Factors that influence the energy cost of free fin swimming

David R. Pendergast and David Hostler

Departments of Physiology and Biophysics and Exercise and Nutrition Sciences

Center for Research and Education in Special Environments

University at Buffalo

Introduction

The energy cost of underwater fin swimming is important as it relates to muscular fatigue and exercise intolerance, as well as gas consumption (VE) and carbon dioxide production (VCO_2) and, in-turn, arterial PCO_2. As divers breathe from a gas supply with a fixed volume, the time they can sustain a swim is determined by their VE. VE is in-turn determined by the VO_2.

Previous studies of exercising in underwater environments have often used cycle exercise while, in practice, divers fin swim.

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):

$$E'_{tot} = V \bullet D \div \eta$$

The total energy expenditure of swimming during steady-state at a given velocity (E'_{tot}) is given by

$$E'_{tot} = VO_2 + \text{rate AnS}$$

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 VO_2, AnS, D and η on E'_{tot}.

Methods

Experienced male SCUBA divers (n = 8-10) participated in this series of studies. On Average, they were 29.0 ± 4.4 yrs old, 80.7 ± 7.9 Kg in weight, 180 ± 27 cm in height, 14.3 ± 4.7% body fat (underwater weighing) and a VO_{2max} of 2.57 ± 0.22 L/min, while fin swimming in 6.5 mm

Protocols

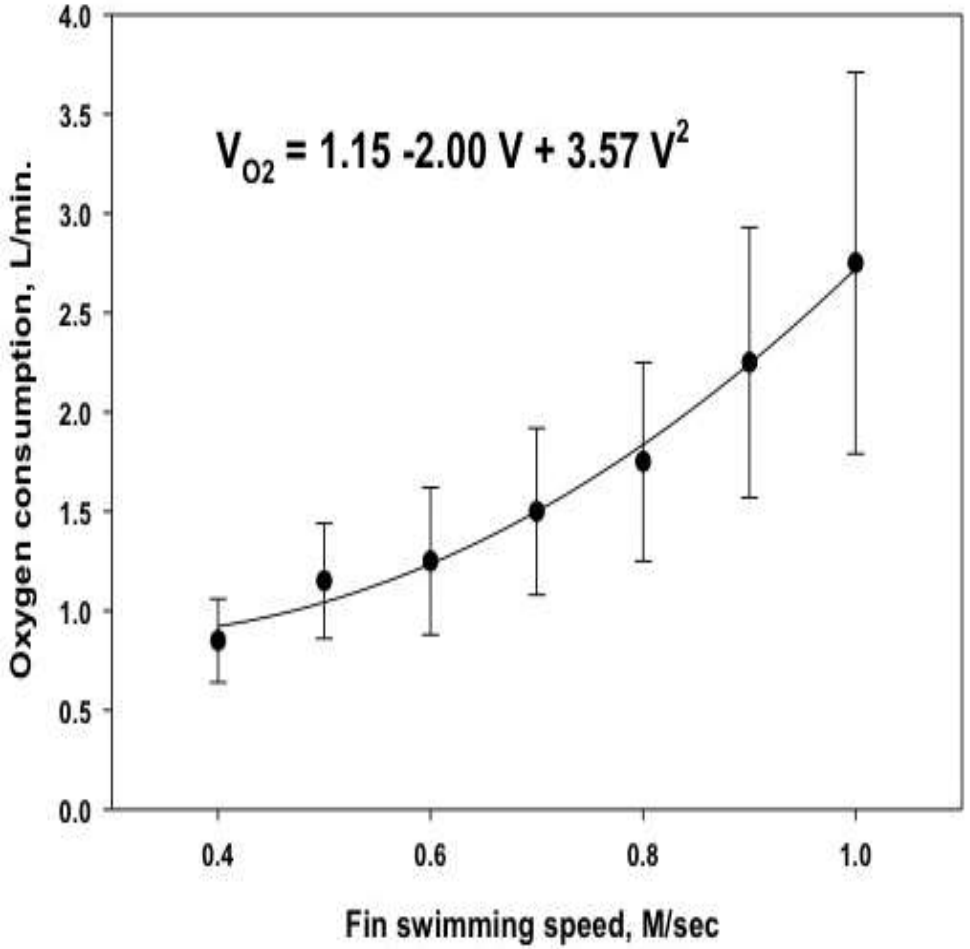
For the study of skill, fins, tanks and suits the subject swam at progressively increasing speeds in an annular pool (2.8 m deep, 2.8 m wide, 58.6 m in circumference) paced by a "rabbit" attached to a monitoring platform that circulated over the pool.

