIP OF TIMING AND VOLUME TO BREATHING PATTERN IN NORMAL INDIVIDUALS

Rapid respiratory maneuvers, particularly rapid shallow respirations are carried out using the active thoraco-abdominal configuration and the accessory muscles of respiration. Slower movements are carried out with greater contribution from abdominal motions (i.e. the relaxed configuration) (Sharp, Goldberg et al. 1975). The velocity of rib cage motion during inspiration is greater than that for the abdomen, so therefore the rib cage tends to be recruited when respiratory is rate increased or during inspiratory maneuvers requiring speed (Sharp, Goldberg et al. 1975; Verschakelen and Demedts 1995).

In normal healthy people, small increases in breathing volume tend to involve greater abdominal motion than smaller volumes (Sharp, Goldberg et al. 1975). As volumes increase beyond those found in normal tidal breathing, abdominal motion gradually decreases and thoracic motion predominates (Sharp, Goldberg et al. 1975; Verschakelen and Demedts 1995). The decrease in abdominal motion during very large volumes of breathing will be functional when it assists in preserving a mechanically advantageous length and radius of curvature of the diaphragm.

In cases of increased respiratory drive where (VT/TI) is increased (Tobin, Tejvir et al. 1983), one would expect to see the active thoraco/abdominal configuration with activation of accessory muscles of respiration. This has been found to be the case in individuals with asthma and COPD (Muller, Bryan et al. 1981; Marchand and Decramer 2000).

REGULARITY OF NORMAL BREATHING

It is generally accepted that normal breathing is not completely regular and is characterised by a balance between stability and variability (Baldwin, Suki et al.

2004). Normal breathing patterns include appropriate changes of rate, volume and respiratory muscle use and respiratory behaviors such sighing and yawing (Leiner and Abrahamowitz 1958). Variability in normal breathing is evidence of its responsiveness and sensitivity to changes in environment, activity levels, emotional arousal and metabolic activity (Wientjes 1992; Boiten 1998). Variability of breathing and respiratory behaviors, such as sighing and yawning are important for the state of dynamic equilibrium needed to promote optimal functioning of respiratory control feedback loops (Aljadeff, Molho et al. 1993; Baldwin, Suki et al. 2004; Qureshi, Khalik et al. 2009; Vlemincx, Van Diest et al. 2009). Sighing is proposed to assist in repartitioning and normalizing lung volumes (Aljadeff, Molho et al. 1993) and to act as a resetter mechanism, promoting structured variability in breathing pattern in situations where variability is abnormally reduced or excessively chaotic (Vlemincx, Van Diest et al. 2009).

DYSFUNCTIONAL PATTERNS OF BREATHING

Dysfunctional breathing patterns include dysfunctions of breathing co-ordination (Lewis 1953; Lum 1975; Folgering 1999), abnormalities of volume and timing (Wientjes 1992) and excessive or reduced variability of breathing (Loveridge, West et al. 1984; Sody, Kiderman et al. 2008). Mouth breathing is also an abnormal breathing habit that adversely affects airway and respiratory muscle function (Lee, Choi et al. 2007; Correa and Berzin 2008; Hallani, Wheatley et al. 2008; Yi, Jardim et al. 2008; Kim, Choi et al. 2010).

DYSFUNCTIONS OF BREATHING CO-ORDINATION

In its normal relaxed state the two compartments of the chest wall, the URC and the LRCA, create an effective respiratory pump which moves in response to co-ordinated actions created by the diaphragm, *scalenes*, intercostals, abdominals and accessory muscles of respiration (Konno and Mead 1966; De Troyer and Estenne 1988). However, under particular circumstances this co-ordinated action is lost and breathing pattern becomes dysfunctional.

The 2 main dysfunctions of breathing co-ordination are:

1. Thoracic dominance in breathing; and
2. Asynchronous and paradoxical breathing.

THORACIC BREATHING

The term thoracic breathing is the common term used to refer to URC breathing (Chaitow 2002). In this type of breathing upper rib cage motion, produced by the accessory muscles of respiration, dominates over lower rib cage and abdominal motion. Thoracic breathing, when present as a habitual mode of breathing and persisting during quiet breathing, can generally be considered as dysfunctional (Lewitt 1980). However its presence can be normal and functional in certain situations, for example when there are sudden increases in ventilatory need, during rapid inspiratory maneuvers and during increased physical activity (Sharp, Goldberg et al. 1975; De Troyer 1983; De Troyer and Estenne 1984; Verschakelen and Demedts 1995). In these cases, increased upper thoracic movement relative to abdominal motion can be evidence of the normal active thoraco-abdominal configuration described by De Troyer (1984), which often helps to preserve diaphragm length during increased activity, postural change, increased ventilatory need and on sudden increases in ventilation.

In popular opinion, decreased abdominal motion, relative to upper thoracic motion confirms poor diaphragm action (Lewis 2004 (accessed 15/10/2010); Kaminoff 2006). While this can be the case, particularly in the case of more pronounced respiratory muscle dysfunction (Fitting and Grassino 1987; De Troyer and Estenne 1988; Hruska 1997), it is not always so and abdominal motion may not have a clear relationship to diaphragm activity (Gilbert and Auchincloss 1981). Maintenance of abdominal tone during inspiration can improve diaphragm efficiency and strength, particularly if there is adequate elevation and lateral expansion of the lower 6 ribs (De Troyer and Estenne 1988).

ASYNCHRONOUS AND PARADOXICAL BREATHING

In normal breathing, the upper rib cage and lower rib cage/abdomen compartments increase their dimensions during inspiration in synchrony. If the

dimensions of either of these compartments decrease during inspiration, it is referred to as asynchronous or paradoxical breathing (Jubran and Tobin 1992; Hammer and Newth 2009).

Thoraco-abdominal asynchrony is generally considered to be dysfunctional because of its association with respiratory distress and with weakness and hypertonicity of respiratory muscles (Wolfson, Strohl et al. 1983; Fitting and Grassino 1987; Jubran and Tobin 1992; Hammer and Newth 2009). However, paradoxical inward motion of the abdomen during inspiration is not always dysfunctional. In fact inward abdominal motion during inspiration can be a normal and functional response to increased lung volume, physical activity, rapid respiratory maneuvers or standing posture, assisting in the maintenance of diaphragm length and curvature (De Troyer 1983; Wolfson, Strohl et al. 1983). Paradoxical breathing is likely to be dysfunctional when it is not adequately compensated by lateral motion of the rib cage and the lower rib cage narrows instead of widening during inspiration (De Troyer 1983). It is also dysfunctional when it is inappropriately present, for example during rest and at times when ventilatory needs are not elevated.

ABNORMALITIES OF TIMING AND VOLUME

Tobin (1983) compared timing and volume parameters between normal individuals and those with anxiety, asthma, COPD and restrictive lung diseases. The general trend across all non-normal individuals studied showed increased volume and rates of breathing, increased minute volume, increased respiratory drive (V_T/T_I), more rapid inspiration (T_1), with a decrease in the duty cycle (T_I/T_{TOT}) (Tobin, Tejvir et al. 1983).

RESPIRATORY INSTABILITY

Excessive respiratory instability with large variations of tidal volumes, frequent respiratory pauses and increased frequency of sighing and/or gasping breaths has often been reported in individuals identified as having breathing dysfunction (Maytum 1934; Magarian 1982; Howell 1990; Butani and O'Connell 1997; Caldirola 2004). While some irregularity of breathing appears to be normal, exaggerated respiratory instability is probably a sign that respiratory

control mechanisms are struggling to maintain homeostasis in the face of increased allostatic load and increased demands on the nervous and respiratory systems (Baldwin, Suki et al. 2004).

Extent of breathing irregularity has been used to characterise the level of entropy or disorder in the respiratory system (Caldirola 2004). It has been proposed that unstructured irregularity in breathing, where patterns of irregularity are random, is a more reliable indicator of disordered breathing than standard static measures of respiratory rate, CO_2 and minute volume. This is because in many situations the mean values of these respiratory parameters are normal and evidence of disorder of homeostatic respiratory control is only indicated by the presence of excessive and random irregularities of breathing (Perna, Caldirola et al. 2004).

Decreased variability of breathing, which often exists in individuals with chronic obstructive and restrictive lung diseases (Loveridge, West et al. 1984; Brack, Jubran et al. 2002) and chronic anxiety (Van Diest, Thayer et al. 2006), is also dysfunctional. The lack of flexibility and responsiveness of breathing results in impaired respiratory control and inhibits appropriate matching of ventilation to conditions of rest and activity (Loveridge, West et al. 1984; Brack, Jubran et al 2002).

MOUTH BREATHING

Mouth breathing affects the biomechanics of upper airway muscles (Tafil-Klawe, 2003; Lee, 2007) and diaphragm action (Yi, Jardim et al. 2008). It adversely affects upper airway collapse in sleep apnea (Kim, Choi et al. 2010) and lung function in asthmatics (Petruson and Theman 1996; Hallani, Wheatley et al. 2008).

INCIDENCE OF BREATHING PATTERN DISORDERS

Breathing pattern disorders and respiratory muscle dysfunction have been reported in individuals with various medical and psychological conditions. A selective overview of these is given in Table7:

TABLE 7 - OVERVIEW OF TYPES OF BREATHING PATTERN DISORDERS REPORTED IN VARIOUS CONDITIONS

Condition	**Types of Breathing Pattern Disorder**	**Reference**
Hyperventilation and Medically Unexplained Symptoms	Thoracic Breathing Irregularity of breathing (tidal volume and respiratory pauses)	(Lum 1976; Magarian 1982; Han 1996).
Anxiety Disorders including Panic Disorder	Thoracic breathing Increased sighing Irregularity of breathing (tidal volume, respiratory pauses)	(Wilhelm 2001; Wilhelm, Gertivz et al. 2001; Caldirola 2004; Blechert, Michael et al. 2007)
Musculo-skeletal Pain	Increased sighing Poor co-ordination Thoracic Breathing Paradoxical Breathing	(Baker 1934; Lewitt 1980; Gardner 1995; Schleifer 2002; Perri and Halford 2004; Kapreli, Vourazanis et al. 2009)
Speech Disorders	Poor breathing co-ordination	(Altman, Atkinson et al. 2005; Vertigan, Gibson et al. 2006)
Asthma	Increased sighing Irregularity of breathing Poor respiratory muscle co-ordination. Hypertonic inspiratory muscles Thoracic breathing Mouth Breathing Altered rate, timing and volume relationships	(Derenne, Macklem et al. 1978; Schiff 1980; Muller, Bryan et al. 1981; Tobin, Tejvir et al. 1983; Hormbrey, Jacobi et al. 1988; Perrin, Perrin et al. 1993; Fokkema, Maarsingh et al. 2006; Prys-Picard, Kellet et al. 2006; Hagman, Janson et al. 2008; Hallani, Wheatley et al. 2008)
COPD	Thoracic breathing Rapid shallow breathing Paradoxical breathing Altered rate, timing and volume relationships Decreased variability of breathing.	(Tobin, Tejvir et al. 1983; Loveridge, West et al. 1984; Sackner and Gonzalez 1984; Gilmartin and Gibson 1986; Ferrari, Goti et al. 1997)
Heart Disease	Diaphragm dysfunction Respiratory muscle weakness	(Ambrosino, Opasich et al. 1994; Witt, Borges et al. 1997; Caruana, Petrie et al. 2001)

References refer to various combinations of the breathing patterns listed.

ETIOLOGY OF DYSFUNCTIONAL BREATHING PATTERNS

The respiratory pump can become distorted and inefficient due to biomechanical disturbances such as compromised strength, co-ordination and efficiency of key respiratory muscles and in response to physiological and psychological factors and to some organic diseases which increase the demands or decrease the efficiency of the respiratory pump (Derenne, Macklem et al. 1978; De Troyer and Estenne 1988; Teixeira, Cherin et al. 2005).

BIOMECHANICAL FACTORS

DIAPHRAGM DYSFUNCTION

The diaphragm is a key driver of the respiratory pump and its function affects the function of other respiratory muscles. Weakness and hypertonicity of the diaphragm can contribute to the development of dysfunctional breathing patterns. The resting length of the diaphragm, its curvature and the size of the zone of apposition, achieved at the end of exhalation, are all important determinants of the power and efficiency of the diaphragm during inspiration (Konno and Mead 1966; De Troyer and Estenne 1988). As with all other muscles, the power and effectiveness of the diaphragm is maximised with greater length and decreased if this muscle is attempting to operate in a shortened hypertonic form (De Troyer and Estenne 1988; Society 2002; Finucane, Panizza et al. 2005). Inefficiency and weakness of the diaphragm leads to the increased recruitment of accessory muscles of respiration and contributes to thoracic and paradoxical breathing (Hruska 1997).

The diaphragm also has important proprioceptive functions that are involved in respiratory control feedback loops. It has a large number of afferent fibers that have functional significance in perception of respiratory sensations. Reduced length of the diaphragm (due to tonic contraction) appears to alter respiratory sensations in ways that contribute to increased respiratory drive (Frazier and Revelette 1991; Zhang and Davenport 2003).

ABDOMINAL WEAKNESS

Abdominal muscle weakness can aggravate diaphragm dysfunction (McConnell 1928; Hruska 1997). Both tonic and phasic contraction of abdominal muscles

assist the function of the diaphragm during inspiration and expiration and can to some extent compensate for diaphragm dysfunction (De Troyer 1983; Cassart, Pettiaux et al. 1997; Finucane, Panizza et al. 2005). Contraction of the abdomen during inspiration prevents the diaphragm from shortening excessively during standing posture and during rapid and large volume respiratory maneuvers (Sharp, Goldberg et al. 1975; De Troyer 1983). During expiration, contraction of the abdomen assists diaphragm doming, increasing its length and curvature in preparation for effective contraction during inspiration. People with dysfunctional diaphragms, such as many individuals with COPD, can become more breathless and develop more abnormal breathing if the abdomen is too relaxed (Cahalin, Braga et al. 2002). Increasing abdominal tone artificially using abdominal binding can assist these individuals (Pryor and Prasad 2002).

HYPERINFLATION AND LUNG VOLUMES

Hyperinflation of the lungs decreases the efficiency, strength and power of several respiratory muscles, particularly the diaphragm and intercostal muscles, and alters the breathing pattern. In hyperinflation, the diaphragm becomes shorter and loses its curvature, as it is forced to take a lower resting position in the thorax (Wolfson, Strohl et al. 1983; Celli 1989). This shortening of the diaphragm fibers decreases the power and efficiency of the diaphragm, due to the laws of length, tension relationships which apply to all contracting muscles (Finucane, Panizza et al. 2005).

Higher lung volume results in less of the diaphragm being apposed to chest wall. This decreases the ability of the diaphragm to move the lower rib cage in a lateral and vertical direction (De Troyer and Estenne 1988). At functional residual capacity the zone of apposition can take up to 1/3 to 1/4 of chest wall. At total lung capacity, the zone of apposition can be reduced to 0 percent (Hruska 1997). With reduction of the zone of apposition, the diaphragm fibers attached to the lower six ribs, become orientated transversely rather than vertically. A transverse orientation of these fibers inhibits their ability to lift and widen the lower six ribs. Instead, there is a tendency for the diaphragm to pull the lower lateral ribcage inward, decreasing the transverse diameter of the lower

rib cage during inhalation (Zocchi, Garzaniti et al. 1987; De Troyer and Estenne 1988; Celli 1989). When the lungs are at 30% of inspiratory capacity, the costal diaphragm no longer expands the rib cage, and above 30% inspiratory capacity the costal diaphragm has a rib cage deflating action (Wolfson, Strohl et al. 1983). At enlarged volumes there is also a tendency for the motion of the abdomen to reverse its timing so that inspiration is accompanied by inward motion of the abdomen and expiration is accompanied by outward motion of the abdomen (Wolfson, Strohl et al. 1983).

Reducing lung volumes can improve the function of the diaphragm. This is clearly demonstrated in COPD patients who experience reductions in lung volume after undertaking surgery to remove sections of their lungs. Lung reduction surgery has been shown in several studies to improve neuromechanical coupling of the diaphragm and individuals who receive this surgery consistently report increased exercise tolerance and reduced symptoms of dyspnea (Laghi, Jubran et al. 1998; Lahrmann, Wild et al. 1999; Cassart, Hamacher et al. 2001).

The actions of the internal and external intercostal muscles are also affected by lung volume. At low lung volumes, stimulation of these muscles will result in a net motion of rib elevation. At high lung volumes, the combined action of the internal and external intercostal muscles causes rib descent (De Troyer, Kelly et al. 1985). During hyperinflation, the ribs shift from their normal oblique position to a more horizontal position, impairing inspiratory action of rib cage muscles and making the rib cage stiff and difficult to expand (Tobin 1988). Restrictions of the rib cage then further inhibit diaphragm function (Hussain, Rabinovitch et al. 1985).

EFFECT OF INCREASED RESPIRATORY DRIVE ON BREATHING PATTERN

Elevated respiratory drive, when persistent, tends to produce chronic hypertonicity of respiratory muscles and this can contribute to abnormal breathing pattern (Hruska 1997; Binazzi, Lanini et al. 2004). Upper chest (thoracic) breathing and asynchronous breathing can be the result of increased respiratory drive (Sharp, Goldberg et al. 1975; De Troyer and Estenne 1984; Verschakelen and Demedts 1995). Persistent increases in inspiratory muscle

tone, not balanced by relaxation and rest of these muscles can overload respiratory muscles and contribute to fatigue (Gorini, Ginanni et al. 1990; Rochester 1993; Ambrosino, Opasich et al. 1994). Hypertonic respiratory muscles, particularly the diaphragm and intercostals, are at a mechanical disadvantage and therefore functionally weak, inefficient and more easily fatigued (Rochester 1993; O'Donnell, Banzett et al. 2007).

BEHAVIORAL AND PSYCHOLOGICAL FACTORS

Psychological and emotional states influence respiratory control and respiratory rhythm generation (Manning, Shea et al. 1992; Wientjes 1992; Boiten 1998; Homma and Masaoka 2008). Inputs from higher centers in the cortex and limbic structures can disrupt respiratory timing and rhythm, normally regulated by the brain stem pacemaker and pre-Botzinger complex neural networks (Perna, Caldirola et al. 2004). These disruptions are often the result of emotional and psychological states, such as fear and anxiety, which are known to influence breathing patterns independently of central and peripheral chemoreceptor input (Boiten 1998; Jack, Rossiter et al. 2003). Persistent activation of fear networks in the hippocampus, cortex, also the amgydala and its projections and dysfunctions in serotonergic, opioid and GABA neurotransmitter systems are proposed to be one mechanism of breathing disruption in individuals with panic disorder (Perna, Caldirola et al. 2004; Nardi, Freire et al. 2009). Abnormal respiratory inputs from the lungs and respiratory muscles can further aggravate this derangement (Whipp 1987; Frazier and Revelette 1991; Binazzi, Lanini et al. 2004).

Hyperarousal, brought on by mental and emotional processes contributes to allostatic load and affects the capacity of the body to maintain its stability and response to change (Sterling and Eyer 1988). Breathing is particularly sensitive to states of hyperarousal, during which signs of increased respiratory drive are evidence of the body's readiness for action. Anticipation of coming physical and emotional events, that contain some element of threat, has the distinct effect of increasing respiratory rate, reducing time of exhalation and changing respiratory pattern (Masaoka and Homma 2001; Homma and Masaoka 2008). Specific effects on the diaphragm are also seen. Fluoroscopic

studies show that in situations of emotional stress, the diaphragm shows signs of hypertonicity becoming flattened and immobile (Faulkner 1941; Wolf 1994) .

Individuals with psychological disorders can exhibit both inflexibility of breathing and excessive breathing irregularity. Both panic disorder and anxiety can be associated with irregularity (Han, Stegen et al. 1996; Wilhelm, Gertivz et al. 2001; Caldirola 2004). However, trait anxiety is specifically characterised by a reduced flexibility and responsiveness of breathing that is proposed to be associated with the wider pervasive reduction in behavioural and psychophysiological responsiveness and adaptability found in these individuals (Van Diest, Thayer et al. 2006).

Inappropriate breathing patterns may be the result of conditioning. It is known that breathing pattern can be conditioned by fear, anxiety and air hunger (Martin, Powell et al. 1980; Gallego and Perruchet 1991; Wan, Van Diest et al. 2008). It has been proposed that breathing habits such as thoracic breathing and excessive sighing, which are appropriate in particular circumstances, are dysfunctional when they persist as conditioned breathing habits that are inflexible and inappropriate (Lum 1976; Gardner 1995; Ley 1999).

ORGANIC DISEASE

CARDIOVASCULAR AND RESPIRATORY DISEASE

Disease processes in the respiratory and cardiovascular systems such as asthma, COPD and heart failure can increase ventilatory needs, stimulate respiratory drive and alter respiratory control with resulting alterations in breathing pattern (Perrin, Perrin et al. 1993; Caruana, Petrie et al. 2001; Hagman, Janson et al. 2008). These breathing patterns, such as rapid shallow breathing, thoracic breathing and paradoxical breathing can be functional adaptations to respiratory and cardiovascular pathology but might also contribute to increased physical symptoms (Gallego, Benammou et al. 1997; Mandak and McConnell 1998; Cahalin, Braga et al. 2002; Bernardi, Hilz et al. 2003; O'Donnell, Banzett et al. 2007). Breathing pattern adaptations to organic disease are presumably more likely to become dysfunctional when complicated

by changes in breathing behavior and perception brought about by psychological and behavioral factors (Butani and O'Connell 1997).

CONSEQUENCES OF BREATHING PATTERN DYSFUNCTIONS

BREATHING SYMPTOMS

DYSPNEA

The term dyspnea describes the sensation of respiratory distress or discomfort. Dyspnea varies not only in intensity but also in the qualities of the sensation which vary according to pathophysiological mechanisms (Simon, Schwartzstein et al. 1989; Elliot, Adams et al. 1991; Mahler, Harver et al. 1996; Harver, Mahler et al. 2000; Scano, Stendardi et al. 2005; Lougheed, Fisher et al. 2006). The ability of muscles to respond appropriately, and in proportion to central motor command is a key factor in determining extent of dyspnea in particular the sense of "unsatisfied respiration"(O'Donnell, Banzett et al. 2007). Inefficient breathing patterns, shortened and hypertonic respiratory muscles, rigidity of the chest wall and respiratory muscle weakness increase the amount of respiratory muscular effort required to move the chest wall (Killian and Jones 1988). Because these factors inhibit the ability of the respiratory muscles to respond appropriately to central respiratory motor command they may contribute to dyspnea (Altose 1992).

Cambell and Howard originally proposed the theory of muscle length-tension inappropriateness as the major cause of dyspnea (Campbell and Howell 1963). Research since that time has shown that dyspnea is a more complex phenomenon than defined by this theory as it is reliant on multiple sensory inputs and affective components with interacting relationships (Manning and Schwartzstein 1995; De Peuter, Van Diest et al. 2004; O'Donnell, Banzett et al. 2007). However, the extent of afferent re-efferent dissociation or disparity between ventilation achieved and ventilation commanded is still accepted as central to the quality and intensity of dyspnea particularly the sense of "unsatisfied respiration" (Manning and Schwartzstein 1995).

Breathing pattern changes are associated with dyspnea as both a cause and a consequence. Dyspnea tends to increase recruitment of the accessory

respiratory muscles rather than the diaphragm and therefore increases thoracic breathing and a tendency to asynchronous breathing (Breslin, Garoutte et al. 1990). Dysfunctions of breathing pattern are also proposed to result in disproportionate breathlessness in asthmatics (Prys-Picard, Kellet et al. 2006; Hagman, Janson et al. 2008). In COPD, rapid shallow and thoracic breathing is correlated with dyspnea ratings (Ferrari, Goti et al. 1997). Voluntary changing of breathing pattern from thoracic to abdominal reduces respiratory drive in patients with COPD (Sackner, Gonzalez et al. 1984) and in some COPD patients helps to reduce dyspnea (Cahalin, Braga et al. 2002).Hyperinflation and the resulting changes in respiratory muscle function, which act as important influences on breathing pattern, are well documented contributors to specific qualities of dyspnea, particularly the sense of unsatisfied respiration (Marchand and Decramer 2000; Lougheed, Fisher et al. 2006; O'Donnell 2006; O'Donnell, Banzett et al. 2007).

Breathing patterns such as slow abdominal breathing or techniques that reduced lung hyperinflation might also reduce dyspnea symptoms because of beneficial influence on lung function. Slow abdominal breathing, at the rate of 4-7 breaths per minute, decreases respiratory resistance in asthmatics (Lehrer, Vaschillo et al. 2004) and improves ventilation to perfusion ratios, maximizing gas exchange (Vascillo, Vaschillo et al. 2004; Yasuma and Hyano 2004). Therapeutic breathing patterns might also include maintaining low lung volumes or emphasising relaxed exhalation and they may assist in maximising diaphragm length and curvature, relaxing accessory and intercostal muscles thus improving neuromechanical coupling of respiratory motor effort to central command and reducing dyspnea (O'Donnell, Banzett et al. 2007).

HYPERVENTILATION AND HYPOVENTILATION

Hyperventilation and abnormal breathing patterns often co-exist, however the exact relationship between breathing pattern and hyperventilation is not entirely clear, as breathing pattern disorders may exist without hypocapnia (Hormbrey, Jacobi et al. 1988). Abnormal breathing pattern and respiratory muscle dysfunctions may reinforce and perpetuate hyperventilation tendencies in susceptible individuals (Gardner 1995). Resolution of respiratory,

psychological and somatic symptoms after breathing training is sometimes associated with changes in breathing pattern and not in changes in carbon dioxide levels (Han 1996).

Hypercapnia can also be a consequence of inspiratory muscle weakness and consequent inefficient breathing patterns. In patients with COPD, rapid and shallow breathing is linked to inefficiency of breathing and to severity of breathlessness (Gorini, Misuri et al. 1996).

HAEMODYNAMICS AND LYMPHATIC SYSTEM

A functional respiratory pump creates rhythmic pressure fluctuations between the thorax and the abdomen that are important for the movement of body fluids such as blood and lymph. Normal pressure development during the respiratory cycle is characterised by a decrease in intra-thoracic pressure during inhalation and an increase in intra-abdominal pressure during expiration (Dornhorst, Howard et al. 1952; DeBoer, Karemaker et al. 1987). Paradoxical motion of the abdomen and dysfunction of the diaphragm alters normal pressure relationships between the thoracic and abdominal compartment during inspiration and expiration. In paradoxical motion of the abdomen during inspiration, abdominal pressures can decrease rather than increase during inspiration (Wolfson, Strohl et al. 1983). This probably affects the amplitude of rhythmic fluctuations of blood volume, which activate homeostatic reflexes involved in maximizing optimal cardiorespiratory interaction and regulating blood pressure (Bernardi, Porta et al. 2001; Yasuma and Hyano 2004).

Respiration is one of the important extrinsic influences on lymphatic flow, interacting with intrinsic motility of lymph vessels and organs to either enhance or dampen their activity (Gashev 2002). The pressure differentials arising as a result of activity of the respiratory pump creates fluctuations in central venous pressure which directly affect lymph drainage from the lungs and abdomen (Lattuada and Hedenstierna 2006; Hedenstierna and Lattuada 2008) and affects transmural pressure in lymphatic vessels, which modulates the function of intrinsic pacemakers in the lymphatic system. Recent research also shows that the lymphatic vessels in the diaphragm itself form a specialised system for

draining fluid from the peritoneal cavity and returning it to the vascular system (Abu-Hijleh, Habbal et al. 1995). This suggests that breathing patterns that alter normal respiratory pressure dynamics have a detrimental effect on the function of the cardiovascular and lymphatic systems.

POSTURE AND MOTOR CONTROL

The respiratory muscles of the lower rib cage, particularly the diaphragm and abdominal muscles, also have movement, postural and other functions that can be compromised when respiratory drive or ventilatory needs increase (McGill, Sharratt et al. 1995; Gandevia, Butler et al. 2002). The respiratory functions of these muscles need to be integrated with their many other functions, such as swallowing, speech, valsalva maneuvers, spinal stabilization and movement of the trunk and limbs. This need for integration of these separate functions places considerable demands on the mechanism of motor control (Rassler and Kohl 2000; Gandevia, Butler et al. 2002). Balance mechanisms, involving the vestibular system and proprioceptive mechanisms in the lower limbs, are also intricately involved with respiration and dysfunctions of balance and respiration often co-exist (Sakellari, Bronstein et al. 1997; Yates, Billig et al. 2002; Janssens, Brumagne et al. 2010). Respiratory muscle overload, such as occurs when ventilatory needs are high or when breathing pattern is dysfunctional, adversely affects postural balance, proprioceptive function of the lower limbs (Sakellari, Bronstein et al. 1997; Janssens, Brumagne et al. 2010) and neuro-muscular co-ordination needed for prevention of spinal and other types of muscular-skeletal injury (McGill, Sharratt et al. 1995; Gandevia, Butler et al. 2002)

In the upper body, breathing dysfunction is known to affect head and neck posture and muscle co-ordination of the upper limbs. A tendency to carry the head forward of the body with anterior rotation of the cranial base is a postural change commonly associated with breathing difficulty. Forward head posture is a well-known response to obstructed breathing and is common in children with chronic nasal allergy and mouth breathing (Cuccia, Lotti et al. 2008; Chaves, De Andrade et al. 2010). Forward head posture can also indicate the presence of a short flat diaphragm and weak abdominals due to the fact

that positioning the head in front of the body tends to increase the resting length of diaphragm (Hruska 1997; Pryor and Prasad 2002). This head posture, while facilitating breathing, has several adverse effects on the biomechanics of the head, neck and jaw and is associated with temporo-mandibular joint syndrome, neck pain and headache (Hruska 1997). Mouth breathing is a key factor in the development of narrow face, crowded teeth and defective jaw alignment (Bresolin 1983).

MUSCULO-SKELETAL PAIN

Dysfunctional breathing patterns have been associated with musculo-skeletal pain in various regions, such as the chest wall (Wheatley 1975), neck and shoulder region (Perri and Halford 2004; Kapreli, Vourazanis et al. 2009), and lower back (Chaitow 2004). Breathing disorders were found in one study to be greater predictors of lower back pain than either obesity or inactivity (Smith, Russell et al. 2006). Shoulder problems may also result because hypertonic trapezius muscles contract during the initial stages of shoulder movement rather than towards the end. This altered pattern of scapular-humeral motion is associated with shoulder pain and rotator cuff dysfunction (Pryor and Prasad 2002).

OTHER

Breathing pattern dysfunctions are also involved in pelvic floor dysfunction and incontinence (Hodges, Sapsford et al. 2007; Hung, Hsiao et al. 2010) and also in disorders of speech and vocalization (Altman, Atkinson et al. 2005; Vertigan, Gibson et al. 2006).

EVALUATION OF BREATHING PATTERN

In the research environment assessment of breathing pattern is often undertaken using magnetometry (Konno and Mead 1966) and respiratory induction plethysmography (Wilhelm and Roth 2003) and in recent years with optoelectronic plethysmography (Aliverti, Dellaca et al. 2000). However, in the clinical environment, observation and palpation are the main methods of

assessment (Chaitow 2002; Pryor and Prasad 2002; Perri 2007). Few of these techniques have been validated.

CONCLUDING REMARKS

Breathing pattern abnormalities represent neuromuscular and biomechanical aspect of dysfunctional breathing. There are various types of breathing pattern disorders including disorders of respiratory muscle co-ordination, timing, stability and responsiveness. Breathing pattern disorders are reported in the similar circumstances and populations as hyperventilation disorders but it is possible that they exist even when carbon dioxide levels are normal. Breathing pattern disorders many contribute to problems of speech, posture, motor control and balance. They may aggravate symptoms of dyspnea and muscular skeletal pain. Habitual presence of breathing pattern dysfunctions, such as thoracic and paradoxical breathing, may impair the function of homeostatic reflexes originating from oscillating hemodynamic fluctuations. Despite their potential importance disorders of breathing pattern are often overlooked, this may be due to a lack of validated clinical tools that can measure and quantify disturbances in breathing pattern.

CHAPTER 5- DYSFUNCTIONAL BREATHING

INTRODUCTION

Dysfunctional breathing is not a precise term and has no rigorous definition (Morgan 2002). In this thesis, dysfunctional breathing is broadly viewed as breathing that results in disturbance or inefficiency of the primary or secondary functions of breathing. The two primary functions of breathing, as discussed in most textbooks on respiratory physiology (Lumb 2000{Levitsky, 1995 #190)}, are biomechanical and biochemical as seen in:

1) the actions of the respiratory pump; and

2) exchange of respiratory gases- O_2, CO_2 and maintenance of the body's pH so that these remain within the normal parameters needed for health.

The secondary functions of breathing include its role in posture, motor control, and speech production. In addition, there are psychophysiological functions of breathing related to its role in self-regulation of stress and arousal.

USE OF THE TERM 'DYSFUNCTIONAL BREATHING'

The term 'dysfunctional breathing' (DB) has been used increasingly over the last decade, particularly by those involved in breathing therapies (Thomas 2003; Hagman, Janson et al. 2008; Stanton, Vaughn et al. 2008). Its use has increased after doubts about the presence of hypocapnia in patients with the hyperventilation syndrome made the use of this term unacceptable (Dixhoorn 1997; Hornsveld 1997). At times it seems that the term dysfunctional breathing has been used as a proxy for the term hyperventilation syndrome, given that the main criteria for diagnosing DB has been the Nijmegen Questionnaire (Thomas, McKinley et al. 2001; Thomas, McKinley et al. 2005), a questionnaire that was originally validated for hyperventilation (Dixhoorn and Duivenvoorden 1985). However, at other times the term dysfunctional breathing has been used to refer exclusively to breathing pattern dysfunction (Prys-Picard and Niven 2008) or when unusual and disordered breathing patterns exist in combination

with medically unexplained symptoms and anxiety (Hagman, Janson et al. 2008; Stanton, Vaughn et al. 2008).

ASSESSMENT OF DYSFUNCTIONAL BREATHING

The assessment of dysfunctional breathing is not standardised and there are no agreed clinical protocols for evaluating dysfunctional breathing. Assessments of dysfunctional breathing may include a range of measures, for example, questionnaires including the Nijmegen Questionnaire (Thomas, McKinley et al. 2005) and other questionnaires that evaluate breathing symptoms and behaviours (White 2005; Hagman, Janson et al. 2008), assessment of breathing pattern using respiratory induction plethysmography (Prys-Picard and Niven 2008) and other (unvalidated) measures of breathing pattern (Perri and Halford 2004; Hagman, Janson et al. 2008), also capnometry (McLaughlin 2009) and breath holding time (Buteyko 1990). The relationship between these measures and the extent to which they overlap is not established. The nature of these relationships, however, may help to further clarify definitions of dysfunctional breathing and assist in the development of clinical protocols for evaluating dysfunctional breathing.

RELATIONSHIP OF DYSFUNCTIONAL BREATHING TO HYPERVENTILATION AND BREATHING PATTERN DISORDERS

Hyperventilation is clearly a type of dysfunctional breathing (Dixhoorn 1997; Warburton and Jack 2006; Stanton, Vaughn et al. 2008). However, it is not possible, on the basis of current research, to evaluate the extent of hypocapnia in patients described as having dysfunctional breathing because most studies have not systematically evaluated carbon dioxide levels (Thomas, McKinley et al. 2001; Thomas 2003; Thomas, McKinley et al. 2005; Hagman, Janson et al. 2008; Prys-Picard and Niven 2008; Stanton, Vaughn et al. 2008; Thomas, McKinley et al. 2009).

Various types of breathing pattern disturbances may be considered to be forms of dysfunctional breathing. The breathing patterns and behaviours described in patients categorised as having dysfunctional breathing at different

times have included excessive sighing (Perrin, Perrin et al. 1993; Prys-Picard, Kellet et al. 2006; Hagman, Janson et al. 2008), thoracic breathing, increased breathing frequency (Hagman, Janson et al. 2008), paradoxical breathing and paradoxical vocal cord dysfunction (Warburton and Jack 2006). Some of these breathing pattern disorders influence the way breathing contributes to its secondary functions in posture, motor control, speech and vocalization.

PSYCHOPHYSIOLOGICAL ASPECTS OF DYSFUNCTIONAL BREATHING

Chapter 2 of this thesis reviewed the secondary functions of breathing and how breathing involves promoting physiological states that support homeostasis and self−regulation of arousal levels, stress and mood.

BREATHING, HOMEOSTASIS AND HYPERAROUSAL

"The biological purpose of the aroused state is to allow an organism to 'cope' physiologically, behaviorally and emotionally with specific environmental demands. Arousal must be followed by a period of relaxation for homeostasis to be restored" (Sterling and Eyer 1988).

The aroused state is generally associated with increased ventilatory drive which may lead to hypocapnia and breathing pattern disorders. Dysfunctional breathing may therefore result from inappropriately sustained arousal (Boiten 1998). Breathing disturbances, therefore, may be indicative of a deeper core dysfunction i.e. inability to achieve physical and psychological states of rest, and functional breathing, needed for recovery of homeostasis. In the early literature on battle fatigued soldiers, which formed the basis for later enquiry into dysfunctional breathing, mental and physical exhaustion resulting from prolonged hyperarousal were considered to be the cause of breathing and cardiovascular symptoms (Da Costa 1871; Lewis 1918). Lewis, in his reports of battle fatigued soldiers, catalogues a typical range of breathing dysfunctions found in these men, including hyperpnoea, depletion of the alkaline buffering system (presumably as a compensation for hyperventilation), gross reduction in breath holding time and upper thoracic breathing pattern (Lewis 1918; Nixon 1995). Lewis called the condition he observed in the soldiers "effort syndrome" and stressed that it was not a disease, but a homeostatic disorder, where the

ability to make and sustain effort was reduced by homeostatic failure. His treatment for this soldiers included proper restoration of sleep, alternating activity and rest and breathing instruction (Nixon 1995).

Disruption of autonomic nervous system function is a key feature of homeostatic dysregulation (Recordati and Bellini 2004). The modulation of physiological states of activity and rest needed for regulation of homeostasis requires fluctuating levels of activity in the sympathetic and parasympathetic branches of the autonomic nervous system. In prolonged hyperarousal, parasympathetic withdrawal occurs, resulting in dominance of the sympathetic nervous system (Thayer and Lane 2000). This is evidenced by increased heart rate and reduced heart rate variability (Berntson, Cacioppo et al. 1993).

Functional breathing modulates arousal, balances autonomic nervous system function and promotes homeostasis (Lehrer, Vaschillo et al. 2000; Bernardi 2001). It can be argued that dysfunctional breathing is breathing that does not perform these autonomic nervous system and homeostatic regulating functions. Habitual presence of thoracic breathing, paradoxical breathing, hyperventilation or excessively irregular breathing might all indicate a general dysfunction of a person's ability to alternate the arousal state with periods of rest. It is also possible that presence of these types of breathing might in some way contribute to perpetuating states of hyperarousal not balanced with periods of rest.

