Post-exercise reduction in diffusing capacity of the lung after moderate intensity running and swimming.

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Thorsen E, Sandsmark H, Ulltang E. Post-exercise reduction in diffusing capacity of the lung after moderate intensity running and swimming. Undersea Hyperb Med 2006; 33(2):103-108. A reduction in transfer factor of the lung for carbon monoxide (Tl_{CO}) is a consistent finding after saturation dives and is reported after some open sea air dives. Several diving associated factors may contribute to this reduction in Tl_{CO} including hyperoxia, venous gas microembolism, increased breathing resistance and immersion. Exercise, which inevitably is associated with open sea diving, may itself cause a reduction in Tl_{CO} up to at least 12 hours post-exercise. Six trained swimmers and six trained runners who had never dived performed 30 min moderate intensity swimming and running on different days and in random order at approximately 75% of their maximal heart rate. Lung function including a flow-volume loop and Tl_{CO} was measured 30 min before and 60-90 min after exercise. There were no significant changes in dynamic lung volumes or maximal expiratory flow rates, but there was a reduction in Tl_{CO} of 4.5 (SD=4.8) and 4.7 (SD=4.6) % after swimming and running respectively ($p<0.01$). There was no difference in this response between runners and swimmers, and the response was not associated with lung size. Even moderate exercise preceding measurements of Tl_{CO} should generally be accounted for, and this effect may contribute significantly to lung function changes immediately after open sea dives.

INTRODUCTION

A reduction in diffusing capacity of the lung or transfer factor for carbon monoxide (Tl_{CO}) has been demonstrated after saturation dives (1-3) and compressed air bounce dives (4,5). Several diving associated factors contribute to this reduction in Tl_{CO} by different mechanisms. Exposure to hyperoxia contributes in saturation diving with prolonged exposure to a partial pressure of oxygen (PO_2) of 40-60 kPa (6). Venous gas microemboli filtered in the pulmonary circulation contribute in saturation dives and in air bounce dives (1,4,7), and the combined effect of immersion and inspiratory breathing resistance at rest has been shown to result in a small reduction in Tl_{CO} (8). The time for recovery of Tl_{CO} after saturation dives is 6-8 weeks, but after air bounce dives not more than 1 – 2 days, indicating different mechanisms for the reduced Tl_{CO}. Inflammatory or purely physiological and mechanical effects may cause reductions in Tl_{CO} with different recovery times.

The effects of exercise preceding the measurements of Tl_{CO} have not always been considered or accounted for in studies of compressed air bounce dives. The Tl_{CO} is reduced by 10 - 20 % up to 12 hrs after exhaustive exercise by running or rowing in athletes (9,10). This effect has also been demonstrated after less intensive exercise (11). The mechanisms for this post-exercise reduction in Tl_{CO} are not clear. Redistribution of pulmonary blood flow and volume (12), and subclinical pulmonary edema (13) or stress failure of the alveolocapillary membrane (14, 15) impeding diffusion are possible mechanisms.

Exercise is a common feature of air bounce dives. In this study we have measured Tl_{CO} after moderate intensity swimming and running to evaluate the contribution of exercise to the reduction in Tl_{CO} that occurs commonly during a dive.

METHODS

Six well-trained swimmers and six well-trained runners (800 and 1500 m) competing at the top regional level within their disiplines participated in the study. Participation was based on written informed consent, and the study was approved by the regional ethics committee. None of the subjects had ever engaged in compressed air diving. They were training regularly at least four times a week, and none had ever smoked. Their anthropometric characteristics and baseline lung function are given in Table 1. The swimmers had a higher body mass index (BMI), and larger lung volumes and Tl_{CO} than the runners.

Lung function was measured 30-45 min before and 60-90 min after a modified training session where the subjects exercised continuously for 30 min at moderate intensity at a heart rate of 140-160, which corresponded to approximately 70-80 % of their maximal heart rate. The predicted maximal heart rate calculated as 220 minus age was approximately 200 in each group. The subjects controlled the heart rate themselves during exercise. The target intensity of the exercise corresponded to grade 7 on a 10 point rating scale of perceived exertion. The grading was thoroughly explained to the subjects before exercise. The subjective rating of exercise intensity after the exercise was a score of 7 for all subjects after running. The runners were not able to perform continuous exercise at this intensity while swimming due to local muscle exhaustion and general fatigue, rating the intensity from 5 to 7 with a median score of 6.5.

