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Characteristics of the response to exercise in professional saturation divers

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Thorsen E, Segadal K, Kambestad BK. Characteristics of the response to exercise in professional saturation divers. Undersea Biomed Res 1991; 18(2):93–101.—Exercise testing with measurements of expired minute ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), and carbon dioxide elimination ($\dot{V}CO_2$) was done in 63 professional saturation divers, in the screening programs for selection of divers, to 10 different experimental and operational saturation dives. Their experience as divers averaged 9.8 yr (range 1–20), and they averaged 276 days (range 5–900) in saturation. The maximal pressure they had ever been exposed to averaged 2.01 MPa (range 0.8–5.1). The divers were compared with a control group of 47 offshore workers and policemen matched for age, height, and smoking habits and with reference values for the general healthy population. There were no significant differences in peak work load achieved, $\dot{V}O_{2peak}$ and $\dot{V}CO_{2peak}$. $\dot{V}E$ at $\dot{V}O_{2peak}$ and the corresponding ventilatory equivalents for oxygen uptake ($\dot{V}E_{peak}/\dot{V}O_{2peak}$) and carbon dioxide elimination ($\dot{V}E_{peak}/\dot{V}CO_{2peak}$) were significantly higher in divers ($P < 0.05$), but $\dot{V}E$, $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$ were not different at lower work loads. $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ correlated positively with years of diving experience when corrected for age ($P < 0.01$). Divers had higher tidal volumes and lower breathing frequencies at ventilations lower than 40% of $\dot{V}E_{peak}$, but maximal tidal volumes were not different. Tidal volume at a $\dot{V}E$ of 30 liter · min^{-1} correlated negatively with FEV_1 ($P<0.05$). The results are in agreement with the transient changes in pulmonary function and exercise tolerance demonstrated after a single saturation dive, and indicate that these changes may not be completely reversible.

oxygen update — pulmonary function — diving

The cross-sectional studies of divers' lung function by Watt (1), Davey et al. (2), and Crosbie et al. (3) showed larger than predicted vital capacity in divers. The ratio of forced expired volume in 1 s and forced vital capacity (FEV_1/FVC) was lower than predicted, and in the study of Davey et al. (2) maximal expiratory flow rates at low lung volumes were reduced. In some cases a transient increase in vital capacity after a single saturation dive has been reported (4–6) and attributed to a training effect of respiratory muscles. The characteristics of divers' lung function could then be a result of the selection of subjects as divers, or adaptation to the hyperbaric environment, as there is a negative correlation between FVC and FEV_1:FVC ratio (3, 7). However, the results may also indicate the development of airflow limitation in divers. We were not able to demonstrate an increase in vital capacity in 43 divers after a deep dive series to pressures of 3.1–4.6 MPa, but total lung capacity, residual volume, and closing volume were increased, and transfer factor for carbon monoxide (Tl_{CO}) and maximal oxygen uptake were reduced (8, 9). In a cross-sectional survey of saturation divers, reductions in forced expiratory volumes and flows and Tl_{CO} were demonstrated, and reductions in lung function variables correlated with cumulative diving exposure (10). In this paper, the characteristics of the response to exercise testing in a subgroup of the divers in this cross-sectional study (10) are described.

SUBJECTS AND METHODS

Divers

Seventy-six professional saturation divers had their pulmonary function tested in the screening programs for selection of divers for 10 different saturation dives to pressures of 1.55–4.6 MPa. They were all included in the cross-sectional study of divers' lung function (10) and their pulmonary function was not different from saturation divers examined outside the screening programs. Sixty-three of the 76 divers had an exercise test on a cycle ergometer with direct measurements of gas exchange. Their experience as divers averaged 9.8 yr (range 1–20), and they averaged 276 days in saturation (range 5–900). The maximal pressure they had ever been exposed to averaged 2.01 MPa (range 0.8–5.1). The other 13 divers had maximal oxygen uptake estimated indirectly or by treadmill exercise and are not included in this study. Table 1 shows the subjects' characteristics compared with controls and with the 152 divers in the cross-sectional study with respect to age, height, smoking habits, and pulmonary function. At the time of this study, at least 4 wk had elapsed since their last saturation dive.

