Lung (2011) 189:131–139
DOI 10.1007/s00408-011-9281-8

Pulmonary Function and Abdominal and Thoracic Kinematic Changes Following Aerobic and Inspiratory Resistive Diaphragmatic Breathing Training in Asthmatics

Brandon S. Shaw · **Ina Shaw**

Received: 19 November 2010 / Accepted: 27 January 2011 / Published online: 12 February 2011

Abstract This study investigated the effect of 8 weeks, three times weekly, of aerobic exercise (AE), diaphragmatic inspiratory resistive breathing (DR), and aerobic exercise combined with diaphragmatic inspiratory resistive breathing (CE) on pulmonary function and abdominal and thoracic dimensions and kinematics in asthmatics. Eighty-eight inactive, moderate-persistent asthmatics were matched and randomly assigned to AE, DR, CE, or non-exercise control (NE) groups ($n = 22$ each). AE subjects walked and/or jogged at 60% of age-predicted maximum heart rate. DR subjects performed diaphragmatic breathing combined with inspiratory resistive breathing at varying inspiration, expiration ratios. CE subjects utilized a combination of the AE and DR programs. AE, DR, and CE significantly ($p \leq 0.05$) improved chest dimensions and kinematics during inspiration at the height of the second intercostal space, during inspiration and expiration at the height of the xiphoid process, and during inspiration and expiration at the height of the midpoint between the xiphoid process and umbilicus. All exercise interventions significantly improved FVC, FEV_1, PEF, and IVC, while MVV improved following AE and CE. However, CE proved superior to AE at improving FVC ($p = 0.001$), FEV_1 ($p = 0.001$), and IVC ($p = 0.009$). There were no significant changes ($p > 0.05$) in any of the measured parameters in the NE group. CE produces adaptations greater than those for single-mode training in moderate-persistent asthmatics. The results suggest synergy rather than interference between aerobic exercise and diaphragmatic inspiratory resistive breathing and that this mode of training might be useful as an adjunct therapy in asthmatic patients.

Keywords Chest excursion · Endurance training · Exercise · Spirometry

B. S. Shaw (✉)
Department of Sport, Rehabilitation and Dental Sciences, Tshwane University of Technology, Private Bag X680, Pretoria, Gauteng 0001, Republic of South Africa
e-mail: shawbs@tut.ac.za

I. Shaw
Department of Marketing and Sport Management, Vaal University of Technology, Private Bag X02, Vanderbijlpark, Gauteng 1900, Republic of South Africa

Introduction

Even though 300 million individuals suffer from asthma and 180,000 asthma-related deaths occur annually worldwide [1], there is still conflicting evidence on the rehabilitative effects of exercise on asthma, with some studies having demonstrated no improvements in asthmatic symptomology [2, 3]. On the other hand, there are those studies that have demonstrated significant improvements in asthmatic symptoms following a period of exercise training stemming from exercise's role in reducing minute ventilation (V_E) at high workloads by stabilizing the variability in expiratory airflow parameters and decreasing bronchodilation, dyspnea, airway resistance, and airway sensitivity [2–4]. Other benefits from exercise training in improving asthmatic symptomology include increases in maximum heart rate (thus an increased oxygen pulse), decreases in airway inflammation, decreases in exertional breathlessness by desensitizing the asthmatic to the uncomfortable breathless sensation, increases in the usage of the ventilatory reserve, and decreases in ventilatory requirements through the increases in aerobic capacity and exercise efficiency [3, 5, 6]. Furthermore, research on asthmatics that has specifically focused on spirometry changes following exercise rehabilitation has mainly come from aerobic exercise programs, despite other modes of training possibly having pulmonary function benefits.

In this regard, diaphragmatic breathing exercise may prove essential to an asthmatic since asthmatics perform thoracic-type breathing in association with decreased chest expansion and chest deformity as a result of a shortened diaphragm, intercostals, and accessory muscles from prolonged spasm causing stenosis of the major airways leading to an abnormal respiratory pattern [7]. Diaphragmatic breathing exercise has also been deemed essential in the treatment of asthma since it results in a compression of the abdominal contents, which increases intra-abdominal pressure causing a lateral transmission of pressure to the lower ribs laterally, upward and outward motion of the lower ribs, and anterior/posterior motion of the upper ribs. This in turn results in an increase in thoracic volume that decreases intrathoracic pressure which facilitates inspiration [8].

The physiological effects of diaphragmatic breathing exercise are varied, and it is claimed that this mode of exercise can decrease the work of breathing and dyspnea and improve ventilation distribution [9]. These changes could occur by shortening inspiration and lengthening expiration [10] by performing expiration via the pulling in of the abdominal muscles dorsally toward the spine while relaxing the abdominal, intercostals, and neck musculature [8]. This is achieved by using weights or belts to increase intra-abdominal pressure, by applying compression to the lower ribs to facilitate expiratory ascent of the diaphragm during expiration which can increase the movement of secretions from the small bronchi into the respiratory passages, by exhaling through a resistive breathing device, or by breathing while creating a hissing noise in order to reduce bronchial constriction [8].

Diaphragmatic breathing exercise has been shown to psychologically reduce anxiety, improve attitudes toward work, and improve quality of life, while physiologically decreasing bronchodilator use and acute exacerbations and improving maximal exercise tolerance and ventilation and oxygen consumption [11–13]. This is achieved by improving expansile forces in hypoventilated areas, dilating airways by forcing mucus into larger airways, re-educating the autonomic diaphragmatic movements, relaxing spasmodic muscle contractions, and mobilizing the ribs and chest wall [7]. However, these physiological benefits have not been unequivocally substantiated through spirometry testing.

