METHODS

Subjects. Fourteen female competitive rowers (mean ± SD, age 23.8 ± 3.8 yr, height 173.4 ± 3.8 cm, weight 68.2 ± 4.6 kg, maximal oxygen uptake ($\dot{V}O_{2max}$) 3.56 ± 0.17 $L \cdot min^{-1}$, maximal power output (P_{max} 229 ± 22 W)) were assigned randomly to either an inspiratory muscle training (IMT) or placebo group. The subjects were informed about the nature and risks involved in participation in the experiments. The experimental protocol was approved by the local ethics committee, and all subjects acknowledged voluntary participation through written informed consent. The subjects were instructed to adhere to their usual diet and not to engage in strenuous activity the day before an exercise test. On test days, the subjects were asked not to drink coffee or other caffeine-containing beverages. The tests were performed at similar times of the day. The initial performance assessment took place at the end of October, which is the first month of the preparatory period of the rowing season. All the subjects where either national team members or candidates for the national team and had been competing for a minimum of 3–4 yr.

Procedure. At the beginning of the study, the subjects performed a submaximal incremental load test followed by a 6-min all-out test on a rowing ergometer (model c, Concept II, Nottingham, UK). On the same occasion, baseline spirometry values and maximum respiratory mouth pressures were taken before and after the rowing tests. Both groups commenced an 11-wk period of inspiratory muscle training. The effects of the intervention were evaluated, with the same battery of tests, at 4 wk and after completion of the training period. Mouth pressure measurements, for evaluation of respiratory muscle function during rowing, took place on all occasions. The maneuvers were performed within 30 s after the completion of the maximum effort.

Submaximal incremental load test. The test protocol consisted of five stages of 4 min each with a 1-min interruption for blood sampling. The initial work rate was individualized based on known work capacity. The rowers where asked to start rowing with a frequency of 18 $strokes \cdot min^{-1}$ at a work rate that they usually perform their daily warm-up. The work rate increments for each subsequent stage was 20 or 25 W, depending on the rower's capacity. Once the protocol for a particular rower was established at the beginning of the study, it was not varied thereafter. Heart rate was monitored via a short-range telemetry system (Polar Sporttester, Polar Electro, Kempele, Finland). A preexercise and poststage blood sample was collected from the earlobe and analyzed for lactate concentration. Stroke ratings ($st \cdot min^{-1}$) and power output (W) were recorded for each stage. Continuous analysis of expired gases and static spirometry (flow-volume loops) were performed with an Oxycon Alpha diagnostic system (Jaeger b.v., Manheim, Germany).

Maximal performance tests. After the submaximal incremental load test, the rowers performed a 6-min all-out effort, which is a simulation of the competitive rowing duration. Rowing events last between 5.5 and 7.5 min, depending on boat type, category, and gender of the rowers. We chose 6-min for our test as it represents the duration of the women's eight events. The rest period between the submaximal test and the 6-min test was standardized at 8–10 min to minimize any fatiguing effect of the submaximal test but at the same time to maintain readiness of the rowers. Additional performance data have been obtained at baseline and after 4 wk of inspiratory muscle training by means of a 5000 m ergometer trial that the subjects performed as part of their training control.

Maximum inspiratory pressure measurement. Maximal static inspiratory mouth pressure (PI_{max}) is commonly used to measure inspiratory muscle strength. A portable hand held mouth pressure meter (Precision Medical, London, United Kingdom) was used for this measurement. This device has been shown to measure inspiratory and expiratory pressures accurately and reliably (12). A minimum of five technically satisfactory measurements were conducted and the highest of three measurements with less than 5% variability or within 5 cm H_2O (1 kPa = 10.3 cm H_2O) difference was defined as maximum (34). 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 empty their lungs slowly to RV, thereby avoiding problems associated with variability in lung volumes and dynamic airway compression. All maneuvers were performed in the upright standing position, and verbal encouragement was given to help the subjects perform maximally. The subjects had been familiarized with the nature of the maneuvers to reduce any learning effect.

Respiratory muscle fatigue. For practical purposes, "fatigue" was defined as the inability to continue to generate a given pressure with the same motor command as when the muscle was still fresh. A condition like this does not necessarily imply any "task failure" in the form of inadequate pressure generation for the required ventilation, but it is an indication that the functional capacity is compromised and it will eventually lead to "task failure." Therefore, the original definition of Edwards (9) of skeletal muscle fatigue as a "failure to maintain the required or expected force" has been extended for respiratory fatigue to include also the state of muscle weakness (27).

Perception of dyspnea. A category scale, the modified Borg (3) scale, was chosen to evaluate the respiratory effort during exercise. The scale consisted of a series of integers from 0 to 10. The rower was asked to estimate the effort required to breathe but not the effort of the exercise. During rowing, the Borg scale remained in front of the rower and an assessment was made at the end of every stage and after the all-out effort.

Inspiratory muscle training. The training group performed 30 inspiratory efforts twice daily. Each effort required the subject to inspire against a resistance equivalent to 50% peak inspiratory mouth pressure (PI_{max}) by using an inspiratory muscle trainer (POWERbreathe®, IMT Tech-