Some laboratory research has shown that increased rate and volume of breathing tends to promote hyperarousal. In one study, healthy subjects were asked to breathe at three different rates and five volumes. As respiration rates and respiratory volumes increased there was a clear, precipitous decrease of parasympathetic nervous system tone that reduced with each increase in breath rate (up to 66% reduction with most rapid breathing) (Meersman, Reisman et al. 1995).

PERCEPTION, DYSPNEA AND CONTROL OF BREATHING: FACTORS IN SELF REGULATION

Three factors necessary for breathing to be effectively used for self regulation include:

1. Accurate perception;
2. The ability to experience breathing sensations as pleasant; and
3. Flexibility and responsiveness of breathing.

INACCURATE PERCEPTION OF BREATHING

Poor perception of whether one's breathing is normal or obstructed and lack of sensitivity or hypersensitivity to sensations arising from breathing modulations are aspects of breathing dysfunction (Klein, Walders et al. 2004). Breathing sensations can be overperceived or underperceived with inaccurate perceptions of breathing sensations being caused by factors that disrupt other aspects of respiratory control. These causative factors include altered chemosensitivity, hyperinflation of the lungs (Lougheed 2007), psychological factors such as anxiety and panic, and personality traits such as defensiveness and tendencies to attention deficit (Gibson 1995; Lehrer, Feldman et al. 2002).

Inaccurate perception of breathing may have implications for the use of breathing as a tool for self-regulation and for conditions associated with dysfunctional breathing such as asthma. As previously discussed in Chapter 2, it has been suggested that individuals who fully, and presumably accurately, sense their breathing are more able to use this as a focus for self−awareness and self-regulation. It is possible that inaccurate perception of breathing sensations is also associated with a more general reduction of interoceptive accuracy, which interferes with overall mind−body self-regulation capability, but also has specific impacts in particular disease states. In the case of asthma, inaccurate perception of breathing sensations can also contribute to morbidity, reduced quality of life and, in the case of underperception, to fatal and near fatal consequences (Gibson 1995; Magadle, Berar-Yanay et al. 2002).

Attention to breathing sensations is an important part of meditation and relaxation techniques that aim to improve psychological, spiritual and physical health (Mijares 2009). Therefore, lack of breathing awareness and inaccurate perception of breathing sensations may have implications for breathing and meditation strategies that aim to increase mind-body connection by focus on the sensations of the breath (Johnson 1995).

PLEASANTNESS AND UNPLEASANTNESS OF BREATHING SENSATIONS

The presence of disproportional and exaggerated dyspnea, which cannot be adequately explained, is often taken as an indicator of the presence of dysfunctional breathing (Prys-Picard, Kellet et al. 2006; Hagman, Janson et al. 2008). Unexplained dyspnea, which contains both sensory and affective components, is thought to be related to anxiety and other psychogenic factors (Howell 1990; Han, Zhu et al. 2004). In conditions such as asthma, the extent of dyspnea symptoms is aggravated by anxiety (Deshmukh, Toelle et al. 2008). The affective component (pleasantness or unpleasantness) of dyspnea is particularly vulnerable to the effect of emotions, increasing with negative emotions and decreasing with positive emotions (von Leupoldt, Mertz et al. 2006). Social and demographic factors which have been shown to increase the incidence of dyspnea include low income, unemployment, living alone and being of the female gender (Currow 2009). The factors suggest a stress related component to dyspnea.

Frequent experience of breathing as unpleasant or frightening may reinforce dysfunctions of breathing and also have an adverse influence on psychophysiological self-regulation and the function of affective neural circuitry (Rosenkranz and Davidson 2009). There are a number of theories proposing that physiological sensations contribute to the development of emotions or affective states (James 1994; Craig 2002; Rosenkranz and Davidson 2009).

Recent research has shown an anatomical basis for dyspnea, primarily involving limbic system structures and a central autonomic network that provides links between physiological sensations, homeostatic regulation and affective states (Craig 2002; Craig 2009; Rosenkranz and Davidson 2009). Dyspnea is

considered to be one of the strongest fear-inducing sensations (Ley 1989). It is proposed that the unpleasant and threatening affective components of dyspnea, which are known to activate these the limbic and autonomic networks (von Leupoldt, Sommer et al. 2008), produce feelings of anxiety and other types of negative affect and increase defensive efferent homeostatic responses, for example bronchoconstriction or other types of muscle tension (Rosenkranz and Davidson 2009). If one accepts that negative emotional states increase the unpleasant affective components of dyspnea (von Leupoldt, Mertz et al. 2006; Schon, Dahme et al. 2008) and fear and catastrophic interpretations associated with dyspnea increase anxiety and negative emotional states (Ley 1989), then it is clear that exaggerated sensations of dyspnea, and its unpleasantness, are important aspects of functional breathing disorders.

The ability to experience, and produce, pleasurable sensations during breathing exercises may enhance a person's ability to use breathing for relaxation and self-regulation. Pleasurable sensations activate some of the same limbic and paralimbic substrates as unpleasant sensations. However pleasurable sensations, which are generally associated with the satisfaction of homeostatic needs, have relaxing and salutogenic effects that differ markedly from those associated with unpleasant sensations (Esch 2004). Several breathing therapies pay particular attention to directing sensory awareness and mental attention to the pleasant nature of breathing (Johnson 1995; Dixhoorn van 2007). Focus on the pleasant aspects of breathing sensations is emphasized in Buddhist meditation techniques that instruct the practitioner to pay attention to the "beautiful breath" (Brahm 206). While there has been little research on this topic, there is some suggestion that the extent to which a person experiences pleasantness of respiratory sensation during breathing modulations affects its usefulness as a tool for self-regulation (Conrad 2007). It is also possible to hypothesize that, when sensations associated with breathing are unpleasant or fear inducing, there is impairment in a person's ability and willingness to use modulation of breathing to reduce arousal.

FLEXIBIILTY AND RESPONSIVENESS OF BREATHING

A key aspect of breathing functionality is its appropriateness and ability to adapt quickly to changing emotional and environmental conditions. This adaptability and responsiveness is influenced by a combination of psychological, physiological, neurological (Thayer and Lane 2000) and muscular factors. It seems reasonable to assume that individuals who are unable to modify breathing patterns are inhibited in their abilities to apply breathing strategies for self-regulation. Lack of flexibility and responsiveness of breathing may also reduce an individual's sense of control and contribute to the negative affective components of dyspnea.

DYSFUNCTIONAL BREATHING AND BREATHING THERAPIES

The idea that a spectrum of breathing functionality exists, from optimal to dysfunctional, forms the basis for most breathing therapies. Subsequently, the implicit aim of most breathing retraining protocols is to correct dysfunctional breathing and optimize breathing functionality. The methodological differences between various approaches to breathing therapy are, to a large extent, influenced by how they conceptualize the construct of 'dysfunctional breathing'. This also influences which aspects of breathing functionality are evaluated and subsequently targeted for rehabilitation by practitioners of these therapies. For example, the Buteyko Breathing Technique targets hypocapnia as the most important aspect of breathing functionality (Stalmatski 1999). Yoga breathing therapists generally target breathing pattern (Sovik 2000). The Papworth Method of breathing and relaxation training was originally devised as a treatment for hyperventilation syndrome by physiotherapists working with Dr. Claud Lum at the Papworth Hospital in Cambridge (Lum 1976), and current usage of this method for dysfunctional breathing targets hyperinflation, hyperventilation, oral breathing and rapid and thoracic breathing (Lum 1976; Holloway and West 2007).

It is difficult to compare the merits and determine the appropriate use of different breathing retraining methods because there has not been adequate research testing the assumptions about the nature of dysfunctional breathing and the various means of assessing it. For example, the proponents of the

Buteyko Breathing Technique focus only on the hypocapnia aspects of dysfunctional breathing and the breathing protocols used in the Buteyko Breathing Technique have as their sole aim the normalization of hypocapnia (Stalmatski 1999; Stark and Stark 2002). The Buteyko Breathing Technique evaluates changes in breath holding time as an indirect means of evaluating carbon dioxide, with the assumption that any changes of carbon dioxide are due to improved carbon dioxide status. Yet most studies on the Buteyko Breathing Technique have not investigated the effects of this breathing therapy on carbon dioxide status, breath holding time or the relationships between these two aspects of breathing functionality.

A series of studies by Thomas (2001, 2003, 2005, 2009) evaluated dysfunctional breathing and its response to treatment on the basis of the Nijmegen Questionnaire (NQ) and reported that standard physiotherapist-taught breathing therapy improved responses to this questionnaire as well as improving dysfunctional breathing. However, since the hyperventilation syndrome has been invalidated, due to lack of consistent relationship of its classic symptoms with either acute or chronic hypocapnia (Hornsveld 1997), it is not entirely clear which aspect of homeostatic or breathing dysfunction are actually measured by the NQ.

CONCLUDING REMARKS

Dysfunctional breathing is not clearly defined, even though the term is in common usage. A working definition is given in this chapter for dysfunctional breathing, which loosely defines dysfunctional breathing as breathing that does not efficiently perform its primary or secondary functions. Hyperventilation, breathing pattern disorders, hyperarousal, excessive dyspnea, inaccurate perceptions of breathing sensation and lack of flexibility and responsiveness of breathing may all contribute to dysfunctional breathing.

Dysfunctional breathing is an important consideration in breathing therapies and there are many different views on breathing dysfunction and its measurement. Measures used to evaluate DB include breath holding time, breathing pattern assessment, symptom questionnaires and capnometry, yet

these measures are not well understood and a number of commonly-used measures require further development and testing.

Further investigation of these measures, particularly of their relationships, will help to elucidate the nature of dysfunctional breathing and indicate the extent to which biochemical, biochemical and symptomatic aspects dysfunctional breathing represent linked or separate dimension.

Understanding the relationships between these measures will also help to indicate the range of measures needed to perform a comprehensive evaluation of dysfunctional breathing and assist in the understanding of the mechanisms of breathing therapies.

OVERVIEW SECTION ONE-
MEASURING BREATHING PATTERN

The following section contains two published studies that investigate manual techniques for evaluating breathing pattern.

Chapter 6- 'Evaluation Of Breathing Pattern: Comparison Of A Manual Assessment Of Respiratory Motion (MARM) And Respiratory Induction Plethysmography'.

Chapter 7- 'Comparison of the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo breathing Assessment in determining a simulated breathing pattern'.

CHAPTER 6 -

EVALUATION OF BREATHING PATTERN: COMPARISON OF A MANUAL ASSESSMENT OF RESPIRATORY MOTION (MARM) AND RESPIRATORY INDUCTION PLETHYSMOGRAPHY

ABSTRACT:

Background - Altered breathing pattern is an aspect of dysfunctional breathing but few standardized techniques exist to evaluate it. This study investigates a technique for evaluating and quantifying breathing pattern, called the Manual Assessment of Respiratory Motion (MARM) and compares it to measures performed with Respiratory Induction Plethysmography (RIP).

Method - Twelve subjects altered their breathing pattern and posture while two examiners assessed their breathing using the MARM. Simultaneous measurements with RIP were taken. Inter-examiner agreement and agreement between MARM and RIP were assessed. The ability of the measurement methods to differentiate between diverse breathing and postural patterns was compared.

Results - High levels of agreement between examiners were found for measures of upper rib cage motion relative to motion of the lower rib cage/abdomen with the MARM. Interexaminer agreement was not evident when measuring lung volume. The measures of upper rib cage dominance during breathing correlated with similar measures obtained from RIP. Both RIP and MARM measures methods were able to differentiate between abdominal and thoracic breathing patterns, but only MARM was able to differentiate between breathing changes occurring as result of slumped versus erect sitting posture.

Conclusion - This study suggests that the MARM is a reliable clinical tool for assessing breathing pattern.

INTRODUCTION:

The aim of this study is to determine the utility of a technique called the Manual Assessment of Respiratory Motion (MARM) to assess and quantify breathing pattern, in particular the distribution of breathing motion between the upper and lower parts of the rib cage and abdomen under various conditions. It is a manual technique that once acquired is practical, quick and inexpensive. Its utility is assessed on the basis of the inter-rater reliability and its ability to differentiate between clearly different breathing patterns.

Non-invasive estimation of breathing movement has been used to derive several respiratory parameters, including time components like breathing frequency, inhalation time, exhalation time and exhalation pauses, as well as volume components like tidal volume and pattern of recruitment of respiratory muscles (Society 2002). Measures of breathing pattern usually involve the assessment of displacement and movement of the two main functional compartments of the body involved in breathing i.e. the upper rib cage and lower rib cage/abdomen.

In the research setting the two main types of instrumentation used to evaluate breathing pattern are Respiratory Induction Plethysmography (RIP) and Magnetometry (Society 2002), whilst in the clinical environment, the cheaper and less time consuming methods of observation and palpation are the mainstay of breathing pattern assessment(Clanton and Diaz 1995). Clinical techniques for evaluating muscle and rib cage movement and recruitment patterns frequently involve manual palpation and visual assessment (Chaitow 2002; Pryor and Prasad 2002), however, these procedures have not been standardised or validated.

The Manual Assessment of Respiratory Movement (MARM)

The MARM is a palpatory procedure based on the examiners interpretation and estimation of motion perceived by their hands at the posterior and lateral lower rib cage. The examiner using the MARM can gauge various aspects of breathing such as rate and regularity, but its particular utility

is for assessing breathing pattern and the relative distribution of breathing motion between the upper rib cage and lower rib cage and abdomen.

The MARM also takes into account the form of the spinal column, whose extended or flexed form constitutes a third degree of freedom of breathing movement (Smith and Mead 1986). Extension of the spinal column increases the distance between the pubic symphysis and xiphoid process elevates the ribcage, facilitating upward motion of the sternum/upper thorax (pump-handle motion) as well as abdominal expansion. Thus, it facilitates inhalation in a vertical direction ('length breathing'). By contrast, a slumped posture inhibits the vertical movement of inhalation, increases pressure of abdominal contents to increase diaphragm length and promotes lateral expansion and sideways elevation of the lower ribs or bucket-handle movement. Thus, it facilitates inhalation in a horizontal direction ('width breathing'). The MARM is able to differentiate between these breathing patterns and assess asymmetry between the two sides of the body. In case of scoliosis or sideways distortion of the spinal column there is a marked difference in breathing movement between the left and right sides of the body and this can be registered clearly by the examiner's two hands. Such asymmetry adds even more degrees of freedom of breathing movement that are unlikely to be adequately assessed by RIP.

An assumption of the MARM procedure is that breathing is a *global* movement of expansion (inhalation) and contraction (exhalation) of the body. From the manual assessment of motion at the lower ribs the examiner constructs a mental picture of global breathing motion, represented by an upper line and a lower line, originating from the centre of a circle or ellipse, together creating a slice in a pie chart, which represents the area of expansion (see figure 1). Specific features of the global change in form that can be estimated are: the degree that the sternum and upper thorax are lifted upwards, the degree that the lower ribs lift and expand sideways and the degree that diaphragmatic descent expands the abdomen outwards. The predominance of motion in either the upper rib cage/sternum or the lower rib cage/abdomen determines the direction of the global change with inhalation, as

either predominantly in an upward or downward direction and the shape change as either elongation or widening.

Individuals may differ in their breathing response to postural change. For example, when the spine is extended, inspiration may result in a general increase in breathing motion with greater involvement of both upper thorax and abdomen or result in upward elevation of the chest with little increase or paradoxical decrease in abdominal motion.

The two lines of the MARM are a simplified way of describing the global form of inhalation. The recent technology of opto-electronic plethysmography (OEP) shares the same assumption of the MARM and uses between 40 and 80 markers on the body that can be followed by several cameras (Aliverti, Dellaca et al. 2000). From these recordings the form and volume of the 'sphere' is calculated, or mathematically recreated, which corresponds accurately with actual breathing movement. The procedure is much like the creation of animation movies. From OEP research it appears that there are many degrees of freedom in respiratory movement (or form changes), all resulting from more or less successful adaptations of breathing to different circumstances (Aliverti, Cala et al. 1997; Aliverti, Ghidoli et al. 2003; Aliverti, Kayser et al. 2007).

With the subject intentionally breathing in different ways, the examiner can use the MARM to test breathing functionality. The procedure is derived from the practice of breathing therapy, which aims to test and increase the functional adaptability or flexibility of breathing (Dixhoorn van 2007). For instance, the subject can be asked to breathe normally and more deeply, to breathe with emphasis on upper thoracic or more abdominal inhalation, to breathe in an upright or easy sitting posture. The range of breathing patterns produced suggests that functional breathing involves flexibility and a range of breathing patterns. This may be operationalised in the MARM as the largest distance between the highest upper line and the lowest lower line across several maneuvers (see figure 1)

The diaphragmatic, abdominal and rib cage muscles all have optimum length tension relationships and co-ordination patterns that make breathing

most efficient when all muscle groups are equally involved (De Troyer and Estenne 1988). This suggests that 'optimal' breathing occurs when there is an even distribution of breathing effort between the two main functional compartments of the body involved in breathing i.e. upper rib cage and lower rib cage/ abdomen. Such a balance also provides the greatest flexibility of the respiratory system to respond to any internal or external alterations to respiratory drive. Efficient breathing therefore occurs when 'percent rib cage' is around 50 and 'balance' (upper half minus lower half) is minimal. An uneven breathing distribution without good reason may be considered to be unnecessary, effortful and dysfunctional. The distribution of breathing effort can be measured using RIP by determining the % rib cage motion and can be assessed using the MARM by deriving measures of 'balance' and % rib cage motion, which indicate the relative contributions of upper and lower half of the body.

The MARM procedure was first developed and applied in a follow-up study of breathing and relaxation therapy with cardiac patients in the 1980s. It appeared that two years after breathing therapy the MARM still showed differences between experimental and control patients (Dixhoorn 1994). The experimental group showed more involvement of the lower half of the body and better balance, both at rest and during deep breathing. Later preliminary tests of inter-examiner reliability indicated that the MARM has potential as a clinical and research tool for evaluating breathing pattern (Dixhoorn 2004) and that further investigations are warranted.

In this study experienced 'breathers' were used to test the ability of the MARM to differentiate between nine different breathing patterns and postures. The study also assessed the validity and inter-examiner reliability of the MARM by comparing the measures made with the MARM to measures made simultaneously with RIP (Vivometrics Lifeshirt system).

The hypotheses were:

1. Different examiners will make similar assessments when using the MARM on the same subject breathing consistently.

2. There will be a significant correlation between MARM and RIP measurements of 'percent ribcage'.

3. RIP measures of 'percent ribcage' and MARM measure of 'balance' are able to differentiate between (a) voluntary thoracic and abdominal breathing, and (b) breathing with an extended and slumped spinal column.

4. Experienced breathers have 'percent ribcage' values of about 50, 'balance' values approaching zero and a large total range of MARM across the different procedures.

The study was undertaken at RMIT University, Biomedical Sciences Laboratory in Melbourne Australia. Ethics approval was received from RMIT University ethics committee and all subjects gave written consent.

METHOD

Examiners

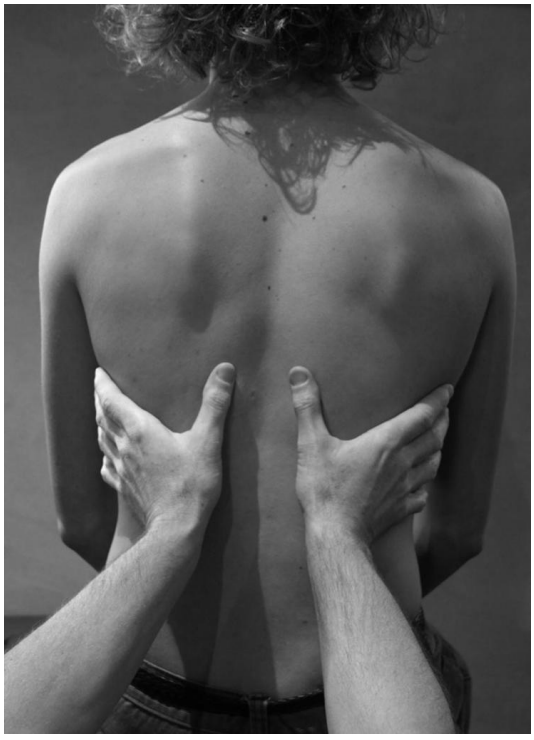
The tests were done by three experienced osteopaths all of who had several years of clinical experience in manual therapy. One of them (RC), the principle investigator, was personally trained in MARM by Van Dixhoorn while the other examiners all had two hours of instruction and practice using the MARM during which time subjects altered their posture and breathing pattern with each examiner being given appropriate feedback about their palpation technique and findings. RC did the MARM on all subjects and her data were used for comparison with results using the Lifeshirt and with the other examiners.

The MARM

The examiners received the following instructions on how to perform and record the MARM:

'Sit behind the subject and place both your hands on the lower lateral rib cage so that your whole hand rests firmly and comfortably and does not restrict breathing motion. Your thumbs should be approximately parallel to the spine, pointing vertically and your hand comfortably open with

fingers spread so that the little finger approaches a horizontal orientation. Note that the 4th and 5th finger reach below the lower ribs and so they can feel abdominal expansion. You will make an assessment of the extent of overall vertical motion that your hands feel relative to the overall lateral motion. Also decide if the motion is predominantly upper rib cage, lower rib cage/abdomen or relatively balanced. Use this information to determine the relative distance from the horizontal line of the upper and lower lines of the MARM diagram. The upper line will be further from the horizontal and closer to the top if there is more vertical and upper rib cage motion. The lower line will be further from the horizontal and closer to the bottom if there is more lateral and lower rib cage/abdomen motion. Finally get a sense of the overall magnitude and freedom of rib cage motion. Place lines further apart to represent greater overall motion and closer for less motion.' For photograph of examiners hand position see Figure 1



Examiners were required to draw two lines to form a 'pie chart' for each event. The MARM graphic notation, which was drawn by the examiner, can be seen in Figure 2. The MARM variables were calculated by measuring angles determined from the two lines drawn by examiners, based on their palpatory impressions, with the top taken to be 180 degrees and the bottom at 0 degrees. An upper line (A) represents the "highest point of inhalation" and is made by the examiners perception and estimation of the relative contribution of the upper rib cage particularly the extent of vertical motion of the sternum and

upper rib cage. The lower line (B) represents the "lowest part of inhalation" and this corresponds to examiners perception and estimation of the relative contribution of lower rib motion and abdominal motion particularly the extent of lateral expansion. With more thoracic breathing the upper line A is placed higher and when breathing is more abdominal with greater lateral expansion of the lower rib cage the lower line B is placed lower.

The three MARM measurement variables are:

1) Volume = angle formed between upper line and lower line (area AB).
2) Balance = difference between angle made by horizontal axis (C) and upper line (B) and horizontal and lower line (AC-CB).
3) Percent rib cage motion= area above horizontal /total area between upper line and lower line x 100 (AC/AB x 100).

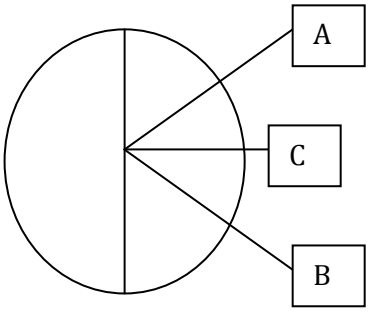


FIGURE 2- THE MARM GRAPHIC NOTATION

Subjects

Subjects were 12 "experienced breathers", who were yoga or breathing therapy teachers and included 7 females and 5 males aged between 25-65 years (average 37 years). Subjects were requested to manipulate their breathing pattern and keep the pattern for some minutes, to allow for each measurement. They were taken through a trial run of breathing and posture requirements to confirm their ability to comply with instructions.

Procedures- Breathing and Posture Instructions

While wearing the Lifeshirt, the subjects were instructed to follow a sequence of nine different posture and breathing combinations. These instructions were displayed on a computer screen and explained verbally in the same order to each person (Table 1). They were asked to keep the same breathing and posture pattern until a digital timer signaled the time to stop after 3 minutes. During each 3-minute interval examiners performed the MARM procedure and recorded their findings without consultation with each other or the subject. The onset of each breathing period was recorded on a handheld electronic diary that is part of the LifeShirt™ system. This enabled subsequent identification and analysis of data for each separate period.

TABLE 1 - ORDER OF 9 BREATHING AND POSTURE INSTRUCTIONS

1. Breathe normally - sit in your normal posture.	4. Breathe normally - sit in slumped posture.	7. Breathe abdominally - sit in slumped posture.
2. Breathe thoracially - sit in your normal posture.	5. Breathe normally - sit in erect posture.	8. Breathe thoracically - sit in erect posture.
3. Breathe abdominally - sit in your normal posture.	6. Breathe thoracically - sit in slumped posture.	9. Breathe abdominally - sit in erect posture.

Data Collection

Respiratory Induction Plethysmography (RIP)

The LifeShirt™ (Vivometrics, Inc. California, USA) was the RIP device used to record electronic data. After measurement of chest dimensions, the subjects were asked to put on the correct size LifeShirt vest to ensure that there was correct body contact with the RIP bands. The motion detecting RIP bands embedded in the LifeShirt vest surround the circumference of the body at the thoracic region under the axilla and around the abdomen. Three ECG

electrodes were also attached to the chest wall. Calibration was performed at the start of each session using a fixed volume calibration bag.

RIP measures were recorded on the Lifeshirt flash card and later downloaded into the Vivologic software (Vivometrics, Inc. California, USA) and data exported for analysis in SPSS.

The Lifeshirt uses RIP along with ECG and other sensors to measure a large number of cardiorespiratory variables, most of which are not comparable to MARM measures. RIP variables with expected correspondence to MARM measures were: Percentage Rib Cage motion (%RC) and Mean Phase Relation of Total Breath (MPRTB). For exploratory purposes we also analyzed: Mean Inspiratory Flow (Vtti), Peak Inspiratory Flow (PifVt), Peak Inspiratory Flow of Rib Cage (PifRC), Peak Inspiratory Flow of Abdomen (PifAB), Ventilation/ Peak Inspiratory Flow Ratio (Ve Pif), Inspiratory Tidal Volume (ViVol).

Data Analysis

Pearson's correlation coefficient and intra-class correlations were calculated to check for agreement between examiners and between Lifeshirt and the MARM. To test the ability of the MARM and RIP to differentiate between the 9 different breathing patterns and postures we performed a within-subject analysis of variance for these jointly, and then individually, for each measurement method.

RESULTS

We were able to extract artifact free raw data of each of the 9 events for at least 2 minutes.

Agreement Between Examiners Using MARM Measures

Pearson's correlation coefficients indicated that examiners using the MARM were in good agreement with each other for the MARM balance measure, r =.851, p=.01 and MARM % rib cage motion, r =.844, p=.01. There was no statistically significant agreement between examiners on the MARM volume measure, r =.134.

Intra-class correlation coefficients calculated for MARM measures using two way random effects model and absolute agreement definition suggest that examiners showed agreement for MARM balance, *ICC*=.850, p=.0001, *CI* (0.788, 0.895) and for MARM percent rib cage motion, *ICC*=.844, p=.0001, *CI* (0.780, 0.891).

Agreement Between MARM and RIP (LifeShirt Measures).

The values for Pearson's correlations coefficient between MARM and RIP measures are shown in Table 2. There was a high and statistically significant correlation between the two measures of 'percent rib cage', *r*=. 597, *p*=. 01, while the RIP 'percent rib cage' correlated equally strongly with MARM balance, *r*=. 591, *p*=. 01, but much less with MARM volume, *r*=0.21, *p*<0.05.

As for the other RIP variables, there was a small correlation between RIP mean phase relation of the total breath (MPRTB) and the MARM %RC measure and a 'Balance' between URC and LRCA measure, implying that as rib cage involvement increased there was a tendency for breathing to become more asynchronous. Also, there were positive correlations between peak inspiratory flow and the two principle MARM measures. Inspiratory flow resulting from rib cage expansion correlated positively with MARM %RC and Balance, whereas inspiratory flow resulting from abdominal expansion correlated negatively with them. Thus, the MARM's assessment of thoracic or abdominal breathing movement confirmed the degree of estimated airflow achieved by thorax or abdomen.

TABLE 2 - CORRELATION BETWEEN MARM MEASURES AND SELECTED LIFESHIRT VARIABLES

	MARM%RC	MARM Balance	MARM Volume
LS%RC	*.597***	*.59***	*.21**
MPRTB	*.202**	*.20**	.081
VTti	.063	.074	-.051
PifVt	.027	.039	-.037

PifRC	*.31***	*.32***	.020
PifAB	*-.45***	*-.44***	-.111
VePif	.022	-.011	-.050
ViVol	-.045	-.032	-.071

* = p < 0.05; ** = p < 0.01

LS%RC - Percentage rib cage motion; MPRTB - Mean Phase Relation of Total Breath; VTti - Mean Inspiratory Flow; PifVt - Peak Inspiratory Flow; PifRC - Peak Inspiratory Flow of Rib Cage; PifAB - Peak Inspiratory Flow of Abdomen; Ve Pif - Ventilation/Peak Inspiratory Flow Ratio; ViVol - Inspiratory Tidal Volume.

Intraclass correlation was calculated for consistency of agreement for single measures. For MARM %RC motion, ICC=.595, p=.0001 and for MARM Balance, ICC=.554, p=.0001.

Ability of MARM and RIP to differentiate between normal, abdominal and thoracic breathing.

The means and standard deviations are given in Table 3:

TABLE 3 - AVERAGE VALUES OF MARM AND RIP MEASUREMENTS

Posture/Breathing Instruction	MARM "percentage rib cage" measure	RIP "percentage rib cage" measure	MARM "balance" measure
1. Normal posture, normal breathing	56 (± 8)*	44(± 6)	6 (± 12)
2.Normal posture, thoracic breathing	73 (±7)	57 (± 15)	29(± 11)
3. Normal posture, abdominal breathing	32 (± 13)	35 (± 17)	-20 (± 16)
4. Slumped posture, normal breathing	41 (± 14)	39 (± 7)	-11 (± 17)
5.Erect posture, normal breathing	55 (± 8)	41 (± 10)	8 (± 12)
6.Slumped posture, thoracic breathing	72 (± 8)	54 (± 13)	26 (± 10)
7.Slumped posture, abdominal breathing	32 (± 8)	35 (± 14)	-23 (± 11)

8.Erect posture, thoracic breathing	76 (± 7)	52 (± 12)	32 (± 8)
9.Erect posture, abdominal breathing	30 (± 9)	31 (± 22)	-25 (± 10)

** mean and standard deviation*

A within-subject analysis of variance using 3 factors (breathing, posture and measurement method) showed significant differences between normal, abdominal and thoracic breathing across all 9 events ($F(2,16)=78.6$, $p=.0001$, eta squared .908). As can be seen in Figure 2, for all 3 types of measurement methods, instructions to breathe thoracically in the 3 postures (normal, erect and slumped) resulted in more rib cage involvement than instructions to breathe normally or breath abdominally. Similarly, instructions to breathe abdominally in all 3 postures resulted in lesser rib cage involvement that that seen in normal or thoracic breathing.

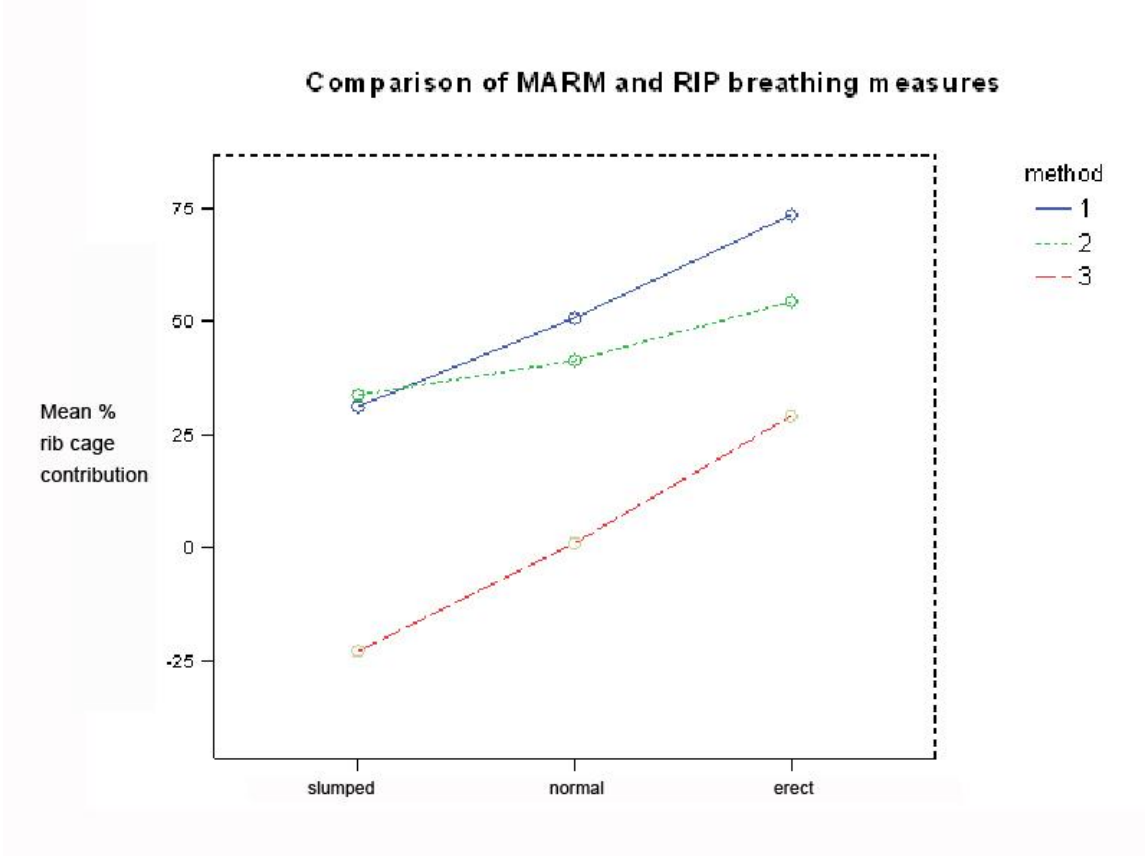


FIGURE 1 - EFFECTS OF ABDOMINAL, NORMAL AND THORACIC BREATHING FOR THE 3 MEASUREMENT METHODS-(10 SUBJECTS)

Method 1 = MARM percentage rib cage, Method 2 = RIP percentage rib cage, Method 3 = MARM balance.

Separate analysis of the 3 measurement methods using within-subject analysis of variance with 2 factors (breathing and posture) showed that each of the measurement methods was able to detect the voluntary breathing changes. For the MARM percentage rib cage measure ($F(2,22) = 191.2$, p=. 0001, partial eta squared .946) and for the MARM balance measure ($F(2,22) = 189.4$, p=.0001, partial eta squared .945) the ability to differentiate between breathing patterns was very high. For the RIP percentage rib cage measure ($F(2,16) = 12.89$, p=. 0001, partial eta squared=. 617), however, the ability was less. This suggests that both the MARM and RIP are able to differentiate between breathing patterns, with the MARM's being markedly better.

MARM and RIP differentiation of effects of postural change on breathing

The within-subject analysis of variance using 3 factors (breathing, posture and measurement method) showed that no overall significant difference resulted from changes in posture ($F(4, 32) = 2.8$, p=. 091, partial eta squared .258). Investigation by analysis of variance of the individual measurement methods showed that the MARM measure of % rib cage motion was able to detect differences in breathing that resulted from changes in posture ($F(2,22) = 6.29$, p=. 007, eta squared= .364) and the MARM measure of balance was also able to detect these differences ($F(2,22) = 189.4$, p=. 006, eta squared=.371). Figure 3 shows the differences in breathing measures brought about by changes in posture, for the 3 measurement methods.

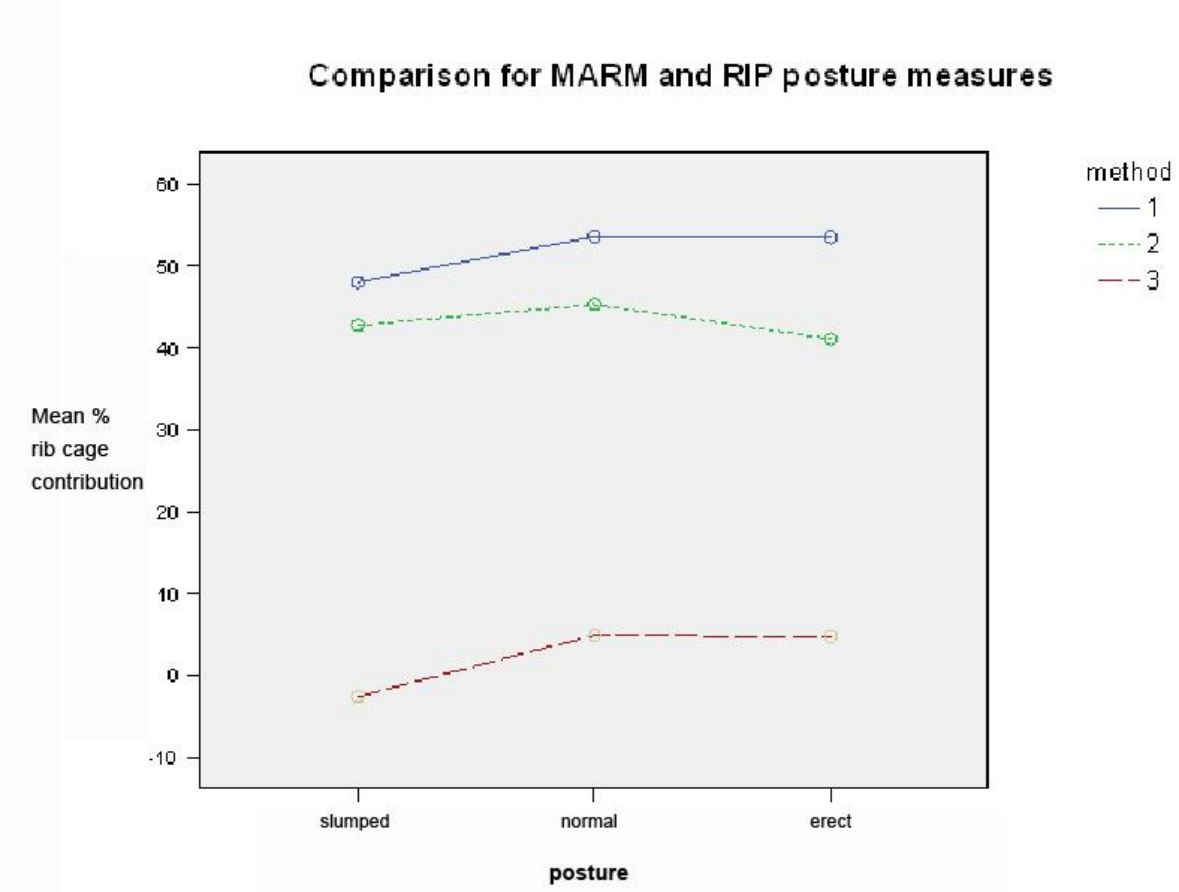


FIGURE 3 - EFFECT OF SLUMPED, NORMAL AND ERECT SITTING POSTURES FOR THREE MEASUREMENT METHODS-(10 SUBJECTS)

Method 1 = MARM percentage rib cage, Method 2 = RIP percentage rib cage, Method 3 = MARM balance.