Despite the numerous possible benefits of diaphragmatic breathing training, the current use of this mode of exercise in asthmatics to improve pulmonary function and abdominal and thoracic dimensions and kinematics is presently insufficient and its clinical benefits not yet justified, hence the present study's investigation on the effects of this mode of exercise on moderate-persistent asthmatics [14]. In the present study we examined the hypothesis that aerobic exercise and diaphragmatic inspiratory resistive breathing and a combination of these modes of exercise will result in improvements in pulmonary function and abdominal and thoracic dimensions and kinematics in order to elicit the unique benefits that each mode of exercise has to offer.

Materials and Methods

Patient Recruitment and Protocol

The present study made use of a single-blind, comparative, randomized controlled trial over an 8-week period, using pre- and post-tests to determine the effects of the various cost-effective, supervised, home-based exercise interventions on moderate-persistent asthmatics. Subjects were matched by age (using years) and gender and randomly assigned using concealed envelopes to one of the following four groups: nonexercise control (NE) group, an aerobic exercise (AE) group, diaphragmatic breathing (DR) group, and combined aerobic exercise and diaphragmatic breathing (CE) group. Each group had a total of 22 subjects with a male:female ratio of 14:8. Group assignment was issued prior to baseline assessments and was not revealed to those conducting baseline tests. The study was approved by the Institutional Review Boards at the University of Johannesburg. All subjects received medical clearance from their personal physician and gave informed consent before participation.

Inactive, moderate-persistent asthmatic males ($n = 56$) and females ($n = 32$) aged between 18 and 34 years and who met the criteria of moderate-persistent asthma based on the National Institutes of Health (NIH) guidelines (60-80% of predicted FVC, FEV_1 and/or PEF) [15] were included in the study. Furthermore, subjects were nonsmokers, were free from any influenza-like or respiratory infection symptoms 2-3 weeks prior to the evaluations, exhibited daily asthmatic symptoms, exhibited nocturnal asthmatic symptoms more than one night weekly, and had peak flow variability of more than 30%. Potential subjects were excluded from participation in the study if they had relative and absolute contraindications to exercise [16], suffered from asthma exacerbations within that last 7 days prior to the inception into the study, were unable to abstain from their prescribed asthma medication use 12 h before each evaluation, and were not weight stable for at least 6 months prior to the study. None of the subjects exhibited preprogram FEV_1 or peak expiratory flow reductions of more than 15% during the maximal cycle ergometer test and could thus not be classified as having exercise-induced

Table 1 Anthropometrical and pulmonary function features of control and intervention groups

Variables	NE group ($n = 22$)	AE group ($n = 22$)	DR group ($n = 22$)	CE group ($n = 22$)
Age (years)	21.90 ± 3.89	21.95 ± 3.87	21.93 ± 3.95	22.00 ± 3.95
Stature (cm)	169.37 ± 10.68	170.88 ± 9.17	168.66 ± 7.53	172.00 ± 10.14
Body mass (kg)	76.05 ± 13.95	78.40 ± 17.80	75.18 ± 12.66	77.08 ± 9.74
Forced vital capacity (FVC) (L)	2.82 ± 0.57	2.77 ± 0.48	3.01 ± 0.58	2.87 ± 0.67

NE nonexercise control, *AE* aerobic exercise, *DR* diaphragmatic inspiratory resistive breathing, *CE* aerobic exercise combined with diaphragmatic inspiratory resistive breathing

Values are mean ± SD

asthma. The anthropometrical and pulmonary function features of the intervention and control groups are presented in Table 1. When the groups were compared, no statistically significant differences ($p > 0.05$) were found for age, stature, body mass, and forced vital capacity (FVC).

Measurements

Anthropometric

All subjects completed the same battery of tests before and after the 8-week period. For descriptive purposes, anthropometric measurements were taken at baseline. Body mass was measured in kilograms (kg) to the nearest 0.1 kg on a calibrated digital medical scale (Seca 843, Switzerland) with participants dressed in a standard T-shirts and shorts. Stature was measured in centimeters (cm) to the nearest 0.5 cm via a standard wall-mounted stadiometer.

Pulmonary Function

Forced vital capacity (FVC) (in liters, L), forced expiratory volume in 1 second (FEV_1) (L), forced expiratory volume in 1 second/forced vital capacity ratio (FEV_1/FVC) (%), 25% of forced expiratory flow (FEF25) (liters per second, L s^{-1}), 50% of forced expiratory flow (FEF50) (L s^{-1}), 75% of forced expiratory flow (FEF75) (L s^{-1}), 25-75% of forced expiratory flow (FEF25-75) (L s^{-1}), peak expiratory flow (PEF) (L), inspiratory vital capacity (IVC) (L), minute ventilation (V_E) (liters per minute, L min^{-1}), breathing frequency (F_b) (breaths min^{-1}), and tidal volume (V_T) (L) were measured with the subject in the upright position with a nose clip tightly fitted to the subject's nostrils. The FVC maneuver required each subject to expire as hard and as fast as possible, then completed the cycle by inspiring as hard and rapidly as possible. The maximal voluntary ventilation (MVV) (L min^{-1}) was measured after each subject completed forceful maximal inspirations and expirations over a period of 12 s [17]. All spirometry tests were conducted before and after the 8-week experimental period and at least 48 h after the last training session [18] using a FX System spirometer (Cosmed, Rome, Italy) which was calibrated as per FX System requirements prior to each test. Each test was performed at least three times, with each test not differing by more than 5% or 100 mL. In the final analysis, the largest value obtained from the three tests was used [19].

