

Targeting pCO₂ in Asthma: Pilot Evaluation of a Capnometry-Assisted Breathing Training

Alicia E. Meuret · Thomas Ritz · Frank H. Wilhelm ·
Walton T. Roth

Published online: 13 June 2007
© Springer Science+Business Media, LLC 2007

Abstract

Objectives This pilot study aimed to evaluate the feasibility and potential benefits of a novel biofeedback breathing training for achieving sustained increases in pCO₂ levels.

Methods Twelve asthma patients were randomly assigned to an immediate 4-week treatment group or waiting list control. Patients were instructed to modify their respiration in order to change levels of end-tidal pCO₂ using a hand-held capnometer. Treatment outcome was assessed in frequency and distress of symptoms, asthma control, lung function, and variability of peak expiratory flow (PEF).

Results We found stable increases in pCO₂ and reductions in respiration rate during treatment and 2-month follow-up. Mean pCO₂ levels rose from a hypocapnic to a normocapnic range at follow-up. Frequency and distress of symptoms was reduced and reported asthma control increased. In addition, mean PEF variability decreased significantly in the treatment group.

Conclusions Our pilot intervention provided evidence for the feasibility of pCO₂-biofeedback training in asthma patients.

Keywords Asthma · Hypocapnia · Breathing training · pCO₂ · Biofeedback

Abbreviations

pCO ₂	Maximum partial pressure of CO ₂
f _R	Respiration rate per minute
FEV1	Forced expiratory volume in the first second
FVC	Forced vital capacity
R _{int}	Interrupter resistance
PEF	Peak expiratory flow

Introduction

Alternative and complementary interventions for asthma have attracted considerable attention in recent years (Wright 2004). Among these, interventions targeting breathing behavior have been recommended as adjunctive treatments for some time. However, little empirical evidence is currently available in support of the efficacy of various forms of breathing training (Ernst 2000; Holloway and Ram 2004; Ritz and Roth 2003). This is surprising because a number of these methods, such as nasal breathing, pursed-lip breathing, hypoventilation, or respiratory muscle relaxation, are based on valid psychophysiological rationales (Ritz and Roth 2003). One recent trial of breathing training teaching slow, regular and abdominal breathing to reduce potential hyperventilation showed positive effects on patients' quality of life (Thomas et al. 2003). However, no physiological measurements were reported that would have confirmed successful manipulation of breathing

A. E. Meuret (✉) · T. Ritz
Department of Psychology, Southern Methodist University,
6424 Hilltop Lane, Dallas, TX 75205, USA
e-mail: ameuret@smu.edu

T. Ritz (✉)
e-mail: tritz@smu.edu

F. H. Wilhelm
University of Basel, Basel, Switzerland

W. T. Roth
Stanford University Medical School, Stanford, CA, USA

W. T. Roth
VA Palo Alto Health Care System, Palo Alto, CA, USA

patterns or treatment effects on lung function. Another breathing training method that promotes a reduction in hypocapnia directly by slow and shallow breathing and breath-hold exercises has generated more systematic research in controlled intervention studies. Originally developed by the Russian physician Buteyko (Stalmatski 1997), the technique is based on the idea that asthma exacerbations are caused by chronic hypocapnic breathing, and that retraining of patients' breathing pattern to achieve a long-term reduction in ventilation will result in an improvement in asthma control. Recent controlled trials of this technique reported reductions in medication (in particular β -adrenergic bronchodilators) and improvements in quality of life of the patients (Bowler et al. 1998; Cooper et al. 2003; Opat et al. 2000; McHugh et al. 2003).

It has been known for some time that hypocapnic hyperventilation exacerbates asthma (Herxheimer 1946). Experimental studies have demonstrated a decline in lung function when carbon dioxide partial pressure ($p\text{CO}_2$) is reduced (Newhouse et al. 1964; van den Elshout et al. 1991; Sterling 1968). Also, lower $p\text{CO}_2$ levels have been linked to airway hyperresponsiveness in asymptomatic asthma patients (Osborne et al. 2000). Excessive ventilation without hypocapnia is a key mechanism in the development of bronchospasm in asthma and has been suggested to explain exercise-induced bronchoconstriction (McFadden and Gilbert 1994). Repeated excessive ventilation with cold dry air has also been shown to result in increases in airway hyperresponsiveness, inflammation and in impairments in response to β -adrenergic bronchodilators in an animal model (Davis and Freed 2001; Davis et al. 2003). There is evidence for basal ventilatory states or ventilatory responses that put asthma patients at greater risk of exacerbations. While oxygen saturation is usually normal in asthma patients except for periods of severe exacerbation (Wagner et al. 1996), studies have found lower resting $p\text{CO}_2$ in patients than in healthy controls (Hombrey et al. 1988; Osborne et al. 2000; Ritz et al. 2003) or stronger minute ventilation or respiratory drive at baseline or in response to exercise (Ritz et al. 1998; Varray and Prefaut 1992), added resistive loads (Kelsen et al. 1979), or methacholine-induced bronchoconstriction (Fujimori et al. 1996). Hypocapnia has also frequently been observed in asthma attacks (McFadden and Lyons 1968).

While there is some evidence in support of the basic assumptions of the Buteyko breathing technique as an adjunctive treatment for asthma, published controlled trial have provided little evidence that $p\text{CO}_2$ had been targeted successfully (Ritz and Roth 2003; Bruton and Holgate 2005; Walters and Johns 2001). None of the reported trials has shown that respiratory gas exchange can be significantly altered by this type of breathing training. Only one included measurements of $p\text{CO}_2$ and minute ventilation, but

significant changes at 4 weeks post-training or 2-months follow-up were only seen in the latter index (Cooper et al. 2003). Demonstrating that stable $p\text{CO}_2$ levels have been brought into a healthy range is necessary to confirm Buteyko's idea of how his hypoventilation training works (Stalmatski 1997). Without that, only nonspecific factors may be responsible for the reported improvements. For example, any therapeutic rationale that strongly emphasizes a reduction in bronchodilator use might well cause patients to report reduction of that use after weeks of training.

Hence, we designed an adjunctive training for asthma patients that directly targets $p\text{CO}_2$ and tested it in a small number of patients. The results would encourage or discourage a more comprehensive clinical intervention trial using hypoventilation training. Feedback of $p\text{CO}_2$ -levels can bring them under the voluntary control of the patient, as has been demonstrated with patients suffering from chronic hyperventilation (Folgering et al. 1980; van Doorn et al. 1982). In prior research, we successfully developed and tested a capnography-assisted breathing training for reducing hypocapnia in patients with panic disorder (Meuret et al. 2001, 2004). The technique resulted in elevations of end-tidal $p\text{CO}_2$ -levels during laboratory testing over weeks and months. In this study we report the adaptation and pilot testing of this technique in asthma patients. Our main goal was to demonstrate the feasibility of the technique and to provide initial evidence of its efficacy.