Control group

Fifty-seven local offshore workers and 49 local policemen were examined. They were recruited by advertising among the 270 policemen in the area and the 170 offshore workers in two companies. The prerequisites were that they had not had any previous heart or lung disease that would have disqualified them from diving, that their age was between 20 and 50 yr, and that they had never practiced any form of diving. Four subjects were excluded because of symptoms of chronic obstructive pulmonary disease and a FEV_1:FVC ratio below 70%. Exercise testing was done in a subgroup of 47 subjects.

Exercise test

Exercise testing was done on an electrically braked cycle ergometer with 30 W increase in workload every 3rd minute, starting with unloaded pedaling. Oxygen uptake ($\dot{V}O_2$, liter · min^{-1} STPD), carbon dioxide elimination ($\dot{V}CO_2$, liter · min^{-1} STPD), expired minute ventilation ($\dot{V}E$, l · min^{-1} BTPS), tidal volume (VT, liter BTPS), breathing frequency (B_f), and heart rate (HR) were measured with a Beckmann MMC horizon computerized pulmonary gas analyzer (11). The ventilatory equivalents for

TABLE 1

Characteristics of Divers and Controls From the Cross-Sectional Study (10), and the Subgroups Having Exercise Test

			Subgroups Exercise Tested	
	Divers, $n = 152$	Controls, $n = 102$	Divers, $n = 63$	Controls, $n = 47$
Age, yr	33.2 ± 5.5	32.7 ± 5.5	32.7 ± 5.2	33.0 ± 5.3
Height, cm	180.2 ± 5.2	181.3 ± 5.0	181.0 ± 5.3	180.8 ± 5.1
Body mass, kg	80.1 ± 6.0	81.1 ± 6.4	80.6 ± 6.3	81.0 ± 6.3
Smokers, %	30	29	28	24
FVC, liter	5.94 ± 0.68	5.97 ± 0.55	5.98 ± 0.61	5.94 ± 0.57
FEV_1, liter	4.55 ± 0.58[a]	4.85 ± 0.45	4.58 ± 0.58[b]	4.81 ± 0.50
Tl_{CO}, $mmol \cdot min^{-1} \cdot kPa^{-1}$	11.9 ± 1.6[a]	12.5 ± 1.3	11.9 ± 1.5[a]	12.7 ± 1.4

[a]Significantly different from corresponding control group $P < 0.01$. [b]Significantly different from corresponding control group $P < 0.05$.

oxygen uptake ($\dot{V}E/\dot{V}O_2$) and carbon dioxide elimination ($\dot{V}E/\dot{V}CO_2$) were calculated. Data were averaged over 1-min intervals and the results from the last minute on every workload were used for analysis. Peak oxygen uptake ($\dot{V}O_{2peak}$), peak carbon dioxide elimination ($\dot{V}CO_{2peak}$), and peak expired minute ventilation ($\dot{V}E_{peak}$) were calculated from the last 15 s of exercise. Tidal volume at a $\dot{V}E$ of 30 liter · min^{-1} (VT_{30}) was found by linear interpolation as described by Cotes (12). Exercise was continued to the symptom-limited maximum. Electrocardiogram was continuously monitored from the chest-head 5 position. Volume and gas calibration was done before each test with a calibrated syringe and with calibration gases with certified analyses for O_2 and CO_2 content (Norsk Hydro A/S, Rjukan Norway). Verification of the calibration was done after each test. The drift of the gas analyzers was always below 2%. The predicted values used for comparison were those of Jones et al. (13) and Wasserman et al. (14). All subjects gave informed consent, and the protocol for the study was approved by the Regional Ethical Review Committee.