Abdominal and Thoracic Dimensions and Kinematics

Abdominal and thoracic dimensions and kinematics measurements can be used as an evaluative method for diaphragmatic breathing excursion to quantify possible alterations in thoracic capacity and abdominal and chest wall compliance as achieved by all expiratory and inspiratory muscles [8]. By measuring the abdomen and thorax with a measuring tape over the second intercostals space, xiphoid process, and midpoint between the xiphoid process and umbilicus, a competency in diaphragmatic breathing can be demonstrated by a reduction in rib cage excursion. These indirect measurements of abdominal and chest wall excursion have an intrarater reliability of 0.96-0.98 and an interrater reliability of 0.84-0.87 with correlation coefficients not less than 0.84 [8, 20]. Abdominal and thoracic dimensions and kinematics were measured by placing a tape measure over the second intercostal space, the xiphoid process, and midpoint between the xiphoid process and the umbilicus [8]. These measurements were taken during rest, maximal inspiration, and expiration using a nondistendable sliding measuring tape in centimeters to the nearest 0.1 cm. In addition to this, this evaluation was used to quantify possible alterations in thoracic capacity and possibly abdominal and chest wall compliance as achieved by all inspiratory and expiratory muscles.

Periodized Exercise Programs

Nonexercise control group subjects were instructed to maintain their normal daily activities throughout the 8-week experimental period and were phoned three times weekly to ensure compliance. All subjects in the intervention groups were trained on how to perform the exercises by a qualified practitioner in exercise therapy and rehabilitation. For each of the exercises, subjects were firstly familiarized with their respective exercise programs and then provided with simple step-by-step written instructions accompanied by illustrations. Exercise sessions were supervised at all times in the home setting by a qualified practitioner and records were kept of each training session to ensure fidelity and promote adherence to the interventions. Sessions were preceded by a 5-min warm-up consisting of easy walking at a heart rate of less than 100 beats per minute [21] and concluded with six stretching exercises for the major muscle groups (erector spine, chest muscles, shoulder muscles, hip flexors, hamstrings, and quadriceps), performed for two sets of 30 seconds on each muscle/limb [22] and a 5-min cool-down consisting of walking at a heart rate of less than 100 beats per minute [21].

Subjects in the AE group walked and/or jogged for 30 min at an intensity of 60% of their individual age-predicted maximum heart rate (HR_{max}) [23], which was determined by subtracting age from 220. Individual age-predicted HR_{max} was utilized instead of the directly tested HR_{max} since it was the aim of the present study to develop a suitable program for all subjects without the need for expensive equipment and direct maximal testing to allow its use by increased numbers of asthmatic patients. To ensure appropriate progressive overload, aerobic exercise intensity was readjusted at week 4 with a general 5% increase in heart rate [24].

Subjects in the DR group were instructed to perform diaphragmatic breathing combined with inspiratory resistive breathing in the semirecumbent position with posterior pelvic tilting, knees flexed, and neck extended [8]. This was achieved by inspiring and expiring maximally through a tube that was 10 cm long and 1 cm in diameter principally using abdominal motion, while reducing upper-rib-cage motion. One hand of the subject was utilized to stabilize a 2.5-kg (weeks 1-4) or a 5-kg weight (weeks 5-8) on the abdominal cavity. The other hand was used to cover the nose to avoid inspiration and expiration through the nose. The subjects were further instructed to watch the rib cage carefully for visual feedback in order to avoid excessive rib movement [9]. The subjects were required to maintain eye contact with a second-timer clock, which was provided to them at the start of the study, while exercising in order to maintain the pace of the exercises effectively. The subjects in the DR group had to complete three sets of 5-10 repetitions using 1 s of inspiration and 2 s of expiration (1:2 inspiration-to-expiration ratio) [24, 25], three sets of 10-15 repetitions of a 2:4 inspiration-to-expiration ratio, and three sets of 15-20 repetitions of a 3:6 inspiration-to-expiration ratio with a 60-90-s rest period between each set [24].

Subjects in the CE group utilized a combination of aerobic exercise and diaphragmatic breathing. The aerobic exercise portion required the patients to perform 15 min of walking and/or jogging at 60% of their individual age-predicted HR_{max} [23], while the diaphragmatic breathing portion was similar to that of the DB group but only required patients to perform two sets of 5-10 repetitions of 1:2 inspiration-to-expiration ratio [24, 25], two sets of 10-15 repetitions of 2:4 inspiration-to-expiration ratio, and two sets of 15-20 repetitions of 3:6 inspiration-to-expiration ratio with 60-90-s rest periods between each set [24].

Statistical Analysis

Statistical analysis consisted of descriptive statistics, and differences between the groups at baseline and after 8 weeks were analyzed with paired-samples *t* tests. Levene's test was used to determine the homogeneity or heterogeneity of pulmonary function parameters between the groups at baseline. An analysis of variance was applied to the data to create a value representing the ratio of between-group and within-group variance. The Scheffe and Dunnett T3 tests were then applied to the variances in order to determine the significance of possible combinations of cell contrasts in order to determine which of the programs was the most effective. A priori, a two-sided level of significance was set at 0.05. Baseline results and differences after 8 weeks are presented as mean ± SD. All analyses were performed using commercially available software (Statistical Package of Social Sciences ver. 14, SPSS, Inc., Chicago, IL, USA).

