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Acute effects of inspiratory muscle warm-up on pulmonary function in healthy subjects

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ABSTRACT

The acute effects of inspiratory muscle warm-up on pulmonary functions were examined in 26 healthy male subjects using the pulmonary function test (PFT) in three different trials. The control trial (CON) did not involve inspiratory muscle warm-up, while the placebo (IMWp) and experimental (IMW) trials involved inspiratory muscle warm-up. There were no significant changes between the IMWp and CON trials ($p > 0.05$). All the PFT measurements, including slow vital capacity, inspiratory vital capacity, forced vital capacity, forced expiratory volume in one second, maximal voluntary ventilation, and maximal inspiratory pressure were significantly increased by 3.55%, 12.52%, 5.00%, 2.75%, 2.66%, and 7.03% respectively, in the subjects in the IMW trial than those in the CON trial ($p < 0.05$). These results show that inspiratory muscle warm-up improved the pulmonary functions. The mechanisms responsible for these improvements are probably associated with the concomitant increase in the inspiratory muscle strength, and the cooperation of the upper thorax, neck, and respiratory muscles, and increased level of reactive O_2 species in muscle tissue, and potentially improvement of muscle O_2 delivery-to-utilization. However, further investigation is required to determine the precise mechanisms responsible from among these candidates.

1. Introduction

The functioning of the respiratory system should be regular and efficient so as to meet the tissue demand. The functioning of the respiratory system mechanically depends substantially on the capacity of the respiratory muscles (Kantarson et al., 2010). Warm-up for the respiratory muscles, known as inspiratory warm-up, can increase the respiratory muscle functional capacity (Volianitis et al., 1999), and decrease the respiratory muscle fatigue (Volianitis et al., 2001a). These aspects highlight the importance of inspiratory warm-up.

Inspiratory warm-up can affect the maximal inspiratory muscle strength (Volianitis et al., 1999), rowing performance (Volianitis et al., 2001b), 100-m swimming performance (Wilson et al., 2013), and 6-min all-out performance among rowers (Volianitis et al., 2001a); repeated running performance (Tong and Fu, 2006), perception of breathlessness and dyspnea during exercise (Lin et al., 2007; Kantarson et al., 2010), and foot-work performance among badminton players (Lin et al., 2007); and 6-min performance during treadmill running (Kantarson et al., 2010). However, there is limited information regarding the acute effects of inspiratory muscle warm-up on pulmonary functions.

We hypothesized that inspiratory muscle warm-up positively affects the spirometer measurements related to pulmonary functions. Therefore, in this study, we investigated the impact of inspiratory muscle warm-up on pulmonary functions obtained through a spirometer in healthy men.

2. Materials and methods

2.1. Experimental approach to the problem

This study was designed as a randomized, placebo-controlled, crossover study. The subjects visited the laboratory four times. During their first visit, they were familiarized with the pulmonary function (PFT), maximal inspiratory pressure (MIP), $VO_{2\,max}$ tests and inspiratory muscle warm-up. During the second visit, a PFT and MIP test were performed without inspiratory muscle warm-up, which was considered as the control trial (CON); moreover, the subjects performed the $VO_{2\,max}$ test. During the third and fourth visits, the subjects randomly performed inspiratory muscle warm-up trial at 40% of MIP (IMW) or placebo inspiratory warm-up trial at

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Table 1
Descriptive information of subjects ($N = 26$).

	Means ± SD
Age (years)	26.31 ± 4.39
Height (cm)	192.23 ± 8.57
Weight (kg)	88.15 ± 10.38
BMI (kg/m^2)	23.80 ± 1.64
MIP (cmH$_2$O)	149.38 ± 15.17
VO$_{2max}$ (L/min)	3.77 ± 0.49

BMI—body mass index, MIP—maximal inspiratory pressure, VO$_{2max}$—maximal oxygen uptake. Note that VO$_{2max}$ was attained on a maximum-effort incremental test, from VO$_{2peak}$ (Day et al., 2003; Barker et al., 2011; Poole et al., 2008).

15% of MIP (IMWp). PFT and MIP test were immediately performed again after the IMW and IMWp trials. The trials were applied at the same time each day (between 16:00 and 20:00 h). Exercise and high-intensity physical activity were not allowed before the trials.

2.2. Subjects

A total of 26 healthy men voluntarily participated in this study (Table 1). The subjects were informed about of the inspiratory warm-up and PFT 2 days before study. Ethical approval was obtained from Gaziantep Clinical Research Ethical Committee. Informed consent was obtained from all individual participants included in the study.

2.3. Procedures

2.3.1. MIP measurement

MIP was measured with the respiratory pressure meter (MicroRPM, CareFusion Micro Medical, Kent, UK), according to the 2002 guidelines of the American Thoracic Society and European Respiratory Society (2002). Measurement started from the residual volume. The nose was occluded throughout the effort. In order to obtain the best value, all subjects performed three to five attempts for not more than a 5% difference between two attempts. An average of three acceptable attempts was used as the MIP value (Arend et al., 2015).

