

Using a Standard Respiratory Air Filtering Device during Moderate Intensity Exercise does not Affect Post Exercise Pulmonary Function

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Abstract Physical exercise requiring oxidative energy transfer increases pulmonary ventilation (V_E). In an air polluted environment, the exercise-induced increase in V_E increases the volume of toxic gases and number of toxic particles to which the pulmonary system is exposed. Using a respiratory air-filtering device (RAFD) during exercise decreases exposure to inhaled toxic gases and particles. However, a RAFD creates external resistance to inspiration and expiration which could decrease pulmonary muscle function and pulmonary volumes, and creates an external mechanical dead-space which produces fractional rebreathing which could increase pulmonary flowrates. This experiment tested the hypotheses that using a RAFD during exercise would; decrease post-exercise peak inspiratory pressure (P_{PI}) and peak expiratory (P_{PE}) pressure, FVC and FEV_1 , and increase post-exercise flowrates. Using a repeated-measures, counter-balanced design, six healthy moderately aerobically-trained, men (mean \pm SD; age 24.7 \pm 1.7 years; peak oxygen utilization [VO_{2peak}] 42.8 \pm 5.3 ml kg^{-1} min^{-1}) completed two 30 min exercise test sessions at a power output equal to 75% VO_{2peak} . One session was performed not using (NORAFD), and one using a RAFD (Moldex 8000) fitted with organic vapor cartridges and combined dust and mist pre-filters (inspiratory resistance = 0.216 kPa, expiratory resistance = 0.094 kPa at 85.0 l min^{-1}). All pulmonary function tests were performed immediately pre-Pre) and 0 (Post-0), 5 (Post-5), and 15 (Post-15) min post-exercise. There was a significant ($p < 0.05$) main effect of time with an increase in FEV_1 , $FEV_1/FVC\%$, PEF, and $FEF_{50\%}$ from Pre to Post-0. There were no other within or between condition differences in any of the pulmonary muscle pressures, volumes or flowrates. It was concluded that using a RAFD during moderate intensity medium duration exercise does not affect post exercise pulmonary function.

Keywords: respiratory protection, pulmonary function, physical activity, exercise

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1. Introduction

During physical exercise requiring oxidative energy transfer pulmonary ventilation [expired (V_E)] is increased 20 - 30 times the amount at rest [1]. When exercise is performed in an environment that contains toxic gases and airborne particles, the exercise-induced increase in V_E increases the volume of toxic gas and number of particles to which the pulmonary system is exposed for a given exercise duration [2]. Using a respiratory air filtering device (RAFD) during exercise can provide protection from toxic gases and particles. However, using a RAFD increases the resistance to inspiration and expiration [3], which could decrease pulmonary muscle pressure generation and, as a result, could reduce pulmonary volumes.

During exercise, both inspiration and expiration are active processes produced by contraction of the relevant ventilatory muscles which produce shifts in intra-thoracic pressure [4]. When an external resistance is added to inspiration or expiration, the force of the muscle contraction must increase if the tidal volume (V_T), breathing frequency, and therefore V_E are to be maintained at the same level. Therefore, the external resistance to breathing produced by a RAFD would be expected to increase the force of contraction of the pulmonary muscles at a given level of V_E . An external resistance to expiratory breathing during exercise increases the magnitude of pre- to post-exercise decreases in pulmonary muscle pressure generation [5]. Therefore, producing continued increased force of contraction/pressure generation to overcome the external resistance of a respirator may result in decreases in the pressure generation capabilities of the pulmonary muscles. A

decrease in the pressure generating capacity of the pulmonary muscles [6,7] and reduced pulmonary volumes [8] can occur following long duration exercise (i.e. marathon and ultra-marathon running), however, values remain within normal limits. It is unknown if the increased work of breathing while using a RAFD during moderate intensity, medium duration exercise reduces the post exercise force generating capacity of ventilatory muscles and decreases pulmonary volumes.

