Pulmonary Dysfunction in Ultramarathon Runners*

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To assess the effects of extreme exercise on lung function we measured maximal expiratory flow volume (MEFV) curves in fifteen runners (mean age, 35.3 years; range, 26-46) before and after an 80.6 to 100 km (50-62.2 mile) road race. Mean running time for 80.6 km was 7 hr, 42 min. Post-race testing showed significant decreases of 12.4 percent in forced vital capacity (FVC), 9.5 percent in forced expiratory volume in one second (FEV1), 13.7 percent in peak expiratory flow (PF), and 28.4 percent in flow at 50 percent of FVC (MEF50). By 2.5 hours after the race lung function had improved. The reduction in flow rates after ultramarathon running may be due to airway obstruction. In contrast, the decrease in FVC with gradual recovery of lung function after rest and nourishment suggests the development of respiratory muscle fatigue.

INTRODUCTION

Although long distance running involves severe metabolic demands [1,2] and provokes strenuous cardiorespiratory responses [3], the effects of prolonged exercise on lung function are not well defined. Over fifty years ago Gordon et al. [4] reported a decrease in the forced vital capacity (FVC) of the lungs in runners completing the 1923 Boston Marathon. Using maximal expiratory flow-volume (MEFV) curves we recently confirmed this finding and showed in addition that airway obstruction did not occur in marathon (42.2 km) runners completing at above freezing ambient temperatures [5].

However, the exact mechanism for the change in post-race FVC has not been determined, and whether extreme endurance exercise results in further alterations in pulmonary function is unknown. To address these questions, we measured MEFV curves in runners before and after an 80.6 to 100 km ultramarathon race (50 to 62.2 miles). To evaluate for recovery of respiratory dysfunction, testing was repeated at 2.5 and 24 hours.

METHODS

Pre- and post-race lung function was measured in fifteen runners at the Lake Waramaug Ultramarathon (LWU) which was held on May 6, 1979, in Preston, Connecticut. The course was a 7.66-mile loop, and the distance of the race was 80.6 or 100 km (50 or 62 miles). Humidity of the ambient air was 54 percent, and the temperature ranged from 10.0°C to 18.3°C. Testing was performed in a building located within 0.05 km from the start and finish of the race. On the morning of race

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day each runner completed a questionnaire on respiratory symptoms, training, and previous running performances. Informed consent was obtained.

Pulmonary function was measured with a pneumotachygraph integrated flow-volume device connected to a Brush 500 High Performance X-Y recorder (Gould Inc., Cleveland, OH), which displayed a maximum expiratory flow-volume curve[6]. Volume was calibrated with a three-liter syringe and flow with a precision bore flowrator tube (Fischer & Porter, Warminster, PA) having a range of 0–10 liters/sec. Four MEFV curves were measured in each runner in the seated position before and immediately after completion of the marathon. From the MEFV curve, forced expiratory volume in one second (FEV₁), FVC, peak expiratory flow (PF), and flow rate at 50 percent of FVC (MEF50) were obtained. The value of these indices was taken from the MEFV curve yielding the largest sum of FVC and FEV₁[7]. The post-race MEF50 was measured from total lung capacity at the same volume at which pre-race MEF50 was determined. The results of pre-race lung function was compared to the predicted normal values of Higgins and Keller[8].

Post-race testing was performed 10 to 15 minutes after each runner finished the race, at which time the subject was breathing comfortably. Ten of the runners were available for retesting of lung function 2.5 hours later, while two runners were also tested 24 hours after the race.

The results from pre- and post-race MEFV curves were compared using the paired t-test; p < 0.05 was considered significant.

RESULTS

Anthropometric and training characteristics are listed in Table 1. Thirteen males and two females with a mean age of 35.3 years (range, 26–46 yr) participated in the study; the majority were experienced long distance runners, nine of whom had previously completed an ultramarathon race. One runner had a history of episodic wheezing. Twelve subjects completed 80.6 km while three athletes ran 100 km; the mean running time for 80.6 km was 7 hr, 42 min (range, 5 hr, 51 min to 9 hr, 39 min).

All subjects had a normal pre-race FVC. The pre-race FVC was 5.00 ± 0.21 liters (mean ± SEM) and the post-race FVC was 4.38 ± 0.20 liters, a 12.4 percent decrease (p < 0.001) (Fig. 1). PF was decreased by 13.7 percent, from 9.12 ± 0.48 1/sec to

| TABLE 1 |
| --- |
| Physical Characteristics and Running Experience in 15 Runners Completing the 1979 Lake Waramaug (Connecticut) Ultramarathon (50 miles and 100 km) |
| Mean | Range |
| --- | --- |
| Age (yr) | 35.3 | (26–46) |
| Height (cm) | 177.6 | (163–188) |
| Training distance (km/week) | 118 | (58–203) |
| Number of marathons completed | 21.2 | (1–144) |
| Best marathon time (hr:min) | 3:07 | (2:37–3:45) |
| 50-mile ultramarathon time (hr:min) | 7:42 | (5:51–9:39) |
PULMONARY DYSFUNCTION IN RUNNERS

7.77 ± 0.48 l/sec (p < 0.001) (Fig. 1). The mean pre-race FEV₁ (3.79 ± 0.21 liters) was also significantly reduced (-9.5 percent) after the race (3.43 ± 0.18 liters) (p < 0.005) (Fig. 2). Similarly, MEF50 was decreased significantly (-28.4 percent) from 4.33 ± 0.31 L/sec to 3.10 ± 0.24 L/sec (p < 0.005) (Fig. 2). There was no significant difference between the pre-race (77.5 ± 2.2 percent) and post-race (78.3 ± 1.5 percent) FEV₁/FVC ratio.