Results

No significant differences in compliance to the exercise programs were found between the groups, with all subjects having 100% adherence to their respective exercise interventions. Further, no dropout of subjects occurred in the present study. At baseline, pulmonary function variables were not significantly different between groups [i.e., FVC ($p = 0.544$), FEV_1 ($p = 0.609$), FEV_1/FVC ($p = 0.148$), PEF ($p = 0.999$), FEF25 ($p = 0.273$), FEF50 ($p = 0.223$), FEF75 ($p = 0.737$), FEF25-75 ($p = 0.428$), MVV ($p = 0.900$), IVC ($p = 0.765$), V_E ($p = 0.385$), F_b ($p = 0.074$), and V_T ($p = 0.092$)]. Similarly, abdominal and thoracic dimensions and kinematic characteristics were equal for all groups at baseline [i.e., resting ($p = 0.961$), inspiratory ($p = 0.968$), and expiratory ($p = 0.968$) chest dimensions at the height of the second intercostal space; resting ($p = 0.881$), inspiratory ($p = 0.801$), and expiratory ($p = 0.928$) chest dimensions at the height of the xiphoid process; resting ($p = 0.932$), inspiratory ($p = 0.955$), and expiratory ($p = 0.981$) abdominal dimensions at the height of the midpoint between the xiphoid process and umbilicus].

Pulmonary Function

Pre- and post-test pulmonary function test responses of the control and intervention groups are presented in Table 2. Spirometry testing showed that AE resulted in significant ($p \leq 0.05$) improvements in FVC ($p = 0.001$), FEV_1 ($p = 0.000$), PEF ($p = 0.012$), MVV ($p = 0.000$), and IVC ($p = 0.006$), but had no significant effect on FEV_1/FVC ratio ($p = 0.254$), FEF25 ($p = 0.854$), FEF50 ($p = 0.501$), FEF75 ($p = 0.095$), FEF25-75 ($p = 0.700$), V_E ($p = 0.188$), F_b ($p = 0.439$), and V_T ($p = 0.078$). Eight weeks of DR resulted in significant changes in FVC ($p = 0.000$), FEV_1 ($p = 0.000$), FEV_1/FVC ratio ($p = 0.003$), PEF ($p = 0.008$), and IVC ($p = 0.000$). However, DR did not result in any significant improvements in FEF25 ($p = 0.067$), FEF50 ($p = 0.431$), FEF75 ($p = 0.175$), FEF25-75 ($p = 0.308$), MVV ($p = 0.701$), V_E ($p = 0.706$), F_b ($p = 0.204$), and V_T ($p = 0.425$). Following CE, FVC ($p = 0.000$), FEV_1 ($p = 0.000$), FEV_1/FVC ratio ($p = 0.031$), PEF ($p = 0.001$), MVV ($p = 0.001$), and IVC ($p = 0.000$) changed significantly from baseline, but no significant improvements were found in FEF25 ($p = 0.332$), FEF50 ($p = 0.569$), FEF75 ($p = 0.077$), FEF25-75 ($p = 0.922$), V_E ($p = 0.331$), F_b ($p = 0.075$), and V_T ($p = 0.581$). No significant changes were found in any of the measured pulmonary function variables in the NE group.

In order to support the superiority of any particular exercise intervention, *post hoc* analysis revealed that 8 weeks of CE was found to be more effective than AE ($p = 0.001$) at improving FVC but equally effective as DR training ($p = 0.070$), while DR and AE were found to be equally effective at improving FVC ($p = 0.504$). CE was shown to be more effective than AE ($p = 0.001$) at altering FEV_1, but equally effective as DR ($p = 0.070$). However, DR and AE were found to be equally effective at improving FEV_1 ($p = 0.582$). Although there were differences in PEF from baseline to post-tests following AE, DR, and CE, it was found that CE was equally effective as DR ($p = 0.813$) and AE ($p = 0.513$) and DR was equally effective as AE ($p = 0.960$). Further, MVV was equally improved following CE and AE ($p = 0.788$). Eight weeks of DR was found to be equally effective at improving IVC when compared to CE and AE ($p = 0.858$ and $p = 0.084$, respectively), while CE proved more effective than AE ($p = 0.009$).

Abdominal and Thoracic Dimensions and Kinematics

Pre- and post-test abdominal and thoracic dimensions and kinematics responses of the control and intervention groups are presented in Table 3. Significant ($p \leq 0.05$) improvements were found in chest circumferences during inspiration at the height of the second intercostal space following AE, DR, and CE ($p = 0.000$, $p = 0.000$, and $p = 0.000$, respectively). However, no significant improvements were found in chest circumferences following AE, DR, and CE during rest ($p = 0.831$, $p = 0.090$, and $p = 0.699$, respectively) and expiration ($p = 0.224$, $p = 0.054$, and $p = 0.171$, respectively) at the height of the second intercostal space. Eight weeks of AE, DR, and CE resulted in significant improvements in chest circumferences during inspiration ($p = 0.000$, $p = 0.000$, and $p = 0.000$, respectively) and expiration ($p = 0.005$, $p = 0.000$, and $p = 0.002$, respectively) at the height of the xiphoid process. Significant improvements were also found in the DR and CE groups' resting circumferences at the height of the xiphoid process ($p = 0.000$ and $p = 0.023$, respectively), while no significant improvement was seen following AE ($p = 0.177$). All training groups demonstrated significant improvements in abdominal circumferences during inspiration (AE: $p = 0.000$; DR: $p = 0.000$; and CE: $p = 0.000$) and expiration (AE: $p = 0.000$; DR: $p = 0.000$; CE: $p = 0.000$) at the height of the midpoint between the xiphoid process and umbilicus. Significant improvements were found in the resting circumferences at the height of the midpoint between the xiphoid process and umbilicus in the DR group ($p = 0.000$) but not following AE ($p = 0.190$) and CE ($p = 0.353$). No significant ($p > 0.05$) changes were observed in the NE group in any of the measured test abdominal and thoracic dimensions and kinematic variables.