Using a RAFD creates a dead-space which causes fractional rebreathing [3,9] which is expected to increase the temperature and humidity of the inspired air. An increase in pulmonary flowrates during submaximal exercise has been reported in asthmatic and nonasthmatic participants when the temperature and humidity of inspired air increases [10] and, therefore, it is possible this could occur when using a RAFD. Furthermore, the added resistance imposed by a RAFD can affect breathing patterns with an increase in V_T and no change in breathing rate when using a RAFD at rest [11]. During low to moderate intensity exercise, using a RAFD has been shown to decrease V_E and breathing rate, and increase V_T [12,13]. However, as a RAFD prevents exposure to pollutants, any change in breathing pattern will not alter the dose of pollutants to which the user is exposed, but could have an effect on exercise performance. Research has shown that using a RAFD can decrease performance and or affect physiological functions (i.e. cardiovascular and pulmonary) as power output and or the level of breathing resistance increases [14,15,16,17]. For example, using a low resistance (i.e. < 0.09 kPa) respirator during low to moderate exercise was shown to have little effect on performance (i.e. exercise tolerance), cardiovascular (i.e. heart rate [HR], respiratory rate) or pulmonary (i.e. V_T , V_E) variables [13,18,19]. However, as exercise intensity increases ($> 80\%$ VO_{2max}) a respirator can reduce V_E ($\sim 21\%$) and breathing rate ($\sim 10\%$), and may reduce HR [3]. Likewise, during moderate intensity exercise on a cycle ergometer (i.e. 120 W for 7 minutes), using a respirator with low inspiratory resistance (i.e. < 0.25 kPa) had no effect on pulmonary function (i.e. breathing rate, V_E , PIF) [20]. However, when inspiratory resistance increased (i.e. from 0.25 to 0.3 kPa), V_E and PIF decreased and increased, respectively [20]. Similarly, during constant work load exercise (80% of VO_{2max} on a treadmill), using a respirator with low inspiratory resistance (i.e. < 0.39 kPa) had no effect on pulmonary function (i.e. breathing rate, V_T , V_E) or performance [21]. However, as inspiratory resistance increased (i.e. from 0.39 to 0.49 kPa), breathing rate, V_E and performance time decreased (46 and 70%), respectively [21]. Limits to inspiratory and expiratory resistance for certified filtering face piece respirators, established by the National Institute for Occupational Safety and Health, are 0.314 (inspiratory) and 0.245 (expiratory) kPa [22]. This study will determine if the resistance of the standard RAFD used in this experiment is appropriate during moderate intensity exercise of medium duration.

Previous research investigating the use of respirators during exercise has involved industrial type devices worn by workers in health care, the military or emergency services, for protection against airborne particulates, such

as gases, vapors, dust and micro-organisms [19,23,24]. There is only one experiment investigating the impact of using a respirator for general use or day to day activities [25]. Aranda et al., [25] investigated the use of a portable respirator during various indoor and outdoor activities, including recreational activity, and concluded the respirator could be a reasonable option to limit exposure to air borne pollutants. To our knowledge there are no studies investigating the impact of using a RAFD during recreational activity on post-exercise pulmonary function. As such, the purpose of this experiment was to determine the effect of using a light weight portable RAFD during exercise on post-exercise peak inspiratory pressure (P_{PI}) and peak expiratory pressure (P_{PE}), force vital capacity (FVC), forced expired volume in 1 second (FEV_1), peak expiratory flow (PEF), forced expiratory flow at 50% FVC (FEF_{50}); peak inspiratory flow (PIF), and forced inspiratory flow at 50% FVC (PIF_{50}). It was hypothesized that compared with no RAFD (NORAFD), using the RAFD would result in:

- 1) a decrease in P_{PI} and P_{PE} ;
- 2) a decrease in FVC and FEV_1 ; and
- 3) an increase in PEF, FEF_{50} , PIF, and FIF_{50}

2. Methods

2.1. Ethics

This experiment was approved by the Medical Research Ethics Committee of The University of Queensland (Ref No: H/90/Human M Stds/94/PhD). Prior to participation in the experiment, the participants were fully informed of the procedures involved following which they provided written informed consent to participate. Participants satisfactorily completed a medical clearance questionnaire and indicated no history of pulmonary dysfunction or use of pulmonary medication.

2.2. Design

This experiment utilized a one factor design with two levels of the independent variable, the RAFD (i.e. NORAFD vs. RAFD). The dependent variables were P_{PI} , P_{PE} , FVC, FEV_1 , $FEV_1/FVC\%$, PEF, FEF_{50} , PIF, and FIF_{50} . The experiment consisted of four separate sessions; the first session was for participant characterization and familiarization; the second session was for a test to verify that the power output used in the test sessions corresponded to 75% of VO_{2peak} ; and the third and fourth sessions were the two test sessions. The order in which the participants performed the two test sessions was counter-balanced within the group.