As can be seen in Figure 4 and 5, for both MARM measures the change in posture from slumped to erect had positive effects in combination with the instruction "breathe thoracically", less so with the instruction "breathe normally" and an opposite effect with the instruction to breathe abdominally. Thus, sitting upright stimulated thoracic breathing movement, and lessened abdominal breathing movement.

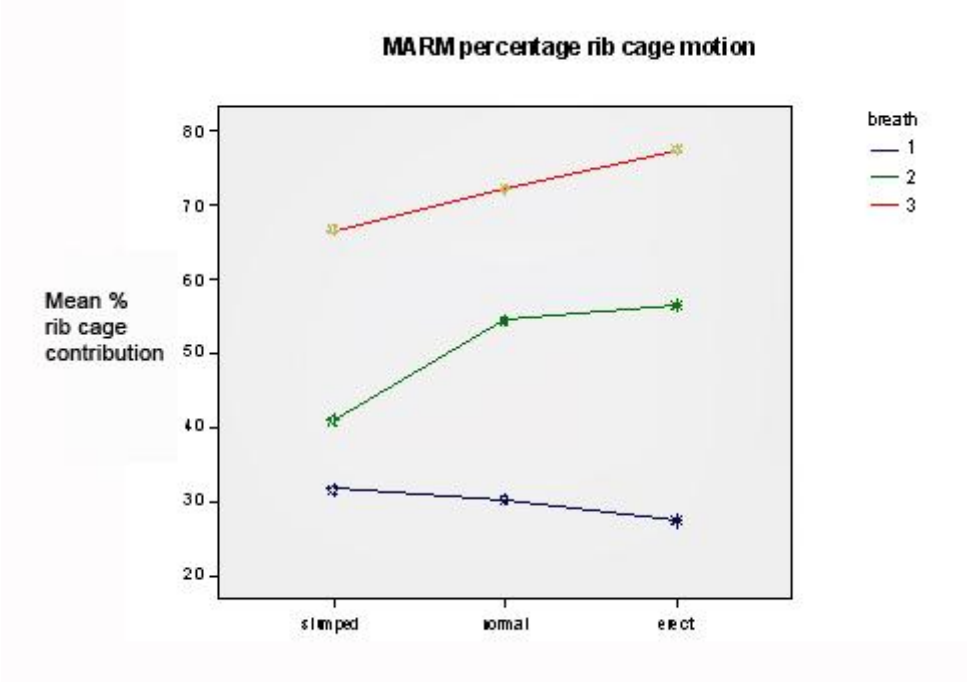


FIGURE 4 - MARM % RIB CAGE MEASURE FOR SLUMPED, NORMAL AND ERECT POSTURES AND THREE DIFFERENT TYPES OF BEATHING INSTRUCTION- (10 SUBJECTS)
Breath 1 = abdominal, Breath 2 = normal, Breath 3 = Thoracic.

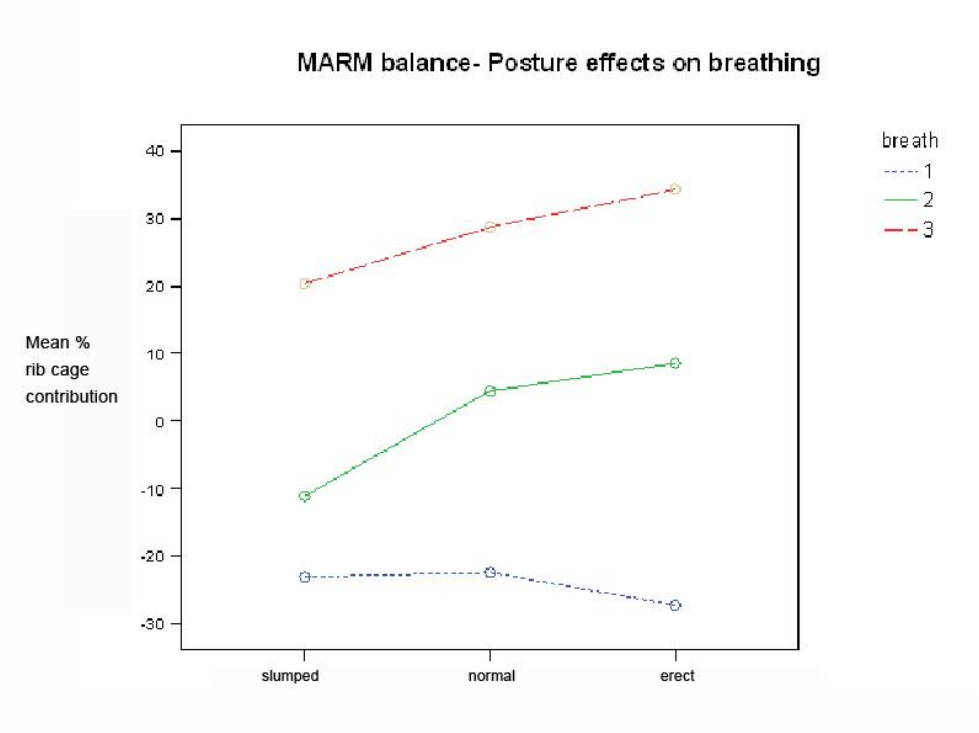


FIGURE 5 - MARM BALANCE MEASURES FOR SLUMPED, NORMAL AND ERECT POSTURES AND 3 DIFFERENT TYPES OF BREATHING INSTRUCTION-10 SUBJECTS
Breath 1 = abdominal, Breath 2= normal, Breath 3 = Thoracic.

With respect to the RIP measures, analysis of variance showed that it only marginally differentiated between postural effects on breathing ($F(2,16)=3.3$, $p=.062$, partial eta squared $=.294$). The results of the RIP percentage rib cage measures can be seen in Figure 6. Interestingly, the results of RIP with posture change are quite different from the results obtained with the MARM. With the RIP, erect posture did not result in a greater measure of thoracic breathing, rather it led to a decrease in the measurement of ribcage motion.

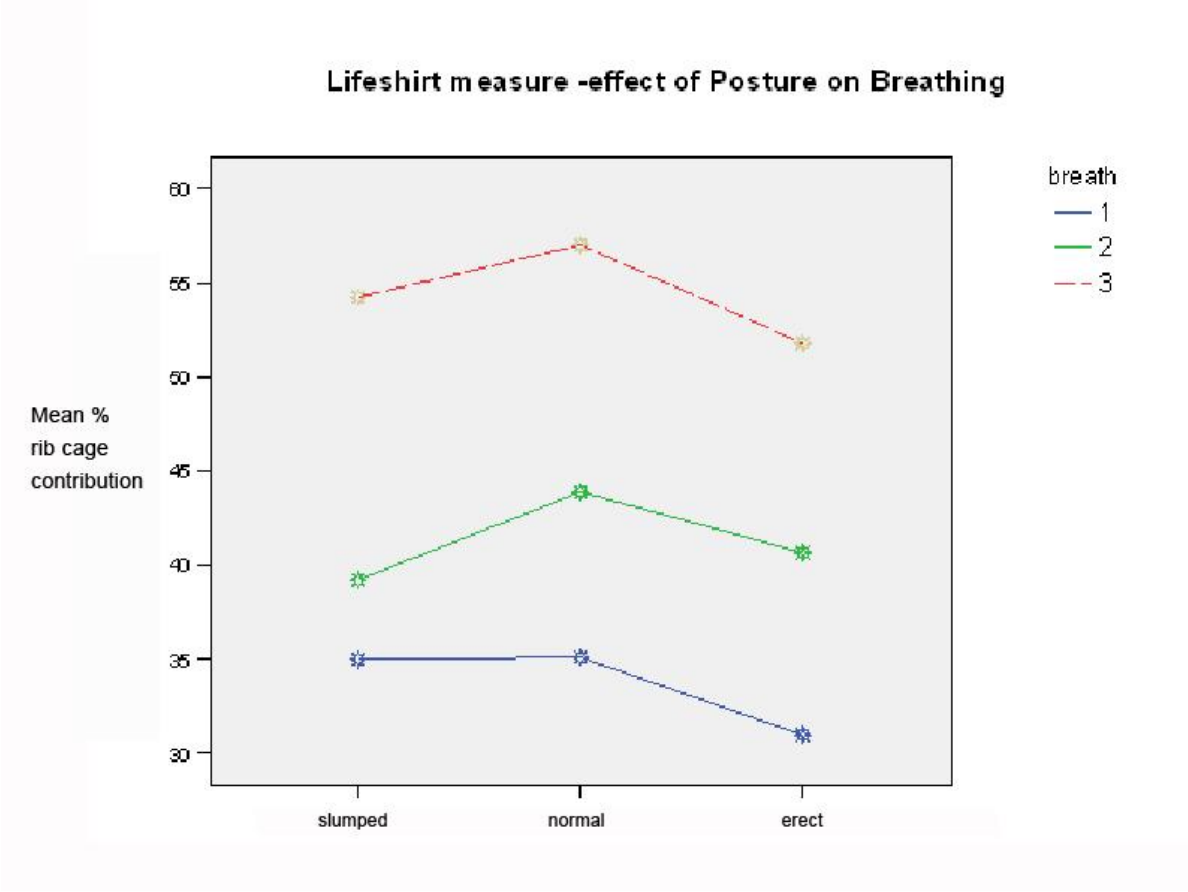


FIGURE 6 - RIP % RC MOTION MEASURES FOR EFFECTS OF POSTURE AND BREATHING INSTRUCTION-10 SUBJECTS
Breath 1 = abdominal, Breath 2 = normal, Breath, 3 = thoracic.

Functional Breathing Parameters

An assumption of the MARM is that functional breathing consists of a balance between upper and lower compartments of breathing. This would result in average values of 'percent ribcage' of around 50 and of 'Balance' of around zero. Another assumption is that functionality of breathing implies

responsiveness to changes in breathing and posture. This would result in a large total range of MARM lines across the different procedures.

In table 4 the values for each subject and the grand mean for all subjects are given. The first column shows the average values of all upper and lower MARM lines, based on their position on the semi-circle, ranging from 0-180 degrees across the 9 events. Its grand mean is 90.8 and it ranges between subjects from 8.4 to 95.3. This corresponds to almost exactly the middle value and horizontal line of the half circle that is used in MARM notation. It implies that the percentage of top half (section AC) to total range (Section AB) is indeed close to 50. Likewise, the bottom half minus the top half is approaching zero.

TABLE 4 - MARM FUNCTIONAL BREATHING PARAMETERS FOR EACH SUBJECT

Subject	Mean	sd	Min.	Max	Range
1	94,2	31,8	40	140	100
2	93,9	34,2	50	145	95
3	87,5	35,2	35	140	105
4	95,3	35,9	47	148	101
5	93,6	32,6	48	140	92
6	84,4	34,1	35	132	97
7	89,6	34,2	45	150	105
8	93,1	33,9	50	140	90
9	90,7	34,2	40	144	104
10	91,7	38,3	35	150	115

11	85,3	35	35	140	105
12	89,9	32,7	45	140	95
mean	90,77	34,34	42,08	142,42	100,33
sd	3,56	1,70	6,11	5,21	7,00

As to the range of MARM values, Table 4 shows the lowest lower line (minimum) and highest upper line (maximum) and the distance between them (range). The average range between lowest and highest MARM line is about 100. In all subjects the maximal range is 90 or larger, which is more than half of the total range of a half circle of 180 degrees.

DISCUSSION

The good agreement between examiners and between the MARM and comparable RIP measures along with the MARM's ability to differentiate clearly divergent patterns of breathing and posture suggest that the MARM is a useful and reliable tool for the assessment of breathing pattern with good inter-rater reliability. This confirms previous results (Dixhoorn 2004; Dixhoorn 2004)

It appears that the MARM is a global assessment in the double meaning of global: general and spherical. The MARM provides a general indication of distribution of breathing pattern in its three dimensional form and was better able to distinguish between thoracic and abdominal breathing than RIP.

All four specific hypotheses relating to the utility of MARM were confirmed. Its ability to distinguish between more thoracic and more abdominal breathing was even greater than RIP.

Given the fact that the subjects were 'experienced breathers', practiced in breath control, it was expected that their MARM values would be close to optimal. The results confirmed that under resting and normal conditions the values of MARM, which theoretically range between 0 and 180, have an average of the almost exact middle value of 90. This implies a percent ribcage

of about 50 and an even distribution of breathing between the two main compartments, which is expressed in the measure of 'balance' approaching zero.

As a measure of functionality MARM can be used to test flexibility of breathing pattern by assessing the response to sufficiently divergent postural and respiratory instructions and by determining the maximum difference between upper and lower lines. The present data suggest that the maximum difference between upper and lower lines of MARM across several instructions should be at least 90. In theory, upward breathing moves fully vertically to lift the sternum and downward breathing moves fully vertically to press on the pelvic floor. The assessor's hands however are placed at the middle of the body and this limits the information acquired. The values of around 100 therefore seem to represent the limits of the range that can be assessed by the MARM. The variation between subjects is remarkably small for all parameters. This indicates that subjects may be taken as a sample of truly experienced breathers who are able to modify their breathing pattern as far as is feasible without creating undue effort.

More studies are needed to establish optimal cutoff scores by comparing the outcome to untrained and less experienced subjects as well as to patients with breathing or other difficulties. Re-analysis of one data set from a previous unpublished study showed that 12 subjects performing 3 different breathing events had comparable average values.

One option for future studies assessing breathing functionality is to have subjects bend sideways, in order to imitate a scoliotic C-curve and test the adaptability of the ribcage to these posture changes. A strong characteristic of the MARM is its ability to distinguish differences between the left and right side of the chest. In case of even slight scoliosis, which is quite common, there may be marked differences between the two sides that remain unnoticed by traditional instrumental recordings. Such distortions may give rise to both disturbance of breathing movement as well as a sense of dyspnea. Currently, only Opto-electronic plethysmography gives an accurate image of the exact

shape of the breathing movement in all its variations (Aliverti, Dellaca et al. 2000).

Several limitations of this study should be noted. One is the low reliability of the absolute distance between the two lines. We called it 'volume' but it may be more accurate to call it 'area'. The exact place and distance of the two lines on the half circle appears to depend on the assessor's personal preference. There was no inter-rater agreement on the distance between the lines and it correlated only to a small degree with the RIP measures. Given the high agreement between assessors across the nine events on the other MARM measures, however, it seems probable that the assessor's preference of the placement of the lines is stable. Thus, it is likely that in clinical practice the clinician may compare his assessment on one occasion with his assessment at another occasion. This remains to be tested in a future study. Possibly, more intensive training is necessary including specific focus on the placement of the lines to increase reliability of 'area' assessment.

Another potential limitation is the requirements to perform the MARM correctly. In applying the MARM, one forms a mental picture of the general change in shape of the body with in- and ex-halation. It requires sensitive hands as well as imagination. The assessors were all trained and experienced osteopaths who were clearly able to perform the MARM correctly. It is not sufficient to simply put one's hands on another person's body and record any movement that one notices locally. The touch should be clear and firm but not intrusive or constrictive or in any way inhibit free breathing movement. The hands need to follow respiratory motion and the assessor should try to picture the origin and direction of the locally experienced movement. Possibly the MARM is particularly useful for clinicians who are experienced in touching other subject's bodies in a sensitive and perceptive way. The first two authors who are experienced practitioners have now taught the MARM to many subjects, with good practical success. However it remains to be seen how less experienced examiners are able to perform.

A limitation of the design of this study is the possibility of observer bias, because of the fixed order of the events and the possibility of visual information

to establish posture. In future studies the order of events could be random. However, there is a natural sequence in difficulty of the events, which should not be ignored. In this study the examiners were not aware of any expected changes in breathing from posture. However they may have responded to visual cues, the assessor may have expected to feel more thoracic breathing when the subject was seen straightening up and the spine was extended. The experience of the author most familiar with this technique (JvD) is that the upper line of MARM can indeed be expected to rise in extended posture and examiners may have quickly discovered this. In future studies it may be advisable to use a random order of events, undisclosed to the assessor. Further blinding could also be achieved by randomly allocating the types of breathing and posture instructions given to the "breathers". Still, the act of extending the spine will always be noticeable by the hands on the back extension on the lower line is open, however, and cannot be firmly predicted. When the distance between symphysis pubis and sternum is increased there is also more space for abdominal expansion. Some subjects may use this space and increase abdominal expansion whereas others may predominantly lift the chest and show decreased abdominal expansion. Thus, it is important for the assessor to be as neutral as possible and observe the actual movements perceived by the hands, and not try to guess the breathing pattern.

The study used a relatively small number of subjects and compared results of only two examiners; this was another limitation of this study.

The correlation between the MARM and the RIP measures at 0.60 was not very high for a reliability assessment. We believe this is because RIP only measures lateral expansion while the MARM also measured vertical motion. It is interesting that RIP measurement did not respond to spinal extension as MARM did. In fact, RIP showed a decrease of ribcage motion while the MARM showed an increase. This may reflect the fact that when the ribcage is lifted upwards 'pump-handle' or vertical motion of the rib cage dominates and there is a loss of some of its sideways expansion or 'bucket-handle' motion. MARM is apparently able to register the real upward motion, whereas RIP is limited to purely sideways expansion.

In future studies the MARM may be used to clarify the concept of 'dysfunctional breathing'. This concept refers on the one hand to functional respiratory complaints, like disproportionate breathlessness and can be measured for instance by Nijmegen Questionnaire for hyperventilation complaints (Thomas, McKinley et al. 2001). On the other hand it refers to disturbances in the biological function of breathing, without real physical causes. Signs include asynchrony of breathing movement between thorax and abdomen, predominantly upper-thoracic breathing, frequent or deep sighs, mouth breathing, exaggerated use of auxiliary respiratory muscles (Chaitow 2002). It is still unclear to what degree the two definitions overlap. Functional respiratory complaints may be caused by uneven distribution of breathing movement, but also by other causes, like stress or anxiety (Morgan 2002). The MARM can be used to measure breathing movement and help to elucidate its role in the etiology of respiratory complaints. More specifically, as a tool in breathing therapy, the MARM is useful to quantify the effect of breathing therapy on the quality of respiratory movement. If such effects are related to improvements in complaints, it may be argued that they were due to disturbances in breathing movement.

CONCLUSION:

The MARM appears to be a valid and reliable clinical and research tool for assessing breathing movement with good inter-examiner and a greater ability to distinguish vertical ribcage motion that RIP. Further studies to confirm its clinical utility are warranted.

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CHAPTER 7-

COMPARISON OF THE MANUAL ASSESSMENT OF RESPIRATORY MOTION (MARM) AND THE HI LO BREATHING ASSESSMENT IN DETERMINING A SIMULATED BREATHING PATTERN.

ABSTRACT

Aims: The aim of this study was to assess and compare the validity and potential utility of two manual breathing assessment procedures: the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo Breathing Assessment. A secondary aim was to gauge the influence of the practitioner's general level of manual therapy experience on their ability to learn and perform these assessment techniques.

Method: 56 osteopaths and osteopathic students were taught the MARM and the Hi Lo Breathing Assessment and trained to simulate breathing patterns. The participants, acting alternatively as breathers and examiners, then attempted to accurately determine whether the breathing patterns simulated by their partner were predominately abdominal, thoracic or, in the case of the Hi Lo, paradoxical. Participants were surveyed on their confidence in the use of each technique, their perceived ease in using each technique, and their intended future use of the techniques. Student and practitioner ability to detect simulated breathing patterns were compared for the MARM and Hi Lo.

Results: Overall scores for correctly determining breathing patterns were not significantly different for the MARM or the Hi Lo, and there was no notable moderation of this effect according to experience, with both practitioners and students demonstrating a high level of performance on both techniques. There were some differences in accuracy of performance across different breathing styles, with Hi Lo assessment of paradoxical breathing being more difficult to identify correctly. Ease of learning was similar for MARM and Hi Lo but confidence in using the techniques, and intended future use were higher for the

MARM. There were some significant relationships between these utility measures and performance, particularly on the MARM.

Conclusions: This study supports the validity of the Hi Lo and builds on previous work to strengthen the evidence for the validity of the MARM. Responses to the survey indicate that, overall, participants preferred the MARM to the Hi Lo. This study is a preliminary investigation of these techniques. Future studies to test the validity of these techniques should be performed in a clinical setting on individuals with actual rather than simulated breathing pattern disturbances.

INTRODUCTION

Breathing pattern disturbance and abnormal function of the respiratory muscles has been proposed to contribute to symptoms such as dyspnea (Breslin, Garoutte et al. 1990; Wolf 1994), neck and shoulder girdle pain (Perri and Halford 2004), and temporomandibular joint disorders (Hruska 1997). It has also been argued that a person's habitual breathing patterns may influence posture and spinal stability, and it has been proposed that correct breathing is the foundation for the correction of dysfunctional movement and postural patterns (Lewitt 1980; Perri 2007). It is difficult to evaluate the impact of breathing pattern on symptoms, movement and postural patterns on the basis of previous studies because the characteristics of correct or dysfunctional breathing pattern are not clearly defined and the measurement techniques used to evaluate breathing pattern have not been standardized or validated.

Nevertheless in the clinical environment, breathing pattern is often assessed by observation and palpation and several palpatory techniques for assessment of breathing pattern have been described in manual therapy texts and other publications (Clanton and Diaz 1995; Hillegass and Sadowsky 2001; Chaitow 2002; Pryor and Prasad 2002; Perri and Halford 2004; Perri 2007) with techniques differing in the hand placement of the operator, and interpretation and recording of palpatory findings.

In a previous study we investigated one technique for evaluating and quantifying breathing pattern, the Manual Assessment of Respiratory Motion (MARM), and compared it with measures performed with Respiratory Induction Plethysmography (RIP), an established standard for measuring breathing pattern (Wilhelm and Roth 2003). We also tested inter-examiner agreement when two examiners used this technique to differentiate between different breathing and postural patterns. High levels of agreement between examiners were found with two MARM measures that reflected balance of thoracic to abdominal breathing, r_{ic} =.85, p < .001. Examiners' MARM measures also correlated with similar measures obtained from RIP, r =.59, p < .01. Both RIP and MARM methods were able to differentiate between abdominal and thoracic

breathing patterns, but only MARM was able to differentiate between breathing changes occurring as an incidental result of postural change. It was concluded that the MARM was a reliable clinical tool for assessing breathing patterns and demonstrated better sensitivity to more dimensions of rib cage motion than RIP (Courtney, van Dixhoorn et al. 2008).

The MARM procedure was first developed and applied in a follow-up study of breathing and relaxation therapy with cardiac patients in the 1980s. It appeared that two years after breathing therapy the MARM still showed differences between experimental and control patients (Dixhoorn 1994). It is similar to other breathing assessment techniques that are based on the examiner's interpretation and estimation of the motion of their hands when placed at the posterior and lateral lower rib cage. However, the MARM is of particular interest as a clinical and research tool because it includes a system of notation that allows the examiner to derive numerical values for two variables related to relative distribution of breathing motion and another numerical variable for area of breathing involvement. The examiner can also gauge, rate and record their general impressions of breathing regularity, rib cage stiffness and symmetry of breathing.

The Hi Lo can be used to assess the motion of the upper rib cage and lower rib cage/abdomen and determine aspects of breathing such as rate, rhythm, relative motion and phase relation of upper and lower breathing compartments (Chaitow 2002). The Hi Lo assesses breathing from the motion observed at the front of the body while the MARM assessment is made with the examiner hands at the back on the mid thoracic and lateral lower rib cage and waist. The Hi Lo findings are reported as qualitative descriptions or as dichotomous variables in comparison with the MARM, which assigns numerical values. To our knowledge, no studies have examined the relationships in scores obtained between these two assessment methods, or compared their accuracy.

In the previous validation study of the MARM, the observed high levels of inter-examiner agreement and agreement between the MARM and RIP may have been due to the fact that the examiners were all experienced osteopaths (Courtney, van Dixhoorn et al. 2008). It is unknown to what extent

performance on various breathing assessments, such as the MARM and the Hi Lo, is moderated by the experience of the administrator; for example, do experienced practitioners and students differ in the accuracy of their assessments derived from these techniques?

The main aim of this study was to examine the relationship between therapists' performance in the use of the MARM and Hi Lo by assessing the sensitivity and consistency of these techniques when used to assess simulated breathing patterns. Another aim was to gauge whether accurate performance in the use of these techniques was dependant on the examiners' general levels of experience in manual therapy. This was done by comparing results achieved by experienced osteopaths with those of osteopathic students. Finally, relationships between performance on the MARM and Hi Lo, and participants' views on their confidence in and perceived ease of use of each technique and their intention to use each technique in the future were also considered.

METHOD

Volunteer examiners who were either osteopathic students (n = 27) or practicing osteopaths (n = 29) who attended a two-hour training class that utilized a structured training format. In the training session, participants were taught how to do the simulated breathing techniques and the MARM and Hi Lo breathing assessment techniques.

Participants were paired, with one acting alternatively as 'examiner' and one as 'breather'. Pre-screening of breathing ability was used to exclude people who were clearly unable to correctly modify their breathing pattern.

The breather was instructed to alter their breathing pattern three times according to randomly selected written instructions, firstly while the examiner performed the MARM and subsequently while the examiner performed the Hi Lo. In the case of the Hi Lo, breathing instructions were various random combinations of thoracic, abdominal or paradoxical breathing. In the case of the MARM the breathing instructions were various random combinations of thoracic or abdominal breathing but not paradoxical breathing. The examiner,

who was blinded to the breathing instruction, performed the MARM procedure three times, followed by the Hi Lo breathing assessment three times, with the aim of accurately determining which breathing pattern was being performed.

Precautions were taken to exclude people who were clearly unable to comply with breathing instructions. People who identified themselves as unable to control their breathing were asked to inform the researcher and were either not involved in the study or excluded from the data set.

Of the 56 volunteers, 29 were practitioners and 27 were students. There were 36 females and 20 males. All performed the MARM and the Hi Lo, but due to errors in the numbering of recording sheets we were only able to analyze data on 55 MARM score sheets and 53 Hi Lo score sheets.

Description of breathing assessment techniques

1. Manual Assessment of Respiratory Motion (MARM)

The examiners were taught how to do the MARM and how to record their findings (see Figure 1) by drawing lines on a pie chart to indicate their estimation of thoracic/vertical or abdominal/lateral dominance, and by ticking a box to indicate either thoracic or abdominal breathing. Usually there are three MARM measurement variables that can be calculated from these lines. These variables were not used in this study but are included here for the reader's interest. Courtney, van Dixhoorn, and Cohen (2008) give a complete description of the MARM procedure and the full system of notation with calculation of variables in a previous publication (Courtney, van Dixhoorn et al. 2008).

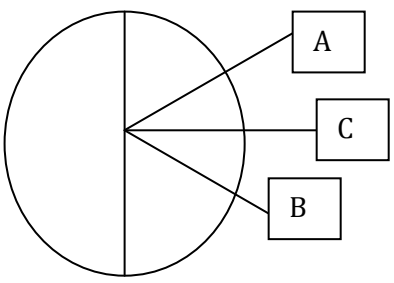

FIGURE 1 -THE MARM GRAPHIC NOTATION

Variables Calculated From MARM Graphic Notation

Variable	Description	Calculation
Area of Breathing	Angle formed between upper line and lower line.	Angle A B
Balance	Difference between angle made by horizontal axis (C) and upper line (A) and horizontal line (C) and lower line (B).	AC - CB
Percent rib cage motion	Area above horizontal/ total area between upper line and lower line x 100.	AC/AB X 100

The following is the description given to examiners for how to perform the MARM:

"The examiner sits behind the subject and places their hands on the lower lateral rib cage. The hands rest firmly but do not direct or restrict breathing motion. The hands are comfortably open with fingers spread so that the little finger approaches a horizontal orientation and the thumbs are approximately vertical. The examiner's lower fingers are below the lower ribs to feel abdominal expansion. The examiner makes an assessment of the overall vertical motion relative to the overall lateral motion. Simultaneously they evaluate to what extent the motion is predominantly upper rib cage, lower rib cage/abdomen, or in balance. The examiner then draws two lines. An upper line (A) represents the degree of vertical and upper thoracic motion and the lower line (B) represents the degree of lower ribs and abdominal motion. The horizontal line (C) represents the thoraco-lumbar junction."

2. Hi Lo Breathing Assessment

The examiners received the following instructions for how to perform and record the Hi Lo:

"Stand at the front and slightly to the side of the person. Place one hand on their sternum and one hand on their upper abdomen. Determine whether thoracic or abdominal motion is dominant during breathing and to what extent this is so. Also check for paradoxical breathing by seeing if the abdomen moves in a direction opposite to the thorax during breathing; this is evident during

inhalation if the abdomen moves toward the spine, and during exhalation if the abdomen moves in an outward direction."

The extent of thoracic or abdominal breathing was rated using a score between 1 and 3. To avoid confusion and to allow direct comparison with MARM scores, examiners were also asked to tick a box indicating if they considered the breathing pattern to be predominantly abdominal or thoracic. Assessment of paradoxical breathing was also recorded by ticking a box.

3. Survey regarding utility of MARM and Hi Lo

Participants were given a questionnaire about their experience of learning and using the MARM and Hi Lo and their self-perceived ability to conduct the breathing techniques. The questions were as follows:

1. *I found the (MARM or Hi Lo) easy to use.*
2. *I felt confident using the (MARM or Hi Lo).*
3. *I intend to use the (MARM or Hi Lo) in the future.*
4. *I was able to do the breathing techniques.*

The responses to these questions were made by circling one of the following:1 = strongly agree, 2 = agree, 3 = unsure, 4 = disagree, 5 = strongly disagree.

RESULTS

Data preparation and coding

All data were entered into a single SPSS spreadsheet for analysis. Examiners' performance on both the MARM and Hi Lo were recorded dichotomously as either correct or incorrect for both thoracic and abdominal breathing, and, in the case of the Hi Lo only, for paradoxical breathing. Given the method of test administration, as outlined above, this meant that there were unequal numbers of tests of thoracic and abdominal breathing across the two methods. The scores for the three testing sessions were totalled to obtain an overall score out of three for both methods, although it should be noted that this total score of three could be made up of any combination of abdominal,

thoracic, and, in the case of the Hi Lo, paradoxical breathing. The data relating to ease, confidence and intention toward future use of the two techniques was recorded in line with the five-point Likert scale described above. Because of the wording of the scale, a low score on these questions indicated a positive response.

Comparison of accuracy between the MARM and Hi Lo

Descriptive results for the MARM and Hi Lo total scores and the utility measures are presented in Table 1. The mean total correct score on the MARM across both practitioners and students was slightly lower than the mean total correct score on the Hi Lo, but a Wilcoxon non-parametric signed ranks test found this difference non-significant. Further, a non-parametric correlation found no significant relationship between the two sets of scores. Non-parametric analyses were used for all significance testing because of the ordinal nature of the data.

These differences were not moderated by the experience of the administrator. Although the differences between the MARM and Hi Lo were slightly higher for the practitioners than the students, no significant differences were found between the scores of the two techniques for each group separately, and no significant correlations were found between performance on the two techniques for each group separately. These analyses used the same statistical methods as those outlined above. Further, a Mann-Whitney U test found no significant difference between practitioners and students in overall performance on either technique.

It is possible that these statistical outcomes were affected by a pronounced ceiling affect in the data. Given a maximum score of 3 for each technique, the mean values indicate nearly perfect performance for many participants. The data reflects this, with 50% (27/54) of participants scoring 3 on both measures. This proportion of perfect performance was higher for practitioners (16/26, 62%) than students, (11/28, 39%).

TABLE 1 - DESCRIPTIVE STATISTICS FOR PERFORMANCE AND UTILITY MEASURES

	Students (*n* = 29)		**Practitioners** (*n* = 27)		**Total** (*n* = 56)	
Measure						
	M	***SD***	***M***	***SD***	***M***	***SD***
MARM – Total Correct	2.46	0.64	2.54	0.99	2.48	0.82
Hi Lo – Total Correct	2.61	0.50	2.77	0.51	2.69	0.51
MARM – Ease of Use	1.36	0.73	1.41	0.97	1.38	0.85
MARM – Confidence in Use	1.57	0.84	1.67	1.07	1.62	0.95
MARM – Intention Future Use	1.61	0.69	1.63	1.01	1.62	0.85
Hi Lo – Ease of Use	1.46	0.64	1.52	0.70	1.49	0.66
Hi Lo – Confidence in Use	2.04	0.79	2.19	0.88	2.11	0.83
Hi Lo – Intention Future Use	2.29	0.81	2.52	1.05	2.40	0.94

There were, however, some notable differences in accuracy across the different breathing styles (i.e. thoracic, abdominal, & paradoxical). Table 2 presents a detailed breakdown on performance for both practitioners and students on each technique for the different breathing styles. A Cochrane's Q test found no significant differences in performance across thoracic and abdominal breathing styles for the MARM for either the sample as a whole or for practitioners and students separately; however, a significant difference across the three breathing styles of the Hi Lo (thoracic, abdominal & paradoxical) was observed for the sample as a whole, $Q(2) = 10.36$, $p = .006$, with performance on paradoxical breathing (66% correct) inferior to both abdominal breathing (94% correct) and thoracic breathing (96% correct). This result was moderated by experience, with no significant difference found for practitioners, but a significant difference found for students, $Q(2) = 6.25$, $p = .044$; again, paradoxical breathing was found to be less easy to identify than either thoracic or abdominal breathing.

TABLE 2 - PERFORMANCE ON SPECIFIC MARM AND HI LO MEASURES

	Measure	Students	Practitioners	Total
MARM		% correct (ratio correct/total)	% correct (ratio correct/total)	% correct (ratio correct/total)
	Thoracic	82% (31/38)	88% (36/41)	85% (67/79)
	Abdominal	87% (40/46)	78% (29/37)	83% (69/83)
HI LO				
	Thoracic	94% (32/34)	97% (32/33)	96% (64/67)
	Abdominal	93% (26/28)	96% (26/27)	95% (52/55)
	Paradoxical	68% (13/19)	78% (14/18)	73% (27/37)

A more focused analysis of the relationships between the two techniques was conducted by considering the performance of participants in identifying abdominal and thoracic breathing patterns separately. A Cochrane's Q test found a significant difference between the MARM and Hi Lo on participants' ability to identify thoracic breathing, $Q(1) = 8.00$, $p = .005$, with superior performance shown using the Hi Lo technique. Interestingly, this difference was moderated by experience: no significant difference was found between the two methods in students' ability to identify thoracic breathing, but there was a significant difference with practitioners, $Q(1) = 5.00$, $p = .025$, with the Hi Lo demonstrating superior outcomes. Identical analyses found no significant differences in identifying abdominal breathing.

Consistency between the two methods was assessed using Cohen's κ ; these analyses were conducted across the entire sample and for practitioners and students separately.

A significant level of agreement was found between the two techniques on their ability to identify thoracic breathing, $\kappa = .29$, $p = .001$, but not with

abdominal breathing. The agreement observed on the thoracic breathing scores was not moderated by experience, with significant agreement being observed for students, $\kappa = .53$, $p = .001$, and practitioners (κ could not be calculated for this group because there were no incorrect assessments using the Hi Lo). Despite the lack of overall agreement between the two methods on their ability to correctly identify abdominal breathing, there was some moderation according to experience, with a significant difference being observed for practitioners, $\kappa = .29$, $p = .037$, but not for students.

Simulated breathing

In response to the statement "I found the breathing techniques easy to do", only 3.8% of participants disagreed or strongly disagreed with this statement, although 14.8% of participants indicated that they were unsure. This figure most likely reflects uncertainty rather than an inability or true difficulty in performing the thoracic, abdominal and paradoxical breathing maneuvers.

Utility measures

Across both practitioner groups, there were no significant differences between the MARM and the Hi Lo with regard to perceived ease in using the technique. A Wilcoxon signed ranks test did, however, find significant overall differences between the two methods in terms of intended future use, $z = 4.73$, $p < .001$, and confidence in using, $z = 3.15$, $p = .002$. In both instances, the more positive impressions were in favor of the MARM. This difference was not notably moderated by experience, with a similar pattern of significant results emerging for both students and practitioners on both confidence and intention toward future use. Further, Mann-Whitney U tests revealed no significant overall differences between students and practitioners on any of these variables.

An interesting pattern of results emerged when ease, confidence and intention toward future use were related to performance on the two techniques. Non-parametric correlations revealed no significant relationships between any

of the utility measures and performance on the Hi Lo; however, performance on the MARM was significantly correlated with its perceived ease of use, $r_\tau = .31$, $p = .018$, perceived confidence in use of the technique, $r_\tau = .28$, $p = .028$, and intention to use the technique in the future, $r_\tau = .43$, $p = .001$. In each instance, high scores on the utility measure (i.e. reflecting higher perceived ease, more confidence, and a more positive intention toward future use) were related to more accurate performance with the technique. Further, these relationships were clearly moderated by experience. For students, intention to use the MARM in the future revealed a strong positive relationship with performance on the method, $r_\tau = .49$, $p = .006$, which was not evident in the practitioners; however, significant positive relationships were found for the practitioners between perceived ease of using the MARM and performance on the MARM, $r_\tau = .51$, $p = .007$, and between confidence in using the MARM and performance, $r_\tau = .53$, $p = .004$.

Additional qualitative written comments and feedback from 6 participants suggested that the hand positioning of the MARM was more effective because it gave a good sense of upper rib cage movement and the balance of upper rib cage to lower rib cage abdomen motion without intruding on the patients' breathing. Comments also indicated participants favored the system of notion used by the MARM and that hand placement on the front of the body with the Hi Lo tended to be more intrusive and was more likely to influence the patient to artificially alter their breathing pattern in response to the examiner's hands.

DISCUSSION

This study indicates that less experienced practitioners with only a small amount of practice and training can use the MARM and Hi Lo with similar levels of accuracy to experienced practitioners. There were only minor differences observed between students and practitioner's performance for example students were better able to identify abdominal breathing using the MARM and in turn practitioners were better able to identify paradoxical breathing using the Hi Lo. More practitioners than students achieved a perfect score. However,

overall both students and practitioners achieved similar levels of accuracy for most simulated breathing patterns.

Paradoxical breathing, performed by the "breather" drawing in the abdomen during inhalation was found to be the most difficult simulated breathing pattern for examiners using the Hi Lo to determine. It is difficult in a simulation to reproduce the actual muscle activity that occurs in real life paradoxical breathing. In individuals with natural paradoxical breathing there is usually heightened respiratory drive resulting in tonic activity of the accessory muscles of inspiration. This produces a strong vertical and upper chest motion during inspiration, which can be accompanied by some dynamic hyperinflation of the lungs. In this scenario the diaphragm tends to become short and flat and inefficient at producing lateral expansion of the lower rib cage during inhalation (Loring, Mead et al. 1985; De Troyer and Estenne 1988; Celli 1989; Hruska 1997).