The subjects refrained from food or caffeinated drinks for at least 2 hours before any measurements, which took place at the same times of the day in the afternoon. At least 24 hours had elapsed since their last training session. All subjects had two exercise sessions,

Table 1. Subjects' characteristics. Mean (SD).

	Runners (n = 6)	Swimmers (n = 6)
Age (years)	21.2 (1.2)	19.2 (1.9)
Height (cm)	182 (6)	178 (8)
Body mass (kg)	71.2 (5.7)	79.7 (3.4)*
BMI ($kg \cdot m^{-2}$)	21.6 (1.5)	25.2 (1.7)**
FVC (L) FVC (% predicted)	5.15 (0.66) 91.7 (8.7)	6.52 (0.30)** 121.7 (12.1)**
FEV_1 (L) FEV_1 (% predicted)	4.30 (0.44) 91.0 (7.4)	5.46 (0.33)** 119.7 (7.1)**
$FEF_{25-75\%}$ ($L \cdot s^{-1}$) $FEF_{25-75\%}$ (% predicted)	4.53 (0.78) 85.2 (12.3)	5.71 (1.33)** 109.2 (13.1)**
PEF ($L \cdot s^{-1}$) PEF (% predicted)	11.79 (1.03) 114.0 (11.6)	10.98 (0.81) 107.2 (9.6)
Tl_{CO} ($mmol \cdot min^{-1} \cdot kPa^{-1}$) Tl_{CO} (% predicted)	12.83 (2.08) 99.3 (13.7)	14.33 (1.59)* 116.1 (13.7)**
K_{CO} ($mmol \cdot min^{-1} \cdot kPa^{-1} \cdot L^{-1}$)	2.15 (0.14)	1.93 (0.17)*
V_A (L)	5.99 (1.00)	7.41 (0.41)*

*: Significantly different between groups, $p<0.05$. **: $p<0.01$

one swimming and one running in random order 3 to 7 days apart. Swimming was done in a 25m indoor pool with water temperature of 27 °C and running was done in an outdoor tracking field at ambient temperatures of 8-12 °C. In the first 30 min after exercise they were requested to drink 500 mL of non-caffeinated fluid to compensate for water loss. The volume was estimated based on a previous study of effects of immersion (8). Body mass was measured just before the lung function measurements, and there was no difference between the pre- and post-exercise measurements. Body mass was not measured immediately after exercise for practical reasons. After transport from the sports fields to the laboratory by car, further recovery took place in the laboratory at an ambient temperature of 21-22 °C.

Lung function

The lung function measurements included forced expiratory lung volumes, maximal expiratory flow rates and the transfer factor for carbon monoxide. The measurements were taken on a Morgan Benchmark lung function testing apparatus (PK Morgan ltd., Kent, England). All measurements were done by the same technician and were done according to the standardized procedures of the European Respiratory Society (16,17). Volume calibration of the spirometer and calibration of the gas analyzers were done before each measurement. All measurements were corrected to the "body temperature pressure saturated" (BTPS) condition.

The forced vital capacity (FVC), forced expired volume in one second (FEV_1) and peak expiratory flow rate (PEF) were taken as the highest readings obtained from at least three satisfactory forced expiratory maneuvers. Mean midexpiratory flow rate ($FEF_{25-75\%}$) was taken as the best value from flow-volume loops not differing by more than 5% from the highest FVC. Tl_{CO} was measured by the single breath holding technique. Effective alveolar volume (V_A) was measured simultaneously by helium dilution and transfer coefficient for carbon monoxide (K_{CO}) was calculated as $Tl_{CO} \cdot V_A^{-1}$. The mean of the best two measurements not differing by more than 10% was used in the analysis.

Statistics

Paired t-test was used for comparison of lung function variables before and after exercise. Unpaired two-sample t-test was used for comparison of the lung function changes after running and swimming, and for comparison of lung function changes between swimmers and runners. All results are given as mean and one standard deviation (SD). A p-value <0.05 was considered statistically significant.

RESULTS

There were no significant differences between the baseline lung function variables taken before exercise on the two days, Table 2.