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 6.5 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).

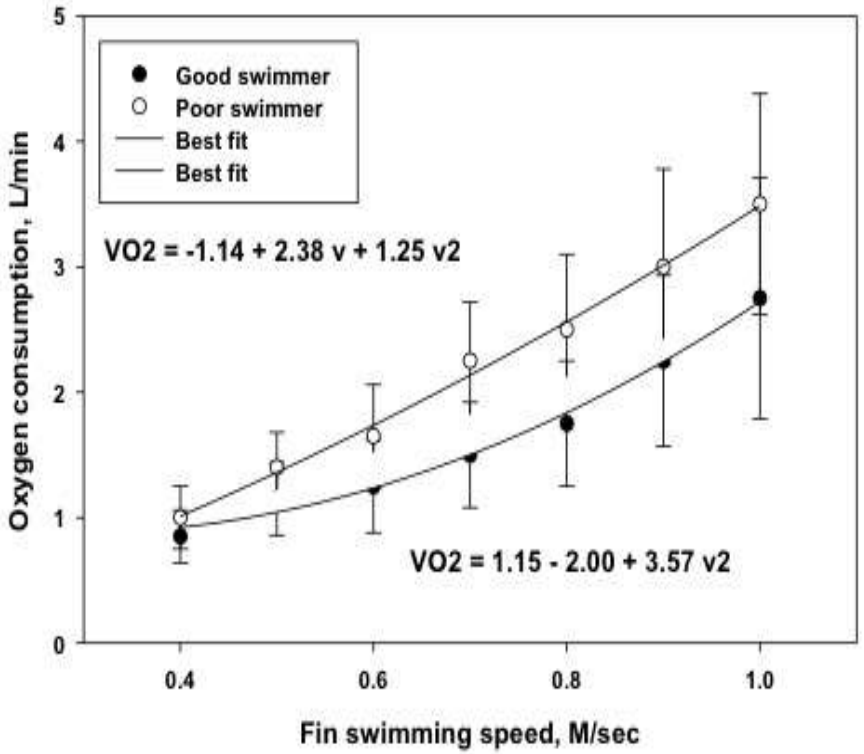
Procedures

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 VE, VO_2. Expired gas was collected using a pressurized bag-in-barrel system. A dry gas was sued for determination of VE. A mass spectrometer mounted on the monitoring platform measured O_2 and CO_2 concentrations. VO_2, VCO_2 and RER (VCO_2/ VO_2) were calculated using standard equations. Resting VO_2 was subtracted from the VO_2 during exercise at each time point to determine the net VO_2, i.e. the energy cost of swimming.

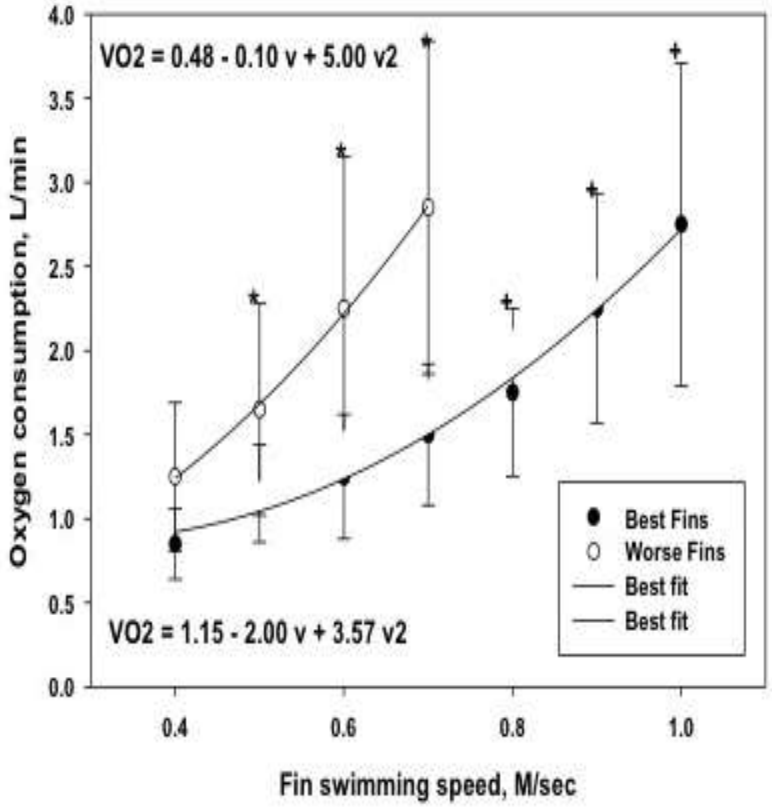
Effect of Velocity on Oxygen Consumption