2.3. Participants

The participant group consisted of six moderately aerobically-trained men. The participant group was characterized by individual and group mean physical and peak oxygen utilization (VO_{2peak}) (Table 1), and pulmonary function (Table 2).

Table 1. Physical, aerobic power and ventilatory characteristics of participants

Participant (No.)	Age (yr)	Mass (kg)	VO _{2peak} (l min ⁻¹)	VO _{2peak} (ml kg ⁻¹ min ⁻¹)	V _{Epeak} (l min ⁻¹)
1	27	81.9	3.13	38.2	121.8
2	24	89.5	3.86	43.1	120.6
3	22	68.0	3.56	52.4	159.0
4	26	84.6	3.39	40.1	121.4
5	24	79.4	3.50	44.1	115.6
6	25	97.5	3.79	38.9	132.7
Mean	24.7	83.5	3.54	42.8	128.5
± SD	1.7	9.9	0.3	5.3	15.9

Abbreviations: (yr) year, (kg) kilogram.

Table 2. Pulmonary characteristics of participants

Participant (No.)	FVC (l)	FEV ₁ (l)	FEV ₁ /FVC (%)	PEF (l s ⁻¹)	FEF (l s ⁻¹)
1	5.13	4.52	88	11.0	6.06
2	5.34	3.74	70	8.35	3.13
3	4.19	3.58	85	7.95	4.87
4	7.07	6.06	86	10.07	7.90
5	5.05	4.13	82	10.88	4.61
6	6.56	5.34	81	15.55	5.58
Mean	5.56	4.56	82.0	9.14	5.36
± SD	1.06	0.97	6.4	1.18	1.60

Abbreviations: FVC: Forced vital capacity; FEV₁: Forced expiratory volume in 1 second; PEF: Peak expiratory flow; FEF₅₀ Forced expiratory flow.

2.4. Equipment

All sessions were conducted in a temperature and humidity controlled laboratory in which the environmental conditions were the same in both testing sessions (mean ± SD); RAFD: barometric pressure = 767 ± 2.8 mmHg; temperature = 23.6 ± 0.5°C; and relative humidity = 50.0 ± 4.2 %; NORAFD: 766 ± 2.8 mmHg; temperature = 23.6 ± 0.5°C; and relative humidity = 49.0 ± 6.7. Exercise was performed on a friction-braked cycle ergometer (Monark, Model No. 818e). The ergometer was modified, having non-standard dropped style handle bars, metal pedals, toe clips, and foot straps. The height of the seat and handle bars were adjusted to each participant.

For the VO_{2peak} tests, inspired pulmonary ventilation (V_I), oxygen utilization (V_{O₂}), and carbon dioxide production (V_{CO₂}) were measured using open circuit spirometry: participants breathed through a two-way valve (Hans Rudolph Model No. 2700: dead space = 100 ml); expired air was routed through 32 mm diameter convoluted tubing; The V_I was measured using a turbine ventilometer (Morgan, Model No. Mark 2); expired gas was sampled from a mixing chamber and O₂ and CO₂ fractional concentrations were analysed using a zirconium cell O₂ analyser (Ametek, Model No. S-3A/1) and an infrared light CO₂ analyser (Ametek, CD-3A) respectively. The volume output of the ventilometer was calibrated prior to each test using a calibration syringe (Vitalograph). The O₂ and CO₂ analysers were calibrated prior to each test using room air and gases of known concentrations (gravimetrically determined: Commonwealth Industrial Gases) within the range of inspired and expired concentrations.

The RAFD used in this experiment (Moldex, Model No. 8102A) was fitted with organic vapor cartridges (Part No. 8100A) and combined dust and mist pre-filters (Part No. 8040A). This respirator set-up has an inspiratory resistance of 0.216 kPa and an expiratory resistance of 0.094 when measured at a flow rate of 85.0 l min⁻¹ (specification from Moldex Metric Inc. 1995). To aid in maintaining a complete seal between the mask and face, participants were required to shave their faces prior to the exercise test during which the respirator was worn.

The P_{PI} and P_{PE} were measured using two separate mouthpieces, inspiratory and expiratory, each connected via 6 mm diameter tubing to opposite ports of a differential pressure transducer (RS Components, Model No. 341-963: 0.0-33.3 kPa). The output signal from the pressure transducer was recorded on a chart recorder (Linear Instruments Corp., Model No. 585). A 20 gauge needle was inserted into the tubing connected to the inspiratory mouthpiece to allow a small amount of airflow, therefore preventing pressure being produced within the mouth due to a closed glottis. The output signal of the pressure transducer was calibrated across the complete range of pressures from 0.0 to 33.3 kPa using a mercury column. Prior to each test the output signal was calibrated at zero (0.0) and maximum (33.3 kPa).