Table 2. Changes in lung function variables 60-90 min after moderate intensity running and swimming and variability of the pre-exercise lung function variables between the two test days. Mean (SD) for all subjects (n=12) are listed.

	Day-to-day variability	Changes after running	Changes after swimming
FVC (% change)	-0.3 (2.4)	-1.2 (1.1)*	-0.7 (1.3)
FEV_1 (% change)	-0.9 (2.4)	-0.1 (2.3)	-0.9 (2.2)
$FEF_{25-75\%}$ (% change)	-1.5 (7.8)	0.3 (7.1)	-0.5 (6.6)
PEF (% change)	0.7 (3.8)	-0.3 (4.4)	-0.3 (4.4)
Tl_{CO} (% change)	0.1 (8.1)	-4.7 (4.6)**	-4.5 (4.8)**
K_{CO} (% change)	-0.1 (9.0)	-4.2 (5.0)*	-5.2 (5.9)*
V_A (% change)	0.4 (3.5)	-0.3 (1.7)	0.7 (3.4)

*: significant change $p < 0.05$; **: $p < 0.01$

There was a significant reduction in Tl_{CO} of 4.5 (SD=4.8) and 4.7 (SD=4.6) % 60-90 min after swimming and running respectively (p = 0.008 and p = 0.004, Table 2).

There was, however, no difference between the two modes of exercise or between the runners and swimmers, Figure 1. There was no change in V_A, and the reductions in K_{CO} were 5.2 and 4.1 % (p=0.011 and p=0.015). There were no significant relationships between baseline lung function expressed as per cent of predicted values of FVC and FEV_1 and the changes in Tl_{CO} after either running (R^2 = 0.018, p=0.799, and R^2 = 0.029, p=0.718) or swimming (R^2 = 0.031, p=0.698, and R^2 = 0.039, p=0.623).

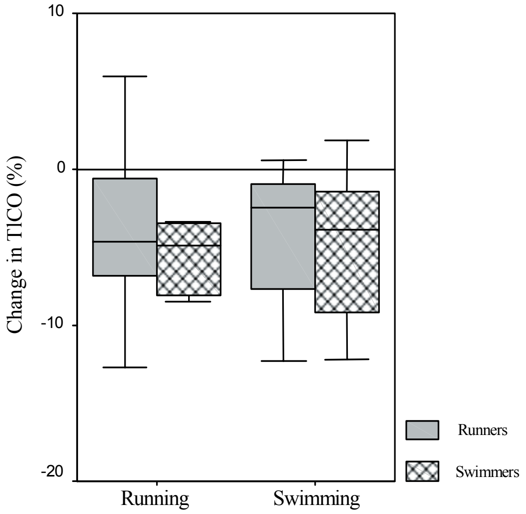

Fig. 1. Changes in Tl_{CO} in swimmers (n=6) and runners (n=6) 60-90 min after 30 min moderate intensity running and swimming exercise. The median, 25-75 % and 2.5-97.5 % percentiles are depicted

There was a small reduction in FVC after running but not after swimming in the runners only. In swimmers there was a small reduction in FEV_1 after running only, but no systematic changes in any other lung function variables derived from the flow-volume loop (Table 2).

DISCUSSION

After moderate intensity exercise comparable to that which may be experienced during scuba diving there was a small reduction in Tl_{CO} at 60-90 min of about 5%. This effect has not always been accounted for in studies reporting a reduction in Tl_{CO} after diving. A reduction in Tl_{CO} of 10-15% is a consistant finding after deep saturation dives (1-3). The measurements have been performed 1-3 days after surfacing, in the morning and always before the assessment of physical exercise capacity. These studies are probably not influenced by any post-exercise reduction in Tl_{CO}. A reduction in Tl_{CO} has also been reported in the first hours after open sea air bounce dives (5). At least some moderate physical activity might have taken place during these dives. In the study by Skogstad et al. (5) there was no significant difference in the changes in Tl_{CO} between dives to 10 and 50 meters, indicating that mechanisms may operate other than venous gas microembolism, breathing resistance and hyperoxia.