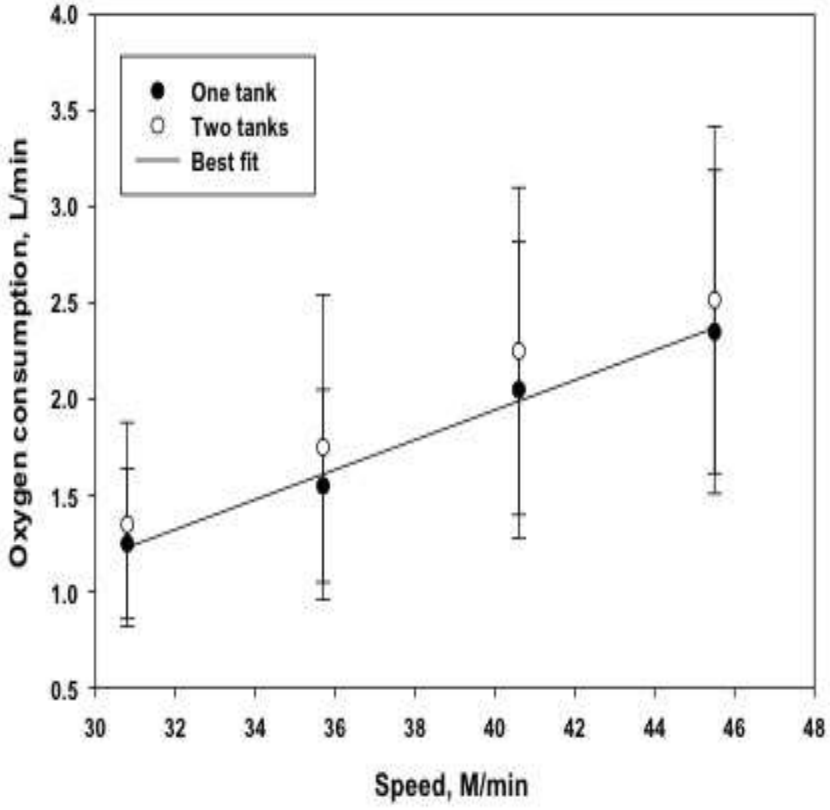
Effect of Skill on Oxygen Consumption



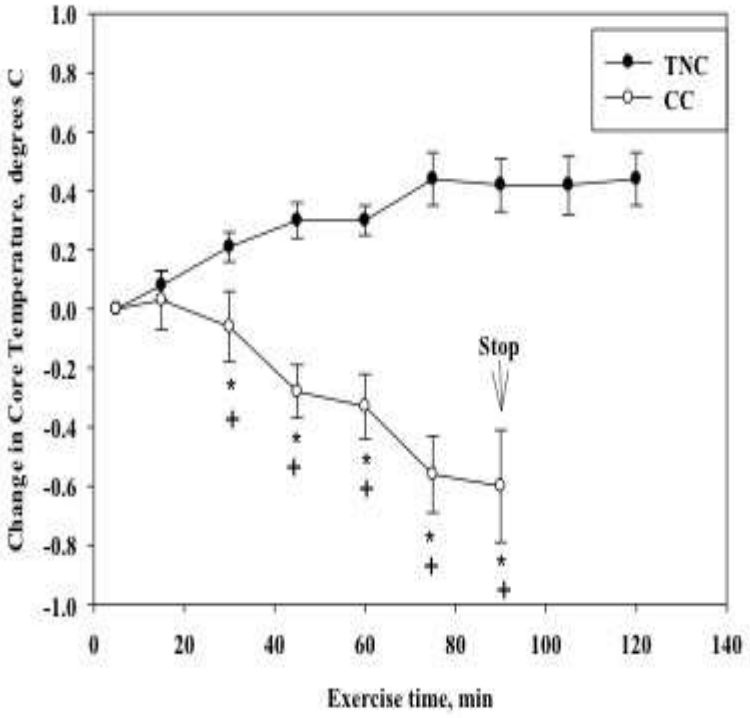
Effect of Fin Selection on Oxygen Consumption