The pulmonary flow-volume loop (FVL) was measured using an electronic open circuit spirometer (Vitalograph, Model No. Compact I) for the determination of FVC, FEV₁, FEV₁/FVC%, PEF, FEF₅₀, PIF, FIF₅₀. The spirometer utilizes a Fleisch type differential pressure pneumotachograph. The volume output of the spirometer was calibrated prior to each test using multiple volumes of a 1.00 l calibration syringe (Vitalograph). Pulmonary function tests were performed according to the American Thoracic Society [26].

Heart rate was measured with an electronic HR monitor (Polar Sportster Model No. 9000e). To avoid any restraint of the chest wall resulting from the use of the standard elastic mounting strap which encircles the chest, the HR monitor transmitter was attached to the chest via two surface electrodes. Heart rate was recorded continuously during the 30 minute test sessions in both conditions. Due to technical reasons, approximately 30% of HR data were not obtained.

2.5. Procedures

The four sessions were separated by a minimum of 24 hr and participants were instructed not to perform any strenuous exercise for 24 hr prior to the sessions, or to take any food or caffeine 4 hr prior to the sessions. For the cycling exercise, the participants were instructed to maintain a pedaling rate of 80 rpm, the pedaling cadence being visible to the participants on a digital display.

The VO_{2peak} for each participant was determined using an incremental-intensity protocol which consisted of 4 min of unloaded cycling followed by step-increments in power output of 40 W at the end of each min. The test was terminated at volitional cessation. Ventilatory and gas exchange data were collected continuously throughout the test. The VO_{2peak} was calculated as the single highest value during the final 60 s before volitional cessation of the test.

The VO_{2peak} was then used to calculate a workload that equaled 75% of VO_{2peak} . HR_{peak} was taken as the value at VO_{2peak} and was used to express the HR as a percentage of peak during the two 30 minute test sessions.

The P_{PI} and P_{PE} , and flow-volume loop tests were performed immediately pre-exercise and at 0, 15, and 30 min post-exercise. For all pulmonary function tests the participant was seated in an upright position in a chair positioned next to the cycle ergometer. Prior to each FVL measurement the participant took three vital capacity breaths designed to standardize lung volumes. For pulmonary volumes and flowrates the pre-exercise measurements consisted of three separate FVL maneuvers and the post-exercise measurements consisted of two FVL separate maneuvers, to minimize the effect of performing the FVL on subsequent measurements. The pulmonary volumes and flowrates from the FVL with the highest value from the summation of FVC and FEV_1 at each measurement time were used [26].

For P_{PI} the measurements were performed at residual volume and for P_{PE} the measurements were performed at total lung capacity [27]. For the P_{PI} and P_{PE} measurements three maneuvers were performed pre-exercise and two maneuvers were performed post-exercise and the highest value at each measurement time was used. For all pulmonary function measurements verbal instructions were given throughout the measurements for when to exhale and inhale. All tests and interpretation were performed according to the American Thoracic Society [26].

Session 1. During Session 1 each participant was familiarized with all of the pulmonary and exercise equipment and procedures and the VO_{2peak} measurement was conducted.

Session 2. During Session 2 the power output used to produce an exercise intensity of 75% of VO_{2peak} for each

participant was verified during four minutes of cycling exercise.

Sessions 3 and 4. Session 3 and Session 4 test sessions (RAFD and NORAFD) were conducted on separate days during which the participants cycled for 30 min at the power output equal to 75% of VO_{2max} .

2.6. Statistical Analysis

Statistical analyses were performed using the statistical program SPSS version 26. All assumptions for the use of parametric analyses were met. Statistical analyses to determine differences in the dependent variables both within (condition and time) and between (condition and time) conditions were conducted using two-way repeated measures (RM) analysis of variance (ANOVA). Where appropriate, significant main effects were followed up with pair wise comparisons using the Bonferroni test. The alpha level for statistical significance was set at $p < 0.05$.