Methods

Participants

Adult asthma patients were recruited by advertisement in local newspapers, online message boards, and posters in medical school departments for a study of breathing training in asthma. The assessment schedule included participation in an initial interview on psychiatric and asthma history, in two laboratory assessments, one 24-h ambulatory monitoring day, and a 4-week breathing training program with an 8-week follow-up assessment. Potential participants had to be non-smokers between 18 and 60 years old, which reduced the risk of including patients with chronic obstructive pulmonary disease. Further exclusion criteria were use of oral corticosteroids in the previous 3 months, cardiovascular disease, neurological disorders, clinically significant levels of depression, or lifetime diagnosis of schizophrenia, dementia, or psychosis. Patients were also screened for the presence of anxiety disorder, which was not an exclusion criterion, but would potentially add to the interpretation of findings. Twenty-one patients were screened initially, of which 9 (42.9%) had scheduling problems or were not eligible because they

did not meet the inclusion criterion. The final 12 patients were randomly assigned to an immediate 4-week treatment group ($n = 8$) or a 4-week waiting list group ($n = 4$). Waiting list patients were offered an identical treatment after the four weeks.

Suitable candidates were invited for medical history taking, which focussed on their asthma, and included lung function testing by spirometry. Patients also filled in a structured questionnaire on various aspects of their disease manifestation and on diagnostic procedures (lung function testing, bronchial provocation tests, allergy tests), for which they had to contact their general practitioner or specialist and ask for documentation. All patients had a present diagnosis of asthma. Only one waiting-list patient reported brief previous contact with training in breathing techniques. Participation was voluntary, and informed consent was obtained from all patients. The study was approved by ethical review committees of the VA Palo Alto Health Care System and Stanford University Medical School.

Instruments and Measures

End-tidal pCO_2

End-tidal pCO_2 was measured with a light (320 g), hand-held ($65 \times 128 \times 35$ mm), battery-operated capnometry device (Capnocount mini, Weinmann, Germany), which analyzes exhaled breath pumped into the device through a nasal cannula (Wilhelm et al. 2001a). The instrument displays breath-by-breath end-tidal pCO_2 (in mmHg) and respiration rate (f_R) (in breaths/min), and records them with the time and date of the measurement.

Mechanical Lung Function

Mechanical Lung Function was measured with an electronic pocket spirometer (Jaeger/Toennies, AM2). The best of three expirations was stored in the electronic memory of the device together with a volume-time profile that allows for detection of submaximal performance of the maneuver. Forced expiratory volume in the first second (FEV_1) was used as the primary outcome measure. In addition, peak expiratory flow (PEF) and FEV_1 divided by forced vital capacity (FVC) were extracted at the first session. Before spirometry, interrupter resistance (R_{int} MicroRint, Micro-Medical Ltd., UK) was measured and R_{int} was determined as the average of the median of 10 inspiratory and 10 expiratory interruptions. These measurements were taken initially at each of the five training sessions by an investigator who did not conduct the sessions. This measure of respiratory resistance has the advantage of being effort-independent and provides a more direct index of airway

constriction (Ritz et al. 2002). Before and after the 4-week treatment and at follow-up, patients recorded their PEF five times daily: in the morning after awakening (before bronchodilator), and at approximately 11am, 2 pm, 5 pm, and 8 pm. A brief tone sequence from the AM2 at those times reminded patients to perform the PEF test. From the 3-day recordings, % PEF variability was extracted as follows (Reddel et al. 1999): the morning value before bronchodilator use divided by the patient's personal best value during the 3-day period, multiplied by 100, and subtracted from 100. While peak flow diaries have been shown to be prone to substantial problems with missing values (e.g., Chowieńczyk et al. 1994), adherence of patients with this brief protocol was excellent, with the average number of measurements per day being 5.5 (range: 3.7–6.7) at pre-training, 5.3 (4.3–5.7) at post-training, and 4.9 (3.3–5.7) at follow-up (patients often performed additional measures beyond the specified times). Compliance did not change significantly throughout the observation period, Friedman-Test $\chi(2) = 1.3$, $p = .527$.

Questionnaire measures

Initially, patients filled out a set of questionnaires at home, which covered demographics and information on asthma history, symptom patterns, recent health care utilization, medication use, and effect of medication. Patients were asked to rate how effective their current medication was (rating 1–4, “always”, “most of the times”, “sometimes”, or “never”). At the beginning of each therapy session they filled out a questionnaire on frequency of asthma symptoms and how much distress they had caused (“symptom bother scale”) (Steen et al. 1994), and self-report items of the Asthma Control Questionnaire (Juniper et al. 1999) for the period of the previous week. At the 1st and 5th session and at follow-up the Health Survey Short Form-12 (Ware et al. 1996) was also administered. Patients undergoing training also filled in the Positive Affect and Negative Affect Schedule (PANAS; Watson et al. 1988), from which we analyzed the negative affect subscale scale to explore whether the training had a nonspecific effect on patients' negative mood.

After follow-up assessments, patients were given a treatment evaluation sheet, which they were asked to complete at home and to return in a stamped envelope. On the sheet were the following questions (rated from 0–10, “not at all” to “extremely”): “How *logical* does this treatment appear to you for helping people with asthma?”, “How *confident* are you that this treatment will improve your symptoms of asthma?”, “How *confident* are you that this treatment will improve the control you have over your asthma?”, “How *confident* would you be to recommend this treatment to a friend with asthma?” “How *successful*

do you think this treatment would be in dealing with other problems, for example, headaches or sleeplessness?”

Treatment Procedures

General Rationale and Goal of the Training

Our breathing training was offered only as an adjunctive treatment. Patients were advised to continue their regular preventative medication as recommended by their physician at a stable level throughout the 4 weeks of treatment. A clinical psychologist experienced in breathing techniques conducted the treatment sessions on an individual basis. The breathing training rationale cited evidence that hypocapnia and excessive ventilation adversely affect lung function in asthma and can be involved in asthma exacerbations. The training was aimed towards voluntarily increasing self-monitored end-tidal $p\text{CO}_2$ by reducing f_R and variability in the respiratory pattern (e.g. intermittent deep breaths, sighing) through breathing exercises. It was adapted from a breathing retraining protocol recently developed for panic patients (Meuret et al. 2001, 2004).

Before treatment, patients underwent a 24-h ambulatory monitoring of autonomic function (electrocardiogram, electrodermal activity, skin temperature), lung function (spirometry) and respiration (inductance plethysmography, capnography). Recordings of respiration were subsequently used qualitatively in the initial session of the breathing training.