The MARM evaluates expansion of the lower lateral rib cage and in some situations this may be a more reliable indicator of diaphragm efficiency than the Hi Lo observation of anterior abdominal displacement. With decreased force of diaphragm , decreased lateral basal expanasion is usually accompanied by a compensatory increase in assessor muscle use and, therefore, an increase in vertical and thoracic motion during inspiration. The fact that these two motions are simultaneously monitored by the MARM is a strength of this technique.

MARM performance in both groups was related to how easy the examiner found this technique and their confidence in using it. Performance on the Hi Lo did not relate to any of the utility measures i.e. ease, confidence, or future use. This indicates that individuals who found the MARM difficult and were not confident in using it did not perform as well. This suggests that some further training in MARM was needed by some individual to improve ease and confidence and it is reasonable to speculate that this would have improved performance of the MARM in these individuals.

Preference for the MARM was shown in 2 ways; survey results showed that both students and practitioners were more confident with the MARM and

more likely to use the MARM in the future. Invited comments showed that participants preferred the hand position and system of notation of the MARM. They found the hand position less intrusive, and felt that breathers were less likely to change their breathing in response to the examiner's hands when the examiner was sitting behind and placing their hands on the lower ribs only. However, most examiners indicated an intention to use both techniques in the future. Student's intention to use the techniques in the future was related to their performance on the MARM and Hi Lo. Interestingly practitioner's intention to use the techniques was not related to their individual performance but rather to their evaluation of the utility of the technique itself based on other factors.

There are other functions and ways of using the MARM and Hi Lo not tested in this study. For instance the MARM can be used to assess and note the examiner's impressions of the stiffness of rib cage and general freedom of breathing motion. MARM can also be used for assessing symmetry of breathing, which can be compromised by scoliosis and also by unilateral diaphragm dysfunction (Hruska 1997). Non-uniform distribution of pressure distorts the rib cage and markedly stiffens it. In normal situations lung volume can increase up to 70% of maximum workload without stiffening the rib cage, however when there is non-uniform distribution of breathing this distorts and stiffens the rib cage (Kenyon, Cala et al. 1997). The Hi Lo and the MARM are best used in various body positions and with different breathing instructions to fully evaluate the flexibility, and thus functionality, of breathing.

There are several limitations to this study, some of which were self-imposed due to the need to maintain uniformity of teaching and testing. In designing the study we decided on a two-hour limit to teach both techniques and tried to maintain consistency across all four teaching sessions despite seeing that a longer training period with more individualized feedback could have been beneficial in some cases. While we did ask individuals to exclude themselves in the pre-test period if they felt they could not modify their breathing pattern as instructed, it was not possible with the current design to check that each breather was simulating each breathing technique correctly in each case. This makes interpretation of the accuracy scores more difficult

because lack of accuracy could have been due to the breather rather than the examiner.

CONCLUSIONS

Both the MARM and the Hi Lo appear to accurately assess thoraco-abdominal relationships in breathing when used by both experienced clinicians and osteopathic students. Both practitioner and students have slightly more positive impressions of the MARM. As each technique has its own strengths and limitations the evaluation of dysfunctional breathing may best be performed using a combination of both techniques. It needs to be recognised that breathing pattern assessment may be more difficult in real life clinical situations where altered thoraco-abdominal breathing patterns occur in response to altered neuro-muscular function, organ pathology and respiratory control mechanisms. Therefore, future studies to validate these techniques should be performed in a clinical setting on individuals with actual rather than simulated breathing pattern disturbances.

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Reference- Courtney R,Reece J (2009). Comparison of the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo breathing assessment determining a simulated breathing pattern. International Journal of Osteopathic Medicine, 12, 86-91

OVERVIEW SECTION 2 -
DYSFUNCTIONAL BREATHING SYMPTOMS

This section contains one published study which describes the development and Factor Analysis of a dysfunctional breathing questionnaire called the Self Evaluation of Breathing Questionnaire (SEBQ).

Chapter 8- 'Preliminary investigation of a measure of dysfunctional breathing symptoms: The Self Evaluation of Breathing Questionnaire (SEBQ)'

CHAPTER 8

PRELIMINARY INVESTIGATION OF A MEASURE OF DYSFUNCTIONAL BREATHING SYMPTOMS: THE SELF EVALUATION OF BREATHING QUESTIONNAIRE (SEBQ).

ABSTRACT

Introduction: Dysfunctional Breathing (DB) can be defined by the presence of unexplained breathing symptoms. However, validated questionnaires to comprehensively evaluate all dimensions of breathing symptoms proposed to be associated with DB are not available. This paper discusses the development and exploration of the dimensionality of a preliminary questionnaire, the Self Evaluation of Breathing Questionnaire, whose items were derived from a popular Internet questionnaire for evaluating breathing functionality and breathing symptoms proposed in the scientific literature to be discriminative for DB.

Method: The 17-item SEBQ was administered to 83 adults. Exploratory factor analysis was performed and correlations calculated between the SEBQ and the Nijmegen Questionnaire (NQ), which is a validated questionnaire for hyperventilation syndrome.

Results/Discussion: Two dimensions were found in the SEBQ. One dimension named "lack of air" appears to reflect sensations of air hunger that may relate more to chemoreceptor aspects of breathing sensation. The other dimension named "perception of inappropriate or restricted breathing" appears to reflect sensations and observations about the work of breathing and may relate more to the biomechanical aspects of breathing sensation. The correlations between the SEBQ and the NQ were .6 for the 17-item SEBQ and .3 for the final 12-item SEBQ, which contained the strongest items of the two dimensions.

Conclusion: Breathing symptoms associated with dysfunctional breathing arising from predominately biomechanical aspects of breathing might be distinguishable from symptoms arising from factors reflecting chemoreceptor

input. The two dimensions of the SEBQ may represent related but distinct aspects of dysfunctional breathing symptoms that appear different to those assessed by the Nijmegen Questionnaire. The SEBQ, if further developed, may be a useful clinical assessment tool that could more discriminatively evaluate the separate dimensions of breathing symptoms and their response to treatments that aim to improve the functionality of breathing.

INTRODUCTION

Despite there being no precise definition, it has been proposed that dysfunctional breathing (DB) exists when there are a number of respiratory complaints in otherwise healthy individuals or in individuals with only mild medical conditions (Howell 1990). Furthermore, aspects of breathing functionality may exacerbate symptoms in various diseases such as asthma and cardiovascular disease (Grossman 1983; Bernardi and Gabutti 2001; Thomas, McKinley et al. 2001). Statements about the prevalence of dysfunctional breathing are difficult to interpret due to the vague nature of this condition and it would be useful to have some way of monitoring breathing symptoms thought to be related to DB (Lum 1975; Fried 1993; Thomas, McKinley et al. 2001).

Practitioners of breathing therapy currently assess breathing functionality on the basis of self-evaluation of breathing behavior and breathing symptoms (Hendricks 1995; Stalmatski 1999; White 2005). Of the few instruments which inquire comprehensively into breathing complaints, there is only one validated questionnaire, the Nijmegen Questionnaire (NQ), which has been used in the scientific literature to identify dysfunctional breathing (Dixhoorn and Duivenvoorden 1985; Thomas, McKinley et al. 2001). However, the NQ has only been validated for the hyperventilation syndrome, which may be just one aspect of dysfunctional breathing (Morgan, 2002; van Dixhoorn, 1985; 1997).

The 15 items of the NQ include 11 items that inquire about psychological, neurological and cardiovascular symptoms commonly found in the hyperventilation syndrome with only 4 questions obviously relating to breathing sensations. These are: 1. Faster and deeper breathing; 2. Short of breath; 3. Constricted chest; and, 4. Unable to breathe deeply. It is possible that this small number of questions on respiratory symptoms in the NQ might not inquire sufficiently into all dimensions of respiratory symptoms. The diagnosis of Hyperventilation Syndrome, which the Nijmegen Questionnaire was originally designed to investigate, has been questioned in recent years and a boarder definition of dysfunctional breathing is being sought. Thus,, the purpose of the SEBQ was to explore the nature of unexplained symptoms that are commonly

reported in people with dysfunctional breathing that may or may not be part of Hyperventilation Syndrome and are not extensively investigated by the NQ.

A literature search of MEDLINE, Science Direct, Cochrane Library and reference lists of original and review articles to find relevant instruments showed a paucity of validated instruments for investigating dysfunctional breathing. It showed that most validated questionnaires, other than the Nijmegen Questionnaire, that investigate breathing complaints have been designed for, and tested on, individuals with cardiorespiratory disease or other chronic illness rather than for individuals with dysfunctional breathing or unexplained breathing disorders. Questionnaires like the St. Georges Questionnaire (Jones, Quirk et al. 1992), the Chronic Respiratory Questionnaire (Wijkstra, TenVergert et al. 1994), and the UCSD Shortness of Breath Questionnaire (Eakin, Resnikoff et al. 1998) assess symptoms, situational measures of dyspnea and impact of symptoms on daily life as a way of monitoring severity of disease states (Meek 2004).

There is a body of literature developed over 20 years on the language of dyspnea, showing that dyspnea has many dimensions and that these various dimensions arise from different pathophysiological mechanisms (Simon 1989, Simon 1990, Mahler 1996, Han 2008).It has also been shown that medically unexplained dyspnea, which is considered to be part of the clinical presentation of dysfunctional breathing, can be differentiated on the basis of particular qualities of dyspnea (Han 2008).The Breathing Descriptor tool is the only validated questionnaire which identifies the various dimensions of respiratory discomfort, but to our knowledge has not been extensively used as a tool for evaluating symptoms in individuals who may have dysfunctional breathing (Mahler, Harver et al. 1996; Harver, Mahler et al. 2000).

The set of items which were devised for this study and named the Self Evaluation of Breathing Questionnaire (SEBQ) were derived from published studies by Burton (Burton 1993) and Howell (Howell 1990) that proposed symptoms discriminative for dysfunctional breathing, from other literature in the field (Fried 1993; Wilhelm, Gertivz et al. 2001), discussion with colleagues, relevant clinical experience and from a public domain internet questionnaire

titled "How Good is your Breathing Test, Take our Free Breathing Test and See" (HGYB) (White 2005). No item of the SEBQ was taken directly from any single source, most items were included because they were suggested by several sources and appeared plausible from our own clinical experience or after discussion with colleagues. The published sources of the major influences for each item of the SEBQ are given in Table 1.

The five very similar symptoms described by Howell and Burton as being discriminative for DB were based on findings from separate studies by each of these authors. In the first study Howell observed the following characteristics of unexplained breathing symptoms in individuals thought to have dysfunctional breathing:

1. Breathlessness occurred at rest;
2. Breathlessness was poorly correlated with level of fitness or physical exertion;
3. Breathlessness was associated with other body symptoms suggestive of hyperventilation; and
4. A sense of difficulty taking a breath in.

A majority of the patients suffering from these symptoms also experienced increased anxiety, depression or chronic unresolved stress (Howell 1990). Burton, in a subsequent study of patients presenting to general practice with functional symptoms associated with many breathing complaints reported the following seemingly related symptoms:

1. Dyspnea at rest;
2. Dyspnea on exertion;
3. Dyspnea occurring with onset of other physical symptoms; and
4. Difficulty taking a deep breath.

In addition Burton found that patients reported experiencing dyspnea when anxious (Burton 1993).

SEBQ items that were based on the symptoms described by Howell and Burton include:

1. "I get breathless even when resting",

2. "I get easily breathless on physical exertion out of proportion to my fitness",
3. "I get breathless in association with my physical symptoms",
4. "I can't take a deep or satisfying breath", and
5. "I get breathless when I am anxious."

Two questions of the SEBQ relate to difficulty in co-coordinating breathing with speech with resulting fatigue and breathlessness associated with speech. This is believed by Fried to be one of the important signs of dysfunctional breathing (Fried 1987; Fried 1993). In the SEBQ, this was investigated with two items: "I get short of breath when speaking or reading out loud"; and, "I have trouble co-ordinating my breathing when I am speaking".

It is frequently described in the literature that excessive irregularity of breathing is a common finding in dysfunctional breathing and that this is mostly in the form of frequent sighing, yawning and gasping for breath (Han, Stegen et al. 1996; Wilhelm 2001). In the SEBQ this symptom is investigated with the item "I sigh, yawn or gasp".

A further nine SEBQ items were partially derived from the HYBG (White 2005). In several instances, a number of questions from the HGYB that seemed overlapping were consolidated into a single SEBQ question. In other instances HGYB questions were rephrased for clarity of meaning and to make them consistent with the language used in the SEBQ. The HGYB questionnaire, while unvalidated, unstructured and containing questionable claims about normal breathing was useful because it contained common assumptions about the type of symptoms that characterise people with either "good" or "bad" breathing. While many items from the HGYB were not considered relevant or plausible the HGYB questions that were used to inform the SEBQ items were chosen because clinical experience and discussion with colleagues suggested that they did seem to reflect the symptoms seen in dysfunctional breathing.

The aim was to explore what dimensions existed in this list of questions. To further explore the items of the SEBQ we compared its dimensions to the NQ, an established questionnaire for hyperventilation, to see if the SEBQ assessed different qualities of breathing symptoms to those investigated by the

NQ. In this study we administered an initial version of the SEBQ to 83 individuals, performed exploratory factor analysis (EFA) to identify the dimensions underlying responses to this questionnaire and then tested for presence of correlations with the NQ.

METHOD

Participants

The 83 individuals who participated in this study were 29 males and 54 females, whose average age was 49 years. They were either healthy or suffered from mild medical conditions, including mild asthma. 29 of these subjects were found to have abnormal spirometry defined by either FEV1 or FVC >15% below predicted.

Participants were recruited from general practices and complementary medicine clinics in Sydney, Australia. Flyers and brochures were placed in waiting rooms and practitioners received a letter about the study. The participants did not have their breathing assessed by practitioners prior to the study and did not necessarily receive a diagnosis of dysfunctional breathing. These individuals who volunteered or were recommended to this study generally were motivated to participate in this study because they had concerns about breathing complaints or interest in knowing if they had correct breathing. This sample is therefore representative of the type of individual who while seeing a practitioner for unrelated complaints might have secondary concerns about breathing and also be likely to self-administer breathing tests such as the Internet “”How good is your breathing test”.

Materials

The SEBQ (Table 1) contains 17 items. Responses to these items were on a 4-point Likert scale:

(0) never/not true at all;
(1) occasionally/a bit true;
(2) frequently-mostly true; and
(3) very frequently/very true.

TABLE 1 - THE SEBQ ITEMS AND THEIR SOURCES

SEBQ Item	Source HGYB Question(s)	Other Sources from Literature
I get easily breathless on physical exertion out of proportion to my fitness.	Even the mildest exertion makes you out of breath. Breathless even walking one city block or climbing a flight of stairs without becoming breathless.	Howell (1990)
I get breathless even when resting.		Howell (1990)
I get breathless when I am anxious.		Howell (1990) Burton (1993)
I get short of breath or very tired when speaking or reading out loud.		Fried (1993)
I feel breathless in association with other physical symptoms.		Howell (1990) Burton (1993)
I have trouble co-ordinating my breathing when I am speaking.		Fried (1993)
I feel that I can't take a deep or satisfying breath.		Burton (1990) Howell (1990)
I sigh, yawn or gasp.	Sigh or yawn often.	Fried (1993) Wilhelm (2001)
I notice myself breathing irregularly.	Breathing is jerky, erratic and irregular. Breathing frequently tentative or hesitant.	Fried (1993) Wilhem (2001)
I feel there is not enough air in the room.	Feelings of suffocation. Air Hunger.	

I can't catch my breath.	Can't catch your breath. Shortness of breath	
My breathing feels stuck or restricted.	Breathing feels stuck. Breathing is labored or restricted. Deep breathing curtailed.	
I feel that my rib cage is tight and can't expand.	Chest is large and stiff. Tightness, soreness or pressure in the chest or below breast bone.	
My clothing often feels too tight or uncomfortable around my chest.	Chest feels large and stiff, feeling like band around chest. Feel bump, lump below breastbone when you try to take a deep breath.	
I find myself holding my breath at various times.	Often catch yourself not breathing during waking hours. Hold your breath a lot.	
I notice myself breathing shallowly using my upper chest and shoulders.	Do you raise your collar bones? Do you raise your shoulders? Do your neck muscles bulge out?	
I notice myself breathing quickly.	Individuals are asked to count and record their breaths per minute.	

The Nijmegen Questionnaire (NQ) is a 15 item questionnaire whose items are based on complaints ascribed to the Hyperventilation Syndrome (Dixhoorn and Duivenvoorden 1985).The NQ contains items relating to respiratory, psychological, cardiovascular, neurological and gastrointestinal complaints. Responses to the items are reported on a 5-point ordinal scale ranging from (1) never to (5) very frequently.

Procedure

The study received approval from the RMIT University Ethics Committee. Participants were informed that this was a study investigating dysfunctional breathing and the ways of measuring it. The study was conducted over a 12 month period.

Statistical Analysis.

As the aim was to identify underlying constructs, the SEBQ items were analyzed using principal axis factoring. We used several guidelines and a series of factor analyses (FA) before making our final decision on number of factors to retain (Ford, MacCallum et al. 1986). Our final decision was guided by the fit of the hypothetical factors produced by the FA to conceptual and theoretical considerations. We used orthogonal rotation for all trial factor analysis and tested both orthogonal and oblique rotations in the final factor analysis to evaluate which of the two gave superior simple structure. Once the likely number of factors was decided, we removed variables with loadings substantially below .6. The decision was based on a rule of thumb recommendation that for a sample size of 85, the smallest meaningful factor loading was .60 (Gardner 2007).

RESULTS

The distribution of responses for each of the items of the SEBQ are shown in Table 2. Most items showed a range of response on the scale from (0) - never/not true at all to (3) - very frequently/very true. SEBQ scores for the sum of the original items ranged from 0 to 30 with a mean of 13.4 (SD=8.2). SEBQ scores for the final 12 retained items ranged from 0 to 24 with a mean of 9.8 (*SD*=6.5) (Table 2 shows frequency of responses for each of SEBQ items).

Scores for the Nijmegen Questionnaire ranged from 0 to 51, with the mean score being 17.5 (*SD*=9.7).

TABLE 2 - FREQUENCY OF RESPONSE (%) TO EACH OF THE SEBQ ITEMS

Order	Item	0	1	2	3
1	I get easily breathless out of proportion to my fitness.	16.9	50.6	20.0	10.6
2	I notice myself breathing shallowly.	17.6	49.4	21.2	9.4
3	I get short of breath reading and talking.	53.1	24.7	13.6	8.6
4	*I sigh yawn or gasp.**	*12.9*	*56.5*	*21.2*	*7.1*
5	I feel I cannot get a deep or satisfying breath.	34.1	42.4	15.3	5.9
6	I notice myself breathing irregularly.	42.4	36.5	12.9	4.7
7	My breathing feels stuck or restricted.	44.7	34.1	15.3	3.5
8	My ribcage feels tight and can't expand.	48.2	35.3	10.6	3.5
9	I notice myself breathing quickly.	35.3	49.4	9.4	3.5
10	*My clothing feels tight and uncomfortable around my chest.*	*72.9*	*11.8*	*9.4*	*3.5*
11	I get breathless when I am anxious.	41.0	38.6	18.1	2.4
12	*I find myself holding my breath.*	*31.8*	*45.9*	*17.6*	*2.4*
13	I feel breathless in association with other physical symptoms.	48.2	40.0	5.9	2.4
14	*I have trouble co-ordinating my breathing when I am speaking.*	*56.6*	*34.1*	*5.9*	*2.4*
15	I can't catch my breath.	57.6	29.4	9.4	1.2
16	I feel that the air is stuffy, as if not enough air in the room.	44.7	43.5	8.4	1.2
17	*I get breathless even when I am resting.*	*64.7*	*29.4*	*2.4*	*0.0*

*Likert Scale: 0.= Never or not true at all, 1.= occasionally, a bit true, 2 = frequently,mostly true,3 = very frequently – very true. *Items in italics deleted in final 12 item version of SEBQ.*

Data were screened for multivariate outliers by calculating Mahalanobis' distances. Four possible outliers had Mahalanobis' distances slightly higher than the cut-off point indicated by chi-squared distribution tables. Visual inspection

of the data gathered from these cases showed no irregularities and due to the low ratio of participants to variables it was decided to retain these cases.

There were a substantial number of correlations between variables. The Kaiser-Myer-Olkin measure of sampling adequacy produced a score of .84 and Bartlett's test of sphericity was significant (p<.0001) indicating that the correlations found in the data set were suitable for principal axis factoring. Anti-image correlations and covariance matrices were calculated to estimate measurement of sampling adequacy (MSA). No variables showed MSA's below .6 indicating that all variables were suitable for inclusion in this analysis. Low communalities (.259) were seen for only one item "my clothing feels tight" and this item was later removed as it also was shown to have low factor loading when the final factor solution was achieved.

The initial solution extracted five factors with eigen values greater than 1 and explained 70% of the variance. However, the scree plot did not support the extraction of 5 factors. Both 4 and 5 factor solutions were rejected, as it was evident after orthogonal rotation that these solutions were not interpretable due to the large number of split loadings. A 2- factor and possibly a 3- factor solution appeared more likely from visual inspection of the scree plot. The factor analysis was then re-run with specifications for a 3- factor and then a 2-factor solution followed by orthogonal rotation of factors. A 3- factor solution explained 56% of the variance and the orthogonally rotated factor matrix showed at least seven split loadings and was not interpretable. A 2- factor solution explained 58% of the variance and the orthogonally rotated factor matrix showed only two items ("can't catch my breath" and "trouble co-ordinating breathing when speaking") with loadings split between the 2-factors. Factor 1 explained 45% of the variance and Factor 2 explained 13% of the variance.

A satisfactory result was seen when oblique factor rotation (direct oblimin) was applied to the 2- factor solution as a simple structure (where items load predominantly on just one factor) was evident. The factor correlation matrix showed a correlation of .63 between factors indicating that the factors are related.

The item with the strongest loading on Factor 1 was "short of breath when talking or reading out loud". Several items loading on this factor use the word "breathless" and items included the phrases "not enough air" and "can't catch my breath". Given these results, Factor 1 was named "lack of air".

The item with the strongest loading on Factor 2 was "unable to take a deep or satisfying breath" and other items seem to indicate perception of inappropriate or restricted breathing pattern. Factor 2 was therefore named "perception of inappropriate or restricted breathing". Table 3 shows rotated factor loadings for each of the 12 retained items of the SEBQ:

TABLE 3 - ROTATED FACTOR LOADING (PATTERN) FOR PRINCIPAL AXIS FACTORING AND OBLIQUE FACTOR ROTATION

	FACTOR 1	**FACTOR 2**
Short of breath talking or reading.	0.706	
*C*an't catch breath.	0.671	
Breathless in association with other physical symptoms.	0.661	
Breathless on physical exertion out of proportion to fitness.	0.653	
Feel that the air is stuffy, as if not enough air in room.	0.622	
Breathless when I am anxious.	0.487	
Can't take a deep or satisfying breath.		0.848
Stuck or restricted breathing.		0.838
Irregular breathing.		0.741
Rib cage tight and cant expand.		0.656
Shallow breathing.		0.594
Quick breathing.		0.500

Factor Loading below 0.3 not shown

Sample size influences the meaningfulness of factor loadings. A factor loading of approximately .6 is considered meaningful when the sample size is 85 (Hair 2006). Using this guideline, items with loadings below .6 were considered for deletion, based on how well they seemed to fit conceptually with the two Factors and on the variability of the item scores. It was decided to retain items with factor loadings above .5 that also had good variability of

scores and seemed to fit conceptually. This reduced the number of items from 17 to 12. Items deleted from Factor 1 were:

"I get breathless even when resting",

"My clothes feel too tight or uncomfortable around my rib cage", and

"I sigh, yawn and gasp".

Items deleted from Factor 2 were:

"I find myself holding my breath at various times", and

"I have trouble coordinating my breathing when I am speaking".

Scores for Factor 1 - "Lack of Air" ranged from 0 to 14, with a mean of 4.7 (SD=3.5). Scores for Factor 2 - "perception of inappropriate or restricted breathing" ranged from 0 to 15, with a mean of 5.2 (SD=3.8). Cronbach's alpha was calculated for the remaining items on Factor 1 and Factor 2 respectively and found to be: .81 and .85.

The SEBQ total score for the 17 items correlated with the Nijmegen Questionnaire, r = .60, p < .0001. When items were deleted, the correlation between the 12 items SEBQ and NQ was still significant, but much smaller, r = .28, p <. 05.

Significant correlations were found between scores on Factor 1 and on the Nijmegen Questionnaire, r = .34, p < .01. No significant correlations were found between Factor 2 and the NQ (Table 4).

TABLE 4 - CORRELATIONS: SELF EVALUATION OF BREATHING QUESTIONNAIRE AND NIJMEGEN QUESTIONNAIRE

	SEBQ initial (17 item)	**SEBQ final** (12 item)	**NQ**	**Factor 1**	**Factor 2**
SEBQ initial	1	.433 p=.0001	.590 p=.0001	.364 p=.001	.399 p=.0001
SEBQ final		1	.275 p=.012	.568 p=.0001	.906 p=.0001
NQ			1	.338 p=.002	.166 p=.134

DISCUSSION

This study was a preliminary exploration of the SEBQ, a compilation of questions suggested by various sources to represent symptoms associated with DB. Two separate but correlated dimensions of breathing sensation were identified with the SEBQ. These may correlate with either biomechanical or chemoreceptor factors. Factor 1 was named "lack of air" because it contained phrases similar to those used by individuals whose chemoreceptors were challenged by hypoxia or hypercapnia (Banzett, Lansing et al. 1990; Lansing 2000). All items using the word breathless loaded on this factor, as did phrases such as "short of breath and "not enough air" and "can't catch my breath". This was differentiated from Factor 2 which we called "perception of inappropriate or restricted breathing" and which appeared to relate more to biomechanical factors. The highest loading items were "I cannot take a deep and satisfying breath" and "My breathing feels stuck or restricted". These items describe a sense of restricted or otherwise unsatisfied respiration. Other items such as "notice myself breathing quickly", "notice myself breathing shallowly using my chest and upper shoulders" and "notice myself breathing irregularly" are related to awareness of the inappropriateness of some aspect of the mechanical work of breathing.

The idea that biomechanical and/or chemoreceptor inputs contribute to DB is consistent with the literature that suggests that sensations akin to "lack of air" and "perception of inappropriate or restricted breathing" may arise predominately from different receptors in the respiratory system and may involve somewhat different physiological mechanisms. Previous research suggests that different phrases are consistently used to describe the sensations associated with particular tasks and that symptom descriptors vary according to whether the afferent signals to the cortex arise predominately from chemoreceptors, chest wall biomechanical receptors or receptors associated with the lungs (Simon, Schwartzstein et al. 1989). Furthermore, subsequent studies showed that individuals with particular diseases could be differentiated according to the phrases they used which suggests that different qualities of breathing discomfort may reflect underlying pathological and physiological processes (Simon and Schwartzstein 1990; Elliot, Adams et al. 1991).

Descriptive phrases for different qualities of breathing sensation have been found in different studies to form from 8 to 12 different clusters (Simon, Schwartzstein et al. 1989; Simon and Schwartzstein 1990; Elliot, Adams et al. 1991; Mahler, Harver et al. 1996). Through multidimensional scaling, Harver et al.(2000) found that underlying these there appear to be three major categories of symptoms (Harver, Mahler et al. 2000). Two of these appear to be related to sensations and perceptions related to the biomechanical work of breathing and the third to sensations arising from chemical drivers of breathing. The two biomechanical factors, which were called "difficulty breathing and phase of respiration" and "depth and frequency of breathing", contain many descriptors similar to items in SEBQ Factor 2, "perception of inappropriate or restricted breathing". Given a larger sample size or a sample with more severe dysfunctional breathing we may also have found two biomechanical factors. It's also likely that the SEBQ does not contain items that properly represent the two biochemical dimensions of breathing symptoms and future versions of the SEBQ should contain more items from the Breathing Descriptor Tool. The category described by Harver as "perceived need and urge to breathe" and also as "air hunger" appears to be similar to the SEBQ Factor 1 "lack of air".

Many items in SEBQ Factor 2 "perception of inappropriate or restricted breathing" are recognisably similar to sensations documented in situations where the work of breathing is made more difficult. For example, chest wall strapping of healthy volunteers sufficient to restrict normal respiratory motion resulted in the sensations of "unsatisfied respiration" and "inspiratory difficulty" (O'Donnell, Hong et al. 2000). "Unsatisfied respiration" and a sense of difficulty taking a deep and satisfying breath is a common symptom in patients with impaired function of the respiratory muscles and rib cage due to hyperinflation of the lungs (Lougheed, Fisher et al. 2006). In hyperinflation, the rib cage stiffens and respiratory muscles, in particular the diaphragm and accessory muscles of respiration, shorten which decreases their ability to respond adequately to efferent command from the motor cortex (Wolfson, Strohl et al. 1983; De Troyer and Estenne 1988; Finucane, Panizza et al. 2005; O'Donnell 2006). The description of the breath as shallow is common in patients with neuromuscular and chest wall disorders and this sensation is

presumed to arise from receptors in the chest wall and muscles of breathing and from efferent-reafferent dissociation (Simon and Schwartzstein 1990). All of these sensations (shallow respiration, difficulty in taking a deep or satisfying breath and feelings of restricted breathing) may arise when there is dissociation between efferent motor command and reafferent ventilatory motor response and when the motor output of the respiratory system is not able to match the expectations generated in the sensory cortex by corollary discharge from the motor cortex (Beach and Schwatrzstein 2006). These sensations are the qualities described by the items in the SEBQ Factor 2.

Items associated with the SEBQ Factor 1 "lack of air" may indicate a state of respiratory awareness associated with afferent input from chemoreceptor activity. The sensory quality of "air hunger" or "urge to breathe" is most strongly linked to changes in blood gases such as carbon dioxide or changes in the respiratory drive and arises predominately from afferent input from central and peripheral chemoreceptors (Lansing 2000). Research has shown that the sensations of "air hunger" or "urge to breathe" are distinguishable from breathing sensations related to the work or effort of breathing (Banzett, Lansing et al. 1990; Lansing 2000).

Another possible way of interpreting the two factors identified in the SEBQ is that they are two different aspects of interoception. Items in Factor 1 "lack or air" are predominately about feeling or sensing. The items in Factor 2 "perception of inappropriate or restricted breathing" are predominately about observing or noticing. It has been proposed that sensory experiences such as breathing discomfort and pain have at least 3 components:

1. A sensory or discriminative component;
2. A cognitive or evaluative component; and
3. An affective or motivational component (Harver, Mahler et al. 2000).

Items on the two factors might be describing different aspects of the sensory and cognitive experience of breathing discomfort. As both over- and under-perception of breathing sensations can be problematic, particularly in individuals with respiratory diseases, it may be useful to monitor how sensory

or feeling aspects of breathing sensations are rated in comparison to evaluative and noticing descriptions of breathing sensations (Klein, Walders et al. 2004).

Dysfunctional breathing has in the past been most associated with hyperventilation, a condition which has a narrow biochemical definition and is dependent on the finding of hypocapnia (Comroe 1974). However, biomechanical aspects of breathing also influence its functionality. Low carbon dioxide was once presumed to be the main cause of hyperventilation symptoms, but this has been shown not to be the case and breathing symptoms are often unexplained (Hornsveld 1997). People with unexplained breathing symptoms, and even those presumed to have hyperventilation syndrome, often show normal levels of carbon dioxide but abnormalities of breathing pattern are common (Han, Stegen et al. 1996; Wilhelm, Gertivz et al. 2001). The function of the respiratory muscles is a cause of respiratory discomfort and could contribute to specific characteristics of the sensation of dyspnea (Killian and Jones 1988).

Relationship of SEBQ with NQ

The correlation between the SEBQ score and NQ was substantially reduced when the SEBQ items with low factor loadings were deleted. This indicates that the NQ does not strongly represent the two factors found in the SEBQ and the SEBQ could not be relied upon to detect hyperventilation syndrome. The SEBQ Factor 1 component "lack of air" showed a small correlation with the NQ, however there was no correlation between Factor 2 "perception of inappropriate and restricted breathing" and the NQ. Interestingly the four breathing items in the Nijmegen Questionnaire, found by van Dixhoorn and Duivenvoorden to have with high loadings (> .55) on the breathing component, conceptually seem to range over both dimensions of the SEBQ. NQ items "constricted chest", "accelerated or deepened breathing" and "unable to breathe deeply" are similar to items in SEBQ Factor 2 "perception of inappropriate or restricted breathing", and NQ item "shortness of breath" appears similar to SEBQ Factor 1 "lack of air" items. However, the finding that SEBQ Factor 2 did not correlate with the NQ suggests that the NQ differs in its representation of sensations arising from possible biomechanical breathing dysfunctions.

Deleted Items

Certain items deleted due to low factor loadings in this study should still be considered for inclusion in future versions of the SEBQ. The item "I feel breathless even while resting" was reported by Howell as being a discriminative symptom in patients with unexplained breathlessness, due to the finding that this symptom was much more prevalent in patients whose breathing symptoms were linked with functional or psychogenic factors rather than cardiorespiratory pathology. In this present study the response to this item showed the lowest variability of response with 65% of responders reporting never experiencing this, 29% reporting it sometimes and only 2% experiencing this symptom frequently. This could be due to the fact that the sample was somewhat diverse and was not adequately representative of individuals with severe unexplained breathing symptoms. Other deleted items such as "I sigh, yawn and gasp" and "I find myself holding my breath" load weakly on Factors 1 and 2 respectively, but show a good variability in response and could contribute useful information about breathing irregularity which is a well-known aspect of disordered breathing (Abelson, Weg et al. 2001; Wilhelm 2001).

Future Items for SEBQ

The SEBQ may benefit from additional items such as those found in the Breathing Descriptor Tool. Suggested items from the Breathing Descriptor Tool that might not be well represented in the SEBQ are:

"Breath does not go in all the way",

"Breath not does go out all the way",

"Breathing is heavy",

"I feel that I am breathing more",

"My breathing requires work", and

"My breathing requires effort".

It is also suggested that any future questionnaire inquires about the prevalence of mouth breathing during the day, at night and during exercise.

Limitations

This study would have benefited from increased number of participants. The study sample may not have adequately represented individuals with

dysfunctional breathing. These factors and omission of items such as those found in the Breathing Descriptor Tool may prevent the identification of some dimensions of breathing symptoms.

Recommendations for Future Research

This study should be viewed as a preliminary exploration of the SEBQ. Further development of the items of the SEBQ and further testing on the specific populations for which it is intended is required to validate this questionnaire. In particular the SEBQ should be tested on sample populations with a diagnosis of dysfunction breathing, with unexplained breathing complaints and with cardiorespiratory disease and the findings between these groups and normals should be compared.

It is recommended that the questionnaire be further developed to clarify wording of questions and that additional items be included so that all dimensions of breathing symptoms and important breathing behaviours are represented. A comprehensive breathing questionnaire would assist in quantifying and monitoring the effects of treatments such as breathing therapy, manual therapy, relaxation training or biofeedback on respiratory symptoms and respiratory behaviours in individuals with and without cardiorespiratory disease. Future versions of the SEBQ should be scrutinized by experts in the field and investigated for test-retest reliability.

CONCLUSION

The two dimensions of the SEBQ may represent strongly related, but distinct, aspects of dysfunctional breathing symptoms representing biochemical and biomechanical mechanisms. The clinical assessment of these two dimensions may prove useful for more specific diagnosis and treatment of dysfunctional breathing. Future work is required to develop the SEBQ and evaluate its performance in terms of discriminating between different patient categories and normal individuals.

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Reference-Courtney R, Greenwood KM (2009). Preliminary investigation of a measure of dysfunctional breathing symptoms: the Self Evaluation of Breathing Questionnaire (SEBQ). *International Journal of Osteopathic Medicine*, 12, 121-127

OVERVIEW OF SECTION 3 - RELATIONSHIP BETWEEN MEAUSURES OF DYSFUNCTIONAL BREATHING

This section contains two published studies which investigate the relationships between measures of dysfunctional breathing.

Chapter 9 - 'Relationships between measures of dysfunctional breathing in a population with concerns about their breathing'.

Chapter 10 - 'Investigating the claims of Dr. K.P. Buteyko: The Relationship of Breath Holding Time to end tidal CO_2 and other proposed measures of dysfunctional breathing'.

CHAPTER 9

RELATIONSHIPS BETWEEN MEASURES OF DYSFUNCTIONAL BREATHING IN A POPULATION WITH CONCERNS ABOUT THEIR BREATHING

ABSTRACT

Background: Dysfunctional breathing (DB) is implicated in physical and psychological health; however evaluation is hampered by lack of rigorous definition and clearly defined measures. Screening tools for DB include biochemical measures such as end-tidal CO_2, biomechanical measures such assessments of breathing pattern, breathing symptom questionnaires and tests of breathing function such as breath holding time.

Aim: This study investigates whether screening tools for dysfunctional breathing measure distinct or associated aspects of breathing functionality.

Method: 84 self-referred or practitioner-referred individuals with concerns about their breathing were assessed using screening tools proposed to identify DB. Correlations between these measures were determined.

Results: Significant correlations where found within categories of measures however correlations between variables in different categories were generally not significant. No measures were found to correlate with carbon dioxide levels.

Conclusion: DB cannot be simply defined. For practical purposes DB is probably best characterized as a multidimensional construct with at least three dimensions, biochemical, biomechanical and breathing symptoms. Comprehensive evaluation of breathing dysfunction should include measures of breathing symptoms, breathing pattern, resting CO_2 and also include functional measures such a breath holding time and response of breathing to physical and psychological challenges.

INTRODUCTION

Dysfunctional Breathing (DB) is commonly used to describe disturbances in breathing functionality that impact on health (Dixhoorn 1997; Morgan 2002 ; Dixhoorn 2004; Thomas, McKinley et al. 2005; Prys-Picard and Niven 2008; Stanton, Vaughn et al. 2008). The definition of DB however is unclear and no gold standards exist to define it. Dysfunctional breathing includes hyperventilation or breathing in excess of metabolic needs but also refers to breathing pattern abnormalities, poor breathing control and presence of breathing symptoms (Dixhoorn 1997; Morgan 2002; Warburton and Jack 2006). Scientists have until recently focused their attention on hyperventilation, which is defined as breathing in excess of metabolic requirements that results in depletion of carbon dioxide (Comroe 1974). However the importance of hyperventilation and hypocapnia in producing the symptoms associated with DB is disputed (Hornsveld, Garsson et al. 1996; Hornsveld 1997). It has been proposed that DB symptoms may arise as a result of non biochemical breathing dysfunctions or have neurological causes (Howell 1997). A broader definition of dysfunctional breathing, which considers the multiple functions of breathing, may be a more useful way to characterize DB and to determine its prevalence and impact (Dixhoorn 1997).

Maintenance of normal levels of blood gases such as carbon dioxide is an important, if not the key function of breathing; however breathing has other important functions. Breathing functions in posture and motor control (Lewitt 1980; McGill, Sharratt et al. 1995; Hodges, Heijnen et al. 2001). It is a key influence on oscillating rhythms that are important for homeostasis, autonomic nervous system regulation and efficient interaction between body systems (Giardino, Lehrer et al. 2000; Bernardi 2001; Song and Lehrer 2003). Normal and precisely controlled breathing is also important for voice production and regulation of speech (MacLarnon and Hewitt 1999; Sivasankar and Erickson 2009).