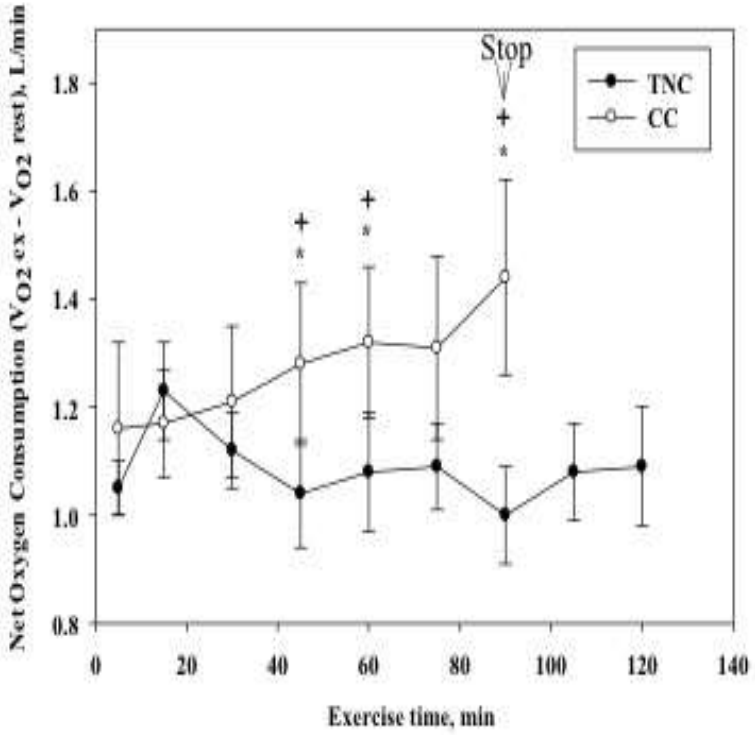


Effect of One vs Two SCUBA tanks on oxygen consumption



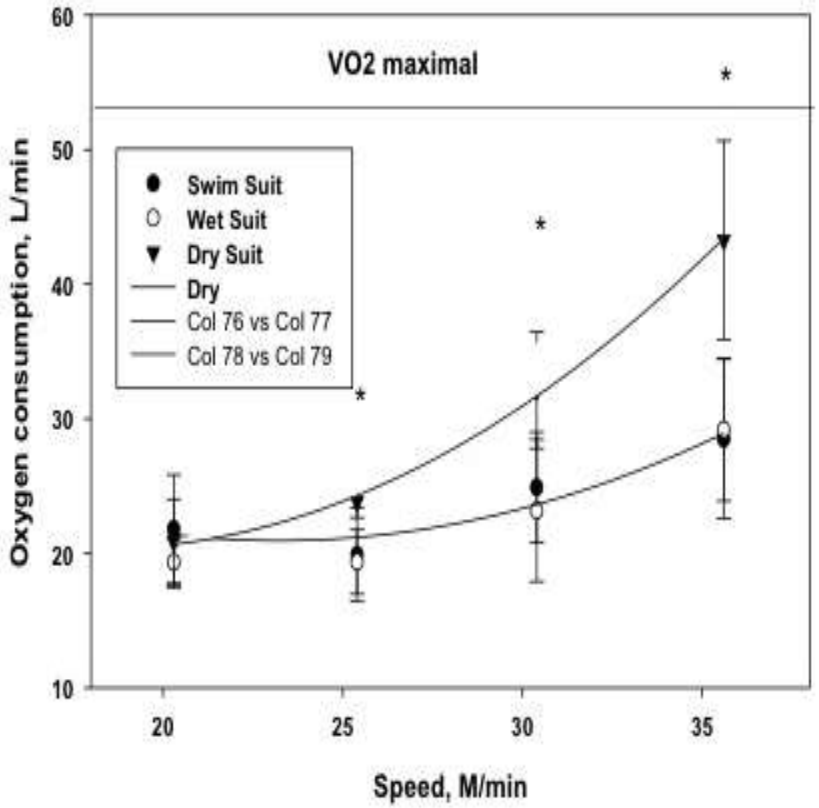
Effect of time and cold water on oxygen consumption