Data processing and statistics

The lung function variables in divers and controls were compared with unpaired Student's *t* tests. For comparison of exercise data, group intervals for the independent variables were defined; for $\dot{V}O_2$ increments of 10% relative to $\dot{V}O_{2peak}$ and for $\dot{V}E$ increments of 10% relative to $\dot{V}E_{peak}$. All observations within each group interval were pooled, and unpaired *t* tests were used for comparison of data within each group interval. Linear regression analysis was used to find relevant correlations between the exercise variables and the lung function variables. Multiple linear regression analysis was used to find relevant correlations between the exercise variables and age, height, body mass, years of diving experience, and days in saturation, with smoking and diving included as interactive variables being present or absent. The method selected was a forward stepwise procedure which at each step included the explanatory variable with the highest partial correlation with the model. All data are given as mean ± 1 SD. A P value less than 0.05 was considered significant.

RESULTS

The subgroups of divers and controls having the exercise test were representative for their respective groups in that there were no differences in the subjects' characteristics (Table 1). No differences were found between the groups in FVC, but FEV_1 and Tl_{CO} were significantly lower in divers, as previously reported (10).

No significant difference occurred in the peak workload achieved between divers and controls, which corresponded to a maximal working time on the cycle ergometer of 28.9 ± 4.3 min in divers and 29.3 ± 3.9 min in controls, nor were there significant differences in $\dot{V}O_{2peak}$, $\dot{V}CO_{2peak}$, or HR_{peak} (Table 2). The relationships between $\dot{V}O_2$ and workload, and between $\dot{V}O_2$ and HR were not different between the groups. The relationships were $\dot{V}O_2 = 0.356 + 0.011$ workload ($R^2 = 0.98$) in divers and $\dot{V}O_2 = 0.343 + 0.011$ W ($R^2 = 0.97$) in controls, and $\dot{V}O_2 = -1.28 + 0.024$ HR ($R^2 = 0.98$) in divers and $\dot{V}O_2 = -1.40 + 0.025$ HR ($R^2 = 0.97$) in controls. $\dot{V}E_{peak}$ and the corresponding $\dot{V}E_{peak}/\dot{V}O_{2peak}$ and $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ were significantly higher in divers ($P < 0.05$), Table 2 and Fig. 1, but there were no differences at 90% of $\dot{V}O_{2peak}$

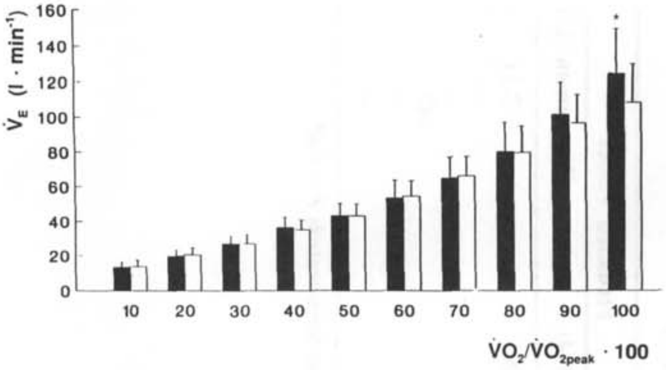

Fig. 1. Relationship between $\dot{V}_E$ and $\dot{V}O_2$. *Filled bars* = divers, *open bars* = controls. Means of each group interval for the independent variable $\dot{V}O_2$ and its standard deviations are shown. *Asterisk* = $P < 0.05$.

or lower. $\dot{V}O_{2peak}$ was positively correlated with Tl_{CO} ($R^2 = 0.05$, $P < 0.05$), and $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ was negatively correlated with Tl_{CO} ($R^2 = 0.05$, $P < 0.05$). $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ was positively correlated with years of diving experience ($R^2 = 0.13$, $P < 0.01$) (Table 3).

At workloads corresponding to minute ventilations less than 40% of $\dot{V}E_{peak}$, the breathing pattern was different in that divers had higher tidal volumes and lower breathing frequencies than controls ($P < 0.05$) (Fig. 2). V_{T30} was 1.68 ± 0.33 liter in controls and 1.87 ± 0.29 liter in divers ($P < 0.05$). At higher ventilations, no differences were seen in the breathing pattern. V_{Tmax} was 3.02 ± 0.38 liter in controls and 3.08 ± 0.37 liter in divers. V_{T30} correlated negatively with FEV_1 ($R^2 = 0.06$, $P < 0.02$). There were no significant correlations between V_{T30} and diving exposure.

