## CARDIOPULMONARY ADJUSTMENTS WITH EXERCISE IN COLD WATER AND HYPERBARIC ENVIRONMENTS

Thomas J. Doubt, Ph.D.
Diving Medicine Department
Naval Medical Research Institute
Bethesda, MD 20889-5055

### INTRODUCTION:

Physiological adjustments to exercise include regulating cardiopulmonary responses to changes in workload. Further adjustments are required when exercise is conducted in cold water (1) or in hyperbaric environments (2) to compensate for the added effects of thermal or high pressure stress.

Ventilatory equivalent (VEQ) is the ratio of minute ventilation ($V_E$) to oxygen consumption ($VO_2$), and provides a useful index of how well $V_E$ remains coupled to $VO_2$ for a given workload. Oxygen pulse (OXP) is the ratio of $VO_2$ to heart rate (HR), and serves as an indirect estimate of the product of cardiac stroke volume and arteriovenous $O_2$ differece; derived from solution of the classical Fick equation.

The purpose of this paper is to describe changes in VEQ and OXP during steady-state leg exercise in water at temperatures of 18-31° C, and during hyperbaric exposures to 31 ATA.

### METHOD:

The data were derived from three human exercise studies conducted between 1987-1990. In each study $V_E$, $VO_2$, and HR were obtained while males performed steady-state leg exercise during head-out immersion. VEQ and OXP were calculated from measured variables and analyzed by a two-way ANOVA for repeated measures. Data are presented in this paper for a workload of 1.5 W/kg, which was common to all studies.

Study I (n=10) involved performing 60 min of exercise at 1.5 W/kg during immersion in 28 and 18° C water at the surface. Steady-state variables were obtained by averaging the last 40 min of exercise. Study II (n=11) entailed 4 consecutive periods of 5 min rest and 25 min exercise at 1.5 W/kg during immersion in 25° C water, once breathing air at 1 ATA and once breathing $HeO_2$ at 5.5 ATA ($PO_2$ = 0.42 ATA). VEQ and OXP did not change among exercise periods and were therefore averaged across all 4 periods. Study III (n=12) used step increases in workload (10 min each at 0.5, 1.0, and 1.5 W/kg) during immersion in 31 and 20° C water. Tests at each water temperature were conducted at 1 ATA breathing air and at 31 ATA breathing $HeO_2$ ($PO_2$ = 0.42 ATA).

### RESULTS:

$V_E$ increases exponentially, as $VO_2$ increases. This relationship is the same in dry and immersed conditions up to a $VO_2$ of about 2.5 L/min. Thereafter the immersed curve increases at a faster rate, but is not influenced by water temperature.

The table below presents VEQ and OXP for the common workload of 1.5 W/kg (mean ± SEM).

| DEPTH | STUDY | WATER T° | VEQ | OXP |
|---|---|---|---|---|
| 1 ATA | I | 18 | 28.1 ± 1.1 | 17.8 ± 6.0 |
| | III | 20 | 30.8 ± 1.6 | 17.9 ± 3.2 |
| | II | 25 | 27.1 ± 0.6 | 16.9 ± 2.8 |
| | I | 28 | 28.6 ± 1.6 | 15.9 ± 4.0 |
| | III | 31 | 29.8 ± 1.2 | 15.5 ± 3.4 |
| 5.5 ATA | II | 25 | 24.3 ± 0.7 | 17.3 ± 2.9 |
| 31 ATA | III | 20 | 27.1 ± 2.2 | 18.2 ± 2.8 |
| | | 31 | 27.5 ± 1.6 | 15.7 ± 3.1 |

At 1 ATA, VEQ did not vary significantly with water temperature because of concurrent increases in $V_E$ and $VO_2$. OXP increased as temperature declined, due to increases in $VO_2$ with little change in HR. Reductions in $V_E$ at depth, with no change in $VO_2$, significantly lowered VEQ. No significant change in HR occurred at depth, thus OXP was not altered relative to corresponding 1 ATA values.

CONCLUSIONS:

These findings demonstrate that colder water temperatures do not affect the coupling of exercise $V_E$ to $VO_2$. Cold induced increases in $VO_2$ were matched by increases in $V_E$ such that VEQ did not change. Lower VEQ at depth was due solely to a reduced $V_E$, which suggests a downward (and more efficient) regulation of ventilation to $O_2$ demand.

Increases in OXP in colder water were largely a result of higher $VO_2$; indicating an increase in the product of stroke volume and a-v $O_2$ difference. Since OXP was not significantly altered at depth (no significant changes in $VO_2$ and HR) it can be concluded that this index of cardiopulmonary adjustment to exercise was not affected by hyperbaric exposure *per se*.

REFERENCES:

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