Methods

Subjects

A total of 23 subjects participated after giving informed written consent to the study that was approved by the local Ethics Committee. Twelve Sport Science students formed the 'rowing' group. Characteristics of the two groups are shown in Table 1. One of the subjects was removed from the study because he developed a respiratory tract infection within two weeks of the data collection, a condition known to have potential effects on respiratory muscle strength [24].

Table 1 Characteristics of the two groups

Mean ± SD	Non-rowing (n = 12)	Rowing (n = 11)
Age (yr)	20 ± 1	20 ± 2
Height (cm)	175 ± 8	180 ± 6
Weight (kg)	70 ± 11	74 ± 8
FVC (l)	5.4 ± 0.9	5.3 ± 0.6
FEV_1 (l)	4.6 ± 0.6	4.5 ± 0.5
FEV_1/FVC (%)	86 ± 8	87.2 ± 7
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	47 ± 7	58 ± 7

Procedure

Before data collection, all subjects visited the lab on two occasions to be familiarised with mouth pressure measurements and flow volume manoeuvres. Subsequently, both groups performed an incremental test to volitional exhaustion, a whole body warm-up, and a specific respiratory warm-up, which took place on three separate occasions. The non-rowing group, which used a cycle ergometer for the incremental test and the whole body warm-up, performed a general warm-up while the rowing group, which used a rowing ergometer for the respective exercise sessions, performed a rowing warm-up consisting of a general and a sport specific warm-up. The specific respiratory warm-up was performed using a pressure threshold inspiratory muscle training device. Maximum mouth pressures and pulmonary function were assessed before and after every treatment condition. Additionally, as an index of the warm-up effect on the peripheral musculature, isokinetic strength of the quadriceps was measured before and after the rowing warm-up.

Maximum inspiratory pressures (MIP)

MIP is commonly used to measure inspiratory muscle strength. It reflects the force-generating capacity of the combined inspiratory muscles during a brief, quasi-static contraction (Mueller manoeuvre) [17]. MIP was recorded using a portable hand held mouth pressure meter (Precision Medical, UK). This device has been shown to measure inspiratory efforts accurately and reliably [9]. A minimum of five and a maximum of nine technically satisfactory measurements were conducted, and the highest of three measurements with 5% variability or within 5 cm H_2O difference was defined as maximum [31]. The initial length of the inspiratory muscles was controlled by initiating each effort from residual volume (RV). This procedure was adopted because, from our experience, RV is more reproducible than functional residual capacity (FRC). Subjects were instructed to take their time and to slowly empty their lungs to RV, thereby avoiding problems associated with variability in lung volumes. All manoeuvres were performed in the upright standing position, and verbal encouragement was given to help the subjects perform maximally.

Static spirometry

Pulmonary function was assessed with a Vitalograph 2120 portable spirometer (Vitalograph Ltd., Buckingham, England), which was calibrated prior to each testing session using a 3 litre calibration syringe (Hans Rudolph Inc., Kansas, USA). Following familiarisation, the best of three manoeuvres were recorded. Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), percentage expired (i.e. $100 \times FEV_1/FVC$) (FEV_1 %) and peak inspiratory flow rate (PIFR) were the parameters recorded before and after every treatment condition.

Incremental test to exhaustion (Peak $\dot{V}O_2$)

The no-rowing group performed a continuous incremental protocol to volitional exhaustion on an Excalibur Sport V2.0 electromagnetically braked cycle ergometer. The work rate was increased every fifteen seconds and was designed to elicit maximal oxygen uptake (peak $\dot{V}O_2$) within ten to twelve minutes. The test was terminated at volitional exhaustion or when the subject failed to maintain a pedalling frequency higher than 50 rpm.

The rowing group performed an incremental test to volitional exhaustion on a wind-resistance braked rowing ergometer (Concept II, model c, Morrisville, USA) starting at an individually chosen light work intensity and increasing the workrate by 50 W every 3 minutes. The wind damper was at the fourth setting. Power was calculated from acceleration of the flywheel and displayed on a monitor. Maximal power (Pmax) was calculated as

$$P_{max} = P_{n-1} + ([[P_n - P_{n-1}] \cdot t_n]/180)$$

with P_n = power of the maximum stage, P_{n-1} = power of the stage before, and t_n = time of work of the maximum stage in seconds [18].

Breath by breath gas analysis was made with an MGA 2000 Mass Spectrometer (Aispec Ltd., Kent, UK) in conjunction with an ultrasonic phase-shift flowmeter (Birmingham Flowmetrics, Birmingham, UK). Data processing was performed on-line (Labview 3, National Instruments, Austin TX, USA) on a Powermac 7100/80 (Macintosh Ltd., USA). Calibration of the flowmeter was performed before each test using a 1 litre calibration syringe (PK Morgan Ltd., Kent, UK). The heart rate was telemetrically monitored with Polar Accurex Plus heart rate monitor (Polar Electro, Finland).

General warm-up

Twenty min of cycling was performed on the same cycle ergometer as in the incremental test. The first 10 min were performed at 30% of peak work rate (WRpeak), the next 5 min at 35%, and the final 5 min at 40%. Pedalling frequency was