Components of the Treatment

The training consisted of five weekly treatment sessions (initial session plus four treatment sessions) of approximately 1 h duration. The treatment had five major components: (a) educating patients about the role of breathing in asthma exacerbations, (b) directing their attention to their respiratory patterns, particularly those observed in 24-h monitoring records, (c) having them perform various breathing maneuvers with capnometer feedback to experience how changes in breathing affect physiology and symptoms, (d) teaching them ways to simultaneously control $p\text{CO}_2$ levels, f_R , and tidal volume, (e) and having them practice breathing exercises at home.

Home exercises

An individual home training exercise consisted of three parts: (a) an initial 2-min period, during which patients sat quietly with their eyes closed (b) a 10-min paced breathing period during which patients breathed in synchrony with tones from a tape while trying to increase $p\text{CO}_2$ and decrease f_R using the display of the capnometer for feedback,

and (c) a 5-min breathing period without pacing tones during which patients were to maintain their previously paced f_R and $p\text{CO}_2$ level using feedback from the display. Pacing tones started at 13 breaths/min in the first week, and switched to 11, 9, and 6 breaths/min in subsequent weeks. Before and after each exercise patients rated their current symptoms and mood in the electronic diary of the pocket spirometer and then measured their lung function. They also filled in a separate diary sheet with information on medication, prior physical activity, and their observed $p\text{CO}_2$ levels, f_R , and PEF. All instructions and pacing tones for home exercises were given on standardized pre-recorded audiotapes, and patients were provided with a pocket-sized cassette player. Patients were instructed to gradually adjust their breathing patterns (f_R , rhythm, and depth) though slow, shallow, and abdominal breathing to reach or maintain a $p\text{CO}_2$ level around 40 mmHg. If levels exceeded 45 mmHg, they should reduce their efforts and let levels fall back closer to 40.

Treatment sessions

In the first two weeks the emphasis was largely on stabilization of breathing patterns (f_R and rhythm), while in the last two weeks it was shifted to normalizing $p\text{CO}_2$. For patients with initial $p\text{CO}_2$ levels within the normal range (37–40 mmHg; 3 patients in the treatment group, 2 in the waiting list), treatment focused on regularity of breathing to prevent $p\text{CO}_2$ fluctuations. Exercises were to be performed twice a day for 17 min, at home or elsewhere.

In the first session patients were presented a series of charts with information about effects of hyperventilation on lung function and symptoms in asthma, the relationship between symptoms, anxiety, and hyperventilation, and the therapy goals. The weekly hourly sessions began with filling out weekly questionnaires on symptoms and asthma control, followed by 3-min $p\text{CO}_2$ measurements and lung function assessments. Capnometer exercise data recorded during the previous week were then reviewed. The trainer examined individual capnometer print-outs with the patient, looking for evidence of concordance between changes in $p\text{CO}_2$ and f_R and changes in symptoms before and after the exercises. Analysis of exercises was followed by further training with the feedback device. At the end of the session, patients were instructed on how to use the new breathing tapes. The final session concentrated on maintenance of treatment gains.

Patients returned to individual treatment and assessment sessions at the same time of the day \pm 2 h. Those who used higher doses of bronchodilator medication were encouraged to reduce those doses and practice the breathing maneuvers as long as symptoms were still tolerable. At the 5th treatment session, the pacing tapes and capnometer

were collected from the patients, who were encouraged to continue applying the breathing techniques whenever they found them helpful.

Waiting List Condition

Waiting-list patients were asked to start treatment after a period of 4 weeks. They received the same assessment of PEF variability, basal $p\text{CO}_2$, lung function, asthma symptoms, and health status as the immediate treatment patients. Following the waiting-list period, two patients chose to participate in the training, while two others had either scheduling problems or an asthma exacerbation requiring oral corticosteroids.

Data Analysis

Because the size of the control group was small, we limited inferential statistics to the treatment group and used control group means for qualitative comparison only. Treatment effects were analyzed with one-way repeated measures ANOVAs with pre-treatment, post-treatment, and follow-up as three time points. Where the sphericity assumption was violated, significance levels were corrected using the Geisser-Greenhouse epsilon. In those cases, we report the original degrees of freedom and the corrected significance levels. Bronchodilator use (item 6 of the asthma control questionnaire) was analyzed using the nonparametric Freedman rank test due to a lack of normal distribution. Post-hoc comparison of post-treatment and follow-up with pre-treatment means used the Newman–Keuls procedure.

Results

Patient Characteristics

Patients in the treatment group were predominantly married women, Caucasian (beyond that, 1 woman reported being 80% African American, 20% Native American, and 1 woman 100% Asian/Pacific Islander), currently employed, and well educated (on average 17 years) (Table 1). Five treatment patients (62.5%) reported onset of asthma before the age 18 years. Control patients were mostly comparable, but were younger and 2 (50%) were Non-Caucasian (1 woman 50% Spanish 50% Tunesian, 1 man 100% Hispanic). Patients had mainly mild intermittent to moderate persistent disease severity; with 50% treatment and 25% control patients reporting daily symptoms. Daily activities were affected every day in 2 (25%) treatment and 1 (25%) control patient. Nighttime symptoms at least up to 2 times per month were reported by 6 (75%) treatment and 2 (50%) control participants. All patients reported that their medication

helped against shortness of breath “most of the time”, while 1 treatment (12.5%) and 1 control patient (25%) reported that it helped against cough and wheezing only “sometimes” or “never”. Patients reported only up to one emergency treatment in the previous year, with proportionally more controls patients reporting such incidences (see Table 1). Also, FEV_1/FVC was somewhat lower in the control group. The beginning of treatment was distributed across one year (one patient in January, one in March, two in April, one in May, one in August, one in September, and one in November), while two waiting-list patients were enrolled in May, and two in October. Most patients except for one in the treatment and one in waiting-list group reported having asthma symptoms typically in more than one season. One patient reported having had panic attacks in the past, but did not have any attacks during treatment or follow-up.

Treatment Outcome

Evidence of Manipulation Success: End-tidal $p\text{CO}_2$ and Respiration Rate

The treatment resulted in significant $p\text{CO}_2$ increases and f_R decreases that were stable through follow-up, as shown by mean values recorded at the beginning of the first and last treatment and follow-up session (Table 2). Data from individual patients showed $p\text{CO}_2$ values at follow-up that were higher than at pre-treatment in all participants of the treatment group, and respiration rate dropped substantially in five participants (Fig. 1). Waiting-list patients remained mostly stable. One participant had rather high $p\text{CO}_2$ -levels (50 mmHg) at post-treatment measurements, but showed more moderate levels (42.7 mmHg) at follow-up. Also, inspection of his records during the 4th training week showed that the maximum $p\text{CO}_2$ values he had reached during individual exercises ranged from 40 to 44 mmHg.