Biomechanical, neurological and psychological aspects of breathing are not always tightly linked to biochemical parameters and their other relationships are complex and not adequately understood (Han, Stegen et al.

1996). Attempts to tie the symptoms associated with dysfunctional breathing to only the biochemical dimension i.e. hyperventilation and hypocapnia have not been successful (Burton 1993; Hornsveld 1997). Physical and psychological causes of breathing dysfunction are often interwoven and can be difficult to separate, however, DB is thought to contribute to additional symptoms not adequately explained by the main presenting complaint (Han, Zhu et al. 2004). Research has shown that symptoms associated with dysfunctional breathing are strongly influenced by anxiety and other emotional states and in some cases the psychological influences are primary (Wientjes and Grossman 1994; Han, Zhu et al. 2004). Other symptoms, particularly various qualities of dyspnea have been linked to breathing pattern abnormalities and poor neuromechanical coupling during breathing (O'Donnell 2006; Prys-Picard and Niven 2008). Muscular skeletal dysfunctions, in addition to speech and voice problems appear to be predominately linked with dysfunctions of breathing pattern and neural control of respiration rather than to the body's carbon dioxide status (McGill, Sharratt et al. 1995; Gandevia, Butler et al. 2002).

The accumulation of studies showing the presence of breathing disturbances in highly symptomatic patients and the results of research showing that patients with a range of symptoms and medical conditions improve after breathing therapy (Lum 1975; Grossman 1984; Tweedale, Rowbottom et al. 1994; Han 1996; Meuret, Rosenfield et al. 2009) lends weight to the importance of assessment and optimization of breathing functionality in patient care. However, evaluation of dysfunctional breathing is currently hampered by lack of clear measurement guidelines. Measures used by practitioners as screening tools to identify dysfunctional breathing include biochemical measures such as end-tidal CO_2 (Hardonk and Beumer 1979; McLaughlin 2009), biomechanical measures such as assessments of breathing pattern (Prys-Picard, Kellett et al. 2004), breathing symptom questionnaires (Thomas, McKinley et al. 2005; Courtney and Greenwood 2009) and tests of breathing function such as breath holding time (Courtney and Cohen 2008).

Symptom questionnaires used to evaluate DB

The Nijmegen Questionnaire (NQ) is the most commonly used questionnaire to identify DB. The 16 item NQ was originally devised to test for HVS and includes 4 questions on respiratory symptoms and another 12 items on peripheral and central neurovascular or general tension related symptoms (Dixhoorn and Duivenvoorden 1985). A questionnaire called the Self Evaluation of Breathing Questionnaire (SEBQ) has also been devised to specifically assess respiratory symptoms and breathing behaviours reported to be associated with DB. The SEBQ includes a larger number of respiratory items than the NQ and can differentiate two distinct dimensions of breathing discomfort - "lack of air", which is probably related to chemoreceptor derived sensations and "perception of inappropriate or restricted breathing", which is probably related to the biomechanics of breathing and breathing perception (Courtney and Greenwood 2009). Normal values for the SEBQ have not been established as yet and this questionnaire is only useful at present for assessing change in breathing symptoms within individuals after treatment. However, it does have potential as a screening tool for DB once further studies are done to validate this instrument. Normal values for the NQ in European studies are generally around a sum score of 10 (Han, Stegen et al. 1996; Han, Stegen et al. 1998; Thomas, McKinley et al. 2005) whereas in China values are lower and average around 5 (Han, Zhu et al. 2004). In categorizing individuals as having DB, cut-offs of both 20 and 22 have been found useful (van Doorn, Folgering et al. 1982; Dixhoorn and Duivenvoorden 1985; Dixhoorn and Hoefman 1985).

Clinical measures of dysfunctional breathing patterns

Clinicians usually assess breathing patterns using observation and palpation and historically have used a range of techniques, most of which have not been validated (Pryor and Prasad 2002; Perri 2007). One component of breathing pattern that is considered dysfunctional, is chronic thoracic dominant breathing at rest. Recently a technique called the Manual Assessment of Respiratory Motion (MARM), which can quantify the extent of thoracic dominant breathing as well as other aspects of breathing pattern, has been found to have high levels of inter-examiner reliability and to agree with measures made

simultaneously with Respiratory Induction Plethysmography (Courtney, van Dixhoorn et al. 2008). Normal healthy individuals appear to have balanced breathing with relatively equal motion of upper rib cage to lower rib cage abdominal motion. Perfectly balanced breathing gives a MARM value of 0. Normal values for the MARM in this study of 12 yoga teachers and breathing therapy practitioners were around 6. MARM values above 30 can be considered dysfunctional, as they are at least 2 standard deviations above the mean values found in normal healthy individuals (Courtney, van Dixhoorn et al. 2008). Another aspect of breathing pattern considered dysfunctional is the presence of paradoxical or asynchronous breathing (Prys-Picard, Kellett et al. 2004). In paradoxical breathing the belly is drawn in and lower rib cage narrows rather than expands during inhalation. Practitioners generally assess the presence of paradoxical breathing simply by asking the patient to breathing in gently, slightly deeply and into the belly while they observe the respiratory phase relationship of chest and belly motion. If the belly moves inward, decreasing its dimensions during inhalation, the breathing is considered to be paradoxical. This simple observation by the practitioner of chest and belly motion sometimes called the Hi Lo breathing assessment has been found to be reasonably accurate for determining different types of simulated breathing patterns including paradoxical breathing (Courtney and Reece 2009).

Carbon dioxide levels and DB

Persistent low levels of resting carbon dioxide might be expected in individuals with dysfunctional breathing as evidenced by chronic persistent hyperventilation. However there is considerable argument about what parameters constitute normal values of resting CO_2, and the usefulness of resting CO_2 as a means of identifying individuals with hyperventilation tendencies, because the tendency to symptom producing hyperventilation can be intermittent rather than chronic and only become apparent in response to physical or psychological challenge testing (Hardonk and Beumer 1979; Warburton and Jack 2006). Some older texts state that levels of carbon dioxide below 37mm Hg indicate hyperventilation (Comroe 1974) and more recent texts place normal CO_2 levels as above 35mmHg (Levitsky 1995). Gardener

found that many individuals had CO_2 levels chronically below 35 mmHg with no apparent symptoms until levels were taken below 30mmHg. In fact he found that mean levels of CO_2 in healthy individuals were around 36.2 mmHg with 2 standard deviations below this level being 32.2 (Gardner 1995). Regardless of arguments over CO_2 cut-offs, it can be concluded that persistently low CO_2 and low CO_2 in response to challenge testing is an aspect of dysfunctional breathing worthy of measurement, particularly as end-tidal CO_2 which fairly accurately represents arterial CO_2, can be easily measured with modern capnometry equipment (McLaughlin 2009).

Breath holding time and dysfunctional breathing

Breath holding ability is an aspect of breathing functionality that is commonly disturbed in individuals with tendencies to hyperventilation and to dysfunctional breathing (Jack, Darke et al. 1998; Warburton and Jack 2006). Breath holding time in individuals with chronic idiopathic hyperventilation has been reported to be only 20 seconds, when held at the end of inhalation, in comparison to normal individuals whose breath holding time is around 60 seconds when performed according to the same instructions (Jack, Rossiter et al. 2004). Breath holding time differs markedly depending on how it is performed, being affected by whether the hold occurs after inhalation or exhalation and by the size of the breath taken at the beginning of the breath hold (Mithoefer 1965). One breath holding time protocol, which uses a somewhat standardized procedure and is used for evaluating and monitoring dysfunctional breathing, is the Buteyko Method technique of the Control Pause. The Control Pause is a post expiratory breath hold and is performed with two slight variations. In one variation the breath is held until the first urge to breathe and in another variation until the first involuntary motion of the respiratory muscles (Courtney and Cohen 2008). Control Pause levels of below 20 seconds are proposed to indicate the presence of dysfunctional breathing and to correlate with low resting carbon dioxide levels (Stalmatski 1999; Stark and Stark 2002).

To date there has been little research into systematically investigating the relationships between biochemical, biomechanical and symptomatic

measures of dysfunctional breathing commonly used by clinicians and therapists to evaluate their patients. The small amount of research that does exists tends to suggest that biochemical, symptomatic and breathing pattern aspects of breathing dysfunction do not necessarily co-exist in individuals suspected of having some type of DB. For example disturbances in breathing pattern are not always associated with chronically decreased baseline levels of CO_2 (Han, Stegen et al. 1996; Pine, Coplan et al. 1998; Caldirola 2004) and changes in breathing pattern and symptoms after breathing therapy may not be accompanied by changes in CO_2 (Han 1996). Symptoms believed to be characteristic of dysfunctional breathing may only be mildly related to chronic CO_2 levels or even acute changes in CO_2 (Burton 1993; Hornsveld 1997). It has been previously reported that Buteyko's Control Pause does not correlate with resting CO_2 levels (Courtney and Cohen 2008). These observations could imply that breathing pattern, symptoms and carbon dioxide levels reflect distinct aspects of breathing functionality and that dysfunctional breathing might best be characterised as a complex condition with multiple dimensions.

While a combination of measurement tools are sometimes used to evaluate dysfunctional breathing and establish its prevalence in particular populations (Stanton, Vaughn et al. 2008), researchers and practitioners of different breathing therapies may for historical or convenience reasons evaluate only one aspect of breathing function. A number of studies have determined prevalence of DB on the basis of symptom questionnaires alone (Thomas, McKinley et al. 2001; Humphriss, Baguley et al. 2004; Thomas, McKinley et al. 2005) or have emphasised the measurement of carbon dioxide levels (McLaughlin 2009) or breathing pattern (Perri and Halford 2004). If the measurement in one dimension of breathing functionality does not prove to be highly correlated with the measure in another dimension, this may result in incorrect assumptions about prevalence. Research into the relationships between measures of DB will help to clarify what range of measures are needed for comprehensive evaluation of DB. This type of research would help to determine what minimum requirements are needed for comprehensive evaluation of the various aspects of breathing dysfunction in the clinical

environment. It would also assist an understanding of how best to characterise DB.

The aims of this study are:

1. To compare the prevalence of DB on the basis of a range of measures, and
2. To evaluate the relationships and correlations between various measures of DB.

Given the difficulties and lack of consensus on gold standard definitions of DB, we have chosen a pragmatic study design and have applied a range of clinically used measures of DB to a population with concerns about their breathing rather than attempting to test a population fitting any particular definition of DB. We believe this approach has greater external validity and applicability for practitioners as it more closely mimics what occurs in "real life" clinical situations.

METHOD

Participants

Participants were recruited from general practices and complementary medicine clinics in Sydney, Australia. Flyers and brochures were placed in waiting rooms and practitioners received a letter about the study that was described as an investigation into the measurement of "incorrect" and dysfunctional breathing and that it presented an opportunity for individuals to have their breathing assessed.

This attracted individuals with a range of mild medical conditions who had concerns or curiosity about their breathing or who wished to improve their breathing. They had not been comprehensively assessed for presence of dysfunctional breathing, however most subjects came to the study because they were referred or self referred for investigation of dysfunctional breathing. As people generally self refer, or are referred for breathing therapies to improve a range of health problems as well as for health optimisation, this

sample represent the types of individuals who might use breathing therapies or go to see a therapist for assessment of their breathing.

The 83 individuals who participated in this study were 29 males and 54 females, whose average age was 49 years. They were either healthy or suffered from mild medical conditions including mild asthma. Twenty-nine of these subjects were found to have abnormal spirometry defined by either Forced Expiratory Volume at 1 second (FEV_1) or Forced Vital Capacity (FVC) >15% below predicted. Descriptive statistics and mean values for the various measures used can be seen in Table 1. Of the 83 participants, 63 (75.9%) had dysfunctional breathing according to at least one measure if the most conservative cut-off for this measure is applied. Number of participants with DB according to each of the individual measures is shown in Table 2.

Most of the participants had not undertaken any breathing training, with the exception of one female who had trained in the Buteyko Breathing Technique. Some participants practiced yoga but the exact numbers were not recorded.

Measures

Spirometry

Spirometry was performed using a laptop-based spirometer (Spirocard, QRS Diagnostics, Plymouth, MN). The variables used were Forced Expiratory Volume in 1 second (FEV1) and Forced Vital Capacity (FVC). Individuals with FEV1 or FVC <15% below predicted were classified as having abnormal spirometry.

Oxygen and end-tidal carbon dioxide measurement

End-tidal carbon dioxide ($ETCO_2$) levels were sampled with a two-pronged nasal canula, and readings were taken with a combined oxymeter and capnometer (BCI, Capnocheck, Waukesha, WI). The equipment was calibrated and checked for accuracy with a known gas mixture. $ETCO_2$, along with O_2 saturation (SPO_2), respiratory rate, and heart rate, were measured continuously for about 25 minutes while the person filled out various

questionnaires including several that were not related to this study but were used for distraction purposes. The filling out of questionnaire was used to distract participants from excessive attention on their breathing, a source of error that tends to alter breathing rate, volume and pattern. They were advised not to speak and to breath nasally at all times. After excluding data from the first 2 minutes to allow for the subject settling in, the average $ETCO_2$ was calculated and used in determining correlation coefficients with other variables. In classifying individuals as having DB based on low resting $ETCO_2$, two cut-offs were used- 35 mmHg and 32 mm Hg.

The Manual Assessment of Respiratory Motion

The Manual Assessment of Respiratory Motion (MARM) is a clinical tool used to assess breathing pattern that has been shown to have clinical utility and validity (Courtney, van Dixhoorn et al. 2008; Courtney and Reece 2009). This palpatory technique permits the examiner to assess the relative contribution of upper thoracic to lower thoracic and abdominal compartments during breathing and calculate quantitative measures of the balance between these two compartments in breathing. A number of variables can be derived from the MARM procedure, and two of these were used in this study. The first of these is % rib cage motion (MARM %RC) and the second is MARM balance. The examiner using the MARM places their open hands over the subject's back at the region of the lower four to six ribs. The examiner's thumbs are about 1 inch from the spine and oriented vertically. The examiner's hands are spread so that the lower three fingers are oriented in a transverse direction. This hand placement makes it possible for the examiner to feel lateral and vertical motion of the rib cage and assess relative contribution from the upper rib cage and the lower rib cage/abdomen. The examiner draws a diagram with an upper line to represent extent of the upper rib cage and vertical motion and a lower line to represent extent of lower rib cage/abdomen motion. Calculations are then made for thoracic diaphragm "balance" and % rib cage motion (Courtney, van Dixhoorn et al. 2008). Mean measures for the MARM balance measure were found in this previous study to be around 6 (+-12). Cut-offs of 30 were used to classify individuals with DB on the basis of the MARM balance measure. For the

MARM % RC measure, where normals had mean levels of 56 (+-8) a cut-off of 70 was used.

The Hi Lo Breathing Assessment

This technique involves simple observation by the practitioner of chest and belly motion. The Hi Lo breathing assessment has been found to be reasonably accurate for determining various types of breathing patterns including simulated paradoxical breathing (Courtney and Reece 2009). In this study patients were asked to slowly and a little bit deeply "breathe into the belly" while the Hi Lo was used to assess presence of paradoxical breathing.

During the Hi Lo, the examiners hands were placed on the anterior central upper chest and clavicular area (Hi) and the anterior upper abdomen (Lo). From this hand position the examiner determined whether abdominal motion was "paradoxical" i.e. whether it moved inward towards the spine, during inspiration despite the patient's attempts to breathe into and expand their belly.

Breath Holding Time Tests

Due to different views on the exact procedure for the Buteyko Control Pause, two breath holding tests were performed (Courtney and Cohen 2008). In the first test, participants held their breath until they experienced a definite sensation of discomfort or recognizable difficulty in holding the breath (BHT-DD). The second test involved the time until the first involuntary movement of the respiratory muscles (BHT-IRM). Participants were instructed to sit quietly and breathe normally. They were then asked to breathe gently and at the end of a normal exhalation to pinch their noses and hold the breath. Of these 2 breath holding procedures, the BHT-IRM is likely to be the most reproducible and physiologically stable because involuntary motion of the respiratory muscles has been found to be a more a consistent measure of breaking point of breath holding than subjective sensation of the urge to breath (Lin 1974). Measurement was done with a stopwatch that measured to 0.01 of a second. This number was rounded to 0.1 of a second. All breath-holding procedures were repeated three times. As the procedure did not require complex learning

and all participants were able to master this procedure easily, the mean rather than the best result was used in calculating correlations. Prolongation of breath holding time, which can occur when subjects are asked to hold their breath to maximal breaking point (Heath 1968), did not occur with either of breath holding procedures used in this study. We presume this was because subjects did not hold their breath "as long as they could" and instead followed instructions to only hold until the first muscular impulse (BHT-IRM) or intensification of dyspnea (BHT-DD).

Cut-offs of 20 and 30 seconds were used to classify people as having dysfunctional breathing for both these 2 breath hold protocols. These cut-offs were based on Buteyko Method claims that BHT less than 30 seconds indicated mild dysfunctional breathing (and correlated with resting ETCO2 of 36 mmHg) and less than 20 indicated more severe dysfunctional breathing (and correlated with resting $ETCO_2$ of approximately 32 mm Hg) (Buteyko 1990; Novozhilov 2010).

The following series of questionnaires were administered and measurements taken:

The Nijmegen Questionnaire

The 17 item Nijmegen Questionnaire (NQ) is a checklist of symptoms initially believed to reflect hyperventilation syndrome (HVS). It was first developed by van Doorn and colleagues who demonstrated that the test-retest reliability was valid (r=.0.87) (van Doorn, Folgering et al. 1982). The NQ has been demonstrated as able to identify patients (identified by clinicians on the basis of symptoms and observation of breathing behaviours) as suffering from HVS (Dixhoorn and Duivenvoorden 1985). Subsequent studies have also shown that the symptoms of the NQ are reproducible by voluntary hyperventilation (Vansteenkiste 1991). In recent years, studies have used the NQ to identify DB as well as hyperventilation syndrome (Thomas, McKinley et al. 2001; Thomas, McKinley et al. 2005). According to van Dixhoorn the mean score for the healthy population is around 11.0 (SD 7.6) (Dixhoorn 2008). Other studies have found mean NQ scores vary around 5-10 in healthy individuals without DB

(Han 1996; Han, Stegen et al. 1998; Han, Zhu et al. 2004; Thomas, McKinley et al. 2005). Values for the Nijmegen Questionnaire greater than 23 are commonly used to signify DB (Dixhoorn and Duivenvoorden 1985). However in one study in a physiotherapy practice comparing patients with a clear musculo-skeletal diagnosis with those with dysfunctional breathing, a cut off score of 20 proved adequate to classify 88% of patients (Dixhoorn and Hoefman 1985).

The Self Evaluation of Breathing Questionnaire (SEBQ)

This questionnaire was compiled from various sources. Its items were derived after considering symptoms proposed by Burton, Howell, Fried and other literature to be discriminative for DB, discussion with colleagues, relevant clinical experience of the author and from a public domain Internet questionnaire titled ''How Good is your Breathing Test, Take our Free Breathing Test and See'' (HGYB) (White 2005). No item of the SEBQ was taken directly from any single source, most items were included because they were suggested by several sources and appeared plausible (Courtney and Greenwood 2009).

Procedure

The Human Research Ethics Committee of RMIT University approved the study. All data collection was completed within a single two-hour visit. The participants were given the series of questionnaires to fill out while attached to a capnometer and pulse oxymeter. While the participants were either reading or filling out the questionnaires the following respiratory parameters were measured, end tidal CO_2, oxygen saturation, respiratory rate and heart rate. These respiratory parameters were measured over approximately 25 minutes. A single examiner (RC) then assessed breathing pattern by performing the Manual Assessment of Respiratory Motion (MARM) (Courtney, van Dixhoorn et al. 2008). Following assessment of breathing pattern, breath-holding times were tested. The final procedure performed was spirometry with participants asked to perform three forced respiratory maneuvers and the best result used to minimise effects of technique error.

RESULTS

As can be seen in Table 1, the mean levels for all dysfunctional breathing measures is not particularly high for this group, however, means for the NQ (18) and the MARM (19) are higher and more dysfunctional than those found in studies of normal individuals. In individuals with normal breathing, mean values for sum scores of the NQ are around 10 (Han 1996; Han, Stegen et al. 1998; Thomas, McKinley et al. 2001) and for the MARM are around 6 (Courtney, van Dixhoorn et al. 2008).

TABLE 1 - DESCRIPTIVE STATISTICS FOR ALL VARIABLES (N=83)

	M	*SD*	*Min*	*Max*
FEV1 (% predicted)	93	13	58	121
Av. SPO_2 (% Hb Sat)	96	2	91	100
Av. $ETCO_2$ (mmHg)	38	4	26	48
Respiration rate	16	4	7	26
MARM (%RC)	73	27	33	178
MARM Balance	19	18	-20	75
Av. BHT-DD (s)	26	12	11	68
Av. BHT-IRM (s)	30	12	13	72
Nijmegen Questionnaire	18	10	0	51
SEBQ	13	8	0	32

The majority of individuals fit criteria of having dysfunctional breathing on the basis of at least one proposed DB measure. Of the 83 participants, 63 (75.9%) had dysfunctional breathing according to at least one measure using the most conservative cut-off criteria for measures such as the NQ, BHT and $ETCO_2$ that had two possible cut-offs. Using the less stringent cut-offs for the NQ (>20) and the two types of BHT (<30), 66 of the 83 participants (79.5%) might have been classified by some practitioners as having dysfunctional breathing. This is illustrated in Table 2.

TABLE 2 - INDIVIDUALS CLASSIFIED AS HAVING DYSFUNCTIONAL BREATHING ACCORDING TO A SINGLE MEASURE

Type of Measure	**Number in whole sample**	**% of whole sample (n=83)**	**Number in abnormal spirometry group**	**% of abnormal spirometry group (n=29)**
Spirometry Measures				
FEV1 or FVC <15% below predicted	29	34.1%	29	100%
Nijmegen Questionnaire (NQ)				
NQ 20 or above	29	34.1%	11	37.9%
NQ 23 or above	23	27.1%	9	31%
SEBQ 11 or above	48	56.5%	21	72.4%
Capnometry				
$ETCO_2$ - 32 mmHg or below	8	9.4%	0	0
$ETCO_2$ - below 35 mmHg	22	26%	5	17.2%
Breath Holding Time				
BHT DD - 20 or below	35	41.2%	21	72.4%
BHT DD - 30 or below	61	71.8%	25	86%
BHT-IRM - 20 or below	14	16.5%	11	37.9%
BHT- IRM - 30 or below	45	52.9%	23	79%
Breathing Pattern				
MARM %rib cage >70%	36	42.4%	15	51.7%
MARM balance > 30	26	30.6%	11	37.9%
Paradoxical breathing	8	9.4%	3	10%

There were 29 individuals who had FEV1 or FVC <15% below predicted. Mean values of the proposed DB measures were compared between the group with normal spirometry and those with normal spirometry; these are shown in Table 3. The group with abnormal spirometry had higher CO_2 levels and lower O_2 levels, and therefore were not more prone to hyperventilation. NQ, MARM

values and respiratory rates were approximately equal in normal and abnormal spirometry groups. The only increased signs of DB in the abnormal spirometry group were shorter BHT and increased SEBQ scores.

TABLE 3 - DESCRIPTIVE STATISTICS AND DIFFERENCES BETWEEN THE NORMAL AND ABNORMAL SPIROMETRY GROUPS

	Normal spirometry (n=54)	Abnormal spirometry (n=29)	Mean Difference	P Values
Males	17	12		
Females	37	17		
Average Age (Yrs)	49(+-13)	48 (+- 14)		
FEV1 (% pred)	99(+- 10)	82(+- 11)	17	.0001
Av. ETCO2 (mmHg)	37(+- 4)	39(+- 4)	2	.01
Av. BHT-DD (s)	28(+-12)	20(+-8)	7.8	.0001
Av. BHT-IRM (s)	33(+- 11)	24(+- 10)	9	.0001
Av. SPO2 (%Hb Sat)	96(+- 2)	95(+- 2)	1	.04
Resp. Rate	16(+-4)	17(+- 4)	1	.79
NQ	17(+- 9)	19(+-11)	2	.35
MARM (%RC)	70(+- 21)	77(+-35)	7	.29
MARM Balance	19(+-16)	(19+-18)	.9	.82
SEBQ - total	12(+-7)	16(+-8)	4.5	.008

Correlations between measures are shown in Table 4. As can be seen, significant correlations where found within the following categories of measures:

1. Symptom questionnaires;
2. Breath holding times; and
3. Breathing pattern measures.

Scores for the two questionnaires, the NQ and the SEBQ, were strongly correlated. The two types of breath holding, BHT-DD and BHT-IRM, were also strongly correlated. The two MARM variables, MARM balance and % RC, were also correlated.

TABLE 4 - CORRELATION MATRIX OF DYSFUNCTIONAL BREATHING MEASURES

	Biochemical measures		**Biomechanical measures**			**Breath holding time**		**Symptom question**	
	PO2	**$ETCO_2$**	**RR**	**MARM %RC**	**MARM bal.**	**BHT-DD**	**BHT-IRM**	**NQ**	**SEBQ**
FEV1	.10 p=.38	-.08 p=.47	-.09 p=.44	-.19 p=.09	-.08 p=.43	.31 p=.004	.31 p=.005**	-.133 p=.23	-.264 p=.02
PO_2	1	-.0.23 p=.84	-.10 p=.10	-.14 p=.22	-.12 p=.26	.24 p=.03	.186 p=.09	.11 p=.26	.02 p=.80
$ETCO_2$		1	-.14 p=.20	-.02 p=.82	-.136 p=.221	-.241 p=.03	-.198 p=.07	-.12 p=.27	.01 p=.96
RR			1	.09 p=.40	.07 p=.55	-.18 p=.11	-.16 p=.14	-.20 p=.08	-.14 p=.22
MARM%RC				1	.82 p=.0001	-.090 p=.42	-.25 p=.02	-.04 p=.70	.11 p=.31
MARM bal.					1	-.07 p=.54	-.204 p=.06	.01 p=.90	.14 p=.20
BHT-DD						1	.84 p=.0001	-.20 p=.07	-.17 p=.12
BHT-IRM							1	-.18 p=.10	-.20 p=.07
NQ								1	.75 p=.0001

Correlations between variables in different categories were generally not significant. The only significant correlation were between BHT-IRM and MARM % rib cage motion. And also FEV1 levels and SEBQ sum scores were correlated.

Carbon dioxide, measured in this study by end tidal CO_2, did not correlate significantly with symptom questionnaires, breathing pattern, PO_2 or FEV_1. A statistically significant, but weak, correlation was found with one type of breathing holding - BHT-DD. It should be noted that this correlation was negative, opposite to the expected direction.

There was a correlation between BHT-DD and SpO_2 levels.

The SEBQ was negatively correlated with FEV_1. FEV_1 also correlated with both types of breath holding time.

DISCUSSION

Strict definitions of DB are not possible at present, but for practical purposes it is probably most useful not to think of DB as a single entity limited to the biochemical dimension of breathing functionality (as in Hyperventilation Syndrome) but to consider breathing symptoms and breathing pattern as potentially separate aspects of DB which need be measured in their own right. This study found that significant correlations exist only within categories of breathing measures, but not between categories. The two symptom questionnaires investigated in this study, the NQ and the SEBQ were found to correlate, as did the two measures of breath holding time and the two similar MARM measures of breathing pattern. Biochemical measures, oxygen and carbon dioxide, were not related. Therefore the clinician who wishes to do a comprehensive evaluation of breathing functionality should consider using a range of measurement tools, including breathing symptom questionnaires, breathing pattern evaluation and CO_2 measurement.

In this sample of people, which on average had only mild dysfunctional breathing, there was very little relationship between the categories of measures. The only significant correlation between categories, was between one type of breath holding BHT-IRM, where the breath was held until the first

involuntary motion of the respiratory muscles, and the extent of the thoracic dominant breathing pattern, represented as percentage of upper rib cage contribution to breathing motion (MARM % rib cage). No measures were found to correlate with end-tidal CO_2. This indicates that individuals with dysfunctions in one aspect of breathing functionality do not necessarily have dysfunctions in other aspects, particularly if the breathing dysfunction is not severe.

In the group with abnormal spirometry it is possible that parenchymal disease influenced their CO2 levels. Poor transfer of blood gases across damaged lung tissue, particularly in individuals with COPD could mean that even in the case of alveolar hyperventilation, CO2 levels appeared normal. However, given the fact that individuals with severe lung disease were excluded from this study this is unlikely.

The negative correlation between FEV1 and the SEBQ indicates that patients with poor lung function were more likely to experience subjective sensations of breathing difficulty.

The most well recognised form of dysfunctional breathing is hyperventilation which is strictly defined by a biochemical definition i.e. breathing in excess of metabolic requirements so that a depletion of carbon dioxide occurs(Comroe 1974). Despite its biochemical criteria, hyperventilation is sometimes presumed to exist on the basis of symptoms, on findings of abnormal breathing patterns or length of breath holding time (Lum 1976; Dixhoorn and Duivenvoorden 1985; Stark and Stark 2002). This study suggests that dysfunctions of breathing pattern, shortened breath holding time and DB symptoms can exist without chronic hypocapnia. This is consistent with previously published studies that have also found that baseline CO_2 does not always relate to symptoms of dysfunctional breathing (Folgering and Colla 1978; Vansteenkiste 1991). However, there is literature that shows that individuals with high levels of hyperventilation type symptoms do have depressed levels of CO_2 when compared to symptom free controls (Gardner 1986). So while it cannot be presumed that there is no association between symptoms of DB and resting CO_2, it should be recognised that the relationship is complex and can be influenced by other moderating factors such as anxiety.

The complex relationship beween hypocapnia and HV was demonstrated by Wintjes and Grossman who showed that in a group of 83 healthy individuals CO_2 contributed only 4% of the variance in HV symptoms (Wientjes and Grossman 1994). The current finding that dysfunctional breathing pattern is not necessarily associated with low resting CO_2 levels is consistent with studies that have also found that symptomatic individuals with disturbed breathing pattern often have normal levels of CO2 (Han, Stegen et al. 1996). Again it cannot be presumed that there is no association between breathing pattern and CO_2 levels, as many clinicians and researchers have observed abnormal breathing pattern in individuals with hyperventilation (Lum 1976). However, it can be concluded that the level of resting CO_2 cannot be presumed from presence of symptoms commonly thought to be associated with dysfunctional breathing, from breath holding time or from breathing pattern. The clinician can only be certain of CO_2 levels if these are specifically measured. It should also be noted that measurement of resting CO_2 might not identify individuals who hyperventilate in response to psychological stress or physical exercise or whose CO2 regulating capacitates are compromised. This is done variously through capnometry combined with exercise or psychological challenge or the Hyperventilation Provocation Test (Hardonk and Beumer 1979; Warburton and Jack 2006).

In this study the MARM measures reflecting thoracic dominance in breathing show a small degree of correlation with breath holding till first desire to breathe (BHT-DD). It seems reasonable to hypothesise that this may be because both these measures reflect respiratory drive, with increased respiratory drive increasing the extent of thoracic breathing and decreasing breath-holding time. It is also possible that thoracic breathing patterns themselves affect perception of dyspnea sensations related to the breaking point of breath holding.

This study did not show an association between general symptoms of dysfunctional breathing, as measured by the SEBQ or the NQ and breathing pattern. These findings are unexpected and not consistent with clinician's observations that individuals with high levels of symptoms associated with DB

tend to have breathing pattern disturbances (Lum 1976; Howell 1997). And that specific qualities of breathing discomfort or dyspnea are affected by patterns of respiratory muscle use (Simon and Schwartzstein 1990; Altose 1992; O'Donnell 2006). The lack of relationship in this current study may be due to the fact that the sample used tended to represent individuals with only mild signs of dysfunctional breathing. Correlations not evident in this sample with mild DB might be stronger in individuals with more severe DB. Also relationships that do exist between breathing pattern and symptoms may be non-linear.

Another factor contributing to the poor correlation found between symptoms and actual physiological and biomechanical aspects of breathing, such as end-tidal CO2 breathing pattern and FEV1 might be the individuality of cognitive processes involved in recognizing, attending to, and then evaluating physical symptoms. Certain individuals show persistent tendencies to over-perceive or under-perceive symptoms related to breathing function (Teeter and Bleeker 1998; Klein, Walders et al. 2004). Thus, while the findings of this study suggest that symptoms do not necessarily correlate with biochemical or biomechanical or breath holding measures across individuals, they do not diminish the possibility or importance of relationships between symptoms and breathing functions within individuals.

Limitations of this study

Not all ways of measuring DB were assessed in this study. For example measurement of carbon dioxide at rest, as was undertaken during this study, will only reveal chronic persistent hyperventilation and may not be adequate for revealing which individuals are prone to intermittent hyperventilation in response to physical or psychological stress (Hardonk and Beumer 1979).

The interpretation of these results is limited to their use as general screening tools, as the patient population used in this study was not representative of individuals with pronounced breathing dysfunction. Relationships not evident in this population might be evident in a sample more representative of individuals with hypocapnia, markedly disturbed breathing

pattern or abnormal Nijmegen Questionnaire scores. Representation from patients in disease categories thought to be affected by dysfunctional breathing is needed to make more robust assumptions.

Future Research

Further Research is required to investigate the presence of more complex relationships between the various dimensions of breathing dysfunction. Research should also target individuals with stronger evidence of breathing dysfunction or with specific ailments.

CONCLUSION

For practical purposes DB is probably best characterised as multi-dimensional. DB can occur in at least 3 dimensions: biochemical, breathing pattern and breathing related symptoms, and these might not co-exist. Screening for DB with measures representing only one of these dimensions may not lead to realistic estimations of the prevalence and impact of the various types of breathing dysfunctions. Comprehensive evaluation of breathing dysfunction should include measures of breathing symptoms, breathing pattern, resting CO_2 and also include functional measures such a breath holding time and response of breathing to physical and psychological challenges.

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CHAPTER 10

INVESTIGATING THE CLAIMS OF DR. K.P. BUTEYKO: THE RELATIONSHIP OF BREATH HOLDING TIME TO END TIDAL CO_2 AND OTHER PROPOSED MEASURES OF DYSFUNCTIONAL BREATHING

ABSTRACT

Objectives: Dr K.P. Buteyko claimed that Breath Holding Time (BHT) can be used to detect chronic hyperventilation and that BHT predicts alveolar CO_2 ($PACO_2$) according to his patented mathematical formula. The Buteyko Breathing Technique (BBT) is believed to correct chronic hyperventilation as evidenced by increased BHT. In this study, we test Buteyko's claims and explore the relationship between BHT and $ETCO_2$ as well as measures of dysfunctional breathing (DB) including the Nijmegen questionnaire (NQ), a self evaluation of breathing questionnaire (SEBQ) and thoracic dominant breathing pattern.

Subjects: 83 adults healthy or suspected of having dysfunctional breathing, 29 with abnormal spirometry readings, 54 with normal spirometry

Outcomes: BHT, performed according to BBT protocols, was measured along with $ETCO_2$ and other measures of DB including the Nijmegen Questionnaire, and the Manual Assessment of Respiratory Motion (MARM), a palpatory technique for measuring thoraco-abdominal balance during breathing. Correlations between measures of DB were made in the whole sample and also in subgroups with normal or abnormal spirometry. DB measures were compared in normal and abnormal spirometry groups.

Results: The results revealed a negative correlation between BHT and $ETCO_2$ (r=.-241, $p<0.05$), directly opposite to Buteyko's claims. BHT was significantly shorter in people with abnormal spirometry (FEV1 or FVC < 15% below predicted) with no difference in $ETCO_2$ levels between the abnormal and normal

spirometry groups. In the abnormal spirometry group, lower BHT was found to correlate with a thoracic dominant breathing pattern, (r= -.408, p< .028).

Conclusion: Although BHT does not predict resting $ETCO_2$; it does correlate with breathing pattern in subjects with abnormal spirometry. It is proposed that altered breathing pattern could contribute to breathing symptoms such as dyspnea and that breathing therapies such as BBT might influence symptoms by improving the efficiency of the biomechanics of breathing.

INTRODUCTION

Dysfunctional breathing (DB) and breath holding time (BHT) and the Buteyko Breathing Technique (BBT)

For many years clinicians and researchers have reported that abnormal or Dysfunction Breathing (DB) influences health and patient's symptoms (Kerr 1937; Magarian 1982; Bass 1989). DB is not clearly defined and diagnosis is made on the basis of symptoms (Dixhoorn and Duivenvoorden 1985; Thomas, McKinley et al. 2001), breathing pattern (Chaitow 2002; Dixhoorn 2004) and presence of hyperventilation and hypocapnia (Magarian 1982; Bass 1989). Practitioners of the Buteyko Breathing Technique (BBT) use Breath Holding Time (BHT) as a way of indicating presence of DB and believe that length of BHT equates to extent of hyperventilation and degree of resulting hypocapnia (Stalmatski 1999). The current medical literature supports a broader definition of DB than one limited to hyperventilation and hypocapnia (Howell 1997; Morgan 2002) because DB related symptoms and abnormal breathing patterns can exist even when carbon dioxide levels are normal (Burton 1993; Hornsveld 1997).

Recent discussions on DB are beginning to consider the impact of non-biochemical aspects of respiration (Howell 1997; Dixhoorn 2004; Bruton and Thomas 2006) such as efficiency of breathing pattern. The work of breathing is most efficient when a co-ordinated contribution from the diaphragm, abdominal muscles and rib cage muscles results in balanced motion between the upper rib cage and the lower rib cage and abdomen (De Troyer and Estenne 1988). Uneven distribution of chest wall motion with dominance of upper rib cage or thoracic motion may be due to normal and transient situations such as emotional arousal or increased respiratory effort and load as well as due to abnormalities of lung function (Sharp, Goldberg et al. 1975; Tobin, Tejvir et al. 1983). Unevenness of motion of the chest wall where the upper rib cage movement dominates and lower rib cage expansion is impaired can indicate biomechanically induced DB that results in hyperinflation and contributes to breathing symptoms such as dyspnea (Tobin 1988; O'Donnell 2006).

BHT is an indicator of a person's ventilatory response to biochemical, biomechanical and psychological factors (Mithoefer 1965; Rassovsky, Kushner et al. 2000; Delapille, Verin et al. 2001) and it seems reasonable to suggest that abnormally shortened BHT may indicate abnormalities in respiratory control that result in DB (Lin 1974; Lumb 2000). The idea that BHT is a simple test of DB has been suggested by various sources, including proponents of the BBT (Jack, Darke et al. 1998).