Discussion

The results of the study clearly showed improvements in FVC, FEV_1, PEF, and IVC following AE, DR, and CE, while increases in MVV were found following only AE and CE. Chest dimensions and kinematics improved (1) during inspiration (but not expiration) at the height of the second intercostal space, (2) during inspiration and expiration at the height of the xiphoid process, and (3) during inspiration and expiration at the height of the midpoint between the xiphoid process and umbilicus following all three interventions. This indicates that aerobic exercise, when combined with diaphragmatic inspiratory resistive breathing, is the optimal exercise strategy for simultaneous

Table 2 Pre- and post-test pulmonary function test responses of the control and intervention groups

Variables	NE group ($n = 22$)		AE group ($n = 22$)		DR group ($n = 22$)		CE group ($n = 22$)	
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test
Forced vital capacity (FVC) (L)	2.82 ± 0.57	2.93 ± 0.57	2.77 ± 0.48	3.11 ± 0.71*	3.01 ± 0.58	3.52 ± 0.74*	2.87 ± 0.67	3.68 ± 0.82*
Forced expiratory volume in 1 second (FEV_1) (L)	2.62 ± 0.53	2.70 ± 0.5	2.72 ± 0.53	2.97 ± 0.65*	2.85 ± 0.57	3.22 ± 0.63*	2.70 ± 0.67	3.30 ± 0.70*
FEV_1/FVC ratio (%)	94.18 ± 4.76	93.09 ± 6.49	96.77 ± 2.52	95.59 ± 3.87	94.86 ± 4.94	90.64 ± 6.67*	93.82 ± 5.47	91.23 ± 5.74*
Peak expiratory flow (PEF) (L)	7.09 ± 1.97	7.04 ± 1.65	7.15 ± 1.45	7.57 ± 1.47*	7.10 ± 1.57	7.68 ± 1.26*	7.14 ± 2.22	7.99 ± 2.22*
25% of forced expiratory flow (FEF25) (L s^{-1})	2.77 ± 2.4	2.30 ± 0.71	2.58 ± 0.72	2.56 ± 0.64	2.51 ± 0.87	2.19 ± 0.63	2.46 ± 1.09	2.29 ± 0.56
50% of forced expiratory flow (FEF50) (L s^{-1})	4.10 ± 0.93	4.16 ± 1.07	4.79 ± 1.00	4.88 ± 0.93	4.51 ± 1.23	4.32 ± 1.16	4.21 ± 1.50	4.31 ± 1.03
75% of forced expiratory flow (FEF75) (L s^{-1})	6.33 ± 1.55	6.16 ± 1.36	6.74 ± 1.30	7.0 ± 1.27	6.39 ± 1.56	6.72 ± 1.50	6.24 ± 1.87	6.61 ± 1.51
25-75% of forced expiratory flow (FEF25-75) (L s^{-1})	3.77 ± 0.91	3.78 ± 1.0	4.30 ± 0.98	4.36 ± 0.89	4.07 ± 1.13	3.87 ± 1.04	3.90 ± 1.44	3.88 ± 0.85
Maximal voluntary ventilation (MVV) (L min^{-1})	106.41 ± 37.85	106.94 ± 37.32	103.65 ± 27.86	128.97 ± 27.56*	107.43 ± 34.65	109.62 ± 38.91	99.90 ± 41.79	119.01 ± 43.93*
Inspiratory vital capacity (IVC) (L)	3.13 ± 0.76	3.02 ± 0.64	3.03 ± 0.71	3.17 ± 0.68*	3.24 ± 0.86	3.67 ± 0.73*	3.26 ± 0.97	3.78 ± 0.93*
Minute ventilation (V_E) (L min^{-1})	15.90 ± 8.01	15.12 ± 8.51	11.57 ± 6.53	13.41 ± 8.72	14.19 ± 8.60	13.73 ± 8.70	14.38 ± 9.76	16.00 ± 11.82
Breathing frequency (F_b) (breaths min^{-1})	23.05 ± 6.77	24.41 ± 6.67	25.35 ± 8.26	24.60 ± 5.90	23.00 ± 8.33	24.14 ± 7.83	23.57 ± 8.18	26.08 ± 8.48
Tidal volume (V_T) (L)	0.85 ± 0.49	0.77 ± 0.48	0.51 ± 0.31	0.64 ± 0.48	0.77 ± 0.52	0.72 ± 0.57	0.72 ± 0.48	0.75 ± 0.59

NE nonexercise control, *AE* aerobic exercise, *DR* diaphragmatic inspiratory resistive breathing, *CE* aerobic exercise combined with diaphragmatic inspiratory resistive breathing

Data are presented as mean ± SD

* Statistically significant, $p \leq 0.05$

Table 3 Pre- and post-test abdominal and thoracic dimensions and kinematics responses of the control and intervention groups