3. Results

There was no significant difference in HR between RAFD and NORAFD (mean \pm SD: RAFD 151 ± 16.3 ; NORAFD 151 ± 17.6 bpm, $p > 0.05$). HR during the test sessions averaged $84\% \pm 11\%$ (RAFD) and $84\% \pm 10\%$ (NORAFD) of HR_{peak} and was not significantly different to 75% of HR_{peak} (136 ± 5.9 bpm, $p > 0.05$) at VO_{2peak} . There was a significant main effect of time with an increase in FEV_1 , $FEV_1/FVC\%$, PEF, and $FEF_{50\%}$ (Table 3) from Pre to Post-0. There were no significant differences in P_{PI} or P_{PE} within or between conditions (Table 4). There were no other within or between condition differences in any of the other pulmonary function variables.

Table 3. Pulmonary flowrates pre- and post-exercise for 30 min of exercise at 75% VO_{2peak} either without or with a respiratory air filtering device

	No Respiratory Air Filtering Device				Respiratory Air Filtering Device			
	Pre	Post			Pre	Post		
		0	5	15		0	5	15
FVC	5.56	5.46	5.64	5.70	5.65	5.66	5.63	5.66
\pm (l)	0.43	0.40	0.41	0.42	0.45	0.40	0.43	0.45
FEV_1	4.56	4.69	4.64	4.68	4.59	4.78	4.68	4.63
\pm (l)	0.39	0.38	0.40	0.41	0.41	0.40	0.43	0.43
$FEV_1/FVC\%$	82.0	86.0	82.5	81.7	81.2	84.8	82.8	82.0
\pm (%)	2.6	2.7	3.2	3.0	2.8	3.8	3.5	3.0
PEF	10.63	11.29	10.57	10.46	10.44	11.11	10.65	10.65
\pm (l s ⁻¹)	1.11	1.23	0.89	1.01	0.70	0.82	0.72	1.02
FEF_{50}	5.36	5.95	5.38	5.70	5.51	6.00	5.46	5.40
\pm (l s ⁻¹)	0.65	0.60	0.65	0.69	0.71	0.76	0.70	0.68
PIF	7.96	9.90	9.48	9.26	9.31	8.58	8.37	8.89
\pm (l s ⁻¹)	1.88	1.01	1.10	1.03	1.37	1.91	1.99	1.04
FIF_{50}	8.19	9.74	9.16	9.03	9.45	9.48	9.42	8.76
\pm (l s ⁻¹)	1.50	1.09	1.16	1.04	1.48	0.86	1.31	1.17

Values are mean \pm SD.

Abbreviations: Pre = pre-exercise, Post = post-exercise, FVC = forced vital capacity, FEV_1 = forced expiratory volume in 1 second, PEF = peak expiratory flow, FEF_{50} = forced expiratory flow at 50% FVC; PIF = peak inspiratory flow, FIF_{50} = forced inspiratory flow at 50% FVC

Table 4. Pulmonary muscle pressure pre- and post-exercise for 30 min of exercise at 75% $\text{VO}_{2\text{peak}}$ either without or with a respiratory air filtering device

	No Respiratory Air Filtering Device				Respiratory Air Filtering Device			
	Pre	Post			Pre	Post		
		0	5	15		0	5	15
P_{PI} ± (kPa)	12.60 1.80	13.65 1.15	13.35 1.46	13.82 1.34	13.26 1.56	12.90 1.51	13.30 1.58	12.82 1.47
P_{PE} ± (kPa)	13.35 0.53	12.23 1.03	13.32 0.55	13.49 1.05	14.07 0.76	13.35 1.34	13.35 1.12	13.15 1.04

Values are mean ± SD.

Abbreviations: Pre = pre-exercise, Post = post-exercise, P_{PI} = peak inspiratory pressure; P_{PE} = peak expiratory pressure.

4. Discussion

This experiment was designed to determine whether using a commercially available standard RAFD during exercise affected pulmonary function following exercise. The results of the experiment showed that using the RAFD did not affect any of the measured components of pulmonary function. The results provide new information that indicates using a standard respiratory air filtering device is acceptable during moderate intensity exercise of medium duration.