The BBT is a breathing therapy that is used to treat at least 99 different symptoms and conditions (www.buteyko.ru/eng/bolenz.shtml) including hypertension, diabetes, sleep apnea, anxiety, depression, insomnia and epilepsy (Stark and Stark 2002) which practitioners claim are related to DB. Asthma is the condition most people associate with BBT and several clinical trials have indicated that the BBT helps symptom control in asthma, along with a reduction in medication use and improved quality of life (Bowler 1998; Opat, Cohen et al. 2000; Cooper, Oborne et al. 2003; McHugh, Aicheson et al. 2003; Slader, Reddel et al. 2006). BBT practitioners believe that the reduction of symptoms and improved health due to the BBT (Stalmatski 1999; Stark and Stark 2002) are a result of increased CO_2 levels and longer BHT (Stalmatski 1999; Stark and Stark 2002), however studies to date do not support this (Bowler 1998).

Measurement of BHT is an essential part of the BBT and is integrated into its theoretical basis as well as to how the technique is practiced. Dr. Konstantin Buteyko originator of the BBT reported that his protocol for measuring breath holding could accurately predict carbon dioxide levels and detect chronic hyperventilation in both healthy and sick individuals (Buteyko 1990). He patented the following formula for calculating PCO2 from BHT:

$PACO_2\% = 3.5 + .05 \times BHT$ (Buteyko 1986)

This formula has never been subjected to rigorous scrutiny.

In this study, we aimed to test the claims of Dr. Buteyko regarding the correlation between BHT and End Tidal CO_2 ($ETCO_2$) in the general population.

We also aimed to explore the relationship between BHT and DB in this same population, by examining the correlation between BHT and thoracic dominant breathing pattern as determined by the MARM, as well as the presence of symptom clusters frequently associated with DB as determined by the Nijmegen Questionnaire (NQ) and the Self Evaluation of Breathing Questionnaire (SEBQ).

Since it has been proposed that people with asthma and chronic respiratory diseases are more likely to have DB (Thomas, McKinley et al. 2001) we were interested to see if these proposed measures of DB and their relationships were influenced by lung function status.

METHODS

The Human Research Ethics Committee of RMIT University approved this study.

Subjects:

Subjects from the general population were recruited from general practices and complementary medicine clinics in Sydney, Australia.

The study was performed on 83 volunteers, aged 18 or over who were either healthy or suffered from mild medical conditions, which did not restrict their capacity to work or significantly affect their lifestyle. Of the 83 subjects, 29 had FEV1 or FVC at least 15% lower than predicted for age, gender and race and were classified as having abnormal spirometry.

Sample Size

We chose our sample size on the basis of a power analysis, which estimated that to detect a significant correlation of 0.3 with 80% power and significance level of .05 would require 85 subjects.

The 83 subjects were analyzed as a whole and also divided into 2 groups, an abnormal spirometry group of 29 subjects and a normal spirometry group of 54 subjects, for purposes of comparison.

Breath Holding Protocol:

The breath hold test used by BBT practitioners to calculate $PACO_2$ is generally referred to as the Control Pause (CP) although the somewhat confusing term Maximum Pause (MP) is also used. CP and MP are both measured after normal exhalation at functional residual capacity (Stark and Stark 2002) (Stalmatski 1999). BBT practitioners were surveyed via the Buteyko Practitioners Support Network website about the precise instructions used to determine correct BHT. This survey revealed that the most common instruction for determining the CP was to hold the breath until the point of definite discomfort or the first sensation of difficulty was experienced. An alternative protocol is to hold the breath until the first Involuntary Respiratory Movement (IRM). This has been described as the physiological breaking point of breath holding (Lin 1974). Private communications with Dr. Buteyko's successor, Dr. Andrey Novolizov and his son Dr. Vladimir Buteyko confirmed that to determine the CP the breath should be held till IRM. In this study both ways of determining BHT were tested; breath holding till first difficulty or first desire to breathe (BHT-DD) and until first involuntary motion of the respiratory muscles (BHT-IRM).

Participants were instructed to sit quietly and breathe normally. They were then asked to breathe gently in and out and at the end of a normal exhalation to pinch their nose and hold the breath. Measurement was done with a stopwatch which measured to 0.01 of a second. This number was rounded down to 0.1 of a second. All breath holding procedures were repeated three times and the mean used in calculating correlations.

End Tidal Carbon Dioxide ($ETCO_2$) Measurement:

$ETCO_2$ levels were sampled with a two pronged nasal canula and readings taken with a capnometer (BCI, Capnocheck, USA, 2001). The equipment was calibrated and checked for accuracy with a known gas mixture. $ETCO_2$, along with O_2 saturation (SPO_2), respiratory rate and heart rate, was measured for about 25 minutes while the person filled out various questionnaires. After excluding data from the first 2 minutes to allow for the subject settling in, the average $ETCO_2$ was calculated and used in determining correlation co-efficients with other variables.

Other Measurements

Spirometry was performed using a laptop-based spirometer (QRS Diagnostics, Spirocard, USA, 2003).

Breathing Questionnaires:

Questionnaires used to detect the possible presence of DB symptoms included the Nijmegen questionnaire (NQ) and the Self Evaluation of Breathing Questionnaire (SEBQ). The items on the Nijmegen Questionnaire (NQ) are an abbreviated list of the most common symptoms of DB and this questionnaire has been validated as an accurate tool for identifying patients likely to suffer from DB (Dixhoorn and Duivenvoorden 1985). Our version of the SEBQ is derived from an abbreviation of a questionnaire available on the internet which claimed to be able to predict whether the responder had breathing dysfunction (White 2005) with emphasis on symptoms which the scientific literature suggested were common in DB. (Howell 1990; Burton 1993). We performed Factor Analysis of the SEBQ and found 2 dimensions of symptoms that we named 'breathlessness' and 'self perception of breathing abnormality'.

Other Questionnaires:

The subjects were given the Hospital Anxiety and Depression Inventory, (HAD) to assess anxiety and depression.

The Manual Assessment of Respiratory Motion (MARM)

Clinical evaluation of breathing pattern is usually performed by observation and palpation (Clanton and Diaz 1995). In this study we used a breathing pattern assessment technique called the Manual Assessment of Respiratory Motion (MARM) to assess 'balance' between upper lower chest wall movements. The MARM has been demonstrated to have good inter-examiner reliability (Dixhoorn 2004) and be consistent with measures performed using Respiratory Induction Plethysmography (Courtney, van Dixhoorn et al. 2006).

This palpatory technique permits the examiner to assesses the relative contribution of thoracic and diaphragmatic action during breathing and

calculate a quantitative measure of thoracic dominance in breathing which we called % rib cage motion (Dixhoorn 2004). The examiner using the MARM places their open hands over the subject's back at the region of the lower 4-6 ribs. The examiner's thumbs are about 1 inch from the spine and orientated vertically. The examiner's hands are spread so that the lower 3 fingers are orientated in a transverse direction. This hand placement makes it possible for the examiner to feel lateral and vertical motion of the rib cage and assess relative contribution from the upper rib cage and the lower rib cage/ abdomen. The examiner draws a diagram with an upper line to represent extent of the upper rib cage and vertical motion and a lower line to represent extent of lower rib cage/abdomen motion. Calculations are then made for thoracic diaphragm "balance" and % rib cage motion. (See figure 1)

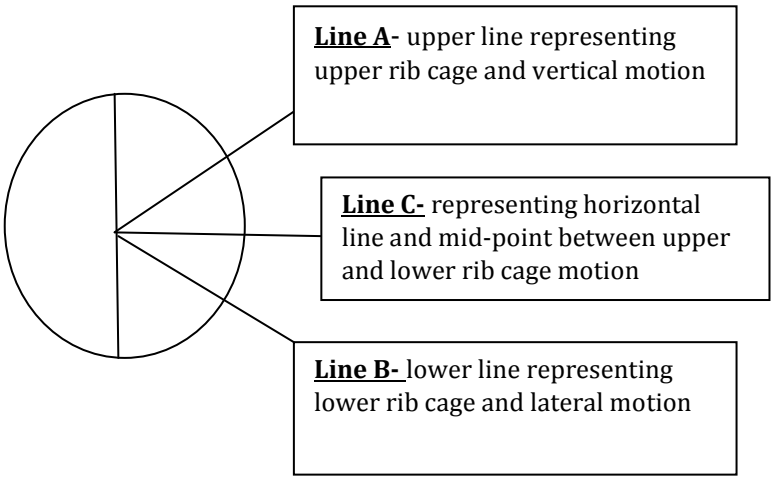


FIGURE 1 - THE MARM GRAPHIC NOTATION

Operator draws Line A to represent upper rib cage and vertical motion and Line B for lower rib cage and lateral motion. MARM measures are Balance = angle AC-angle CB, % Rib Cage Motion = % of angle AC/angleAB.

Statistical Analysis:

The data was entered, checked for any abnormalities or errors and then analysed using SPSS (ref and place). Pearson's correlation coefficient was used to test for association between the 2 measures of BHT: BHT-DD and BHT-IRM, and all measures of DB. Students T test was used to detect differences between

means of respiratory parameters and measures of DB between normal and abnormal spirometry groups.

Order of Procedure:

All data collection was completed within one 2-hour visit. The subjects were given the series of questionnaires to fill out while attached to the capnometer. This device was used to continuously measure $ETCO_2$, SPO_2, respiratory rate and heart rate over approximately 25 minutes. The MARM was then performed followed by the BHT tests. BHT-DD was performed first and then BHT-IRM. The final procedure performed was Spirometry with subjects asked to perform 3 forced respiratory maneuvers and the best result used.

RESULTS.

Whole Group Characteristics

Characteristics of subjects making up the total sample (n=83) are shown in Table 1. In this sample females (n=54) outnumbered males (n=29) and average age was 49 years. Means values for respiratory variables such as respiratory rate, SpO_2, $ETCO_2$, FEV1 were all in the normal range. Scores for the Hospital Anxiety Questionnaire showed that mean scores for anxiety and depression were below the diagnostic level of 7. Similarly mean score for the Nijmegen Questionnaire was below 23, the level which indicates dysfunctional breathing. Normal ranges for other measures of DB are not known.

TABLE 1 - DESCRIPTIVES FOR THE WHOLE GROUP

	Whole Group (n=83)	**Normal Ranges**
Males	29	_
Females	54	_
Average age (years)	49 (+-14)	_
FEV1 (% predicted)	93 (+-13)	>85
Av. $ETCO_2$ (mmHg)	38 (+-4)	36-42

Av. BHT-DD (s)	26 (+-12)	_
Av. BHT-IRM (s)	30 (+-12)	_
Av. SPO_2 (% Hb Sat)	96 (+-2)	>94
Resp. rate	16 (+-4)	<16
Nijmegen Questionnaire	18 (+-10)	<23
MARM (%RC)	73 (+-27)	_
MARM Bal.	19 (+-18)	_
Anxiety (HAD)	6 (+-3)	<7
Depression (HAD)	3 (+-3)	<7
SEBQ - total	13 (+-8)	_
SEBQ -dyspnea	4 (+-3)	_
SEBQ - abnormal br. sensation	4 (+-3)	_

KEY TO ABBREVIATED VARIABLES IN TABLE 1 AND 2:

FEV1% predicted - Forced Expiratory Volume at one second as a percentage of that predicted for age, race and gender.
Av.$ETCO_2$ - average end tidal CO_2 from 25 minutes collection time.
Av. BHT-DD - average Breath Holding Time until first definite desire to breath.
Av. BHT-IRM - average Breath Holding Time until first involuntary motion of the respiratory muscles.
Av. SpO_2 - average percentage saturation of Hemoglobin over 25 minutes.
Resp. rate - respirations per minute
MARM (%RC) - % contribution of chest or rib cage motion to breathing.
MARM bal - Difference between total chest wall and upper rib cage motion.
Anxiety (HAD) - Anxiety score on Hospital and Anxiety and Depression Scale
Depression (HAD) - Depression score on Hospital and Anxiety Scale
SEBQ - total - total score of SEBQ
SEBQ – dyspnea - Self-evaluation of breathing questionnaire - dyspnea score
SEBQ - abnormal br - Self-evaluation of breathing questionnaire - perception of breathing abnormality score.

Comparisons between the whole, normal and abnormal spirometry groups.

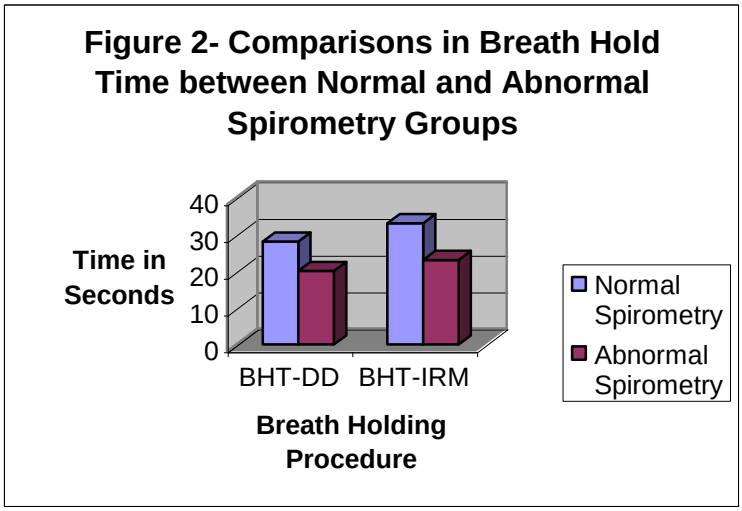
Table 2 compares values for breathing parameters and DB measures between subjects with normal and abnormal spirometry i.e. FEV1 or FVC less than 15% below predicted.

Subjects in the abnormal spirometry group had a mean difference in % predicted FEV1 of 17% (p=0.0001). Table 2 shows that the abnormal Spirometry groups had $ETCO_2$ levels, 2mm Hg higher (p=0.01) and SpO_2 levels 1% lower (p=0.04). They also scored 4.5 points higher on the SEBQ (p=0.008). People with abnormal spiromety readings had shorter BHT for both types of breath holding (illustrated in Figure 2) and a greater % of rib cage contribution to breathing as measured by the MARM. The difference in BHT-DD was 7.8 seconds (p=0.0001) and 9 seconds for BHT-IRM (p=0.0001) however the 7% difference in MARM % rib cage was not statistically significant (p=0.29).

TABLE 2 - DESCRIPTIVES AND DIFFERENCES BETWEEN THE NORMAL AND ABNORMAL SPIROMETRY GROUPS

	Normal spirometry (n=54)	**Abnormal spirometry (n=29)**	**Mean Difference Normal & Abnormal spirometry**	**P Values**
Males	17	12		
Females	37	17		
Average Age (years)	49(+-13)	48 (+- 14)		
FEV1 (% predicted)	99(+- 10)	82(+- 11)	17	.0001
Av ETCO2 (mmHg)	37(+- 4)	39(+- 4)	2	.01
Av BHT-DD (s)	28(+-12)	20(+-8)	7.8	.0001
Av. BHT-IRM (s)	33(+- 11)	24(+- 10)	9	.0001
Av. SPO2 (%Hb Sat)	96(+- 2)	95(+- 2)	1	.04
Resp. Rate	16(+-4)	17(+- 4)	1	.79
Nijmegen Questionnaire	17(+- 9)	19(+-11)	2	.35
MARM (%RC)	70(+- 21)	77(+-35)	7	.29
MARM Bal.	19(+-16)	(19+-18)	.9	.82

Anxiety (HAD)	6(+- 3)	6(+-3)	.2	.79
Depression (HAD)	3(+-3)	3(+-3)	.2	.75
SEBQ-total	12(+-7)	16(+-8)	4.5	.008
SEBQ-dyspnea	4(+-3)	4(+-3)	.3	.62
SEBQ-abnormal br. sensation	4(+-3)	5(+- 4)	.6	.36



Bar Graph comparing the two types of breath holding in people with normal spirometry and abnormal spirometry (FEV1 or FVC 15% < predicted) 1. Breath holding at functional residual capacity till first feelings of definite discomfort (BHT-DD) 2. Breath holding at functional residual capacity until first involuntary motion of the respiratory muscles (BHT-IRM).

Correlations between BHT, $ETCO_2$ and other measures of DB were performed separately on the whole group n=83, the abnormal spirometry group (n=29) and the normal spirometry group (n=54).

Correlations between BHT, $ETCO_2$ and other measures of DB in the whole group

Correlations between BHT and $ETCO_2$ and other measures of dysfunctional breathing were performed in the whole group (n=83). There was a statistically significant negative correlation for $ETCO_2$ and BHT-DD (r=-0.241, p=0.028). This correlation was strongly influenced by 2 cases that had very long breath holding times and very low $ETCO_2$ levels. When these 2 cases were excluded, no statistically significant correlations were evident (See Table 3).

TABLE 3 - CORRELATIONS BETWEEN BREATH HOLDING TIME (BHT) AND CARBON DIOXIDE – IN THE WHOLE SAMPLE SHOWING DIFFERENCE WHEN EXCLUDING OUTLIERS.

		BHT-DD All cases (n=83)	BHT-DD Excluding 2 outliers (n=81)	BHT-IRM All cases (n=83)	BHT-IRM Excluding 2 outliers (n=81)
PCO_2	Pearsons Correlation	-.241	-.099	-.198	-.040
	Sig. (2-tailed)	.028	.376	.073	.720

It was decided to keep these 2 cases in the data because there did not appear to be any actual measurement error to justify excluding them. As can be seen in Table 4 when the whole group was analyzed there was also a small correlation between SpO_2 and BHT-DD (r=0.238, p =0.031). However, there was no correlation between BHT and any of the other measures of DB.

TABLE 4 - CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING – WHOLE GROUP (N=83)

		SpO_2	RR	NQ	MARM	SEBQ	$ETCO_2$
BHT-DD	Pearsons Correlation	.238*	-.178	-.198	-.068	-.174	-.241*
	Sig. (2 tailed)	.031	.107	.073	.539	.116	.028
BHT-IRM	Pearsons Correlation	.186	-.165	-.185	-.204	-.201	-.198
	Sig. (2 tailed)	.093	.137	.095	.064	.069	.073

**Statistically significant correlations for BHT-DD with $ETCO_2$ and SpO_2*

Correlations between BHT, $ETCO_2$ and other measures of DB- abnormal spirometry group

A thoracic dominant breathing pattern determined by the MARM measure of % rib cage motion was found to correlate with BHT in the abnormal spiromety group. In this group a significant correlation (r=-0.408, p=0.02) existed between the MARM % rib cage motion and BHT-IRM. There was no correlation between the MARM % rib cage motion and BHT-DD (r=0.163,

p=0.398). In this group with abnormal spirometry, BHT did not correlate with lower $ETCO_2$, SPO_2, respiratory rate or any other measures of DB (see Table 5).

TABLE 5 - CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING – ABNORMAL SPIROMETRY GROUP (N=29)

		SpO_2	RR	NQ	MARM	SEBQ	$ETCO_2$
BHT-DD	Pearsons Correlation	.309	-.217	.154	.163	.208	-.225
	Sig. (2 tailed)	.103	.258	.424	.398	.278	.241
BHT-IRM	PearsonsCorrelation	.027	-.210	.156	-.408*	.122	-.107
	Sig. (2 tailed)	.891	.275	.418	.028	.528	.580

**Statistically significant correlations for BHT-IRM and MARM (p<.05)*

Correlations between BHT, $ETCO_2$ and other measures of DB-normal spirometry group

The only statistically significant correlations in this group were found between the Nijmegen Questionnaire and BHT-IRM (*r*=-0.317, *p*=0.02) and Nijmegen Questionnaire and BHT-DD (*r*=-0.315, *p*=0.02). There was no correlation between BHT and any of the other measures of DB (See table 6).

TABLE 6 - CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING – *NORMAL SPIROMETRY GROUP (N=54)*

		SpO2	RR	NQ	MARM	SEBQ	CO_2
BHT-DD	Pearsons Correlation	.127	-.113	-.317*	-.174	-.198	-.180
	Sig. (2 tailed)	.360	.417	.020	.209	.150	.193
BHT-IRM	Pearsons Correlation	.138	-.079	-.315	-.113	-.206	-.145
	Sig. (2 tailed)	.319	.571	.020	.418	.136	.295

Statistically significant correlations for BHT-DD and NQ and BHT-IRM and NQ. (p<.05)

DISCUSSION

Relationship between BHT and $ETCO_2$

Buteyko's claim that BHT can be used to determine hypocapnia and chronic hyperventilation in the general population was not supported in this study.

The statical significance of the negative correlation between BHT and $ETCO_2$ which is opposite to the positive correlation claimed by Buteyko, was dependant on two extreme cases who had both previously undertaken breathing training, one using yoga and the other using the BBT. The finding of long BHT with low $ETCO_2$ in these 2 cases was completely opposite to what would have been predicted by Buteyko's formula but in keeping with results of at least one other study which found an inverse relationship between BHT and alveolar CO_2 tension. (Stanley, Cunningham et al. 1975). It is possible that breath holding ability may have been increased by breathing training in these individuals and that breathing training may have led to a blunted chemoreceptor response to CO_2.

Because patients with symptomatic hyperventilation or DB are more likely to have instability of breathing rather than chronic hypocapnia (Folgering and Colla 1978; Han, Stegen et al. 1996) a relationship between low BHT and intermittent hypocapnia remains a possibility.

Validity of breath holding time procedure

Our study found that average BHT for both types of breath holding protocols, BHT-DD and BHT-IRM was well below the 60 second goal of Buteyko practitioners (Stark and Stark 2002) but consistent with three separate studies that reported average breath holding at functional residual capacity to be 31 seconds. (Mithoefer 1965). This value is very close to the average BHT-IRM that we found to be 30 seconds. A maximal breath hold may have given a higher value closer to Buteyko's ideal however we found that there was a very inconsistent response when people were asked to hold their breath as long as they possibly could. This instruction sometimes led to BHT that was even

shorter than BHT-DD perhaps due to fearful anticipation of the uncomfortable sensations of prolonged breath holding. We decided to use BHT-IRM in preference to simple instruction to "hold as long as you possibly can" as our maximal BHT. It seemed that this was a more objective or physiological endpoint to breath holding (Lin 1974). That this was a true test of Buteyko's patent was confirmed by communications with Buteyko's Russian successors (Private communications 9/04/05).

Relationship between BHT and thoracic breathing pattern

The group of subjects in this study with abnormal spirometry were found to have shorter BHT than the normal spirometry group. The type of breath holding performed to first involuntary motion of respiratory muscles i.e. BHT-IRM was found to correspond to thoracic breathing pattern in this group but not to $ETCO_2$.

It has been shown that in people with abnormal lung function, breathing pattern can reflect increases in respiratory centre drive without causing changes in minute ventilation or carbon dioxide levels (Chadha, Schneider et al. 1984). Breathing pattern shows a tendency to become more thoracic when stimulated by a variety of factors that increase respiratory centre drive such as anxiety, breathing obstruction or increased respiratory load (Sharp, Goldberg et al. 1975; Tobin, Tejvir et al. 1983; Verschakelen and Demedts 1995). Factors that stimulate respiratory centre drive could also shorten BHT because of heightened response to sensations of dyspnea. Whether this correlation indicates any type of causal relationship between thoracic breathing pattern and length of BHT needs to be elucidated by future studies.

BHT and symptom perception in asthma

Abnormal spirometry findings do not give a complete indication of lung function and the findings of this study need to be repeated on diagnosed asthmatics. We speculate that the relationship we found in the abnormal spirometry group between short BHT and thoracic dominant breathing exists in asthmatics. Our speculation is supported by reports of other studies which report that asthmatics and others with chronic airway obstruction exhibit

profound changes in respiratory muscle function that decrease the efficiency of the biomechanics of breathing (Tobin 1988; O'Donnell 2006). Increased respiratory drive and tonic contraction of inspiratory muscles, hyperinflation of the lungs and the resulting poor diaphragm function leads to poor co-ordination of rib cage to diaphragm muscles and a thoracic dominant breathing pattern. The presence of hyperinflation in particular contributes to breathing symptoms such as dyspnea and respiratory sensations such as inability to take a satisfying breath (Brennan, Morris et al. 1983; Altose 1992; Mannning and Schwartzstein 1995; O'Donnell 2006).

Considering that our study showed that shorter BHT correlates with a more thoracic dominant breathing pattern, one can assume that the lengthening of BHT which is reported to occur after BBT training (Stalmatski 1999; Stark and Stark 2002) could be accompanied by a more balanced and efficient breathing pattern.

A limitation of this study is that insufficient numbers of subjects in the abnormal spirometry sub-group may not have allowed us to detect significant correlations that existed in this group. Future studies should be conducted with a larger sample size to test our findings.

Another limitation of this study may have been the inclusion of subjects who had previous Buteyko or Yoga training as in this study the two subjects with previous breathing training had a disproportionately large influence on our finding of a negative correlation between BHT and CO_2.

Future studies are needed to clarify whether BBT training actually does result in an improved breathing pattern and whether this improved breathing pattern is a mechanism of symptom improvement in asthma.

CONCLUSION

BHT does not show a positive correlation with $ETCO_2$ as predicted by the Buteyko formula; however BHT does correlate with the degree of thoracic dominance in breathing pattern.

A thoracic dominant breathing pattern and poor neuromechanical coupling of respiratory muscles due to hyperinflation might influence symptom perception in asthmatics. It remains to be established whether breathing pattern is responsive to breathing training and whether this is one of the therapeutic mechanisms of breathing therapies such as BBT or Yoga.

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Reference; Courtney R, Cohen M (2008). Investigating the claims of Konstantin Buteyko M.D., PhD: The relationship of Breath Holding Time to end tidal CO_2 and other measures of dysfunctional breathing. *Journal of Alternative and Complementary Medicine*, 14(2),115-123

OVERVIEW OF SECTION 4 - MEASURES OF DYSFUNCTIONAL BREATHING AND BREATHING THERAPY

This section contains two studies that are currently in press. These two studies explore the relationships between dysfunctional breathing and response to breathing therapy.

Chapter 11 - Relationship between dysfunctional breathing patterns and ability to achieve target heart rate variability with features of "coherence" during biofeedback.

Chapter 12 - Medically unexplained dyspnea: partly moderated by a dysfunctional (thoracic dominant) breathing pattern.

CHAPTER 11

RELATIONSHIP BETWEEN DYSFUNCTIONAL BREATHING PATTERNS AND ABILITY TO ACHIEVE TARGET HEART RATE VARIABILITY WITH FEATURES OF "COHERENCE" DURING BIOFEEDBACK

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Reference: Courtney R., Cohen M., Dixhoorn, Jv., Greenwood K. (2011) "Relationship of spontaneous breathing pattern and ability to achieve "coherence" of heart rate variability". *Alternative Therapies in Health and Medicine, 17(3)*

CHAPTER 12

MEDICALLY UNEXPLAINED DYSPNEA: PARTLY MODERATED BY DYSFUNCTIONAL (THORACIC DOMINANT) BREATHING PATTERN

ABSTRACT

Dysfunctional breathing (DB) may contribute to disproportionate dyspnea and other medically unexplained symptoms. The extent of dysfunctional breathing is often evaluated using the Nijmegen Questionnaire (NQ) or by the presence of abnormal breathing patterns. The NQ was originally devised to evaluate one form of dysfunctional breathing - hyperventilation syndrome. However, the symptoms identified by the NQ are not primarily due to hypocapnia and may be due to other causes including breathing pattern dysfunction. The relationships between breathing pattern abnormalities and NQ symptoms have not been investigated. This study investigates these relationships.

Method: 62 patients with medically unexplained complaints, that seemed to be associated with tension and breathing dysfunction, were referred, or self-referred, for breathing and relaxation therapy. Dysfunctional breathing symptoms and breathing patterns were assessed at the beginning and end of treatments using the NQ for assessment of DB symptoms, and the Manual Assessment of Respiratory Motion (MARM) to quantify the extent of thoracic dominant breathing. Subscales for the NQ were created in four categories-tension, central neurovascular, peripheral neurovascular and dyspnea. Relationships between the NQ (sum scores and subscales) and the MARM were explored.

Results: Mean NQ scores were elevated and mean MARM values for thoracic breathing were also elevated. There was a small correlation pre-treatment between MARM and NQ ($r=0.26$, $p<0.05$), but classification of subjects as normal/abnormal on both measurements agreed in 74% ($p < 0.001$) of patients. From the sub scores of NQ only the respiratory or 'dyspnea' items

correlated with the MARM values. Dyspnea was only elevated for subjects with abnormal MARM. After treatment, both MARM and NQ returned to normal values ($p < 0.0001$). Changes in NQ were largest for subjects with abnormal MARM pre-treatment. There was a large interaction between the change in the NQ sub score dyspnea and initial MARM values ($p<0.001$).

Conclusion: Symptoms associated with dysfunctional breathing, particularly dyspnea, are related to thoracic dominant breathing in patients with medically unexplained complaints. Breathing therapy, using the Whole Body Breathing method, can effectively restore normal breathing pattern and reduce dysfunctional breathing symptoms. Medically unexplained dyspnea is partly moderated by dysfunctional breathing pattern.

INTRODUCTION

Dysfunctional Breathing (DB) is thought to exist in patients with asthma although it is not well defined (Morgan 2002). DB is proposed to have several dimensions related to biomechanical, biochemical and other psychophysiological functions of breathing (Courtney, Greenwood et al. 2011). In the clinical and research setting patients have been categorised as having DB on the basis of symptoms scores from the Nijmegen Questionnaire (NQ) (Thomas, McKinley et al. 2005) and also on the basis of abnormalities of breathing pattern (Prys-Picard and Niven 2008).

The causes of dysfunctional breathing symptoms measured by the NQ are not well understood. Originally NQ symptoms were thought to be primarily due to hyperventilation and hypocapnia but recent findings have shown that this is not the case for all symptoms (Hornsveld 1997). Central and peripheral neurovascular symptoms, such as tingling and numbness can be linked to abnormalities of CO_2 levels (Hornsveld and Garssen 1996) however, respiratory complaints appear to have a stronger relationship to breathing pattern (Han, Schepers et al. 2000; Prys-Picard, Kellet et al. 2006).

The NQ contains three subscales of symptoms that relate primarily to either respiratory, peripheral neurovascular or central neurovascular dimensions and a fourth dimension which contains symptoms commonly associated with tension (Dixhoorn and Duivenvoorden 1985). These four symptom dimensions may arise from different pathophysiological and/or psychological causes.

Alterations in breathing pattern are often reported in individuals with functional breathing disorders (Lum 1975; Howell 1997). Shallow upper chest or thoracic dominant breathing is one type of breathing pattern that has been observed in people with DB. Lum describes this breathing as "heaving of the upper sternum and lack of lateral costal expansion" (Lum 1975). Thoracic dominant breathing is a normal response to certain conditions- change to more upright posture, sudden increases in the ventilation needs, rapid inspiration and increased respiratory drive (Sharp, Goldberg et al. 1975; De Troyer and

Estenne 1988). However, normal healthy individuals tend to have "balanced" breathing at rest with relatively equal contributions from upper chest/thoracic and lower chest/abdominal compartments (Courtney, van Dixhoorn et al. 2008). In patients without somatic disease, the presence of habitual upper chest/thoracic breathing is considered dysfunctional. This type of breathing pattern is commonly found in patients with respiratory and cardiac disease and is thought to be due to increased respiratory drive and subsequent increased neural output to inspiratory muscles, which can become shortened and hypertonic (Schiff 1980; Muller, Bryan et al. 1981; Loveridge, West et al. 1984). Upper chest breathing might sometimes be helpful in patients with lung or heart disease but might also disadvantage the operating conditions of respiratory muscles, contribute to hyperinflation and increase patient's perception of respiratory difficulty and dyspnea (Killian and Jones 1988; Lougheed, Fisher et al. 2006).

In asthmatics DB in the form of hyperventilation or breathing pattern disorders may contribute to dyspnea and other symptoms. Asthmatics have been found to have higher scores on the Nijmegen Questionnaire (NQ) than non-asthmatics (Thomas, McKinley et al. 2005). Breathing retraining in asthmatics has been found to reduce NQ scores and to improve asthma control (Holloway and West 2007; Cowie, Underwood et al. 2008; Thomas, McKinley et al. 2009). The reason for the reduced symptoms in asthmatics after breathing therapy is not clear. It proposed that breathing techniques might improve asthma because they increase carbon dioxide levels, which may be low due to the hyperventilation tendencies that exist in some asthmatics (Osbourne 2000;Bruton 2005). Some breathing therapies such as the Buteyko Breathing Technique (BBT) and Capnometry assisted biofeedback specifically aim to raise CO_2 levels as a means to improving asthma (Cowie, Underwood et al. 2008; Ritz, Meuret et al. 2009 (Bowler 1998 ;Cooper, 2003). There is some evidence that normalization of CO_2 levels by capnometry is beneficial in asthma (Ritz, Meuret et al. 2009) although it is unlikely that this is the sole mode of action of BBT (Al-Delaimy 2001; Courtney and Cohen 2008). Dysfunctional patterns of breathing have also been proposed to contribute to exaggerated dyspnea in asthmatics (Lougheed 2007) and the presence of abnormal breathing patterns

are thought to provide one possible means of identifying asthma patients who might benefit from breathing therapy (Prys-Picard and Niven 2008).

Instrumentation for measuring breathing pattern includes Respiratory Induction Plethysmography (RIP) and more recently Opto Electronic Plethysmography (OEP), however clinicians often use observation and palpation (Aliverti, Ghidoli et al. 2003; Wilhelm and Roth 2003). One recently validated clinical tool is the Manual Assessment of Respiratory Motion (MARM) (Courtney, van Dixhoorn et al. 2008). The MARM has high inter-examiner reliability and was found to be able to evaluate more dimensions of rib cage motion than RIP. This is because the MARM includes the vertical motion of the upper rib cage in the calculation of thoracic dominance variables. The RIP, by contrast, only considers the lateral expansion of the upper thoracic relative to the lower thoracic/ abdominal compartments.

To our knowledge no studies have systematically explored the relationship between NQ and breathing pattern. In addition, while it has been shown that breathing therapy, which reduces patient's symptoms, may also improve breathing pattern (Han 1996 th), the specific effects on thoracic breathing have not been investigated. These considerations have led to the questions addressed in this study:

- What types of relationships exist between breathing pattern (MARM) and dysfunctional breathing symptoms (NQ) in patients prior to treatment?
- Do breathing pattern and the dysfunctional breathing symptoms respond similarly to treatment?
- Does breathing pattern abnormality (thoracic dominance) affect the response of NQ scores to breathing therapy?

METHOD

Participants

The participants were consecutive patients receiving treatment with a method of breathing and relaxation therapy called Whole Body Breathing (WBB) in the private practice of one of the authors (EA) from Jan 2008 to May 2009. There were 62 patients - 16 men and 46 women, aged on average 39 (± 16) years and treated for 5.9 (± 1.5) individual sessions of one hour. Patients were referred by medical practitioners, psychologists or self-referred. They suffered from a range of complaints, all classified as 'functional' or 'medically unexplained'. Patient data used in this study was conditional on the patient's consent that their data, in anonymous form, could be used for research purposes.

Materials/ Measures

The Manual Assessment of Respiratory Motion

The Manual Assessment of Respiratory Motion (MARM) was used to quantify the extent of thoracic dominance in breathing. The MARM procedure, which has been described previously (Courtney, van Dixhoorn et al. 2008), allows the examiner to record a graphic representation of their impression of the direction and relative dominance of upper rib cage motion to lower rib cage/abdomen motion. The MARM balance measure has been demonstrated to have good inter-examiner reliability and to be consistent with measures performed using respiratory induction plethysmography (RIP) (Courtney, van Dixhoorn et al. 2008). In this previous study, by Courtney and van Dixhoorn, balance values were on average 6 ±12 and in another study of 16 normal individuals values were similar at 1.6 ±15 (unpublished data). Thus, as a rather strict criterion for 'thoracic dominance', we choose a value of MARM balance of 30 as a cut-off as this represents a value more than 2 standard deviations from the theoretical optimal value of zero and from the mean found in normal individuals.

Nijmegen Questionnaire

The Nijmegen Questionnaire (NQ) was originally developed as a symptom checklist to identify persons with hyperventilation syndrome (Dixhoorn and Duivenvoorden 1985). It is a 16 item questionnaire asking about the frequency of incidence of complaints and indicated on a five point ordinal scale:

- never = 0,
- rarely =1,
- seldom=2,
- often =3, and
- very often=4.

Test-retest reliability of NQ is excellent (r = .87; p < .01). A cut-off score of 23 is commonly used as a criterion of abnormal values. This is based on the original validation study that differentiated patients with a positive from those with a negative hyperventilation provocation test (Doorn, Folgering et al. 1983). However, since the provocation test is no longer a valid gold standard, we use a lower value of 20 as the cut-off criterion as a result of subsequent studies which showed that this score was best able to differentiate hyperventilation patients form normals (Dixhoorn 2008) (Dixhoorn & Courtney, Nijmegen Questionnaire revisited − submitted for publication).

The 16 items correspond to the classical hyperventilation symptoms of dyspnoea, dizziness and paresthaesias, in addition to symptoms of tension and anxiety. On the basis of principal components analysis (Dixhoorn and Duivenvoorden 1985), as well as the actual content, we calculated four subscores. We were particularly interested in the four respiratory items and grouped them in one subscore 'dyspnea' (range 0 − 16). The criterion value of abnormality for this subscore was calculated as 4/16 of the value of 20, which is equal to a cut-off value of 5. The items reflecting tingling, stiffness and cold extremities were grouped in the subscore 'peripheral'. The items reflecting blurred vision and dizziness were grouped in the subscore 'central'. The items referring to anxiety, tension, palpitations and chest pain were grouped in the subscore, labeled 'tension'.

The Intervention: Whole Body Breathing

Whole Body Breathing (WBB) is a breathing and relaxation protocol. It is individualised so that modifications to the protocol are made according to the patient's response. It includes a repertoire of approximately 50 instructions using movement, attention and breathing, manual techniques, and talking about the patient's experiences (Dixhoorn van 2007). Central to the therapy is training in self-regulation of tension. The number of treatments in this study ranged from 4 to 11 treatments. Practitioners trained in Whole Body Breathing undertake a 3 year training course in which they are trained in this comprehensive therapy and its implementation. A comprehensive discussion of this therapy is beyond the scope of this paper. For a more complete overview of this intervention the reader is referred to the chapter titled. Whole-Body Breathing: a systems perspective on respiratory retraining, pages 291-332 in Principles and Practice of Stress Management, edited by Lehrer, Woolfolk and Sime (Dixhoorn van 2007)

Procedure

Data were collected and entered directly into a computer database. Patients were classified by their main complaint into one of several categories of functional complaints (including: tension, hyperventilation complaints, burnout, chronic fatigue, headache, insomnia, anxiety/panic/phobia, depression, low back pain, chronic neck/arm/shoulder pain (CANS), fibromyalgia, whiplash, chronic pain, functional breathing problems). The NQ was completed and the MARM was performed. After the session NQ sum score was calculated and MARM values were measured and entered into the database. This procedure was repeated at the 4th or 5th session and at the end of treatment. At a later stage of the data collection period NQ subscale scores were calculated and entered.

RESULTS

MARM and NQ Pre-Treatment

At the beginning of treatment mean Nijmegen scores and MARM balance scores were substantially elevated and the majority of patients had NQ scores and MARM levels above the chosen cut-offs (Table 1). For the average NQ sub scores, the score on Tension was the only one with a value above the cut-off score of 5.