Variables	NE group ($n = 22$)		AE group ($n = 22$)		DR group ($n = 22$)		CE group ($n = 22$)	
	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test	Pretest	Post-test
Mean chest circumferences at the height of the second intercostal space								
Resting circumference (cm)	88.91 ± 10.42	89.30 ± 10.73	87.76 ± 8.64	87.73 ± 8.46	87.61 ± 2.32	87.45 ± 12.4	87.52 ± 6.36	87.47 ± 6.33
Inspiratory circumference (cm)	92.51 ± 10.06	92.54 ± 10.49	92.33 ± 8.71	94.87 ± 8.80*	91.17 ± 11.94	95.36 ± 12.53*	92.18 ± 6.38	94.76 ± 6.49*
Expiratory circumference (cm)	87.36 ± 9.98	87.12 ± 10.24	86.32 ± 8.69	86.24 ± 8.68	87.19 ± 11.75	87.02 ± 11.85	86.21 ± 6.96	86.04 ± 6.95
Mean chest circumferences at the height of the xiphoid process								
Resting circumference (cm)	79.42 ± 7.02	79.70 ± 7.0	78.83 ± 7.42	78.96 ± 7.38	78.91 ± 9.53	75.62 ± 8.58*	80.18 ± 6.55	79.07 ± 7.03*
Inspiratory circumference (cm)	83.00 ± 7.21	82.88 ± 7.65	82.94 ± 7.85	84.92 ± 8.48*	82.41 ± 9.81	85.69 ± 10.65*	84.30 ± 6.66	87.48 ± 6.88*
Expiratory circumference (cm)	78.16 ± 7.21	78.66 ± 7.25	77.48 ± 7.88	76.13 ± 7.56*	77.85 ± 10.11	76.96 ± 9.66*	79.06 ± 7.06	77.82 ± 7.57*
Mean abdominal circumferences at the height of the midpoint between the xiphoid process and umbilicus								
Resting circumference (cm)	73.36 ± 7.86	73.62 ± 7.95	72.43 ± 8.55	72.54 ± 8.61	73.23 ± 11.47	70.81 ± 1.35*	74.23 ± 7.95	73.60 ± 8.56
Inspiratory circumference (cm)	74.14 ± 7.86	73.84 ± 8.74	74.07 ± 8.95	77.03 ± 10.22*	74.93 ± 11.48	76.35 ± 11.72*	75.42 ± 8.49	78.40 ± 8.90*
Expiratory circumference (cm)	72.06 ± 8.71	72.10 ± 8.85	71.45 ± 8.71	68.00 ± 8.57*	71.88 ± 11.78	70.87 ± 11.83*	72.54 ± 8.58	69.65 ± 8.29*

NE nonexercise control, *AE* aerobic exercise, *DR* diaphragmatic inspiratory resistive breathing, *CE* aerobic exercise combined with diaphragmatic inspiratory resistive breathing

Data are presented as mean ± SD

* Statistically significant, $p \leq 0.05$

improvement of pulmonary function and abdominal and thoracic dimensions and kinematics in moderate-persistent asthmatics. This is so since CE, and not AE, improved resting circumferences at the height of the xiphoid process. Further, CE proved superior to AE at improving FVC, FEV_1, and IVC.

The results of the present study corroborate the improvements of FVC following DR in asthmatics. In this regard, Fluge et al. [26] previously showed a positive trend toward the treatment effect of DR on FVC, with a mean improvement of 225 ± 65.5 mL in their sample of asthmatics. Similarly, Weiner et al. [27] demonstrated that inspiratory muscle training improved FVC by 11.32% in moderate-severe asthmatics. In contrast, Ramazanoglu and Kraemer [28] found no significant increase in FVC following AE. Their exercise was comparable with that of the present study, however, differences existed in frequency (three versus one session per week). The improvements in FVC could be attributed to an increased inspiratory force, as required during a FVC maneuver, which may have resulted from the lengthening of the intercostals and accessory muscle and a trained diaphragm being elongated and thus placed at a mechanical advantage [7, 29]. This improvement in FVC is essential to the treatment of asthma since it could indicate a reduction in small-airway obstruction [30].

Following AE, DR, and CE, improvements in FEV_1 were seen in the present study. The observed improvement in FEV_1 following DR in the present study is supported by Fluge et al. [26] when their study found a mean increase of 356.3 ± 146.2 mL. Similarly, the results of Weiner et al. [27] demonstrated a 12.12% increase in FEV_1 following inspiratory muscle training in moderate-severe asthmatics. However, the results of DR on FEV_1 in the present study are not supported by Anderson [31], possibly due to a different breathing technique, namely, the Buteyko Breathing Technique, and the greater variability in subject age in their study (range = 12-70 years). Even though the breathing technique was similar to that used in a study conducted by Singh et al. [25], the results differed possibly due to the shorter experimental period of 2 weeks and the subjects having mild asthma. The improvements in FEV_1 following AE differ from the results of Ramazanoglu and Kraemer [28], likely because of the differences in the prescribed frequency (three versus one session per week, respectively), and the results of Nickerson et al. [32], possibly because of a shorter (6-week) experimental period. Based on these observations, it is apparent that to achieve improvements in FEV_1, exercise training should incorporate some form of breathing retraining.

Despite the improvement in FVC and FEV_1 of the AE, DR, and CE groups, this did not result in a significant change in the FEV_1/FVC in the AE group. This confirms that the FEV_1/FVC ratio is not a reliable index of reversibility as the FVC can increase more than FEV_1 causing the FEV_1/FVC to decrease (as in the case of the DR and CE groups) in the presence of a useful degree of bronchodilation [33].

The present study showed that AE was effective at improving PEF which was in contrast to the results of Nickerson et al. [32], probably because of the shorter study duration of 6 weeks and because their study required their subjects to complete 3.2 km of running with no prescribed intensity which could have resulted in the subjects training at inadequate workloads to bring about significant changes in PEF. Although the results of the present study demonstrated improvements in PEF following DR in asthmatics, this is in contrast to the results of Anderson [31] and Singh et al. [25] whose studies had a similar breathing program but demonstrated no improvements in PEF following breathing training. This is likely since the study by Singh et al. [25] utilized a shorter period of training (6 weeks) and shorter training durations (15 min daily). The improvements observed in PEF following AE, DR, and CE could signify a decrease in the obstruction of the large airways and thus an increased bronchodilation [34], which could be related to an increased number of motor unit recruitment during forced inspiration and expiration, increasing power and in effect the rate of muscle shortening [35].