The post-exercise reduction in Tl_{CO} persists for up to 12 hrs. The effect can be demonstrated after maximal as well as submaximal exercise (11). The mechanisms are not clear, but intrathoracic fluid volume assessed by transthoracic impedance is reduced after exhaustive exercise (12). A lower pulmonary and pulmonary capillary blood volume reduces the blood component of the Tl_{CO}. An increase in hemoglobin concentration due to dehydration has the opposite effect. To reduce any effect of dehydration the subjects were requested to drink 500 mL of fluid immediately after exercise. Body mass was not different between the lung function measurements, but the extent to which the fluid was absorbed can not be answered since relevant control measurements, like hemoglobin concentration, were not done. The organs to which the blood is redistributed could be recovering muscles and the skin as part of the thermoregulatory response to exercise.

Interstitial edema of the alveolocapillary membrane or disruption of the membrane impeding diffusion may contribute to this effect with exhaustive exercise, but probably not with moderate intensity exercise when pulmonary arterial pressure is lower (18). Stress failure of the pulmonary capillaries may take place with pulmonary arterial systolic pressure higher than 40 mmHg (15,19). Red blood cells and increased protein content of bronchoalveolar lavage fluid has been demonstrated in athletes after exhaustive exercise but not after exercise at 77% of their maximal oxygen uptake (18). Lung scintigraphy and clearance of ^{99m}Tc-labelled di ethylenetriaminepentaacetic acid (DTPA) from the lung after exhaustive exercise support these findings, and indicate that the alveolocapillary barrier is disrupted with increased permeability and interstitial edema (14).

There was no change in V_A, and the changes in K_{CO} were the same as in Tl_{CO}. An increase in V_A would be expected with a reduction in the intrathoracic blood volume, and a reduction would be expected with interstitial edema and airway closure. Air trapping and an increase in closing volume can be induced by immersion. The V_A is, however, not a good measure of total lung capacity, and measurements of total lung capacity with helium dilution or body plethysmography were not included in this study. The changes in FVC were within 1.2 % (Table 2) and neither FVC nor V_A indicate any large changes in lung volume which can explain the changes in Tl_{CO}. The change in FVC was statistically significant after running, but the small change in volume is not considered to have any physiological effect, and there were no systematic changes in the dynamic lung volumes or maximal expiratory flow rates.

It is well known that swimmers and divers have larger than predicted lung volumes (20). In this study there was no difference in the responses to exercise between trained swimmers having large lung volumes compared with trained runners having significantly lower lung volumes. Studies of mountaineers indicate that those who are prone to high altitude pulmonary edema have smaller lungs than those not prone (21). It may be speculated that subjects with large lungs have a larger capacitance of the pulmonary vascular bed and thereby a lower increase in pulmonary arterial pressure with exercise and the accompanying increase in cardiac output, protecting against fluid accumulation in the alveolocapillary membrane. With immersion there will be an additional increase in intrathoracic blood volume due to microgravity. The exercise intensity in this study was at approximately 70% of their maximal capacity and may not have been large enough to cause extravasation of fluid. There was no relationship between changes in Tl_{CO} and lung volume expressed as % predicted FVC, indicating that subjects with small lungs has a greater reduction in Tl_{CO} compared with subjects having large lungs in this study with moderate exercise intensity.

Other diving-related studies have shown that there is no effect on the Tl_{CO} one hour after 30-40 minutes of head out immersion at rest in thermoneutral water and one hour after normobaric oxygen breathing for 30-40 minutes (7,8). The control experiments for these studies have not shown significant change in Tl_{CO} over comparable time periods of 2-3 hrs with the subjects resting in the sitting position. No change in Tl_{CO} was demonstrated over the 3-7 day period between measurements taken at the same time of the day. The day to day variation in Tl_{CO} is however larger than the within day variation, usually reported to be 7-10 % and 3-5 % respectively (17). The European Respiratory Society and the American Thoracic Society, in the recommendations for standardization of the measurement of Tl_{CO}, account for ongoing exercise and increased cardiac output in the immediate post-exercise period as an influence on Tl_{CO}. Any effect of exercise of later onset is not considered.

We conclude that exercise of even moderate intensity must be accounted for in studies of lung function in general, not only in studies of pulmonary effects of diving. Effects of open sea air bounce dives on Tl_{CO} may have been overestimated due to the post-exercise effect.

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