TABLE 1 - PRE-TREATMENT VALUES FOR NQ TOTAL, NQ SUBSCALE SCORES AND MARM BALANCE

	n	M (SD)	Range
MARM balance	62	44.27 (20.38)	-6, 86
NQ Total	62	22.77 (8.32)	10, 42
NQ dyspnea	40	4.93 (3.61)	0, 14
NQ peripheral	40	4.25 (2.60)	0, 11
NQ central	40	3.90 (2.48)	0, 10
NQ tension	40	7.00 (2.99)	1, 14

Cut-offs for MARM balance, normal <30, abnormal 30 and above
Cut- offs for NQ Total, normal <20, abnormal 20 and above
Cut-offs for NQ subscores, normal < 5, abnormal 5 and above.

Table 2 shows that classifications of normal or abnormal on both instruments were congruent for 46 (74%) individuals (Fisher's exact test: p=0.009). Some individuals had abnormal MARM (*n*=12) and showed thoracic dominance in breathing pattern, but had normal NQ and few complaints. A minority of individuals (*n* = 4) had normal MARM and balanced breathing movement, but abnormal NQ and elevated complaints.

TABLE 2 - CROSSTABULATION OF NQ AND MARM CLASSIFICATION

		MARM balance		Total
		Normal	Abnormal	
NQ	Normal	12	12	24
	Abnormal	4	34	38
Total		16	46	62

Cut-offs for MARM balance, normal <30, abnormal 30 and above

Cut- offs for NQ Total, normal <20, abnormal 20 and above

Relationships between MARM and NQ scores

At pre-treatment there was a weak, but significant, correlation between total NQ scores and MARM balance scores in this clinical sample - r (60) = .26, p = .04. NQ subscale scores showed only significant correlation for dyspnea - r (38) =.32, p=.04. The score on Tension approached significance – r (38) =.30, p=.06. Figure 1 shows that individuals with abnormal MARM did not have significantly different scores for NQ Peripheral or NQ Central subscale scores, but had significantly higher scores for Tension, p=.03 and Dyspnea, p=.002.

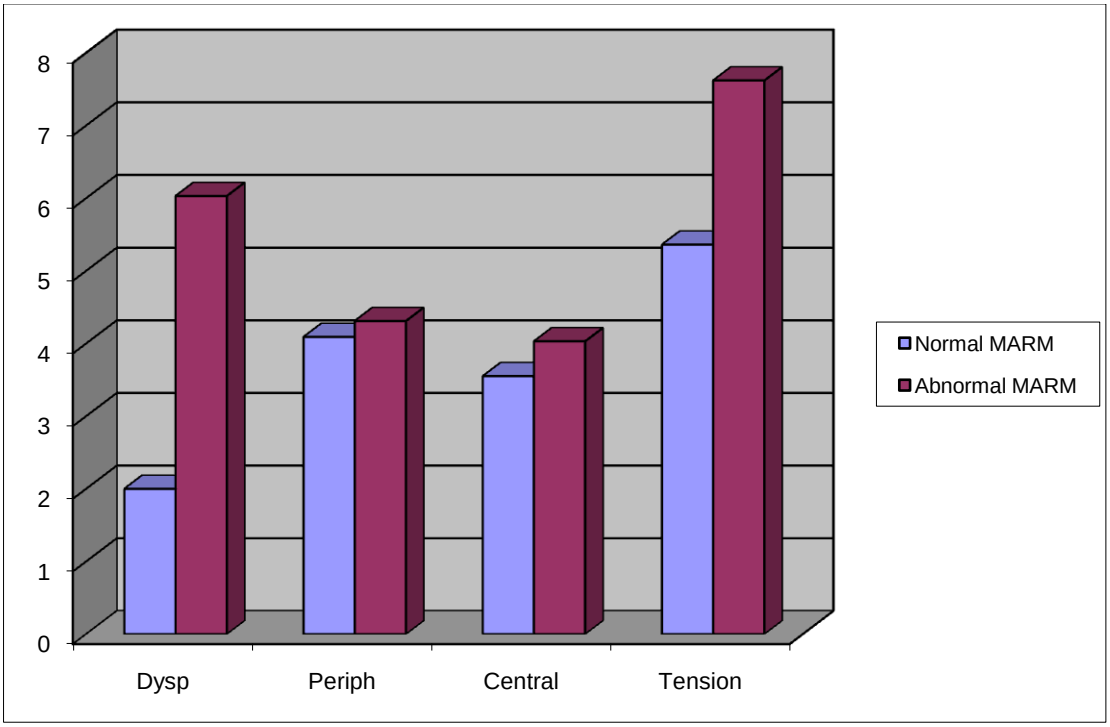

FIGURE 1 - COMPARISON OF NQ SUBSCORES ACCORDING TO MARM CATEGORY

Classification as normal or abnormal on the MARM 'balance' score and the NQ sub score Dyspnea was congruent for 65% of subjects:

- Normal MARM and normal Dyspnea: n=9;
- Abnormal MARM and abnormal Dyspnea: n=17;
- Normal MARM, abnormal Dyspnea: n=2; and
- Abnormal MARM, normal Dyspnea: n=12.

The association between MARM and dyspnea classifications was statistically significant (Fisher exact test, p <0.03). It is remarkable that only two subjects with normal MARM had high dyspnea scores. In the scatterplot (Figure 2) the upper left quadrant is practically empty, implying that all subjects with high NQ dyspnea scores breathe thoracically. By contrast, a thoracic dominant breathing pattern can be present without the presence of dyspnea

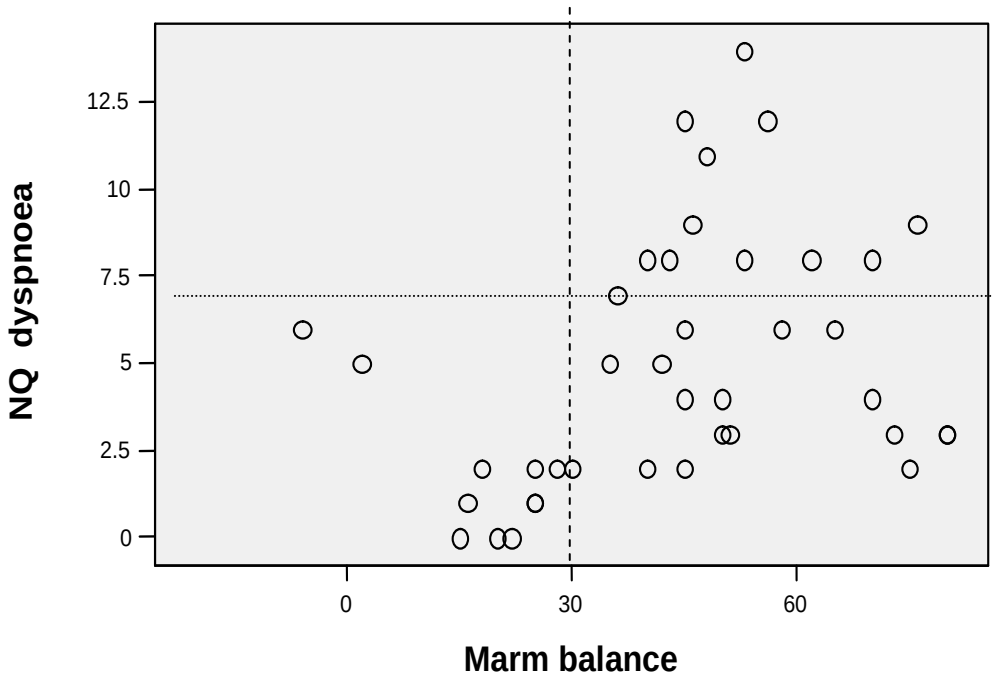

Figure 2 Relationships between categories on NQ dyspnoea and MARM Balance.

Normalization of MARM and NQ after treatment

The response of MARM and NQ to breathing and relaxation therapy was positive (table 3): average MARM and NQ scores (both total and sub scores) greatly improved after treatment by WBB (p < .0001) and moved into the normal zone.

TABLE 3 - *NQ AND MARM SCORES AND SUBSCALE SCORES AT BEGINNING AND END OF TREATMENT*

	Initial *M*	*SD*	Final *M*	*SD*	*r*	*t*	*df*	*p*	*d*
MARM balance *n*=62	44.27	20.38	13.72	9.10	.25	11.94	61	.0001	2.39
NQ Total *n*=62	22.77	8.32	10.30	5.41	.32	11.78	61	.0001	2.10
NQ Dyspnea *n*=40	4.93	3.61	2.75	2.18	-.13	3.09	39	.004	0.71
NQ Peripheral *n*=40	4.24	2.60	2.47	1.87	.33	4.23	39	.0001	0.97
NQ Central *n*=40	3.90	2.48	3.00	2.25	.74	3.31	39	.002	0.75
NQ Tension *n*=40	7.00	2.99	3.82	2.38	.25	6.03	39	.0001	1.37

Cut-offs for MARM balance, normal <30, abnormal 30 and above
Cut- offs for NQ Total, normal <20, abnormal 20 and above
Cut-offs for NQ subscores, normal < 5, abnormal 5 and above.

Cross tabulating normal and abnormal MARM and NQ scores, before and after treatment, showed that of 43 cases with initial abnormal MARM only 3 remained abnormal after WBB and no one became abnormal during treatment. Of 34 cases with elevated initial NQ only 4 remained abnormal and in one subject NQ became elevated. After treatment there was no participant with

both elevated NQ and thoracic dominance. Thus, treatment was effective in normalizing dysfunctional breathing.

The nature of the response to treatment was further studied by calculating correlations between the changes in the measurements. Changes in MARM balance were only correlated with changes in NQ dyspnea but not with changes in NQ total or other NQ subscale scores (Table 4). However, changes in NQ dyspnea also correlated with changes in NQ tension and NQ total, implying that dyspnea was also related to tension and possibly to other factors.

TABLE 4 - *CORRELATION MATRIX FOR CHANGES IN NQ AND MARM VARIABLES*

	Change Dyspnea	**Change Peripheral**	**Change Central**	**Change Tension**	**Change MARM Balance**
Change NQ	.54 p<.0001	.66 p<.0001	.12 p=.44	.64 p<.0001	.10 p=.44
Change Dyspnea		.18 p=.274	-.20 p=.212	.39 p=.01	.32 p=.05
Change Peripheral			-.02 p=.89	.36 p=.02	-.14 p=.40
Change Central				.10 p=.533	-.03 p=.858
Change Tension					.11 p=.492

The final question was whether thoracic dominance moderates the effect of treatment on complaints. A two factor, mixed design ANOVA was conducted to compare NQ total scores between those with normal and abnormal MARM (between subject's factor) prior to therapy, at the beginning and at the end of therapy (within subjects factor). The ANOVA yielded three *F* values that examined the main effect for the MARM group, the main effect for TIME, and the INTERACTION between the MARM group and TIME. The results are shown in Table 5:

TABLE 5 - RESULTS OF TWO-FACTOR ANOVAS COMPARING SCORES ACROSS MARM GROUPS AND TIME

Dependent Variable	Main Effect of MARM group	Main Effect of TIME	Interaction Effect
NQ Total	$F(1,60) = 7.47$ $p = .008$	$F(1,60) = 10.26$ $p < .001$	$F(1,60) = 4.41$ $p = .04$
NQ Dyspnea	$F(1,38) = 11.00$ $p = .002$	$F(1,38) = 3.28$ $p = .08$	$F(1,38) = 12.53$ $p = .001$
NQ Peripheral	$F(1,38) = 0.12$ $p = .732$	$F(1,38) = 16.21$ $p < .001$	$F(1,38) = 0.23$ $p = .637$
NQ Central	$F(1,38) = 1.61$ $p = .303$	$F(1,38) = 11.91$ $p = .001$	$F(1,38) = 1.09$ $p = .303$
NQ Tension	$F(1,38) = 1.92$ $p = .174$	$F(1,38) = 27.10$ $p < .001$	$F(1,38) = 0.54$ $p = .469$

For NQ total, main effects of both MARM group and TIME were highly significant and the interaction just reached significance. NQ scores were higher in the abnormal MARM group than the normal MARM group prior to therapy. Over therapy NQ total scores decreased in both groups, but more in the abnormal MARM group resulting in the groups having similar NQ total scores after therapy (Table 6). Thus, there is a weak indication of moderation of the MARM on treatment effect.

TABLE 6-NQ SCORES- BEFORE AND AFTER TREATMENT ACCORDING TO MARM CATEGORY

	Pre-treatment	Post-treatment
	Mean (SD)	Mean (SD)
Normal MARM	17.3 (6.4)	10.1 (7.1)
Abnormal MARM	24.7 (8.1)	10.3 (4.7)

Cut-offs for MARM balance, normal <30, abnormal 30 and above

The same analysis was done for the NQ Dyspnea score. A significant main effect for MARM group was found, as was a highly significant interaction. For this variable, the groups were different prior to therapy with elevated average scores in the abnormal MARM group and normal scores in the normal MARM group. In the abnormal group, scores decreased after therapy, whereas a small increase was found in the normal MARM group, resulting in similar values for both groups after therapy (Table 7). Thus, there is a clear indication of MARM moderating the treatment effect in dyspnea.

TABLE 7 - DYSPNEA SCORES- BEFORE AND AFTER TREATMENT ACCORDING TO MARM CATEGORY

	Pre-treatment	**Post-treatment**
	Mean (SD)	Mean (SD)
Normal MARM	2.0 (2.1)	3.5 (3.2)
Abnormal MARM	6.0 (3.4)	2.4 (1.6)

Cut-offs for MARM balance, normal <30, abnormal 30 and above

For the remaining NQ subscale scores, the only significant effect was a main effect of time. For these variables, the normal and abnormal MARM groups had similar mean scores prior to and after therapy. Scores in both groups decreased over therapy. MARM did not mediate treatment effect at all.

DISCUSSION

This study shows that while there is only a weak linear relationship between hyperventilation symptoms and breathing pattern, classifications of dysfunctional breathing made on the basis of normal or abnormal NQ and MARM scores agree in 74% of patients. The majority of patients with elevated Nijmegen Questionnaire scores also have a thoracic dominant breathing pattern. Only a minimal number of patients with high NQ scores had a 'balanced' or evenly distributed (thoracic to abdominal) breathing pattern. This supports clinical observation that individuals with 'hyperventilation' symptoms tend to have disturbed (upper thoracic) breathing pattern (Lum 1975). Thoracic dominant breathing pattern seems to be particularly related to the group of

respiratory items of the NQ. Only participants with abnormal MARM have elevated scores on dyspnea.

The second major finding of the study is that breathing and relaxation therapy, by the method of Whole Body Breathing (WBB), reduced dysfunctional breathing symptoms and improved breathing pattern. Both MARM and NQ returned to normal values. After therapy no subject was classified as having dysfunctional breathing on the basis of these two variables. However, it appeared that the breathing pattern only moderated dyspnea items and not other NQ subscales. By implication, treatment effect on all other NQ subscales was not due to the pattern of breathing movement but to other psychological or physiological processes. These processes, which are also targeted by Whole Body Breathing (WBB), include psychophysiological self-regulatory processes such as mental or physical relaxation, body awareness and cognitive restructuring (Giardino, Chan et al. 2004).

The single largest reduction of symptoms occurred in NQ subscale "tension" which includes items relating to tension, anxiety, heart palpitations and chest pain. Reduction in these symptoms was not mediated by breathing pattern and it may have been due to other respiratory variables like CO_2 level (Meuret, Rosenfield et al. 2009) or to various physical and psychological effects of relaxation (Ost and Breitholtz 2000; Conrad and Roth 2007).

To our knowledge, this is the first study that documents the importance of thoracic dominant breathing pattern for the experience of medically unexplained dyspnea. It needs to be emphasized however, that the association is found in patients without a somatic cause for dyspnea. The relationship of breathing pattern to dyspnea perception may be different in patients with respiratory or cardiovascular disease.

In patients with COPD and the presence of rapid and shallow pattern of breathing, a mode of breathing that is also usually thoracic dominant, were found to correspond with extent of dyspnea (Ferrari, Goti et al. 1997). However the authors of this study suggest that this mode of breathing is an adaptive response that might actually assist in reducing excessive respiratory drive.

Preliminary data on 33 patients with COPD showed they had thoracic dominant breathing and a higher score on MARM balance (27.8 ± 42.4) than normal individuals; however, there was no relationship with grading of disease severity (Gold1-4) (Dixhoorn 2009).

There are no MARM data yet on patients with asthma or cardiovascular disease. However there is some evidence that abnormal breathing patterns occur in individuals with these diseases. In asthmatic patients, exaggerated dyspnea and unexplained complaints have been attributed to 'dysfunctional breathing', (Thomas, McKinley et al. 2001; Prys-Picard, Kellet et al. 2006; Hagman, Janson et al. 2008; Prys-Picard and Niven 2008; Thomas, McKinley et al. 2009) although only a few of these studies include data on breathing pattern (Prys-Picard, Kellet et al. 2006). In asthma, even mild broncho constriction has been found to produce shortening and hypertonicity of inspiratory muscles and these muscle changes would tend to favor thoracic dominant breathing (Muller, Bryan et al. 1981; Lougheed, Fisher et al. 2006). Patients with heart failure often complain of dyspnea and this has been attributed in part to 'inefficient pattern of rapid shallow respiration' (Mandak and McConnell 1998). Assessment of MARM within these populations will be necessary to establish values of MARM balance, both before and after treatment. Possibly MARM may be helpful to establish the pathway of therapy effect for various treatments, including medication, biofeedback or exercise training (Giardino, Chan et al. 2004). Few studies on breathing therapies for asthma have investigated their effects on breathing pattern and this may prove useful in the refinement of the application and development of these types of therapies.

Implementation of MARM in the clinical setting may be hampered by the need for training and the time required for the complete protocol. Test-retest reliability of the therapist in the present study was not determined, but the very high correlation between pre test MARM and change in MARM indicates that reliability would be satisfactory. This issue will be important however in future studies that employ MARM.

An important limitation of the study is the absence of any longer term follow-up to assess whether the changes in breathing pattern and complaints are stable and sustained. Previous studies using the MARM in a two-year follow-up of myocardial infarction patients showed a stable effect of treatment and prompted later validation studies (Dixhoorn 1994).

CONCLUSION

The majority of individuals with a large number of dysfunctional breathing symptoms are also likely to have a thoracic dominant breathing pattern. Breathing pattern and symptoms can normalize after breathing therapy. The extent of thoracic dominant breathing seems an important moderator for dyspnea symptoms and an important component of treatment.

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CHAPTER 13

DISCUSSION

INTRODUCTION

Discussions of the each of the seven studies conducted have been included in the empirical chapters of this thesis. This final chapter seeks to draw together and highlight the principal findings of these studies and discuss their implications.

AIMS AND OBJECTIVES

As will be recalled from Chapter 1 (p.23), the overall aims of this thesis were:

- To further develop and validate some clinical tools for assessment of dysfunctional breathing;
- To explore and evaluate current methods for assessing dysfunctional breathing particularly those used by breathing therapists;
- To investigate the relationships between measures of dysfunctional breathing with a view to understanding the possible definitions and dimensions of dysfunctional breathing; and
- To explore possible mechanisms of breathing therapy.

PRINCIPAL FINDINGS

The principal findings of the seven studies will be discussed in relationship to how they have contributed to knowledge on:

1. the measures of dysfunctional breathing and their role in its assessment;
2. the possible definitions and dimensions of dysfunctional breathing; and,
3. the possible mechanisms of breathing therapy.

ASSESSMENT OF DYSFUNCTIONAL BREATHING AND ITS MEASURES

BREATHING PATTERN

Dysfunctional breathing measures that were either developed or investigated in detail in this thesis include two measures for evaluating breathing pattern - the MARM and the Hi Lo.

Clinicians often use observation and palpation and techniques similar to the MARM and Hi Lo to assess breathing pattern rather than instrumentation, such as respiratory induction plethysmograph, which is the most common instrument used in the research setting (Pryor and Prasad 2002).

Results of the study reported in Chapter 6 indicate that the MARM is a useful and reliable tool, with high inter-rater reliability (r =.851, p=.01) for assessment of one aspect of breathing pattern - thoracic dominant breathing. This research identified a number of advantages of the MARM over respiratory induction plethysmography in that the MARM is relatively easy to learn, inexpensive, applicable to clinical environments and unlike RIP, which only evaluates rib cage motion in the lateral and anterior/posterior planes, the examiner using the MARM is able to perceive vertical motion of the rib cage during inspiration. This vertical motion, produced by the accessory muscles of inspiration, is an important component of thoracic dominant breathing and inclusion of this third (vertical) plane of motion is necessary for accurate representation of thoracic dominant breathing. Like the MARM, the Hi Lo breathing assessment is also easy to learn and reasonably accurate in detecting simulated breathing patterns.

In comparing the MARM and the Hi Lo it appears that both techniques have their particular strengths. A strength of the MARM is that it provides a means to measure and assign numerical values, in contrast to the Hi Lo, which only reports dichotomous variables. Also, the MARM, by evaluating the lateral motion of the lower rib cage rather than the anterior protrusion of the abdomen, may give a better representation of diaphragm action, while the Hi Lo appears to be better for assessing paradoxical breathing and asynchrony of

breathing. The evaluation of dysfunctional breathing pattern is probably best performed using a combination of both techniques.

The MARM and Hi Lo are useful for the clinical environment because they are cheap and accessible. In the research environment, instrumentation such as respiratory induction plethysmography is preferable due to greater precision of measurement. However, limitations were identified in the ability of respiratory induction plethysmography to evaluate the vertical dimension of rib cage motion. This vertical motion of the upper rib cage, produced by the accessory muscles of respiration, is an important aspect of thoracic breathing. The inability of respiratory induction plethysmography to measure this aspect of thoracic breathing may significantly impair its ability to evaluate thoracic dominant breathing. Opto electronic plethysmography which measures more dimensions of breathing gives a more complete representation of breathing pattern and is superior to respiratory induction plethysmography in this regard.

Breathing pattern is often not measured in a systematic manner in the clinical environment and most research into dysfunctional breathing has not included detailed investigations of breathing pattern. This may have resulted in this aspect of dysfunctional breathing being overlooked.

The treatment of conditions, such as disorders of continence (Hung, Hsiao et al. 2010), speech (Altman, Atkinson et al. 2005), lower back and neck pain (Smith, Russell et al. 2006; Perri 2007; Correa and Berzin 2008; Kapreli, Vourazanis et al. 2009) and dysfunctions of posture, balance and motor control (Lewitt 1980; Gandevia, Butler et al. 2002), which are believed to be aggravated by dysfunctional breathing patterns would benefit from careful monitoring and systematic measurement of breathing pattern to monitor patient's response to treatment. Given that the MARM and Hi Lo appear to be easily learnt, practitioners with differing backgrounds could probably be trained to identify dysfunctional breathing patterns using these techniques.

Research into the role of breathing pattern dysfunction in these types of conditions and others could include measures such as the MARM and Hi Lo in

addition to instrumentation such as respiratory induction plethysmography and opto electronic plethysmography.

SYMPTOM QUESTIONNAIRES

The SEBQ was constructed because an extensive search of the literature showed that there were no validated questionnaires for assessing dysfunctional breathing. The Nijmegen Questionnaire, sometimes used for identifying dysfunctional breathing, was designed to measure hyperventilation syndrome, which is just one aspect of dysfunctional breathing.

The SEBQ contains many more items specific to breathing than the NQ and factor analysis of these SEBQ items identified the presence of two separate, but correlated, dimensions. These two dimensions appear to represent biochemical and biomechanical aspects of dyspnea. The first of these dimensions named 'lack of air' contains items very similar to those identified by other researchers as "air hunger" or "urge to breathe". These verbal descriptors are believed to be associated with afferent input from chemoreceptor activity (Banzett, Lansing et al. 1990; Lansing 2000).

The second dimension, which contained items that appear to relate to biomechanical factors, was labeled "perception of inappropriate or restricted breathing". The items loading highest on this dimension such as "I cannot take a deep and satisfying breath" and "My breathing feels stuck or restricted" convey a sense of restricted or otherwise unsatisfied respiration. These items are recognisably similar to sensations documented in situations where the work of breathing is made more difficult, such as when the chest wall is strapped (O'Donnell, Hong et al. 2000) and are reported by patients with impaired function of the respiratory muscles and rib cage (Lougheed, Fisher et al. 2006, Simon and Schwartzstein 1990). The types of sensations identified are believed to arise, as least in part, from receptors in the chest wall and muscles of breathing (Simon and Schwartzstein 1990) and also represent the qualities of dyspnea that arise when the motor output of respiratory system is not able to match the expectations generated in the sensory cortex by corresponding discharges from the motor cortex (Beach and Schwatrzstein 2006).

Another possible way of interpreting the two dimensions identified in the SEBQ is that they are two different aspects of interoception with the first being related to the sensory or feeling aspect of interoception and the second being related to the cognitive or evaluative aspects of interoception. These two dimensions of the SEBQ may thus be representative of perceptual as well as biochemical and biomechanical aspects of dysfunctional breathing. However, this needs to be clarified in future studies.

The SEBQ has potential as a tool for evaluating dysfunctional breathing, but needs further development and testing. The two dimensions of the SEBQ may represent strongly related, but distinct, aspects of dysfunctional breathing symptoms, representing biochemical and biomechanical mechanisms, and also sensory and cognitive aspects of interoception. The clinical assessment of these two dimensions may prove useful for more specific diagnosis and treatment of dysfunctional breathing.

It has been suggested that the weak association between dysfunctional breathing (hyperventilation syndrome) symptoms and hypocapnia may be partly explained by the fact that these arise from other causes such as tense breathing patterns (Hornsveld 1997). The presence of a separate biomechanical and evaluative dimension to dysfunctional breathing symptoms in the SEBQ tends to support this assertion.

To evaluate dysfunctional breathing symptoms, there may be value in administering both the SEBQ and the NQ.

There are several problems associated with the NQ. Firstly, the hyperventilation syndrome, which it was designed to measure, is no longer considered to be a valid diagnosis. So the question arises, what aspects of breathing dysfunction does the NQ measure? The fact that improvements in breathing pattern were only associated with improvements in the NQ subscale "dyspnea" suggests that only this part of NQ questionnaire is closely linked with breathing pattern, while other NQ subscales may be more closely linked to psychological or biochemical aspects of breathing.

Also, because the NQ focuses on the hyperventilation syndrome, it includes many items that are traditionally identified with the pathophysiology of hypocapnia (e.g. dizziness, parestheisas, blurred vision, stiffness in extremities) and only four items that specifically refer to respiratory sensations (e.g. faster deeper breathing, inability to breathe deeply, shortness of breath and tight feelings in the chest).

Overall the NQ was found to correlate with the SEBQ total score and with Factor 1 of the SEBQ - "Lack of Air". However, the NQ does not correlate with Factor 2 of the SEBQ - "Perception of inappropriate or restricted breathing". This suggests that the NQ may not adequately encompass items associated with the biomechanical aspects of breathing dysfunction or from the cognitive/evaluative aspects of interoception. Administration of the SEBQ in addition to the NQ allows monitoring of a larger number of symptoms, which may assist in ongoing patient evaluation.

BREATH HOLDING TIME

Breath holding time (BHT) has been found to be shorter in individuals with hyperventilation disorders (Jack, Darke et al. 1998 {Warburton 2006). Dr KP Buteyko, originator of the Buteyko breathing technique which is predominately used for the treatment of asthma, patented a formula for determining CO_2 on the basis of breath holding time.

In the study reported in Chapter 10 of this thesis, it was found that breath holding time did not correlate with end tidal CO_2 as predicted by the formula patented by Dr. K.P. Buteyko. In fact, the results revealed a slight negative correlation between BHT and $ETCO_2$, ($r = -.241$) directly opposite to Buteyko's claims. This negative relationship does not appear to be an artefact as an inverse relationship between breath holding time and alveolar CO_2 tension as has been reported by researchers in the past (Godfrey and Campbell 1969), and it seems reasonable to assume that in individuals with relatively normal CO_2 thresholds, the lower the starting CO_2 the longer it will take for CO_2 to accumulate to the level where intensity of dyspnea results in the termination of breath holding.

Breath holding time has a long history as a test of chemosensitivity and the findings in Chapter 10 do not disprove an association between chemoreceptor thresholds and breath holding time but they do indicate that mechanisms other than chemosensitivty are involved (Stanley, Cunningham et al. 1975). Studies in the past have shown that individuals with greater chemosensitivity to CO_2 will, for a given level of starting CO_2 tension, have a shorter breath holding time (Stanley, Cunningham et al. 1975). However more recent studies have shown that individuals with chronic and intermittent hypocapnia and short breath holding time do not generally have altered chemosensitivity. These contradictory findings between older and more recent studies suggests that mechanisms in addition to altered chemoreceptor thresholds, including behavioural and mechanical factors contribute to short breath holding time in hyperventilation and in other types of dysfunctional breathing (Jack, Rossiter et al. 2003).

The finding that breath holding time does not correlate with $ETCO_2$, according to Buteyko's formula, has implications for the Buteyko Breathing Technique. The therapeutic rationale of the Buteyko Breathing Technique is tied to beliefs about the importance of hypocapnia and beliefs that effectiveness of this technique is dependent on normalisation of $PACO_2$. This finding seriously questions the validity of this rationale because the main outcome measure used by Buteyko practitioners to identify normalisation of CO_2 levels in patients is increased length of breath holding time.

In this study, breath holding time was found to be linked with breathing pattern rather than with CO_2 levels, raising the possibility that this might be a more significant mechanism of breathing therapies than correction of hypocapnia. Length of breath holding time is considered to be an important index of dyspnea threshold (Nishino 2009). In the study reported in Chapter 10 of this thesis, breath holding time was found to be significantly lower in individuals with abnormal spirometry, and, in these individuals breath holding time was found to correlate with thoracic dominant breathing pattern (r=.408, p =.028). This association between the presence of thoracic dominant breathing pattern and shortened breath holding time suggests an increased

tendency to dyspnea in those with thoracic breathing. The detection of thoracic breathing may therefore be a more useful measure for Buteyko and other therapists than BHT and may provide insight into people who are more likely to respond to Buteyko-type therapies.

Despite the fact that breath holding time does not appear to accurately reflect carbon dioxide status, it is still a useful tool for assessing breathing. Breath holding induces dyspneic sensations and the time taken till breath holding first produces dyspnea sensations can indicate the threshold of dyspneic sensation, while final breaking point of breath holding can indicate maximum tolerance of dyspnea (Nishino 2009). The length of breath holding time at functional residual capacity, for the initial period of no sensation and until the person feels the first desire to breathe is similar to the Buteyko Control Pause (Buteyko 1990). This measure has been shown to be a relatively stable measure that is less susceptible to behavioral influence than the period of maximum tolerance to breath holding (Nishino, Sugimori et al. 1996) which is similar to the Buteyko Maximum Pause (Stalmatski 1999). Breath holding time has also been proposed to be a useful measure of perceptual inaccuracy in patients with near fatal asthma (Nannini, Zaietta et al. 2007). It is possible that improvements in breath holding time after breathing therapy such as BBT, not associated with improved lung function, might indicate a blunting of dyspnea perception. Increased breath holding time after BBT and other breathing therapy might also be associated with improvements in breathing pattern. These issues need to be explored in future research.

In conclusion, despite the fact that breath holding time tends to be lower in individuals with established hyperventilation disorders, breath holding time does not correlate precisely with resting carbon dioxide in all individuals. This is probably due to the fact that factors other than carbon dioxide, including breathing pattern, presence of respiratory disease and psychological factors are of importance.

CAPNOGRAPHY

It appears that hyperventilation can only be evaluated by measurement of carbon dioxide, yet dysfunctions of breathing pattern, shortened breath holding

time and dysfunctional breathing symptoms can exist without chronic hypocapnia. Therefore, hyperventilation cannot be diagnosed on the basis of abnormal breathing patterns, length of breath holding time or symptoms.

Acute, chronic or intermittent hyperventilation can only be diagnosed by direct measurement of arterial CO_2, either transdermally or from extracted blood or indirectly through measurement of end tidal CO_2 using a capnograph. Relying on resting CO_2 might not identify individuals with frequently recurrent, intermittent hyperventilation that is indicative of poor regulation of CO_2 (Warburton and Jack 2006). In these individuals, the problems of CO_2 may only become evident when capnometry is performed to measure the CO_2 response to physical or psychological challenge. These individuals, once induced to hyperventilate, after an exercise stress test or some form of psychological stress, tend to have very slow recovery of CO_2 to pre-challenge levels (Hardonk and Beumer 1979; Warburton and Jack 2006).

COMPREHENSIVE ASSESSMENT OF DYSFUNCTIONAL BREATHING

Screening for dysfunctional breathing with measures representing only one of its dimensions may not lead to realistic estimations of the true prevalence and impact of the various types of breathing dysfunctions.

Comprehensive evaluation of breathing dysfunction should include measures of breathing symptoms, breathing pattern, resting CO_2 and also include functional measures such a breath holding time and response of breathing to physical and psychological challenges.

DEFININING DYSFUNCTIONAL BREATHING

DYSFUNCTIONAL BREATHING IS MULTIDIMENSIONAL

In the literature review section of this thesis (Chapter 5), dysfunctional breathing is proposed to exist when any of the functions of breathing are impaired. Given all of the possible functions of breathing, this definition is rather broad. Subsequently, a working definition of dysfunctional breathing was derived from the study reported in Chapter 9, which concluded that dysfunctional breathing cannot be simply defined and that for practical

purposes it is probably best characterized as a multidimensional construct with at least three dimensions: biochemical, biomechanical, and breathing symptoms. This conclusion was reached because, while significant correlations were found within biochemical, biomechanical and symptom categories of dysfunctional breathing measures, no correlations were found between categories.

Despite controversies about the hyperventilation syndrome, hyperventilation is still the most well recognized physiological aspect of dysfunctional breathing. Other aspects of dysfunctional breathing such as breathing pattern are often ignored. In the study reported in Chapter 9, the lack of correlations between breathing pattern and symptomatic measures with $ETCO_2$ supports the view that dysfunctional breathing is not limited to hyperventilation and that it includes biomechanical and symptomatic aspects as well. This has implications for future research into dysfunctional breathing which should include measurements of all these various aspects.

The working definition of dysfunctional breathing proposed in this thesis is in keeping with a substantial body of research which also reports findings that biochemical, symptomatic and breathing pattern aspects of breathing dysfunction do not necessarily co-exist in individuals suspected of having dysfunctional breathing (Burton 1993; Han 1996;Hornsveld 1997). However, it cannot be presumed that there is no association between dysfunctional breathing symptoms, breathing pattern, breath holding time and resting CO_2, as it has been observed on repeated occasions that these do sometimes co-exist (Lum 1976; Gardner 1986; Howell 1997) even though the relationships are complex.

In patients with more severe breathing dysfunction, relationships between categories of measures are more likely to exist and these individuals are also more likely to have disturbances in several aspects of breathing functionality. In a subsequent study, reported in Chapter 13, which investigated patients with more severe breathing disturbance than that those in Chapter 9, there was evidence of stronger relationships between categories of breathing dysfunction. A small linear correlation between breathing pattern and

dysfunctional breathing symptoms (as measured by the NQ) could be seen in these patients (r=0.26, p<0.05). It also found that classification as normal or dysfunctional on the basis of breathing pattern, as measured by the MARM and on the basis of the NQ, agreed in 74% (p < 0.001) of patients.

The view that biochemical and biomechanical aspects of dysfunctional breathing are distinct was also suggested from the factor analysis of the SEBQ which showed separate loadings for items similar to symptoms known to arise from biomechanical aspects of breathing and symptoms known to arise from altered chemoreceptor inputs. As previously discussed in this thesis, the two factors of the SEBQ may also indicate separate dimensions for the sensory or feeling aspects of interoception and the cognitive or evaluative aspects.

PYSCHOLOGICAL INFLUENCES ON DYSFUNCTIONAL BREATHING AND ITS SYMPTOMS

It is clear from the literature that psychological factors play an important role in producing dysfunctional breathing and also in influencing symptom perception.

Psychological factors need to be considered in explaining some of the more difficult to interpret findings in this thesis. For example, the poor correlations between the SEBQ scores and other measures of dysfunctional breathing were unexpected. This lack of correlation might have been due to the study participants who, as a group, only had mild dysfunctional breathing. It could also be partly due to the influence of social, cognitive and emotional factors on interoception and symptom reporting which confound these relationships between subjective and objective measures (Lougheed 2007;Bogaerts, Van Eylen et al. 2010).

Accurate perception and normal sensory awareness of breathing contribute to normal control of breathing and are probably important for the effective use of breathing for therapeutic and salutogenic purposes. Poor perception of asthma symptoms can contribute to increased morbidity and mortality (Magadle, Berar-Yanay et al. 2002) while poor perception of breathing related sensations and lack of breathing awareness, as well as over-perception or excessive awareness of physiological sensations associated with breathing, are possible aspects of breathing dysfunction. If the two factors of the SEBQ

are interpreted as relating to the sensory and cognitive aspects of interoception, very high scores or very low scores that do not correspond to objective findings might, in some individuals, indicate a disturbance in interoception.

BREATHING PATTERN AS AN ASPECT OF DYSFUNCTIONAL BREATHING

Functional breathing is 'balanced' between the upper rib cage and the lower rib cage/abdomen when a person is at rest. It is also flexible and responsive to changes in posture and can be modulated at will to become either thoracic or abdominal. These conclusions were reached as a result of the first MARM study (Chapter 6) based on the data gathered from the breathing patterns of yoga practitioners and breathing therapy teachers who participated in this study. In the study in Chapter 12, it was found that after breathing therapy, breathing pattern became more 'balanced' and less thoracic. This more balanced breathing pattern was associated with decreased symptoms scores in general and decreased dyspnea in particular.

A predominately thoracic breathing pattern at rest is likely to be dysfunctional, particularly if it is fixed and unresponsive to changes in posture or attempts at voluntary modulation. Under the same circumstances, paradoxical breathing can also be considered dysfunctional. The finding in Chapter 11 that thoracic breathing and paradoxical breathing were associated with decreased 'coherence' suggests that these types of breathing are less physiologically efficient and the presence of these types of breathing pattern may inhibit homeostasis. HRV patterns similar to those described indicating 'coherence' are believed to reflect resonance effects between the respiratory, cardiovascular and autonomic nervous systems (Lehrer, Vaschillo et al. 2000; Vaschillo and Lehrer 2002). In this study, thoracic dominant breathing was associated with decreased ability to produce 'coherence' of HRV (r=-.463, p = .0001) and individuals with paradoxical breathing had the lowest HRV coherence ($t(8)$ = 10.7, p = .001) with the negative relationship between coherence of HRV and thoracic breathing being strongest in this group (r = -.768, p = .03).

It is evident from the studies performed and the above discussions that dysfunctional breathing cannot be defined precisely at this time, and that for practical purposes dysfunctional breathing is probably best characterized as a multidimensional construct with at least three dimensions: biochemical, biomechanical and breathing symptoms. Other dimensions may include sensory, cognitive and psychological aspects with all these aspects being potentially important in different populations.