DISCUSSION

In previous cross-sectional studies (1–3), divers were compared with reference values not specific for the group studied. The possibility of development of bronchial obstruction in divers was raised, but selection of subjects or adaptation to the hyperbaric environment could not be excluded. In the cross-sectional survey including the divers in this study (10), divers in general had reduced pulmonary function consistent with small airways dysfunction, and reductions in the pulmonary function variables

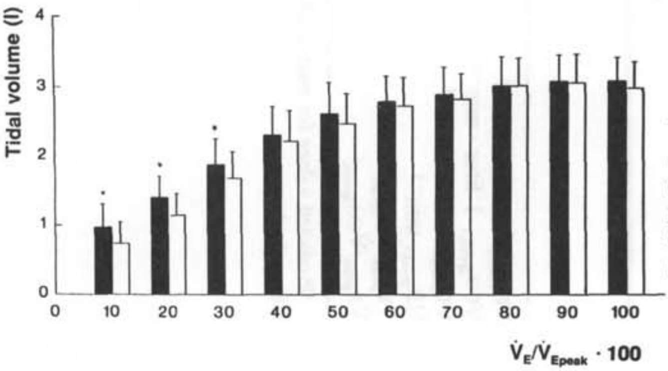

Fig. 2. Relationship between V_T and $\dot{V}E$. *Filled bars* = divers, *open bars* = controls. Means of each group interval for the independent variable $\dot{V}E$ and its standard deviations are shown. *Asterisk* = $P < 0.05$.

TABLE 2

RESULTS FROM THE EXERCISE TESTS AT THE MAXIMAL WORKLOAD ACHIEVED

	Divers, $n = 63$	Controls, $n = 47$	Predicted Values[a]	
			Jones (14)	Wasserman (15)
$\dot{V}O_{2peak}$, 1 liter · min^{-1}	3.21 ± 0.53	3.24 ± 0.49	3.20	3.11
$\dot{V}CO_{2peak}$, 1 liter · min^{-1}	3.78 ± 0.64	3.70 ± 0.60	—	—
$\dot{V}E_{peak}$, 1 liter · min^{-1}	121 ± 25[b]	109 ± 23	112	—
HR_{peak}, min^{-1}	184 ± 7	181 ± 6	187	187
$\dot{V}E_{peak}/\dot{V}O_{2peak}$[c]	37.7 ± 6.1[b]	33.6 ± 6.4	—	—
$\dot{V}E_{peak}/\dot{V}CO_{2peak}$[c]	32.0 ± 4.8[b]	29.5 ± 4.3	—	—

[a]Predicted values for men of 181 cm height, age 33 yr, and 81 kg weight were calculated; [b]significantly different from controls $P < 0.05$; [c]dimensionless.

TABLE 3

REGRESSION COEFFICIENTS OF AGE, HEIGHT, DIVING, AND DIVING EXPERIENCE ON THE EXERCISE VARIABLES[a]

	Intercept	Age, yr	Height, cm	Diving,[b] (1/0)	Experience, yr	R^2
$\dot{V}O_{2peak}$, 1 liter · min^{-1}	−0.9	—	0.023	—	—	0.07
$\dot{V}CO_{2peak}$, 1 liter · min^{-1}	4.7	−0.03	—	—	—	0.09
$\dot{V}E_{peak}$, 1 liter · min^{-1}	152.8	−1.53	—	18.1	—	0.13
$\dot{V}E_{peak}/\dot{V}O_{2peak}$[c]	31.9	—	—	6.0	—	0.11
$\dot{V}E_{peak}/\dot{V}CO_{2peak}$[c]	37.6	−0.30	—	—	0.40	0.13

[a]Only significant relations are given ($P<0.05$). Weight, smoking, and days in saturation were also included in the regression analyses; [b]1 = diver, 0 = control subject; [c] = dimensionless.