In contrast to our hypotheses, the pressure generating capacity of the pulmonary muscles was not different when using a RAFD, and also did not decrease following 30 minutes of moderate intensity exercise. These results indicate that even though the pulmonary muscles are working at an increased rate, at a relative high level, the addition of resistance to both inspiration and expiration did not lead to decreases in pressure generation capabilities. However, a decrease in the pressure generating capacity of pulmonary muscle has been observed following moderate intensity exercise of long duration while not using a RAFD (i.e. marathon running) [28]. As such, it is possible using a RAFD during exercise of longer duration may affect the pressure generating capacity of pulmonary muscles. The inspiratory and expiratory resistances of the standard RAFD used in the current study are lower than the limits for filtering face piece respirators as set out by the National Institute for Occupational Safety and Health [22]. As the results from the current study showed no negative effect on pulmonary function, the resistances used in the standard RAFD are appropriate for use during moderate intensity, medium duration exercise.

There are some studies that suggest the forced expiratory volume (FEV_1) and forced expiratory flowrates (i.e. PEF) measured prior to dynamic airways compression are dependent on the force production of the pulmonary muscles [29,30]. Therefore, these variables can indicate the pressure generation capacity of the pulmonary muscles. There are two fundamental factors that affect pulmonary volumes and flow rates: 1) the force generating capacity of the pulmonary muscles and 2) the diameter of the airways. As there were no changes in P_{PI} or P_{PE} , it is possible the increase in FEV_1 and flow rates in this study were due to changes in the diameter of the airway, which could occur as the airway expands due to the increased ventilation that occurs during exercise.

Although, this study did not measure the temperature and humidity inside the RAFD the laboratory conditions

during both exercise sessions were not different. It is possible that any changes in water content within the airways due to exercise were not affected by any increase in humidified air within the mask and the fractional re-breathing of this air. These results may be particularly relevant to individuals with exercise induced asthma who may benefit from breathing warm, humidified air and, at the same time, limit exposure to outdoor pollutants that could exacerbate symptoms of asthma [31,32].

The current study did not measure VO_2 during the two test sessions. As such, a percentage of HR_{peak} was used as a measure of exercise intensity to verify participants were working at an intensity equal to 75% of HR_{peak} . Results showed HR during both test sessions was not different to 75% of HR_{peak} . In addition, there was no difference in HR between either condition during 30 minutes of moderate intensity exercise. This is supported by previous research that has shown no difference in HR while using a RAFD during moderate intensity exercise [13,15]. Overall, our results show that as HR was not different between conditions, the participants exercised at the same intensity during both test sessions and that using a RAFD has no effect on systemic physical effort.

Comfort is an important factor related to wearer acceptance of respirators and is influenced by the fit, weight and breathing resistance imposed by the respirator [21]. In a study using a larger and heavier (i.e. > 1 kg) portable respirator, participants reported the respirator was light and easy to wear while cycling [25]. In general, the respirator used in the present study was well tolerated during moderate intensity cycling. However, results may differ with other forms of exercise, such as running, and this requires further investigation.

4.1. Limitations

Limitations of the present study include the small sample size, the inclusion of men only, and not collecting data on the humidity within the mask. Also, the present study was conducted on healthy aerobically trained men during moderate intensity exercise of medium duration and findings may differ with higher intensity exercise of longer duration.

5. Conclusions

Engaging in regular physical activity is an important part of a healthy lifestyle and helps reduce the risk of

chronic disease [33]. However, in areas with high levels of air pollution, people who exercise outdoors are at increased health risk due to breathing polluted air [34]. To our knowledge this is the first study to investigate the impact of using a standard RAFD during exercise on post exercise pulmonary function. Results of the current study are directly relevant to physically active individuals who may limit outdoor activities due to air pollution [33,34]. Results support using a standard RAFD during outdoor physical activity and could allow individuals to continue activity while limiting exposure to airborne pollutants. Future research investigating the use of a standard RAFD during recreational activity in different populations (i.e. women), and during different modes (i.e. running), durations and intensities of exercise is needed. In conclusion, results of this study indicate using a standard RAFD during moderate intensity physical exercise had no negative effect on pulmonary function in healthy, recreationally active individuals.

Abbreviations

HR: Heart rate
 FVC: Forced vital capacity
 FEV₁: Forced expiratory volume in one second
 PEF: Peak expiratory flow
 FEF₅₀: Forced expiratory flow at 50% FVC
 PIF: Peak inspiratory flow
 FIF₅₀: Forced inspiratory flow at 50% FVC
 V_E: Pulmonary ventilation
 kPa: kilopascal
 P_{PI}: Peak inspiratory pressure
 P_{PE}: Peak expiratory pressure
 RAFD: respiratory air filtering device
 NORAFD: no respiratory air filtering device
 V_T: Tidal volume

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