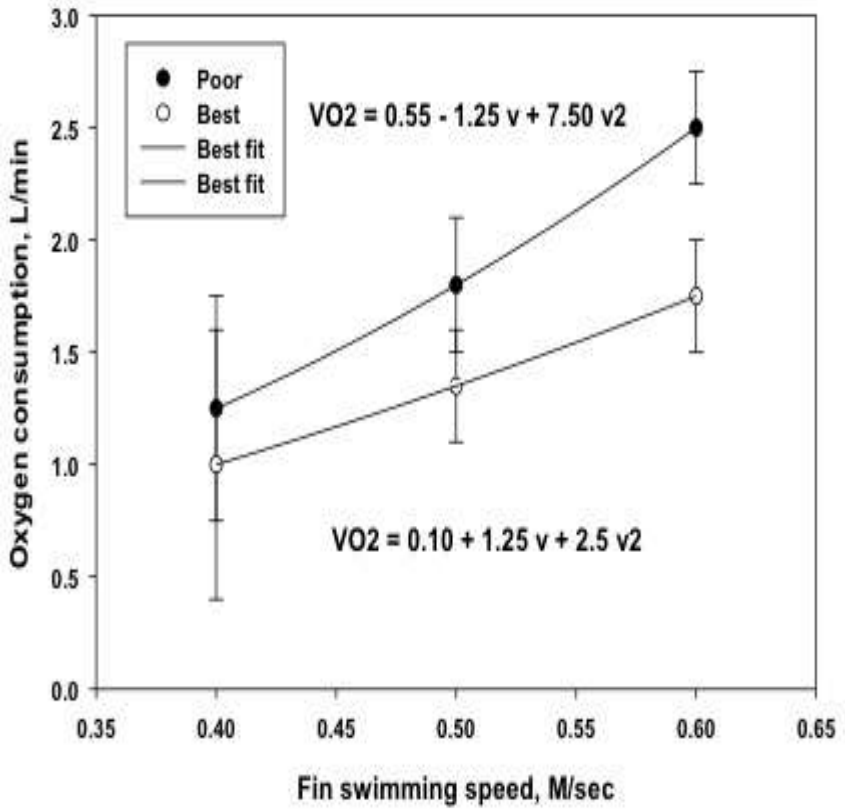


Effect of Thermal Protection Suits: VO2

- VO_2 increased exponentially with speed in all conditions.
- Values in swim and wet suits were not different from each other. However in the dry suit values are significantly higher at speeds faster than 25 M/min.
- RER was not affected by VO_2 for the Swim or Wet suits, however it was higher for the dry suit and increased with VO2 (0.97 to 1.03 (DF = 8/2; F = 25.403 P = 0.001



Effect of different dry suits on Oxygen Consumption



Summary

Energy cost of fin swimming increases exponentially with speed for velocities that can be sustained with oxygen consumption, secondary to body drag (kV^2)

Fin swimming skill does not affect VO_2 below 0.5 m/sec, however at faster speeds it can increase VO_2 nominally 50%

Fin selection influences VO_2, with large heavy rigid fins costing as much as 60% more energy to swim than narrow, light and flexible fins.

Swimming with two tanks, compared to one, only increased VO_2 about 10%, which could also be the case for a back mounted rebreather

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, however a dry suit, including different styles, increased the VO_2 40-57%

Conclusions

Training divers to fin kick skillfully can reduce the energy cost of swimming at speeds that can be accomplished with oxygen consumption.

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.