Following AE, DR, and CE no improvements in 25-75% of forced expiratory flow (FEF25-75) were seen possibly because this parameter was considered effort-independent [19].

Following AE and CE, improvements in MVV were seen in the present study. This observed improvement is contrary to the findings of Nickerson et al. [32], who demonstrated no improvements in MVV following a 6-week running program. These findings on MVV were likely in contrast since the study of Nickerson et al. [32] did not prescribe a fixed intensity and had a shorter training period which could have resulted in an inadequate training stimulus. No improvements in MVV were seen following DR; this finding alludes to the necessity of aerobic-type exercise to improve MVV. This is likely due to the MVV maneuver requiring a simulated "heavy-breathing" effect [36]. The improvements in MVV could demonstrate a reduction in airflow obstruction, airway hyperresponsiveness [3], and developing fatigue during activities of daily living [37].

After AE, DR, and CE, improvements in IVC were found and have not been reported previously. Since IVC is the maximum amount of air that can be inhaled from forced maximal expiration, improvements in this pulmonary function parameter are essential to asthmatics [38].

None of the groups demonstrated improvements in V_E, which is an important determinant of exercise-induced bronchospasm [3]. However, these findings are in contrast to Anderson [31] who found improvements in V_E following breathing training.

The present study showed that AE, DR, and CE did not change F_b, which is a pulmonary variable used to assess the work of breathing of asthmatics [38]. Similarly, no changes were found in V_T following any of the exercise training programs. This is disconcerting in that alveolar ventilation increases in response to changes in breathing pattern, which is exemplified by decreases in F_b and increases in V_T. However, since none of the groups in the present study altered F_b and V_T, no increase in alveolar ventilation could have occurred [9].

Following 8 weeks of AE, DR, and CE, the changes in inspiratory abdominal and chest dimensions at all levels could possibly have been due to concomitant changes in respiratory muscle strength. This increase in strength could have assisted forced inspiration by elevating and expanding the thoracic cage, effectively increasing thoracic antero-posterior diameter as measured by the abdominal and thoracic dimensions and kinematics measurements [39, 40]. The abdominal and thoracic kinematics could have been improved due to improved respiratory muscle strength, efficacy, and/or mobilization of the costavertebral articulations which would enable an improved interaction between the diaphragm and intercostal muscles thereby relaxing the inspiratory muscles leading to a decrease in the end-expiratory resting volume and reduced hyperinflation [7, 9, 28]. The improvements in abdominal and thoracic dimensions and kinematics is notable in that they quantify possible alterations in thoracic capacity and possibly abdominal and chest wall compliance as achieved by all expiratory and inspiratory muscles [8].

Conclusions

The improvements in pulmonary function and abdominal and thoracic kinematics lend empirical support for exercise programing and training in individuals with chronic lung disease as endorsed by the position paper of the American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) [41]. The results of this study further suggest synergy rather than interference between aerobic exercise and diaphragmatic inspiratory resistive breathing as demonstrated by the vast and superior pulmonary function and abdominal and thoracic kinematics improvements following combined aerobic exercise and diaphragmatic breathing.

Acknowledgments The authors are grateful to the University of Johannesburg (formerly Rand Afrikaans University), Johannesburg, South Africa, for the use of their laboratories and to the Vaal University of Technology, Vanderbijlpark, South Africa, for its statistical consultation services.

