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D51 Factors that influence the energy cost of free fin swimming

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Introduction

- The energy cost of underwater fin swimming is related to muscular fatigue and exercise intolerance, as well as gas consumption (V̇E) and carbon dioxide production (V̇CO2) and arterial PCO2. As divers breathe from a gas supply with a fixed volume, the time they can sustain a swim is determined by their V̇E, which is determined by the V̇O2, substrate used (respiratory exchange ratio, RER) and non-oxidative metabolism (lactic acid, La).
- Previous studies of exercising in underwater environments have often used cycle exercise. Fin swimming is characterized by the intermittent application of a propulsive force (thrust) to overcome a velocity (V) - dependent water resistance (drag, D). The energy cost of swimming (E'tot) is determined by the drag (D) and net mechanical efficiency (η): E'tot = V • D ÷ η
- The total energy expenditure of swimming during steady-state at a given velocity (E'tot) is given by E'tot = V̇O2 + rate AnS
- V̇O2 is the oxygen consumption and AnS is the energy derived from the anaerobic stores. V̇O2 can be directly measured.
- We hypothesized that the energy cost of fin swimming is affected by velocity and swim time, equipment used (fins types, gas tanks, buoyancy compensators, water temperature, thermal protection suits as they may affect V̇O2, AnS, D and η on E'tot.

Methods

Subjects

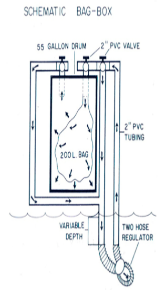
- Experienced male SCUBA divers (n = 8-10) participated in this series of studies.
- On average, the subjects were 29.0 ± 4.4 yrs old, 80.7 ± 7.9 kg in mass, 180 ± 27 cm in height, 14.3 ± 4.7% body fat (underwater weighing)
- Measured V̇O2max was 2.57 ± 0.22 L/min while fin swimming in 6.5 mm wet suits, which created a thermal neutral condition (TNC).

Methods

Protocols

- For the study of skill, fins, tanks and suits the subject swam at progressively increasing speeds in an annular pool (2.8 m deep, 2.8 m wide, 58.6 m in circumference)
- For the effect of swim time and body cooling the swims were performed stationary against a current of 30 m/min. In these experiments the pool water temperature was set at 24.2 ± 0.3 °C. In the first swim, the subjects wore a complete 6 mm wet suit which created a TNC. In the second swim, the subjects swam wearing only a swim suit to create a condition of body cooling (CC).
- The velocity, as was determined in pilot studies, caused voluntary exhaustion in approximately 120 min in the TNC.

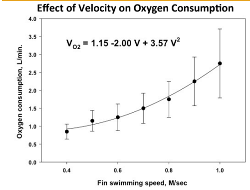
Procedures



- Expired gas was collected at rest and during swimming at each speed or at 5 min, and then every 15 min until exhaustion for determination of V̇E, V̇O2. Expired gas was collected using a pressurized bag-in-barrel system interfaced with a two-hose regulator used by the swimmer.
- The divers' breathed from the SCUBA tank
- Gas collections were timed and typically were one minute
- A mass spectrometer measured O2 and CO2 concentrations. Gas temperature was read with a thermistor.
- V̇O2, V̇CO2 and RER (V̇CO2/ V̇O2) were calculated using standard equations.

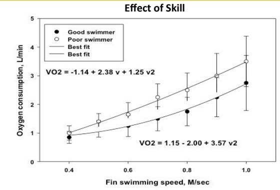
Results

Effect of Velocity on Oxygen Consumption



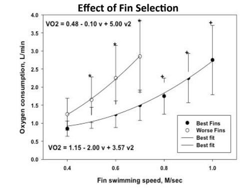
Oxygen consumption is plotted as a function of fin swimming velocity. V̇O2 increases exponentially as a function of speed: V̇O2 = 1.15 – 2.00 v + 3.57 V2

Effect of Skill



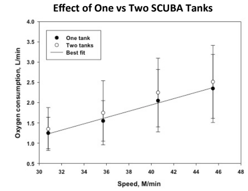
Oxygen consumption plotted as a function of fin swimming velocity for skilled and unskilled divers. V̇O2 increases exponentially as a function of speed: V̇O2 = 1.14 + 2.38 v + 1.25 V2 unskilled V̇O2 = 1.15 - 2.00 v + 3.57 V2 skilled

Effect of Fin Selection



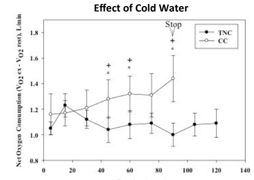
Oxygen consumption plotted as a function of swimming velocity for the highest and lowest energy cost fins. V̇O2 increases exponentially as a function of speed: V̇O2 = 0.48 – 0.10 v + 5.00 V2 (poor fins) V̇O2 = 1.15 - 2.00 v + 3.57 V2 (good fins)

Effect of One vs Two SCUBA Tanks



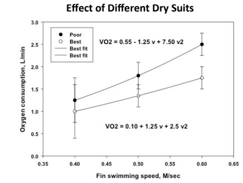
The oxygen consumption of fin swimming was significantly greater with two tanks (p = 0.006), however this amounted to only 10%

Effect of Cold Water



The V̇O2 when thermally protected was not affected by swimming time, however when body cooling occurred the V̇O2 increased significantly as a function of time and was greater than when protected.

Effect of Different Dry Suits



Divers' swam, on different occasions, with five different dry suits. The suits with the highest V̇O2 (V̇O2 = 0.55 - 1.25 v + 7.50 v2) were significantly different then suits with the lowest V̇O2 (V̇O2 = 0.10 + 1.25 + 2.5 v2).

Discussion

Summary

- Energy cost of fin swimming increases exponentially with speed for velocities that can be sustained with oxygen consumption, secondary to body drag (kV2)
- Fin swimming skill does not affect VO_2 below 0.5 m/sec but at faster speeds it can increase VO_2 by 50%.
- Fin selection influences VO_2, with large heavy rigid fins costing as much as 60% more energy to swim.
- Swimming with two tanks, compared to one, only increased VO_2 about 10%.
- The energy cost of fin swimming with body cooling (-0.6°C) is increased about 23%.
- Preventing body cooling with wet suit thermal protection did not significantly increase VO_2, but a dry suit increased the VO_2 40-57%.

Conclusions

- Appropriate selection of diving equipment can optimize the energy cost of swimming at speeds that can be accomplished with oxygen consumption.
- Body cooling increases the energy cost of fin swimming, which can be prevented by wearing a wet suit. If a dry suit is required to prevent body cooling in colder water, the energy cost of swimming is increased
- Fin swimming speed has to be modified to the gear, skill, and body cooling of the diver to enable swimming for various distances.

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