Treatment Adherence

None of the recruited patients ended their participation in the trial prematurely. Of the required 13 weekly home exercises, patients completed 11.3 ± 2.7 , 13.0 ± 1.1 , 12.6 ± 1.8 , 11.3 ± 4.1 home exercises, for the 1st, 2nd, 3rd, and 4th week, respectively. Some patients performed one additional exercise and one of them 3 additional exercises in one week. Only one patient showed a low compliance during the 4th week of the training with a total of 3 home exercises.

Questionnaire Measures

Significant decreases in frequency of symptoms and distress by symptoms were reported in the treatment group (Table 2).

Table 1 Demographics and asthma-related variables among patients in immediate treatment and waiting list conditions

	Treatment (<i>n</i> = 8)	Wait-list control (<i>n</i> = 4)
Patient characteristics		
Gender, women (%)	75.0	75.0
Age in years (mean, range)	43.5 ± 11.0	34.0 ± 15.5
Ethnicity, White Caucasian (%)	75.0	50.0
Family and educational background		
Married (%)	87.5	50.0
Years of education	17.0 ± 1.9	17.3 ± 2.5
Currently working (%)	75.0	75.0
Asthma characteristics		
Age of asthma onset, years, (mean ± SD)	18.1 ± 15.9	17.0 ± 15.4
Family history of asthma and/or allergies positive, (%)	75.0	75.0
Skin test for allergy, positive (%)	100	100
Frequency of symptoms, rating 1–4, (mean ± SD)	2.1 ± 1.0	1.5 ± 1.0
Limitation of daily activities, rating 1–4, (mean ± SD)	2.0 ± 0.8	1.5 ± 1.0
Night time symptoms, rating 0–4, (mean ± SD)	1.8 ± 1.5	1.0 ± 1.4
Asthma care		
Short-acting bronchodilators (%)	87.5	50.0
Long-acting bronchodilators (%)	25.0	50.0
Inhaled corticosteroids (%)	87.5	100.0
Leucotriene inhibitors (%)	50.0	50.0
Anti-histaminics (%)	12.5	50.0
Mast cell stabilizers (%)	25.0	0.0
Effective for short of breath, rating 1–4, (mean ± SD)	2.0 ± 0.0	2.0 ± 0.0
Effective for cough, rating 1–4, (mean ± SD)	2.1 ± 0.4	3.0 ± 1.4
Effective for wheezing, rating 1–4, (mean ± SD)	1.9 ± 0.6	2.7 ± 1.2
Emergency treatment, frequency previous year (%)	12.5%	50%
Lung function		
PEF % predicted (mean ± SD)	99.3 ± 16.8	103.1 ± 18.7
FEV ₁ /FVC (mean ± SD)	0.82 ± 0.11	0.62 ± 0.18

At the same time, self-reported asthma control increased. General health status measured by the SF-12 and negative affects measured by the PANAS remained unchanged.

Lung Function

Basal lung function with regard to FEV₁ and R_{int} remained stable. On the other hand, PEF variability fell through follow-up. Individual values suggested a rather uniform decrease in symptoms and PEF variability for treatment patients (Fig. 2).

Medication

All patients except for one in the treatment group remained on a stable level of preventative medication during the four weeks of treatment. This patient increased his inhaled

corticosteroid dose in the 4th week due to a cold. He then discontinued all medication for the 8 weeks leading up to follow-up assessments, and reported being able to control symptoms (which were mainly cough) usually within one minute using breathing techniques. Recalculating the analyses without this patient did not change findings substantially. At follow-up one more patient had discontinued all medication, and one had reduced the inhaler corticosteroid dose, while one patient had been prescribed additional leukotriene inhibitor medication and for one, the leukotriene inhibitor had been replaced by an inhaled corticosteroid. Preventative medication levels remained stable in waiting-list patients.

On average, bronchodilator use remained unchanged, at rather low levels. Initially, only four patients in the treatment group reported bronchodilator use, and none in the control group. After four weeks, three treatment patients

Table 2 Manipulation success and treatment outcome variables among patients in immediate treatment ($n = 8$) and waiting list ($n = 4$) conditions

	Pre-Treatment	Post-Treatment ^a	Follow-up ^a	Time effect for $df = 2,14^b$	Effect size d
End-tidal pCO ₂					
Treatment	34.4 ± 4.3	38.5 ± 5.8*	40.3 ± 2.6**	$F = 8.71, p = .011$	1.83
Waiting-list	35.9 ± 4.2	35.3 ± 3.9			
Respiration Rate					
Treatment	15.1 ± 3.9	10.0 ± 3.6*	8.9 ± 4.9**	$F = 6.79, p = .030$	0.81
Waiting-list	16.3 ± 4.1	16.4 ± 3.4			
Asthma Symptoms					
Treatment	1.3 ± 0.5	0.8 ± 0.5**	0.4 ± 0.3**	$F = 14.03, p < .001$	1.29
Waiting-list	0.6 ± 0.4	0.6 ± 0.5			
Asthma Symptom (Distress)					
Treatment	1.1 ± 0.6	0.6 ± 0.7**	0.5 ± 0.5**	$F = 7.34, p = .007$	0.89
Waiting-list ^d	0.6 ± 0.3	0.9 ± 0.4			
Asthma Control ^c					
Treatment	1.3 ± 0.9	1.0 ± 0.8	0.5 ± 0.4*	$F = 5.45, p = .021$	1.01
Waiting-list	0.8 ± 0.8	0.9 ± 0.8			
FEV ₁					
Treatment	2.33 ± 0.47	2.32 ± 0.33	2.36 ± 0.46	$F = 0.05, p = .857$	0.07
Waiting-list	2.24 ± 0.73	2.53 ± 0.42			
R _{int}					
Treatment ^e	0.49 ± 0.18	0.44 ± 0.10	0.39 ± 0.10	$F = 1.53, p = .257$	0.51
Waiting-list ^d	0.42 ± 0.20	0.42 ± 0.17			
PEF Variability (%)					
Treatment	25.5 ± 15.4	19.8 ± 12.2*	18.2 ± 11.4*	$F = 4.41, p = .035$	0.78
Waiting-list	17.6 ± 14.8	22.0 ± 20.3			

^a significant difference from pre-treatment values: * $p < .05$, ** $p < .01$

^b Time effect for treatment group ($n = 8$) only

^c Scoring direction: lower values equals higher control

^d $n = 3$

^e $n = 7$

had increased their use or started use, while three had decreased their use. Two patients in the control group had started to use their bronchodilators after the 4 weeks on waiting list. At follow-up, four treatment patients had decreased, and one increased their use. One patient reported having had a cold-induced exacerbation a few weeks before the follow-up assessments, which had required an increase in bronchodilator doses. She reported no benefits of breathing exercises for these symptoms, but thought that the exercises had speeded up recovery from her asthma exacerbation.