2.3.2. Determination of VO$_{2max}$

VO$_{2max}$ test was applied on all subjects to eliminate abnormal pulmonary function data during exercise and insufficient endurance performance so as to determine their wellness and health. Measurement was conducted with a cycle ergometer (SanaBike 450F, Ergosana GMBH, Bitz, Germany) and an ergospirometer (Ergo100 PFT System, Medical Electronic Construction R&D, Brussels, Belgium). Exercise load was started at 50 W and increased by 25 W/min. The subjects cycled at 60 rpm during the entire exercise time. When the subjects felt exhaustion, the exercise was stopped and VO$_{2max}$ value recorded (Buchfuhrer et al., 1983).

2.3.3. Pulmonary function test

The pulmonary functions were evaluated using a spirometer (PocketSpiro USB100, Medical Electronic Construction R&D, Brussels, Belgium). Slow and forced vital capacity tests were selected for PFT and measured according to the above-mentioned guidelines. Slow vital capacity (SVC), inspiratory vital capacity (IVC), forced vital capacity (FVC), forced expiratory volume in one second (FEV1) and calculated maximal voluntary ventilation (MVV) variables were recorded using PFT (Miller et al., 2005).

2.3.4. Inspiratory warm-up procedure

A specific inspiratory training device (POWER®Breathe Classic, IMT Technologies Ltd., Birmingham, UK) was used for inspiratory warm-up procedures. For IMW, two sets of 30 inspirations were performed at an intensity of 40% of MIP with 2 min rest between each set. For IMWp, the same procedure was performed at an intensity of 15% of MIP (Cheng et al., 2013).

2.4. Statistical analyses

SPSS version 22.0 (SPSS Inc., Chicago, IL) program was used for statistical analyses. The data were expressed as the mean, standard deviation, and percentage of mean difference. The Shapiro–Wilk test was used for assessing normality. Repeated measures one-way analysis of variance test and Bonferroni correction were used for analyzing the differences in the PFT measurements among the trials. Significance was defined as $p \le 0.05$.

3. Results

3.1. Effects on PFT measurements

Table 2 shows a comparison of the trials in terms of the PFT measurements. Significant changes in all PFT measurements and MIP were observed among the IMW, IMWp, and CON ($p < 0.05$). Significant differences were found in SVC (CON = 5.65 ± 0.62 L, IMWp = 5.66 ± 0.58 L, IMW = 5.85 ± 0.60 L) between the IMW and IMWp, and between the IMW and CON trials. Similarly, IVC (CON = 3.77 ± 0.49 L, IMWp = 3.78 ± 0.46 L, IMW = 4.24 ± 0.59 L) showed significant differences between the IMW and IMWp, and between the IMW and CON. FVC (CON = 5.33 ± 0.48 L, IMWp = 5.34 ± 0.49 L, IMW = 5.59 ± 0.46 L) also exhibited significant changes between the IMW and IMWp, and between the IMW and CON. Significant increases were also observed in FEV1 (CON = 4.59 ± 0.44 L, IMWp = 4.56 ± 0.40 L, IMW = 4.72 ± 0.40 L), MVV (CON = 159.93 ± 14.65 L/min, IMWp = 160.13 ± 14.41 L/min, IMW = 164.19 ± 14.35 L/min) and MIP (CON = 149.38 ± 15.17 cmH$_2$O, IMWp = 150.12 ± 14.77 cmH$_2$O, IMW = 159.88 ± 12.07 cmH$_2$O) between the IMW and IMWp, and between the IMW and CON trials.

Compared to the baseline levels of PFT measurements in the CON trial; the SVC, IVC, FVC, FEV1, MVV, and MIP differed by 0.19%, 0.43%, 0.32%, −0.62%, 0.13%, and 0.49%, respectively, in the IMWp trial and by 3.55%, 12.52%, 5.00%, 2.75%, 2.66%, and 7.03%, respectively in the IMW trial (Fig. 1).

4. Discussion

The aim of this study was to investigate the effects of IMW on pulmonary functions. There were two major findings of the present study: (1) after the IMW, IVC showed a large increment by 12.52% from the initial level ($p < 0.05$) and (2) MIP also showed a significant increase by 7.03% compared to the CON trial ($p < 0.05$). All other PFT measurements also showed significant improvements after the IMW trial ($p < 0.05$). However, the PFT measurements and MIP did not show any significant differences after the IMWp trial ($p > 0.05$).

Previous studies have demonstrated the effects of respiratory muscle training on pulmonary functions in healthy individuals (Enright et al., 2006; Enright and Unnithan, 2011; Leith and Bradley, 1976), obese subjects (Villiot-Danger et al., 2011; Tenório et al., 2013), patients with cystic fibrosis (Enright et al., 2004), wheelchair athletes (Soosey-Tolfrey et al., 2010), and persons with multiple sclerosis (Chiara et al., 2006). The effect of inspiratory muscle warm-up on exercise performance was studied by some researchers (Kantarson et al., 2010; Volianitis et al., 2001a,b; Wilson et al., 2013; Tong and Fu, 2006; Lin et al., 2007). An earlier study showed that inspiratory muscle warm-up was ineffective on lung function (Volianitis et al., 1999). However, that study had used only "flow-volume loops" for determining the lung functions. The acute