FUNCTIONAL OPTIMAL BREATHING- WHAT IS IT?

If dysfunctional breathing cannot be adequately defined perhaps optimal breathing can be defined as breathing that provides the greatest efficiency, balance and flexibility of response in any particular situation and that optimally fulfills all its functions.

POSSIBLE MECHANISMS OF BREATHING THERAPY

PHYSIOLOGICAL-BIOCHEMICAL AND NEUROMECHANICAL

Normalisation of carbon dioxide levels is unlikely to be the only mechanism of breathing therapies such as the BBT. Normalisation of breathing pattern is likely to be another possible mechanism. The lack of correlation between Butyeko's breath holding time formula and carbon dioxide levels throws serious doubt onto Buteyko's claim that clinical improvements from people learning these techniques are only due to changes in CO_2. Several studies have tested CO_2 levels after BBT (Bowler 1998) and other breathing therapies and have found that despite signs of clinical improvement, mean CO_2 levels have not increased (Holloway and West 2007; Thomas, McKinley et al. 2009). However, it cannot be assumed that there is no relationship between clinical improvements from breathing therapies and carbon dioxide.

There is evidence that hypocapnia has clear pathogenic effects, and normalisation of carbon dioxide has been shown to be protective in disease states (Laffey and Kavanagh 2002;Laffey 2003), Studies that have looked at individual changes in CO_2 have found that increased levels of carbon dioxide occurring as a result of breathing therapy does, to some extent, explain the reduced number of symptoms in asthmatics (Ritz, Meuret et al. 2009) and

sufferers of panic disorder (Meuret, Rosenfield et al. 2009). However, a substantial amount of research has also shown that this is not a simple relationship (Hormbrey 1988;Hornsveld 1997) and that other mechanisms involving, for example, psychological and biomechanical factors also play a role. The finding that breath holding time correlates with extent of thoracic dominant breathing pattern also suggests that breathing pattern may influence the outcomes of breathing therapy.

The increased breath holding time reported by Buteyko practitioners in individuals learning the BBT are proposed to be associated with many different types of health improvements including reduced dyspnea (Stalmatski 1999). Breath holding effectively produces the dyspneic sensation, and increases in the length of a person's breath holding time after breathing training imply that their threshold to dyspneic sensation has increased (Pryor and Prasad 2002). Furthermore, a correlation between breath holding time and breathing pattern suggests an association also exist between dyspnea and breathing pattern and thus increased breath holding time after BBT might be associated with a change in dyspnea thresholds and/or more 'balanced' breathing.

The literature suggests that breathing pattern changes are both a cause and effect of dyspnea. It has often been reported that individuals with asthma and other respiratory diseases have an increased tendency to breathing pattern disorders such as thoracic breathing and paradoxical breathing (Muller, Bryan et al. 1981; Tobin 1983; Loveridge, West et al. 1984). But the literature also suggests that breathing pattern disturbances can be a cause of dyspnea, particularly dyspnea that is unexplained or disproportionate to the amount of pathology present (Lougheed, Fisher et al. 2006; O'Donnell 2006; Prys-Picard, Kellet et al. 2006).

The conclusion of the final study reported in this thesis in Chapter 12, *"Medically unexplained dyspnea: Partly moderated by dysfunctional (thoracic dominant) breathing pattern"*, was that breathing pattern partially moderates dyspnea. In this study it was found that, before treatment, dyspnea scores were only elevated in patients with thoracic dominant breathing. After

treatment, NQ dyspnea scores and breathing pattern as measured by the MARM normalised. Improvement in NQ dyspnea scores was largest for subjects with abnormal MARM measurements pre-treatment and reduction in dyspnea scores were strongly related to the extent of improvement in breathing pattern.

Several authors have proposed that there is an association between abnormal function of the respiratory muscles and the extent of respiratory drive and dyspnea (Sackner 1984;Sharp 1985; Breslin, Garoutte et al. 1990; Wolf 1994). Breathing therapies conventionally used by physical therapists have often targeted breathing pattern dysfunctions (Pryor and Prasad 2002). The inconsistent success of the more mechanistic breathing therapies, which narrowly target breathing pattern rather than broader breathing functions, suggests that they need refinement and might benefit from a more holistic approach (Cahalin, Braga et al. 2002). Therapies that consider mind-body interactions and factors such as relaxation appear to be more successful than those that do not (Conrad 2007;Holloway 2007).

Breathing techniques that reduce hyperinflation would tend to improve breathing pattern and reduce dyspnea (O'Donnell 2006). Different types of breathing techniques could potentially reduce hyperinflation (e.g. slow abdominal breathing can reduce respiratory drive and indirectly effect hyperinflation (Sackner, Gonzalez et al. 1984), and training in effective exhalation techniques may be another route (Ferrari, Goti et al. 1997; Nield, Soo Hoo et al. 2007), as could the low volume breathing used by the BBT. It is not possible on the basis of the studies in this thesis to do anything other than speculate that reduced volume breathing might improve hyperinflation, but, if this is the case, it might act in similar ways to lung volume reduction surgery which is known to decrease ventilatory drive, improve neuromechanical coupling of respiratory muscles and significantly improve dyspnea (Laghi, Jubran et al. 1998; Hida 1999; Lahrmann, Wild et al. 1999; Cassart, Hamacher et al. 2001).

PSYCHOLOGICAL

Breathing techniques often produce psychophysiological and relaxation effects even if these are not actively pursued. A key breathing instruction of BBT is to "gradually reduce your breathing by relaxing the muscle of respiration until you feel a light lack of air" (personal communication, Dr. Buteyko, 1993). The fact that patients are then instructed to do this as frequently as possible during the day is likely, in those who practice this technique, to induce a more relaxed, mindful and embodied state. Also, the person who is focusing on breathing during the day is distracted from rumination and other types of negative cognitions. The effect is likely to be similar to mindfulness-based stress reduction techniques (Salmon, Sephton et al. 2004).

Another aspect of the BBT is the person actively pursues the "lack of air" sensation; this may decrease fear of dyspnea and increase sense of control. Given that experiential avoidance and fear of bodily sensations is likely to increase the discomfort associated with dyspnea (Hayes, Wilson et al. 1996; Tull, Rodman et al. 2008), willingness to accept and even actively pursue dyspnea-like sensations might create a positive emotional affect that mitigates the sensory and affective components of dyspnea (von Leupoldt, Mertz et al. 2006). Willingness to experience the uncomfortable and fear-inducing sensation of dyspnea perhaps changes one's relationship to this sensation in a way that increases one's sense of control and reduces anxiety (Rosenkranz and Davidson 2009). Decreased fear of dyspnea may also increase perceptual accuracy, as it has been shown that the greater a person's fear of bodily sensations, the lower their self-awareness (Petersen and Ritz 2010).

Relaxation effects of breathing therapies might be an important aspect of their clinical effectiveness (Dixhoorn van 2007; Lahmann, Nickel et al. 2009). Lehrer (2010) has pointed out that, in the case of asthma, relaxation effects are not sufficient to explain the positive response to breathing therapies and has proposed that biomechanical factors (i.e. bronchodilation from deep slow breathing) may play a key role (Lehrer 2010). Interestingly, research exists to show that both large volume (Duggan, Chan et al. 1990) and low volume

(Douglas, Drummond et al. 1981) breathing can reduce bronchoconstriction, although the bronchodilating effect of increased lung volumes related to lung stretching, when a large breath is taken, termed pulmonary hysteresis, is much better known (Nadel and Tierney 1961). The effects of pulmonary hysteresis are blunted in asthmatics and individuals with COPD and are inhibited by corticosteroids, which can lead one to speculate that the therapeutic potency of taking large volume or deep breaths in people with severe chronic respiratory disease may be limited (Fairshter 1985; Pellegrino, Sterk et al. 1998), but still a factor worth considering. One beneficial effect of low volume breathing might be to reduce hyperinflation.

Thus, it appears likely that symptoms associated with dysfunctional breathing, particularly dyspnea, are related to thoracic dominant breathing in patients with medically unexplained complaints and that breathing therapy can effectively restore normal breathing pattern and reduce dysfunctional breathing symptoms.

IMPLICATIONS FOR BREATHING THERAPIES

Breathing therapies, particularly those that target dysfunctional breathing, may improve their success by evaluating the various aspects of dysfunctional breathing reflected in the different categories of measures explored in this thesis.

Comprehensive evaluation with these measures is one means for monitoring the effects of different types of breathing instructions on specific types of breathing dysfunction. The obvious benefit of this is that the breathing therapy can be tailored and the practice refined for each individual. Lack of response of a particular dysfunctional breathing parameter might suggest the need for refinement of technique or indicate the need for a change in approach.

Closer attention to measurement of breathing pattern may improve the effectiveness of breathing therapies. In the study reported in Chapter 11 "Relationship between dysfunctional breathing patterns and ability to achieve target heart rate variability with features of "coherence" during biofeedback", it

was found that resting breathing pattern influences a person's ability to achieve the heart rate variability targets that are associated with positive response to HRV biofeedback. Patients not responding to this type of therapy may be held back by the fact that their habitual thoracic or paradoxical breathing pattern is dysfunctional and correction and restitution of normal balanced breathing may improve therapy outcomes.

Monitoring of breathing pattern may also improve the outcomes of breathing therapies that aim to improve dyspnea. This is relevant because breathing therapy is commonly used in the treatment of chronic respiratory diseases such as asthma and chronic obstructive pulmonary disease.

LIMITATIONS

Each study presented in this thesis has its limitations and these have been mentioned in the relevant chapters describing these studies and will not be repeated here.

There are a number of general limitations regarding how the seven studies were able to satisfy the three main objectives stated in the introduction relating to definitions of dysfunctional breathing, its measurement and its role in breathing therapy. Given the scope and breadth of these questions, it can be appreciated that these could only be partially answered by the limited number of studies undertaken in this thesis.

The nature of the sample used in the study reported in Chapter 9 means that the practical working definition given for dysfunctional breathing in this chapter applies only to individuals with mild dysfunctional breathing. In individuals with more severe signs of breathing dysfunction relationships between measures appear to be stronger indicating that the findings in Chapter 9 may be different when breathing dysfunction is severe.

It is proposed that dysfunctional breathing exists when there is impairment of any of the functions of breathing. Some of these functions of breathing might include its role in posture and motor control, speech and vocalization and use as a tool for psychophysiological self-regulation and

salutogenesis. This thesis has not investigated these aspects of breathing functionality, nor explored their relationship to the biochemical, biomechanical and symptomatic measures that were investigated.

Only limited conclusions can be reached on the mechanisms of breathing therapies. These mechanisms are likely to be complex and to involve the interaction of psychological and physiological factors not explored in this thesis.

FUTURE RESEARCH

Further studies to confirm the validity and clinical utility of the MARM and Hi Lo are warranted. These should be conducted in populations with real rather than simulated breathing pattern dysfunction.

It is recommended that the SEBQ questionnaire be further developed to clarify wording of questions and that additional items be included so that all dimensions of breathing symptoms and important breathing behaviors are represented. Future work is required to evaluate the performance of the SEBQ in terms of discriminating between different patient categories and normal individuals.

Future investigations into the mechanisms of breathing therapies are necessary and these would benefit from inclusion of the biochemical, biomechanical and symptomatic measures of dysfunctional breathing to assess pre-treatment status and as outcome measures. Assessing changes in these measures and the relationships of these changes to improvement in disease status, psychometric measures and quality of life would help to further elucidate whether the therapeutic pathways of breathing therapy are purely psychosomatic or involve physiological factors. As discussed previously, the mechanisms of breathing therapy are likely to be complex, but research to identify these mechanisms would assist in the further development of breathing therapies and also would help to improve their effectiveness.

Further research is needed to identify which patients most benefit from breathing therapy, whether on the basis of medical or psychological complaint or type of breathing dysfunction. Given the large numbers of breathing

therapies and large array of breathing techniques it is often difficult to choose which breathing techniques might be most suitable for a particular individual. It is likely that some breathing therapy will be more effective than others for particular types of breathing dysfunctions, for particular personality types or in particular disease conditions.

Future research might also explore the philosophical and spiritual aspects of breathing identified in the literature review of this thesis. And whether it is possible to facilitate optimal breathing in otherwise healthy individuals and thereby circumvent disease as postulated by yogis and other mystics? It would be interesting to investigate how psychological therapies or perhaps psychospiritual practices might be combined with breathing practices to facilitate optimal breathing.

FINAL CONCLUSIONS

This thesis has helped to clarify the characteristics of dysfunctional breathing and identified that it has at least three dimensions - biochemical, biomechanical and symptomatic. This highlights the need to include a range of measures that represent these various dimensions for a thorough assessment of dysfunctional breathing.

The presence of different aspects of dysfunctional breathing identified in this thesis - hyperventilation, breathing pattern disorders and breathing related symptoms- can all potentially have adverse effects on health and quality of life. However, dysfunctional breathing can easily be overlooked if a range of measures of breathing functionality are not applied. The availability of simple and accessible tools to measure the different types of dysfunctional breathing should help to facilitate this. Some simple tools that have been developed or explored in this thesis include the MARM, the Hi Lo breathing assessment, the SEBQ and breath holding time. All these measures are simple to use and accessible.

All of the dimensions of dysfunctional breathing identified in this thesis are potentially important for understanding the mechanisms of breathing

therapy. At the time of completing this thesis there appears to be a chasm between the beliefs of practitioners of the Buteyko method about the mechanisms of breathing therapies and the evidence to support these beliefs. This chasm will prevent the widespread acceptance of the Buteyko method craved by its practitioners.

Lack of general understanding of the mechanisms of breathing therapy inhibits the refinement and development of this therapeutic approach generally. Understanding of the mechanisms for possible therapeutic benefits of breathing therapies is an essential step in the development of best practice protocols for this type of therapy.

There is also the likehood that without an exploration of both physiological and psychological mechanisms, breathing therapy may be undervalued and insufficiently developed.

It has been stated that anecdotal reports and personal testimonials of the success of breathing therapy tend to overstate their effectiveness and this has led to a predjudice in the scientific community against these types of therapies (Bruton and Holgate 2005). As evidence for the effectiveness of breathing therapy accumulates it is becoming clearer that further investigation of their mechanisms is necessary (Bruton and Thomas 2011).

Lack of understanding of what are probably complex physiological and psychological mechanisms underlying these therapies may result in positive treatment outcomes being inappropriately dismissed as being due only to placebo effects. If this was the case and breathing therapies were consequently condemned to linger forever as fringe therapies, this would be an unfortunate loss.

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APPENDICES

QUESTIONNAIRES

Self Evaluation of Breathing Questionnaire (Version 1)

Self Evaluation of Breathing Questionnaire (Version 2)

Self Evaluation of Breathing Questinnaire (Version 3)

The Nijmegen Questionnaire

PLAIN LANGUAGE STATEMENTS

Measures of Dysfunctional Breathing

MARM Study 1-Inter-Examiner Reliability and Comparison with Lifeshirt

MARM Study 2-Comparison of MARM and Hi Lo in Osteopaths and Students

Breathing Therapy-Effects on MARM, NQ and Dyspnea

The Questionnaires presented in this appendix include

The Self Evaluation of Breathing Questionnaire (SEBQ) – Version 1, 2 and 3

SEBQ Version 1 – was the original questionnaire administer to research participants

SEBQ Version 2- was the questionnaire attached as an appendix to the published manuscript. . It includes additional items recommended in discussion of this manuscript.

> Courtney, R., & Greenwood, K. M. (2009). Preliminary Investigation of a measure of dysfunctional breathing symptoms: the Self Evaluation of Breathing Questionnaire (SEBQ). *International Journal of Osteopathic Medicine, 12, 121-127*

SEB Q Version 3-is the latest version currently being used by practitioners and scheduled to be published in a book. It includes the same items as SEBQ version 2 but some wording of items is changed.

The Nijmegen Questionnaire

SELF EVALUATION OF BREATHING QUESTIONNAIRE- (VERSION 1)

	Never or not true at all	Occasionally a bit true	Frequently mostly true	Very frequently – very true
I get easily breathless on physical exertion out of proportion to my fitness	0	1	2	3
I get breathless even when resting	0	1	2	3
I get breathless when I am anxious	0	1	2	3
I get short of breath or very tired when reading out loud or talking a lot	0	1	2	3
I feel breathlessness in association with other physical symptoms	0	1	2	3
I feel that the air is stuffy, as if there is not enough air in the room.	0	1	2	3
I feel I cannot get a deep or satisfying breath	0	1	2	3
I can't catch my breath	0	1	2	3
My breathing feels stuck, restricted	0	1	2	3
I Feel that my ribcage is tight and can't expand.	0	1	2	3
My clothing often feels too tight or uncomfortable around my chest.	0	1	2	3
I sigh, yawn or gasp.	0	1	2	3
I find myself holding my breath at various times	0	1	2	3
I notice myself breathing shallowly using my upper chest and shoulders.	0	1	2	3
I notice myself breathing quickly.	0	1	2	3
I notice myself mouth breathing	0	1	2	3
I have trouble co-ordinating my breathing when I am speaking	0	1	2	3
I notice myself breathing irregularly.	0	1	2	3

THE SELF EVALUATION OF BREATHING QUESTIONNAIRE (VERSION 2)

Scoring this questionnaire: *(0) never/not true at all; (1) occasionally/a bit true; (2) frequently-mostly true; and, (3) very frequently/very true*

1	I get easily breathless out of proportion to my fitness	*0*	*1*	*2*	*3*
2	I notice myself breathing shallowly	*0*	*1*	*2*	*3*
3	I get short of breath reading and talking	*0*	*1*	*2*	*3*
4	I notice myself sighing	*0*	*1*	*2*	*3*
5	I noticing myself yawning	*0*	*1*	*2*	*3*
6	I feel I cannot get a deep or satisfying breath	*0*	*1*	*2*	*3*
7	I notice that I am breathing irregularly	*0*	*1*	*2*	*3*
8	My breathing feels stuck or restricted	*0*	*1*	*2*	*3*
9	My ribcage feels tight and cant expand	*0*	*1*	*2*	*3*
10	I notice that I am breathing quickly	*0*	*1*	*2*	*3*
11	I get breathless when I am anxious	*0*	*1*	*2*	*3*
12	I find myself holding my breath	*0*	*1*	*2*	*3*
13	I feel breathless in association with other physical symptoms	*0*	*1*	*2*	*3*
14	I have trouble coordinating my breathing when I am speaking	*0*	*1*	*2*	*3*
15	I cant catch my breath	*0*	*1*	*2*	*3*
16	I feel that the air is stuffy, as if not enough air in the room	*0*	*1*	*2*	*3*
17	I get breathless even when I am resting	*0*	*1*	*2*	*3*
18	My breath feels like it does not go in all the way	*0*	*1*	*2*	*3*
19	My breath feels like it does not go out all the way	*0*	*1*	*2*	*3*
20	My breathing is heavy	*0*	*1*	*2*	*3*
21	I feel that I am breathing more	*0*	*1*	*2*	*3*
22	My breathing requires work	*0*	*1*	*2*	*3*
23	My breathing requires effort	*0*	*1*	*2*	*3*
24	I find myself breathing through my mouth during the day	*0*	*1*	*2*	*3*
25	I breathe through my mouth at night while I am asleep	*0*	*1*	*2*	*3*

THE SELF EVALUATION OF BREATHING QUESTIONNAIRE (VERSION 3)

Scoring this questionnaire: *(0) never/not true at all; (1) occasionally/a bit true; (2) frequently-mostly true; and, (3) very frequently/very true*

1	I get easily breathless out of proportion to my fitness	*0*	*1*	*2*	*3*
2	I notice myself breathing shallowly	*0*	*1*	*2*	*3*
3	I get short of breath reading and talking	*0*	*1*	*2*	*3*
4	I notice myself sighing	*0*	*1*	*2*	*3*
5	I noticing myself yawning	*0*	*1*	*2*	*3*
6	I feel I cannot get a deep or satisfying breath	*0*	*1*	*2*	*3*
7	I notice that I am breathing irregularly	*0*	*1*	*2*	*3*
8	My breathing feels stuck or restricted	*0*	*1*	*2*	*3*
9	My ribcage feels tight and cant expand	*0*	*1*	*2*	*3*
10	I notice myself breathing quickly	*0*	*1*	*2*	*3*
11	I get breathless when I'm anxious	*0*	*1*	*2*	*3*
12	I find myself holding my breath	*0*	*1*	*2*	*3*
13	I feel breathless in association with other physical symptoms	*0*	*1*	*2*	*3*
14	I have trouble coordinating my breathing when I am speaking	*0*	*1*	*2*	*3*
15	I can't catch my breath	*0*	*1*	*2*	*3*
16	I feel that the air is stuffy, as if not enough air in the room	*0*	*1*	*2*	*3*
17	I get breathless even when I am resting	*0*	*1*	*2*	*3*
18	My breath feels like it does not go in all the way	*0*	*1*	*2*	*3*
19	My breath feels like it does not go out all the way	*0*	*1*	*2*	*3*
20	My breathing is heavy	*0*	*1*	*2*	*3*
21	I feel that I am breathing more	*0*	*1*	*2*	*3*
22	My breathing requires work	*0*	*1*	*2*	*3*
23	My breathing requires effort	*0*	*1*	*2*	*3*
24	I find myself breathing through my mouth during the day	*0*	*1*	*2*	*3*
25	I breathe through my mouth at night while I sleep	*0*	*1*	*2*	*3*

THE NIJMEGEN QUESTIONNAIRE

Please tick how often you suffer from the symptoms listed.

	Never 0	Rare 1	Sometimes 2	Often 3	Very often 4
Chest pain					
Feeling tense					
Blurred vision					
Dizzy spells					
Feeling confused					
Faster & 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					
Feelings of anxiety					

2.1 Measures of Dysfunctional Breathing

2.2 MARM Study 1- Inter-examiner Reliability and Comparison with RIP

2.3 MARM Study 2- Comparison of MARM and Hi Lo in Osteopaths and Students

2.4 Breathing Therapy- Effects on MARM, NQ and Dyspnea

PATIENT EXPLANATORY STATEMENT

Research Project-ASSESSMENT OF MEASUREMENT TOOLS USED TO IDENTIFY DYSFUNCTIONAL BREATHING

Investigators: Professor Marc Cohen, Dr. Ray Myers, Rosalba Courtney.

Dear Volunteer,

Thank you for considering volunteering for this project. This purpose of this statement is to ensure that you have a clear understanding of this project and what it is trying to achieve. Also this statement will tell you what is required of you and what to expect from us.

This study is being undertaken by Rosalba Courtney, through the School of Life Sciences at RMIT University, Melbourne, Australia. The primary supervisor of this project is Professor Marc Cohen ,the second supervisor is Dr. Ray Myers.

THE PROJECT EXPLAINED.

This project hopes to contribute to the understanding of some of the measurement tools used to determine dysfunctional breathing so that clinicians can more confidently decide when dysfunctional breathing may be a contributing factor to a person's health problems.

Many research studies over the last 50 years have indicated that between 5-10% of the healthy population has "dysfunctional breathing". The figure is much higher in people suffering from anxiety (up to 80%) or conditions such as asthma (up to 30%). Some people consider that having normal breathing is very important in the maintenance of optimal health; however dysfunctional breathing is often overlooked by clinicians.

Definition of Dysfunctional Breathing:

Dysfunctional breathing is breathing that contributes to the aggravation of physical or psychological symptoms.

Dysfunctional breathing includes hyperventilation, a condition where people breathe more than their body's need, this results in acute or chronic deficiency of carbon dioxide in the blood. Dysfunctional breathing also includes other types of breathing pattern disorders which may not result in carbon dioxide depletion.

In this project we will apply some measurements that have been used for identifying dysfunctional breathing and see how well they correlate with carbon dioxide levels and how the various measures correlate with each other.

Measures of Dysfunctional Breathing we are hoping to further understand:

Carbon dioxide levels in exhaled air.

This tells us about the carbon dioxide levels in the blood. When we are overbreathing or hyperventilating, carbon dioxide levels will be lower than normal. Exactly what levels definitely indicate hyperventilation are controversial and vary according to individual factors.

Breath HoldingTime.

It has been shown by many investigators that dysfunctional breathing and hyperventilation are associated with shortened breath holding ability.

One of the important things this project hopes to clarify is the claim made by Russian physician Dr. Buteyko that a person's breath holding time correlates precisely with their carbon dioxide levels.

The Nijmegen Questionnaire

This questionnaire has been shown to have a strong ability to predict people whose symptoms are related to hyperventilation syndrome or dysfunctional breathing. This research project hopes to see how test response on this questionnaire correlate with carbon dioxide levels. We also wish to see if there is a correlation between test scores on this questionnaire and breath holding time.

Variability of the Heart Rate

The heart rate usually responds to changes in breathing and to whether a person is inhaling or exhaling. In people with dysfunctional breathing the heart rate may not be as responsive to changes in breathing. Information about heart rate variability may be useful as part of the overall picture of dysfunctional breathing. The investigators will see how this correlates with the other measures of dysfunctional breathing.

The pattern of muscle use in breathing.

Unusual use of the muscles of breathing is one aspect of dysfunctional breathing**.**

The electrical resistance of points on your fingers and toes

This may indicate the amount of activity in your nervous system, a factor that may be reflected in your breathing.

OVERVIEW OF WHAT YOU WILL BE ASKED TO DO IF YOU PARTICIPATE IN THIS PROJECT

You will only be required to attend for one session of assessment. The time anticipated for the tests is 60 to 90 minutes.

After giving us some basic health details

You will undertake a lung function test with a spirometer. This involves you blowing hard into a tube attached to a computer based spirometry program. The purpose of this is to see what your lung capacity is and to determine if there may be some undetected lung problem.

As you fill out other questionnaires ** we will measure.

The amount of carbon dioxide in the air you exhale during normal breathing.-This is done with a device called a capnometer. A small plastic tube will be placed in the entrance to each nostril and then hooked over your ears.

The movement of your respiratory muscles.-This is measured with 2 tension sensing band that you will wear on your upper and lower chest.

Variations in the heart rate and relationship between respiration and heart rate-This will be measured either with a finger sensor that picks up changes in pulse pressure and also measures oxygen saturation or a chest strap that picks up information from the heart.

The electrical resistance at your fingers and toes.

As you finish filling out questionnaires we will test

Breath Holding Time.-You will be asked to perform some tests of your (unforced) breath holding time. You will to asked to hold your breath 3 times until you feel the first clear and distinct desire to breath or until you get some involuntary muscle movement. Each breath hold is separated by a couple of minutes of normal breathing in between.

EXPLANATION OF QUESTIONNAIRES**

You will be asked to fill in 4 questionnaires.

A general health and medication questionnaire

A questionnaire that is used to give a score on symptoms that are indicators of hyperventilation or dysfunctional breathing.(The Nijmegen questionnaire)

A breathing self evaluation questionnaire- this looks in detail at your breathing symptoms.

An anxiety and depression index.

EXCLUSION FROM THE STUDY

Participation in this trial is limited to adults between the ages of 18-65.

You may be excluded from the study if you have a severe health problem in which the symptoms can not be controlled with medication and/or which prevents you working or independently carrying out the activities of daily life.

KEEPING OF RECORDS AND CONFIDENTIALITY

You will not be identified by name when measurements or results of questionnaires are recorded. All the data that is collected will be grouped together so that individuals can not be identified and so that statistical analysis can be performed.

All data will be stored securely in a locked filing cabinet and/or in a password protected computer. Only authorized personnel will have access to the information. Data will be kept by the researchers for 7 years.

RESULTS OF THE TESTS

You may request a copy of the results of your tests for your own personal records. This can be given to you at the time of the testing.

The tests given to you during this research project are primarily for the purposes of research they are not for diagnostic purposes.

Test results that are suggestive of dysfunctional breathing should be interpreted by your physician. He or she will be able to view the results in the context of your whole medical history and can request further tests if necessary.

RESULTS OF THE RESEARCH

The results will be used to write reports of the research, this may be published in medical or other journal or magazines. The results may also be presented at conferences. You may access the results of the research by contacting the researchers. You will not be personally identified in any dissemination of the results of the research.

WITHDRAWAL FROM PROJECT

You can withdraw at any time, if you so choose and are under no obligation to complete any of the tests or questionnaires.

QUESTIONS ABOUT THE RESEARCH

If you have any questions at any stage about this research project or your involvement you can contact Rosalba Courtney on 02-99183460 or 0414918819

ADVERSE EVENTS OR COMPLAINTS

The measurements are safe and non invasive, however in the unlikely event that adverse events do occur you will be referred to your local doctor. I am also required to notify the RM IT University Human Research Ethics Committee.

Thank you for taking the time to read this form.

Professor Marc Cohen (Supervisor) Dr. Ray Myers (Supervisor) Rosalba Courtney (Principal Investigator)

Any complaints about your participation in this study may be directed to The Secretary of Human Research Ethics Committee, RMIT, 124 La Trobe St. Melbourne Vic. 3000. Telephone 99251745

PATIENT EXPLANATORY STATEMENT

Research Project- COMPARISON OF A MANUAL ASSESSMENT OF RESPIRATORY MOTION (MARM) WITH AMBULATORY RESPIRATORY PLETHYSMOGRAPH MEASUREMENTS USING THE "LIFE SHIRT"

Investigators- Professor Marc Cohen, Dr. Ray Myers, Rosalba Courtney

Dear Participant

You are invited to participate in a research project being conducted by RMIT University. This information sheet describes the project in straight forward language or "plain English". Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate. If you have any questions about the project, please ask any of the investigators.

WHO IS INVOLVED IN THE RESEARCH PROJECT? WHY IS IT BEING CONDUCTED?

This research is being undertaken by Rosalba Courtney through the division of Osteopathy, School of Health Sciences, RMIT University. The supervisors of this project are Professor Marc Cohen and Dr. Ray Myers.

WHY YOU HAVE BEEN APPROACHED?

This research requires the participation of individuals who have an understanding of how to modify their breathing pattern. We have approached yoga teachers, singing teachers and breathing therapy teachers and others who are used to working with their breath.

WHAT IS THE PROJECT ABOUT? WHAT ARE THE QUESTIONS BEING ADDRESSED?

Alteration in the normal balance of thoracic to abdominal motion during breathing is one aspect of dysfunctional breathing. We are testing the reliability of a hands on technique used to measure the balance between thoracic and abdominal motion during breathing. This technique is called the Manual Assessment of Respiratory Motion or MARM. We are trying to see how well this technique is able to pick up subtle changes in breathing. We will test the accuracy of this technique by comparing results from two examiners using the MARRM and with measurements made by a device, the Vivometrics lifeshirt which also measures and records changes in breathing pattern. We are planning to test 10 people.

IF I AGREE TO PARTICIPATE WHAT WILL I BE REQUIRED TO DO?

You will be asked to wear the lifeshirt while the breathing tests are being done. This may be for a period of up to 1 hour. During this time 2 separate examiners will measure the movements of your chest and abdomen during breathing, by placing their hands on your back over the middle and lower rib cage. You will be asked to breathe normally and then to make a series of simple alterations to your posture and breathing while the two examiners test your breathing with the MARM and record their measures.

WHAT ARE THE RISKS OR DISADVANTAGES ASSOCIATED WITH PARTICIPATION?

There are no perceived risks associated with participation in this project. You will only be asked to make ordinary adjustments in your breathing and posture similar to what you would make in your day to day life.The lifshirt does not in any way alter the functions of your body. It measures changes in heart rate and breathing by electrical sensors placed on the outside of your body in the manner of a heart rate monitor.

WHAT ARE THE BENEFITS ASSOCIATED WITH PARTICIPATION?

Your participation will contribute to the furthering of knowledge of dysfunctional breathing patterns and their assessment. You may also personally gain some knowledge about breathing patterns and measurement of dysfunctional *breathing from participating in this research.*

WHAT WILL HAPPEN TO THE INFORMATION I PROVIDE?

All information gathered from your participation will form part of pooled data and you will not be identified personally. Any information given by you will be kept confidential and will be disclosed only if 1) It is to protect you or others from harm 2) a court order is produced or 3) you provide the researchers with written permission.

Results from MARM and Lifeshirt measurements will be combined with other participants results then analysed and findings written up as part of a research thesis for RMIT University. Results may also be presented at conferences and written up for publication in research papers.

Data will be kept in a password protected computer and in a locked filing cabinet. On completion of the study the data will be kept at RMIT for a period of 5 years before being destroyed.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

You have the rights to withdraw your participation at any time without prejudice. You can also ask to have your unprocessed data withdrawn and destroyed provided that it can be reliably identified, and provided that doing so does not increase any risk for you. You also have the right to have any questions answered at any time.

WHOM SHOULD I CONTACT IF I HAVE ANY QUESTIONS?

If you have any questions please contact Rosalba Courtney 02-99183460, crthouse@tpg.com.au or Professor Marc Cohen 03-99257440, marc.cohen@rmit.edu.au

Yours Sincerely,

Rosalba Courtney Professor Marc Cohen
Dr. Ray Myers

Any complaints about your participation in this project may be directed to the Executive Officer, RMIT Human Research Ethics Committee, Research and Innovation, RMIT, GPO Box 2476V, Melbourne, 3001.
The telephone number is (03) 9925 2251. Details of the complaints procedure are available from the above address.

MARM STUDY 2- COMPARISON OF MARM AND HI LO IN OSTEOPATHS AND STUDENTS

INVITATION TO PARTICIPATE IN A RESEARCH PROJECT

PROJECT INFORMATION STATEMENT

PROJECT TITLE- ASSESSMENT OF BREATHING PATTERN USING 2 PALPATION TECHNIQUES: THE MANUAL ASSESSMENT OF RESPIRATORY MOTION (MARM) AND THE HI LO BREATHING ASSESSMENT.

INVESTIGATORS

Rosalba Courtney (PhD candidate, Science, School of Health Sciences, Division of Osteopathy, RMIT University) crthouse@tph.com.au, w) 02-99183460, Professor Marc Cohen (Primary Supervisor, School Health Sciences, RMIT University)marc.cohen@rmit.edu.au, 03-99257440

Dear Participant,

You are invited to participate in a research project being conducted by RMIT University. This information sheet describes the project in straightforward language or "plain English". Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate. If you have any questions about the project, please ask any of the investigators.

WHO IS INVOLVED IN THE RESEARCH PROJECT? WHY IS IT BEING CONDUCTED?

Rosalba Courtney through the School of Health Sciences, at RMIT University, is undertaking this research as part of a PhD project. Professor Marc Cohen is supervising this project.

WHY YOU HAVE BEEN APPROACHED?

This research requires the participation of individuals who are practitioners or student of manual therapy and who 1. Have an interest in learning these techniques 2. Are willing to assist in research.

WHAT IS THE PROJECT ABOUT? WHAT ARE THE QUESTIONS BEING ADDRESSED?

In this study we will be teaching experienced manual therapists, such as Osteopaths, Chiropractors and Physiotherapists and manual therapy students some techniques for evaluating breathing pattern. We then plan to test how well the techniques work in determining breathing pattern in the hands of experienced as compared to less experienced practitioners. The person being examined (the breather) will be told to follow certain breathing instructions, which will be unknown to the examiner. The examiner will have to determine what breathing instruction the breather is following. Two breathing assessment techniques will be used to assess breathing pattern. These techniques are the Manual Assessment of Respiratory Motion (MARM) and the Hi Lo breathing assessment. We have 2 aims: (1) to compare examiners accuracy while using the MARM and Hi Lo to test the usefulness of these techniques (2) To determine if there are differences between relatively inexperienced manual therapists and experienced practitioners when predicting breathing pattern using the MARM and the Hi Lo breathing assessment.

IF I AGREE TO PARTICIPATE WHAT WILL I BE REQUIRED TO DO?

You will be asked to participate in training session during which you will be taught the theoretical and practical aspects of these techniques. At the end of the training session you will work with a partner and takes turns in assessing each others breathing pattern using the 2 techniques. You will be participating in this research as a "breather" and as a breathing examiner taking turns with a partner in these two activities.

WHAT ARE THE RISKS OR DISADVANTAGES ASSOCIATED WITH PARTICIPATION?

There are no perceived risks associated with participation in this project. You will only be asked to make ordinary adjustments in your breathing similar to what you would make in your day-to-day life. Your personal accuracy with using these techniques is not being tested: we are interested in the overall performance of the group and the usefulness of the technique.

WHAT ARE THE BENEFITS ASSOCIATED WITH PARTICIPATION?

You will increase your understanding of dysfunctional breathing and of the manual techniques used to assess it. Your participation will help validate a potentially useful clinical test for dysfunctional breathing.

WHAT WILL HAPPEN TO THE INFORMATION I PROVIDE?

All information gathered from your participation will form part of pooled data and you will not be identified personally. Any information given by you will be kept confidential and will be disclosed only if 1) It is to protect you or others from harm 2) a court order is produced or 3) you provide the researchers with written permission.

Your results from MARM and Hi Lo measurements will be combined with other participants results then analysed and findings written up as part of a research thesis for RMIT University. Results may also be presented at conferences and written up for publication in research papers.

Data will be kept in a password-protected computer and in a locked filing cabinet. On completion of the study the data will be kept at RMIT for a period of 5 years before being destroyed.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

You have the rights to withdraw your participation at any time without prejudice. You can also ask to have your unprocessed data withdrawn and destroyed provided that it can be reliably identified, and provided that doing so does not increase any risk for you. You also have the right to have any questions answered at any time.

WHOM SHOULD I CONTACT IF I HAVE ANY QUESTIONS?

If you have any questions please contact Rosalba Courtney on work phone number 02-99183460, crthouse@tpg.com.au or Professor Marc Cohen 03-99257440, marc.cohen@rmit.edu.au

Yours Sincerely,

Rosalba Courtney Professor Marc Cohen

Any complaints about your participation in this project may be directed to the Executive Officer, RMIT Human Research Ethics Committee, Research and Innovation, RMIT, GPO Box 2476V, Melbourne, 3001.

The telephone number is (03) 9925 2251. Details of the complaints procedure are available from the above address

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Amersfoort 7 – 5 - 2010

Consent form regarding participating in research project 'Resultaten Project Adem en Ontspanningstherapie'

All patients who are admitted for breathing and relaxation therapy have been explained

1. that a number of their outcome data will be submitted to and included in an online database for 'outcome assessment of breathing therapy', if they agree to that.

2. that the outcome data include sex and age, the main complaint, effect on treatment on main complaint, questionnaire scores and MARM assessment before and after treatment, and number of treatment sessions. The data include a personal identification number, which corresponds to the patient information of the therapist that is doing the treatment, and which is the only way the data may be checked for errors by the therapist.

3. that the data will be strictly used to collect evidence of treatment outcome on a group basis and no attempt will be made to trace the individual subject, unless the subject consents to that. The data will be used to publish outcome results.

4. that the subject is free to withhold consent, now and also at a later stage. The data will be submitted only at the end of treatment.

Only when the subject understood and consented, treatment data were submitted. Otherwise the file received a mark 'not for research project'.

E L M Anthonissen
J van Dixhoorn