Patients' Treatment Evaluation

Five patients in the treatment group returned their evaluation sheets. Most of them found the treatment rationale logical (ratings ≥ 7 ; mean = 7.2, range 5–9); only one patient found it “somewhat logical”. On average, patients

were confident that it would enable them to control their symptoms (mean = 6.6, range 2–10) and control their asthma (mean = 6.0, range 2–10). They were likely to recommend the training to a friend (mean = 7.2, range 5–10), and thought it may be helpful for other diseases as well (mean = 6.8, range 5–9). The two control patients participating in the training after the waiting period also returned their forms and showed evaluations closely matching these, with ratings between 5 and 10 on individual scales.

Discussion

In this pilot-study we tested a new breathing training with capnometer feedback to increase asthma patients' pCO₂ levels. We found stable increase in pCO₂ across an 8-week follow-up period in patients trained with this method. Prior studies attempting to train hypoventilation did not attempt

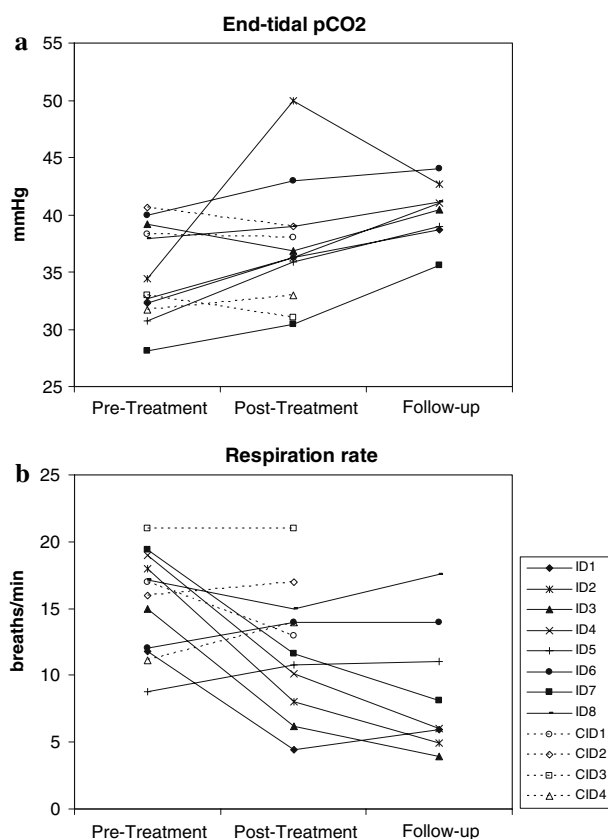


Fig. 1 End-tidal pCO₂ (a) and respiration rate (b) across pre-treatment, post-treatment, and follow-up measurements in 8 asthma patients participating in pCO₂-biofeedback assisted breathing training and 4 control patients

to measure changes in this key parameter or were not able to demonstrate substantial changes (Bowler et al. 1998; Cooper et al. 2003; Opat et al. 2000; McHugh et al. 2003). Compared to other methods our training had the advantage of allowing for an immediate manipulation check by the patient and a systematic evaluation of pCO₂-changes by the therapist. The feedback of a key physiological parameter increases the plausibility of the training and rewards the patient for successful breathing change. Electronic storage of the data allows a review of exercises and serves as an important element in increasing patients' compliance with the home training schedule. Using an electronic spirometer with diary function, our home training relied strongly on electronic recording techniques, which have become state-of-the-art in ambulatory and self-management studies with asthma patients (Chowienzyk et al. 1994; Milgrom et al. 2002; Ritz and Steptoe 2000). Future evaluations of this training could be enhanced by additional electronic monitoring of medication usage (Berg et al. 1998).

These initial results also suggest benefits of the training on patients' asthma control. Frequency and distress of symptoms was reduced, and asthma control increased, over

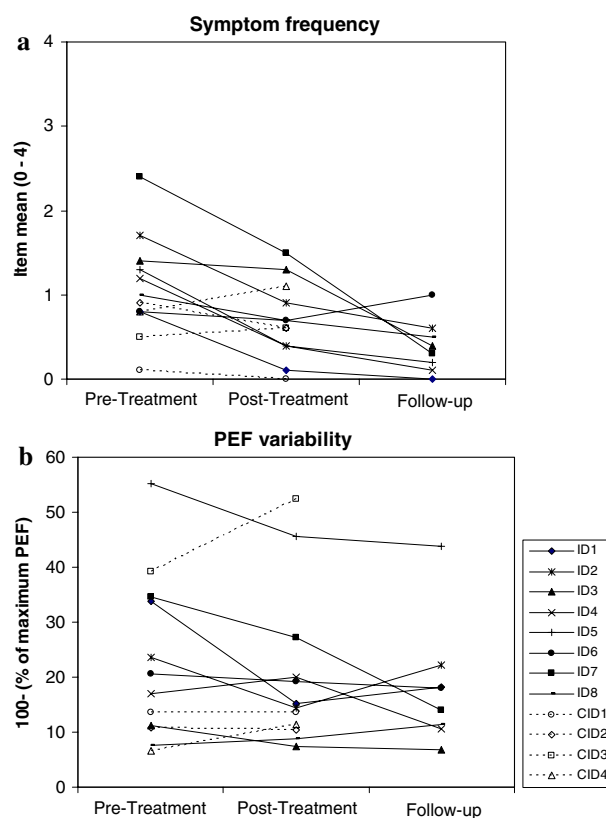


Fig. 2 Treatment outcome in asthma symptoms (a) and PEF variability (b) for 8 asthma patients participating in pCO₂-biofeedback assisted breathing training and 4 control patients

the weeks leading up to follow-up assessments. Lung function remained stable, although decreases were seen in respiratory resistance that might have been significant with a larger sample size. A greater sensitivity of these more direct measures of airway obstruction to the effects psychosocial interventions has been observed before (Lehrer et al. 2004; Ritz et al. 2002).