None of the runners experienced shortness of breath. The runner with a history of wheezing had a 9.3 percent decrease in FVC, but FEV₁ and MEF50 did not change after the ultramarathon.

Repeat testing 2.5 hours later in ten runners showed an increase of 3 percent, 6 percent, and 9 percent from immediate post-race measurements in FEV₁, FVC, and MEF50, respectively. Two subjects were also retested 24 hours after the ultramarathon at which time lung function had returned to pre-race values.

DISCUSSION

The results of this study demonstrate a reduction in pulmonary function after extreme endurance exercise. Except for the individual with a history of wheezing, all runners had a decrease in FVC, PF, FEV₁, and MEF50. The percentage decrease in FVC after the ultramarathon (-12.4 percent) was greater than we have observed after a 20 km (-4.2 percent) [9] or 42.2 km (-3.9 percent and -5.9 percent) [5] race.
although less than the change noted in runners at the 1923 Boston Marathon (-17 percent) [4]. In previous studies we have shown that flow rates did not change after running 20 km and 42.2 km at above freezing ambient temperatures [5,9]. In contrast, at the LWU there were significant decreases in FEV₁, PF, and MEF50, while the FEV₁/FVC ratio was unchanged.

Based on previous investigations [10,11] we assumed that total lung capacity remained constant after the LWU and measured the post-race MEF50 at 50 percent of the pre-race FVC. Since it is possible that TLC may change after endurance exercise, we also measured the post-race MEF50 at 50 percent of the post-race FVC which should approximate mid-flow rates at the same relative lung volume. Using this method, there was also a significant decrease in the post-race MEF50 (3.60 ± 0.26 L/sec; p < 0.005).

It is interesting that the runner with a history of wheezing did not experience a decrement in flow rates after the ultramarathon. Although use of bronchodilator medication could account for the preservation of lung function, the runner denied any drug therapy. Subsequent testing in the Pulmonary Function Laboratory demonstrated the presence of reversible airway obstruction consistent with asthma. One possible explanation for the findings at the LWU is that the release of endogenous catecholamines during exercise might contribute to bronchodilation, or at least prevent bronchoconstriction, in asthmatic individuals [12].

Air flow is dependent on resistance of the airways and the driving pressure of the thorax [13]. Any decrease in flow rates may be due to an alteration in the state of the airways and/or a reduction in the effective driving force. Although the FEV₁/FVC ratio remained constant after the ultramarathon indicating that large airway obstruction did not develop, small airways dysfunction cannot be excluded. Another mechanism for the decrease in flow rates may be related to a change in the elastic properties of the lungs. However, information on compliance of the lungs during exercise is conflicting with decrease [11,14], increase [15], and no change [16,17] being reported.

The decreases in lung function after the LWU, excluding the change in MEF50, may also be due to fatigue of the respiratory muscles. The force generated by the thoracic musculature is one of the major determinants in the performance of the MEFV curve [18], and weakness or fatigue of these muscles can cause a decrease in FVC, FEV₁, and PF [19,20]. Direct measurement of ventilatory muscle function would be necessary in order to document respiratory muscle fatigue in runners.

Muscle function during prolonged exercise is dependent on several factors, including skeletal muscle respiratory enzymes [21], energy sources [22], circulation [23], and the contractile properties of the muscle [24]. Of these, muscle glycogen appears necessary for sustained muscular effort [25]. Previous investigators have shown that physical exhaustion coincided with extremely low muscle glycogen levels despite the availability of circulating free fatty acids [26–28]. Although the accumulation of blood lactate during exercise has been associated with muscular distress and exhaustion [1], long distance running is primarily an aerobic process and only low levels of lactic acid are found in runners at the finish of a marathon race [2]. In fit individuals, anaerobic metabolism with associated lactate production occurs at a relatively high intensity of exercise or maximal oxygen consumption [29]. Accordingly, the ultramarathon runners could achieve high levels of ventilation for prolonged time periods without the development of lactic acidosis, reflecting efficient gas exchange and transport. Thus, it appears that fuel metabolism and efficiency of
respiration are important factors in muscle performance during endurance exercise.

Serial measurements throughout a marathon race have shown that minute ventilation averaged over 80 L/min in two proficient runners [30]. Such increased levels of ventilation during 6 to 10 hours of ultramarathon running might lead to respiratory muscle fatigue which presumably reflects a general muscle phenomenon associated with prolonged exertion. The greater decrease in FVC at the LWU (80.6 km) compared to the marathon distance (42.4 km) [5] as well as the partial recovery of respiratory function after 2.5 hours of rest and nourishment after the ultramarathon support this concept.

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