References

1. Braman SS (2006) The global burden of asthma. Chest 130(1 Suppl):4S–12S
2. Cochrane LM, Clark CJ (1990) Benefits and problems of a physical training programme for asthmatic patients. Thorax 45: 345–351
3. Hallstrand TS, Bates PW, Schoene RB (2000) Aerobic conditioning in mild asthma decreases the hypernea of exercise and ventilatory capacity. Chest 18:1460–1469
4. Haas F, Pasierski S, Levine N, Bishop M, Axen K, Pineda H, Haas A (1987) Effect of aerobic training on forced expiratory airflow in exercising asthmatic humans. J Appl Physiol 63(3): 1230–1235
5. Counil FP, Varray A, Matecki S, Beurey A, Marchal P, Voisin M, Préfaut C (2003) Training of aerobic and anaerobic fitness in children with asthma. J Pediatr 142(2):179–184
6. Jenkinson SG (1992) Obstructive lung disease. Churchill Livingstone, New York
7. Goyeche JRM, Ago Y, Ikemi Y (1980) Asthma: the yoga perspective part I: the somatopsychic imbalance in asthma: towards a holistic therapy. J Asthma Res 17(3):111–121
8. Cahalin LP, Braga M, Matsuo Y, Hernandez ED (2002) Efficacy of diaphragmatic breathing in persons with chronic obstructive pulmonary disease: a review of the literature. J Cardiopulm Rehabil 22(1):7–21
9. Vitacca M, Clini E, Bianchi L, Ambrosino N (1998) Acute effects of deep diaphragmatic breathing in COPD patients with chronic respiratory insufficiency. Eur Respir J 11:408–415
10. Bouchard C, Shephard RJ, Stephens T (1993) Physical activity, fitness and health: a consensus statement. Human Kinetics, Champaign, IL
11. Holloway E, Ram FS (2004) Breathing exercises for asthma. Cochrane Database Syst Rev (1):CD001277 (review)
12. Ambrosino N, Paggiaro PL, Macchi M, Filieri M, Toma G, Lombardi FA, Del Cesta F, Parlanti A, Loi AM, Baschieri L (1981) A study of short-term effect of rehabilitative therapy in chronic obstructive pulmonary disease. Respiration 41(1):40–44
13. Strunk RC, Mascia AV, Lipkowitz MA, Wolf SI (1991) Rehabilitation of a patient with asthma in the outpatient setting. J Allergy Clin Immunol 87(3):601–611
14. Ram FS, Wellington SR, Barnes NC (2003) Inspiratory muscle training for asthma. Cochrane Database Syst Rev (4):CD003792
15. National Institutes of Health (NIH) (1997) Management of asthma. Available at http://www.fpnotebook.com. Accessed 25 July 2006
16. American College of Sports Medicine (ACSM) (2006) ACSM's guidelines for exercise testing and prescription. Williams & Wilkins, Baltimore
17. Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J, ATS/ERS Task Force (2005) Standardisation of spirometry. Eur Respir J 26:319–338
18. Klausen K, Andersen C, Nandrup S (1983) Acute effects of cigarette smoking and inhalation of carbon monoxide during maximal exercise. Eur J Appl Physiol Occup Physiol 51(3):3 71–379
19. George RB, Light RW, Matthay MA, Matthay RA (1995) Chest medicine: essentials of pulmonary and critical care medicine, 3rd edn. Williams & Wilkins, Baltimore
20. Gosselink RA, Wagenaar RC, Rijswijk H, Sargeant AJ, Decramer ML (1995) Diaphragmatic breathing reduces efficiency of breathing in patients with chronic obstructive pulmonary disease. Am J Respir Crit Care Med 151:1136–1142
21. Clark CJ, Cochrane LM, Mackay E, Paton B (2000) Skeletal muscle strength and endurance in patients with mild COPD and the effects of weight training. Eur Respir J 15(1):92–97
22. Alter MJ (1990) Sport stretch. Leisure Press, Champaign, IL
23. Ludwick SK, Jones JW, Jones TK, Fukuhara JT, Strunk RC (1986) Normalization of cardiopulmonary endurance in severely asthmatic children after bicycle ergometry therapy. J Pediatr 109(3):446–451
24. Shaw I, Shaw BS, Brown GA (2010) Role of diaphragmatic breathing and aerobic exercise in improving maximal oxygen consumption in asthmatics. Sci Sports 25(3):139–145
25. Singh V, Wisniewski A, Britton J, Tattersfield A (1990) Effect of yoga breathing exercises (Pranayama) on airway reactivity in subjects with asthma. Lancet 335:1381–1383
26. Fluge T, Richter J, Fabel H, Zysno E, Weller E, Wagner TO (1994) Long-term effects of breathing exercises and yoga in patients with bronchial asthma. Pneumologie 48(7):484–490
27. Weiner P, Azgad Y, Ganam R (1992) Inspiratory muscle training for bronchial asthma. Harefuah 122(3):155–159
28. Ramazanoglu YM, Kraemer R (1985) Cardiorespiratory response to physical conditioning in children with bronchial asthma. Pediatr Pulmonol 1(5):272–277
29. Hudgel DW (1989) Bronchial asthma. In: Baum GL, Wolinsky E (eds) Textbook of pulmonary diseases, vol 1. Little, Brown, Boston/Toronto
30. Hakala K, Stenius-Aarniala B, Sovijärvi A (2000) Effects of weight loss on peak flow variability, airways obstruction, and lung volumes in obese patients with asthma. Chest 118:1315–1321
31. Anderson RA (2006) Asthma and breathing. Townsend letter for doctors and patients. Available at http://www.findarticles.com. Accessed 23 Feb 2007
32. Nickerson BG, Bautista DB, Namey MA, Richards W, Keens TG (1983) Distance running improves fitness in asthmatic children without pulmonary complications or changes in exercise-induced bronchospasm. Pediatrics 71(2):147–152
33. Ramsey CD, Celedon JC, Sredl DL, Weiss ST, Cloutier MM (2005) Predictors of disease severity in children with asthma in Hartford, Connecticut. Pediatr Pulmonol 39:268–275
34. Carter R, Nicotra B, Clark L, Zinkgraf S, Williams J, Peavler M, Fields S, Berry J (1988) Exercise conditioning in the rehabilitation of patients with chronic obstructive pulmonary disease. Arch Phys Med Rehabil 69(2):118–122
35. Haas F, Pineda H, Axen K, Gaudino D, Haas A (1985) Effects of physical fitness on expiratory airflow in exercising asthmatic people. Med Sci Sports Exerc 17(5):585–592
36. Altose MD (1989) Practical aspects of pulmonary function testing. In: Baum GL, Wolinsky E (eds) Textbook of pulmonary diseases, vol 1. Little, Brown, Boston/Toronto
37. Scanlan CL (1995) Chest physical therapy. In: Scanlan CL, Spearman CB, Sheldon RL (eds) Egan's fundamentals of respiratory care, 6th edn. Mosby, St. Louis
38. Scanlan CL, Ruppel GL (1995) Ventilation. In: Scanlan CL, Spearman CB, Sheldon RL (eds) Egan's fundamentals of respiratory care, 6th edn. Mosby, St. Louis
39. Kendall FP, McCreary EK, Provance PG (1993) Muscles testing and function, 4th edn. Lippincott Williams & Wilkins, Philadelphia
40. Luttgens K, Deutsch H, Hamilton N (1992) Kinesiology: scientific basis of human motion, 8th edn. WCB Brown & Benchmark, Madison, WI
41. Ries AL (1990) Position paper of the American Association of Cardiovascular and Pulmonary Rehabilitation. Scientific basis of pulmonary rehabilitation. J Cardiopulm Rehabil 10(11):418–441