We also observed a substantial decrease in variability of lung function across weeks to below values typically used as criteria of asthma diagnosis (NHLBI 2003). Thus, improvement through training extended beyond patients' perception of their disease to a somatic outcome measure central to the pathophysiology of asthma. Although the relationship between PEF variability and airway hyperresponsiveness has been debated (Douma et al. 2000; Reddel et al. 1995), such findings are compatible with prior findings of a negative correlation between pCO₂ and hyperresponsiveness to methacholine challenge (Osborne et al. 2000). It is likely that additional benefits of an adjunctive breathing training will be less apparent in basal lung function (or only be visible in more direct measures of airway obstruction) than in a reduction of fluctuations in symptoms. At follow-up, in addition to reduction in

symptoms and greater asthma control through questionnaires, two patients also reported that they felt improvements in their ability to control symptoms and to recover from asthma exacerbation. Although spirometric indices of lung function are typically dependent on patients' effort (Ritz et al. 2002), we do not think that the observed reductions in PEF variability could easily be explained by this factor. Complicated and less plausible assumptions would have to be invoked to explain this finding, such as a reduction in the inconsistency in patients' effort due to therapy. Given the particular index we chose for PEF variability, which contrasts lowest morning values with the maximum value during the measurement period (Reddel et al. 1999), this assumed reduction in inconsistency, would also have to be specific to certain times of the day.

Because our sample was not selected for high levels of severity or low asthma control, we may have been less able to show substantial changes in some of the outcome variables. On average, initial lung function was close to 100% of predicted, and bronchodilator medication use was low. Studies of the Buteyko technique have especially demonstrated reductions at high levels of bronchodilator use. Reductions are important, but assessment by self-report has limitations (Berg et al. 1998). It is not surprising that an intervention that stresses reduction in reliever medication as an important goal leads patients to report such reductions at the end of the training, at least in part because patients have some decision latitude in the level of usage of this medication for symptoms. Future trials may profit from inclusion of more severe cases of asthma or patients with overuse of bronchodilator medication.

The range of applicability of hypoventilation training for asthma patients remains to be determined. Although excessive minute ventilation and low $p\text{CO}_2$ are often reported in asthma (Osborne et al. 2000; Ritz et al. 1998; Varray and Prefaut 1992, Kelsen et al. 1979), a sizable number of patients show normal or close to normal levels of $p\text{CO}_2$. The target for such patients can be stabilization of normal levels of $p\text{CO}_2$ by more regular breathing. However, little is known about the importance of variability of breathing patterns in daily life for asthma symptoms. Highly variable breathing patterns with intermittent deep breaths (sighs) are often observed in panic patients (Abelson et al. 2001; Wilhelm et al. 2001b) and could lead to maintenance of low $p\text{CO}_2$ levels. Intermittent deep inspirations dilate the airways and decrease hyperresponsiveness of the airways, but may also lead to bronchoconstriction in more severe asthma (Fish et al. 1981; Lutchen et al. 2001). In our study, three patients with high initial $p\text{CO}_2$ levels showed only small increases from pre-treatment (39.0 ± 1.1 mmHg) to post-treatment (39.6 ± 3.1 mmHg) and follow-up (41.6 ± 1.9 mmHg), and further qualitative inspection of their means in outcome variables suggested

lower initial symptom scores (1.1 ± 0.3 vs. 1.5 ± 0.6) and PEF variability (13.2 ± 6.7 vs. $32.9 \pm 14.5\%$), combined with smaller reductions across training than in the 5 patients starting with lower $p\text{CO}_2$ levels (31.7 ± 2.4 mmHg). Although patients were relatively positive in their final evaluation of the training, measurable benefits of the training in terms of asthma control may be restricted to patients in the hypocapnic range.

Our breathing training was originally developed to correct hypocapnic breathing patterns in patients with panic disorder (Meuret et al. 2001). In a recent clinical trial we demonstrated substantial reductions in panic symptomatology over a 1-year period (Meuret, Wilhelm, Ritz, et al., under review) in these patients. Asthma patients are more likely than the general population to also suffer from panic disorder (Carr 1998; Hasler et al. 2005; Ritz et al. 2005), and emotion-induced overbreathing has been observed in asthma patients (Clarke and Gibson 1980), particularly in anxious states surrounding asthma attacks. Panic-fear has been linked to suboptimal management of asthma, such as greater use oral corticosteroid (Hyland et al. 1993; Kinsman et al. 1974; Ritz et al. 2001). Thus, an additional benefit of the training could lie in teaching of skills to reduce comorbid panic, particularly the risk of panic-induced overbreathing in the event of severe asthma symptoms.

Our current findings do not allow disentangling effects of slow breathing training from effects of systematic biofeedback-induced increases in $p\text{CO}_2$. Slow breathing training has been shown to be beneficial in cardiovascular disease (Bernardi et al. 1998; Schein et al. 2001), probably due to its potential to increase baroreflex sensitivity (Bernardi et al. 2002; Joseph et al. 2005). However, little is known about changes in breathing pattern or slow breathing alone in asthma (Ritz and Roth 2003). Recent research combining slow breathing with heart rate variability biofeedback has demonstrated beneficial effects on lung function and steroid medication needs in asthma (Lehrer et al. 2004), as well as symptomatic and functional improvements in chronic obstructive pulmonary disease (Giardino et al. 2004), but mechanisms behind such effects are largely unexplored. Although improvements in oxygen saturation have been observed for typical breathing frequencies (6–8 breaths/min) employed by such studies (see also Bernardi et al. 1998), these effects cannot easily explain changes in mechanical lung function, such as in basal respiratory resistance (Lehrer et al. 2004), or PEF variability, as observed in the present study. Future studies need to address the relative importance of various breathing maneuvers in respiration-oriented interventions and pathways through which they can affect organic disease manifestations.

Our study was clearly limited in its sample size and its lack of a control group large enough for meaningful inferential statistics. However, our main goal was to

pilot-test the feasibility and benefits of this newly developed training. The substantial increases we observed in pCO₂ across training are difficult to attribute to nonspecific factors such as attention or mere temporal fluctuations. Although qualitative comparison with the control group suggested superiority of the intervention, nonspecific factors may have contributed to the improvements. Greater awareness of the disease and our requirements to continue regular medication may have resulted in an improved asthma self-management. In addition, expectancy of improvement generated by the treatment rationale may have impacted on self-report of symptoms and asthma control, but improvement in PEF variability would be difficult to explain by such effects. Also, the lack of changes in negative affect throughout the observation period argue against nonspecific effects through anxiety reduction, which might be invoked as an explanation derived from the original application of the pCO₂ biofeedback training to panic patients (Meuret et al., under review). Future studies will have to implement comparison interventions that follow monitoring protocols controlling closely for the amount of self-attention, attention directed to the patient by the therapist, and expectancy of improvement by the patient.