correlated with cumulative diving exposure. The control group did not differ from submariners or healthy subsamples of the general population, giving no evidence for the selection or adaptation mechanisms. Concerning exercise tolerance, our control group does not differ from commonly used reference values for maximal oxygen update on cycle ergometry. The reference values of Jones et al. (13) are based on a sample of healthy men reflecting the general population with respect to height, recreational exercise activity, and pulmonary function. The characteristics of that reference group in the age range of 15–45 yr were a mean height of 180 cm, body mass 79 kg, FEV_1 4.8 liter, and FVC 5.8 liter, which are comparable with our divers and controls. Our control group, as well as the specific reference values chosen, should be adequate for comparison with divers.

Subjects who took part in exercise testing were representative for the groups of divers and controls with respect to pulmonary function, age, height, body mass, and smoking habits. There were no significant differences in $\dot{V}O_{2peak}$, VCO_{2peak}, or HR_{peak}. $\dot{V}E_{peak}$ and the corresponding $\dot{V}E_{peak}/\dot{V}O_{2peak}$ and $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ were significantly higher in divers. Maximal voluntary ventilation (MVV) was not measured, but MVV is related to FEV_1. The predicted MVV is 161 liter $\cdot$ min^{-1} in the divers and 168 liter $\cdot$ min^{-1} in the controls using the formula $MVV = 35 \cdot FEV_1$ (15), indicating an adequate breathing reserve in both groups and that pulmonary function is not limiting exercise performance under ordinary conditions. When working at depth however, the differences in lung function and $\dot{V}E$ are in the disfavor of the divers because increased gas density, immersion, and breathing equipment already are limiting ventilatory capacity.

The control group was, by its selection, a healthy worker group, but did not differ from the general healthy population with respect to pulmonary function and exercise tolerance. The group of divers was also influenced by a healthy-worker effect because they were all active as professional divers having an annual medical certification, and the diving companies usually did a preliminary screening of their divers before the final screening programs for the dives. The prevalence of divers that have to stop diving because of reduced pulmonary function is not known and they would not have been available for this study. If our results are influenced by a healthy-worker effect, it would be on the part of the divers, and the overall effect would be a reduction of any differences between divers and controls.

Immediately after a single saturation dive, a reduction in maximal $\dot{V}O_2$ has been demonstrated (9). $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$ were increased over the whole range of $\dot{V}O_2$ and the physiologic dead space was increased. Tl_{CO} was reduced. The reduction in maximal $\dot{V}O_2$ correlated with accumulated bubble load during decompression. Exposure to hyperoxia and detraining could have contributed to this effect. The increased $\dot{V}E_{peak}/\dot{V}O_{2peak}$ and $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ seen in this study are in agreement with these changes. The difference from the controls appears when the demands of the cardiopulmonary system are increased, and the correlation between $\dot{V}E_{peak}/\dot{V}CO_{2peak}$ and diving experience indicates that the immediate changes after a single saturation dive may not be completely reversible. Effects of physical training, or detraining during long decompression periods, do not seem to play a significant role since the relationship between $\dot{V}O_2$ and HR was not different between divers and controls. In the study of Crosbie et al. (3), increased $\dot{V}E/\dot{V}O_2$ was demonstrated at maximal $\dot{V}O_2$ in a group of divers with reduced FEV_1:FVC ratio, but where maximal $\dot{V}O_2$ was not different from divers with a FEV_1:FVC ratio within normal limits. Our results are in agreement with that study, and show that the changes are related to the diving exposure.

The differences in breathing pattern at low minute ventilations have also been demonstrated in other studies (3, 16). Increased V_T and lower B_f may be an effect of the increased breathing resistance in the mouthpiece and valves, and in divers an effect of habituation to breathing on a mouthpiece (16–18). However, the difference between divers and controls could also be a result of compensation for increased airways resistance. V_{T30} was negatively correlated with FEV_1. Loss of pulmonary elastic tissue and peripheral airflow limitation will be compensated for by breathing on a more favorable part of the pressure-volume curve and minimizing the work of breathing (19).

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