Conclusion

Our pilot intervention has provided initial evidence for the feasibility of 4-week pCO₂-biofeedback training in asthma patients. Stable increases in pCO₂ can be achieved by a combination of five expert-guided sessions and daily home exercises using slow paced breathing and feedback of actual pCO₂-levels. The training allows for a more direct test of the assumptions underlying breathing interventions such as the Buteyko technique, because it targets directly the basic physiological parameter of the pathophysiological rationale of the technique. The training was well tolerated by our patients and reduced symptoms and variability of PEF. We therefore recommend a more thorough investigation of its benefits as an adjunctive behavioral self-management technique for asthma patients.

Acknowledgements This research was supported by the National Institutes of Mental Health and the Department of Veterans Affairs

References

- Abelson, J. L., Weg, J. G., Nesse, R. M., et al. (2001). Persistent respiratory irregularity in patients with panic disorder. *Biological Psychiatry*, 49, 588–595.
- Berg, J., Dunbar-Jacob, J., & Rohay, J. M. (1998). Compliance with inhaled medications: the relationship between diary and electronic monitor. *Annals of Behavioral Medicine*, 20, 36–38.
- Bernardi, L., Porta, C., Spicuzza, L., et al. (2002). Slow breathing increases arterial baroreflex sensitivity in patients with chronic heart failure. *Circulation*, 105, 143–145.
- Bernardi, L., Spadacini, G., Bellwon, J., et al. (1998). Effect of breathing rate on oxygen saturation and exercise performance in chronic heart failure. *Lancet*, 351, 1308–1311.
- Bowler, S. D., Green, A. G., & Mitchell, C. A. (1998). Buteyko breathing techniques in asthma: A blinded randomised controlled trial. *Medical Journal of Australia*, 169, 575–578.
- Bruton, A., & Holgate, S. T. (2005). Hypocapnia and asthma: a mechanism for breathing retraining? *Chest*, 127, 1808–1811.
- Carr, R. E. (1998). Panic disorder and asthma: causes, effects and research implications. *Journal of Psychosomatic Research*, 44, 43–52.
- Chowienzyk, P. J., Parkin, D. H., Lawson, C. P., et al. (1994). Do asthmatic patients correctly record home spirometry measurements? *BMJ*, 309, 1618.
- Clarke, P. S., & Gibson, J. R. (1980). Asthma hyperventilation and emotion. *Aust Fam Physician*, 9, 715–9.
- Cooper, S., Osborne, J., Newton, S., et al. (2003). Effects of two breathing exercises (buteyko and pranayama) in asthma: A randomized controlled trial. *Thorax*, 58, 674–679.
- Davis, M. S., & Freed, A. N. (2001). Repeated hyperventilation causes peripheral airways inflammation, hyperreactivity, and impaired bronchodilation in dogs. *American Journal of Respiratory and Critical Care Medicine*, 164, 785–789.
- Davis, M. S., Schofield, B., & Freed, A. N. (2003). Repeated peripheral airway hyperpnea causes inflammation and remodeling in dogs. *Medicine and Science in Sports and Exercise*, 35, 608–616.
- Douma, W. R., Kerstjens, H. A., Roos, C. M., et al. (2000). Changes in peak expiratory flow indices as a proxy for changes in bronchial hyperresponsiveness. Dutch Chronic Non-Specific Lung Disease study group. *European Respiratory Journal*, 16, 220–225.
- Ernst, E. (2000). Breathing techniques—adjunctive treatment modalities for asthma? A systematic review. *European Respiratory Journal*, 15, 969–972.
- Fish, J. E., Ankin, M. G., Kelly, J. F., et al. (1981). Regulation of bronchomotor tone by lung inflation in asthmatic and nonasthmatic subjects. *Journal of Applied Physiology*, 50, 1079–1086.
- Folgering H. T. M., Lenders J., & Rosier I. (1980). Biofeedback control of P_{aco2}, a prospective therapy in hyperventilation. Progress in respiratory research, vol. 14, Asthma. In: H. Herzog et al. (Eds.), Karger, Basel, pp.26–30.
- Fujimori, K., Satoh, M., & Arakawa, M. (1996). Ventilatory response to continuous incremental changes in respiratory resistance in patients with mild asthma. *Chest*, 109, 1525–1531.
- Giardino, N. D., Chan, L., & Borson, S. (2004). Combined heart rate variability and pulse oximetry biofeedback for chronic obstructive pulmonary disease: preliminary findings. *Applied Psychophysiology and Biofeedback* 29, 121–133.
- Hasler, G., Gergen, P. J., Kleinbaum, D. G., Ajdacic, V., et al. (2005). Asthma and panic in young adults. A twenty year prospective community study. *American Journal of Respiratory and Critical Care Medicine*, 171, 1224–30.
- Herxheimer, H. (1946). Hyperventilation asthma. *Lancet*, 1, 83–87.
- Holloway, E., & Ram, F. S. (2004). *Breathing exercises for asthma*. Cochrane Database Syst Rev (1):CD001277.
- Hornbrey, J., Jacobi, M. S., Patil, C. P., & Saunders, K. B. (1988). CO₂ response and pattern of breathing in patients with symptomatic hyperventilation, compared to asthmatic and normal subjects. *European Respiratory Journal*, 1, 846–851.
- Hyland, M. E., Kenyon, C. A. P., Taylor, M., et al. (1993). Steroid prescribing for asthmatics: Relationship with Asthma Symptom Checklist and Living with Asthma Questionnaire. *British Journal of Clinical Psychology*, 32, 505–511.

- Joseph, C. N., Porta, C., Casucci, G., Casiraghi, N., Maffei, M., Rossi, M., & Bernardi, L. (2005). Slow breathing improves arterial baroreflex sensitivity and decreases blood pressure in essential hypertension. *Hypertension*, 46, 714–718.
- Juniper, E. F., O'Byrne, P. M., Guyatt, G. H., et al. (1999). Development and validation of a questionnaire to measure asthma control. *European Respiratory Journal*, 14, 902–907.
- Kelsen, S. G., Fleegler, B., & Altose, M. D. (1979). The respiratory neuromuscular response to hypoxia, hypercapnia, and obstruction to airflow in asthma. *American Review of Respiratory Disease*, 120, 517–527.
- Kinsman, R. A., Spector, S., Shucard, D. W., et al. (1974). Observations on patterns of subjective symptomatology of acute asthma. *Psychosomatic Medicine*, 36, 129–143.
- Lehrer, P. M., Vaschillo, E., Vaschillo, B., et al. (2004). Biofeedback treatment for asthma. *Chest*, 126, 352–61.
- Lutchen, K. R., Jensen, A., Atileh, H., et al. (2001). Airway constriction pattern is a central component of asthma severity: the role of deep inspirations. *American Journal of Respiratory and Critical Care Medicine*, 164, 207–215.
- McFadden, E. R. Jr, & Gilbert, I. A. (1994). Exercise-induced asthma. *New England Journal of Medicine*, 330, 1362–1367.
- McFadden, E. R. Jr, & Lyons, H. A. (1968). Arterial-blood gas tension in asthma. *New England Journal of Medicine*, 278, 1027–1032.
- McHugh, P., Aitcheson, F., & Duncan, B., et al. (2003). Buteyko Breathing Technique for asthma: an effective intervention. *New Zealand Medical Journal*, 116, U710.
- Meuret, A. E., Wilhelm, F. H., Ritz, T. et al. *Feedback of end-tidal pCO₂ as a therapeutic approach for panic disorder*. Submitted.
- Meuret, A. E., Wilhelm, F. H., & Roth, W. T. (2001). Respiratory biofeedback-assisted therapy in panic disorder. *Behavior Modification*, 25, 584–605.
- Meuret, A. E., Wilhelm, F. H., & Roth, W. T. (2004). Respiratory feedback for treating panic disorder. *Journal of Clinical Psychology*, 60, 197–207.
- Milgrom, H., Wamboldt, F., & Bender, B. (2002). Monitoring adherence to the therapy of asthma. *Current Opinion in Allergy and Clinical Immunology*, 2, 201–205.
- National Heart Lung and Blood Institute. Expert panel report: Guidelines for the diagnosis and management of asthma. Update on selected topics 2002. NIH publication #02–5074. National Institutes of Health, Bethesda, MD 2003.
- Newhouse, M. T., Becklake, M. R., Macklem, P. T., et al. (1964). Effect of alterations in end-tidal CO₂ tension on flow resistance. *Journal of Applied Physiology*, 19, 745–749.
- Opat, A. J., Cohen, M. M., & Bailey, M. J., et al. (2000). A clinical trial of the buteyko breathing technique in asthma as taught by video. *Journal of Asthma*, 37, 557–564.
- Osborne, C. A., O'Connor, B. J., Lewis, A., et al. (2000). Hyperventilation and asymptomatic chronic asthma. *Thorax*, 55, 1016–1022.
- Reddel, H., Jenkins, C., & Woolcock, A. (1999). Diurnal variability—time to change asthma guidelines? *BMJ*, 319, 45–7.
- Reddel, H. K., Salome, C. M., Peat, J. K., et al. (1995). Which index of peak expiratory flow is most useful in the management of stable asthma? *American Journal of Respiratory and Critical Care Medicine*, 151, 1320–1325.
- Ritz, T., Bobb, C., Edwards, M., et al. (2001). The structure of symptom report in asthma. A re-evaluation. *Journal of Psychosomatic Research*, 51, 639–645.
- Ritz, T., Dahme, B., DuBois, A. B., et al. (2002). Guidelines for mechanical lung function measurements in psychophysiology. *Psychophysiology*, 39, 546–567.
- Ritz, T., Dahme, B., & Wagner, C. (1998). Effects of static forehead and forearm muscle tension on total respiratory resistance in healthy and asthmatic participants. *Psychophysiology*, 35, 549–562.
- Ritz, T., Meuret, A. E., Wilhelm, F., & Roth, W. T. (2003). End-tidal PCO₂ levels in asthma patients in the laboratory and at home. *Biological Psychology*, 2, 233–234 (abstract).
- Ritz, T., & Roth, W. T. (2003). Behavioral interventions in asthma: Breathing training. *Behavior Modification*, 27, 710–730.
- Ritz, T., & Steptoe, A. (2000). Emotion and pulmonary function in asthma: Reactivity in the field and relationship with laboratory induction of emotion. *Psychosomatic Medicine*, 62, 808–815.
- Ritz, T., Thöns, M., Fahrenkrug, S., et al. (2005). Airways, respiration, and respiratory sinus arrhythmia during picture viewing. *Psychophysiology*, 42, 568–78.
- Schein, M. H., Gavish, B., Herz, M., et al. (2001). Treating hypertension with a device that slows and regularises breathing: a randomised, double-blind controlled study. *Journal of Human Hypertension*, 15, 271–278.
- Stalmatski, A. (1997). *Freedom from asthma. Buteyko's revolutionary treatment*. London: Kyle Cathie.
- Steen, N., Hutchinson, A., McColl, E., et al. (1994). Development of a symptom based outcome measure for asthma. *BMJ* 309, 1065–1068.
- Sterling, G. M. (1968). The mechanism of bronchoconstriction due to hypocapnia in man. *Clinical Science*, 34, 277–285.
- Thomas, M., McKinley, R. K., Freeman, E., et al. (2003). Breathing retraining for dysfunctional breathing in asthma: a randomized controlled trial. *Thorax*, 58, 110–5.
- van den Elshout, F. J. J., van Herwaarden, C. L. A., & Folgering, H. T. M. (1991). Effects of hypercapnia and hypocapnia on respiratory resistance in normal and asthmatic subjects. *Thorax*, 46, 28–32.
- van Doorn, P., Folgering, H. T. M., & Colla, P. (1982). Control of the end-tidal pCO₂ in the hyperventilation syndrome: effects of biofeedback and breathing instructions compared. *Bulletin of European Physiopathol and Respiration*, 18, 829–36.
- Varray, A., & Prefaut, C. (1992). Importance of physical exercise training in asthmatics. *Journal of Asthma* 29, 229–234.
- Wagner, P. D., Hedenstierna, G., & Rodriguez-Roisin, R. (1996). Gas exchange, expiratory flow obstruction and the clinical spectrum of asthma. *European Respiratory Journal*, 9, 1278–1282.
- Walters, E. H., & Johns, D. P. (2001). Unravelling the Buteyko effect. *Medical Journal of Australia*, 174, 64–65.
- Ware, J. E., Kosinski, M., & Keller, S. D. (1996). A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care*, 34, 220–233.
- Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, 54, 1063–1070.
- Wilhelm, F. H., Alpers, G. W., Meuret, A. E., et al. (2001a). Respiratory pathophysiology of clinical anxiety outside the laboratory: Assessment of end-tidal pCO₂, respiratory pattern variability, and transfer function RSA. In: J. Fahrenberg (Ed.), *Progress in ambulatory assessment* (pp. 313–343). Göttingen: Hogrefe & Huber.
- Wilhelm, F. H., Gerlach, A. L., & Roth, W. T. (2001b). Slow recovery from voluntary hyperventilation in panic disorder. *Psychosomatic Medicine*, 63, 638–649.
- Wright, R. J. (2004). Alternative modalities for asthma that reduce stress and modify mood states: evidence for underlying psychobiologic mechanisms. *Annals of Allergy Asthma & Immunology*, 93(2 Suppl 1), S18–23.

Copyright of *Applied Psychophysiology & Biofeedback* is the property of Springer Science & Business Media B.V. and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.