Optimization of fin-swim training for SCUBA Divers.

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Wylegala J, Schafer-Owczarzak M, Pendergast DR. Optimization of fin-swim training for SCUBA Divers. Undersea Hyperb Med 2007; 34(6):431-438. Underwater swimming is a unique exercise and its fitness is not accomplished by other types of training. This study compared high intensity intermittent fin-swim training (HIIT) with moderate intensity continuous (MICT). Divers (n = 20; age = 23 ± 4 yrs; weight = 82.57 ± 10.38 kg; height = 180 ± 6 cm) were assigned to MICT (65%-75% heart rate max (HRmax), for 45 min) or HIIT three 10 min swims/rest cycles (77%, 83%, and 92% HRmax, respectively) for 50 min. They trained using snorkel and fins at the surface paced by an underwater light system 3 times per week for 4 weeks. Swim tests were the energy cost of swimming, $\dot{V}_{O2}$max and timed endurance swim (at 70%$\dot{V}_{O2}$max). The $\dot{V}_{O2}$ was a non-significantly reduced at any velocity with either HIIT or MICT. Maximal swim velocity increased after HIIT (10%) ($p \leq 0.05$) but not after MICT ($p > 0.05$). $\dot{V}_{O2}$max increased 18% after HIIT and 6% after MICT ($p \leq 0.05$). The endurance times increased 131% after HIIT and 78% after MICT ($p \leq 0.05$), and in spite of this post-swim lactate was not significantly different and averaged 4.69 ± 1.10mM ($p > 0.05$). Although both training methods significantly improved fin swimming performance with similar time commitments, the HIIT improved $\dot{V}_{O2}$max and endurance more than MICT ($p \leq 0.05$). As no improvements in ventilation were observed, combining HIIT with respiratory muscle training could optimize diver swim fitness.

INTRODUCTION

Fitness for the swimming involved in diving is dependent upon a combination of neuromuscular and metabolic factors. As most, but not all, swimming during diving is continuous, with intermittent higher velocities, it fits the category of an endurance exercise. Although the performance in fin swimming is influenced by the diver's anatomy and fin selection, for a given speed the major determining factors are energy cost and the percentage of the maximal $\dot{V}_{O2}$ (during fin swimming) that can be sustained for the duration of the swim (1,2). These latter variables can be influenced by the diver's skill (3) and training status (1). The enhancement of endurance performance during exercise has traditionally been accomplished through participation in long-duration, low-, or moderate-intensity training lasting up to an hour, 4 to 7 times per week for at least 12 weeks (MICT) (4,5).

Swimming and diving $\dot{V}_{O2max}$ is significantly lower than the absolute $\dot{V}_{O2max}$, the latter typically observed in running (5,2), thus training for fin kicking must focus on the specific muscles used in fin kicking. A more productive, time efficient training protocol would be more beneficial to divers than a traditional approach, as they have compressed time schedules and limited time in the water; whether they are recreational, professional or military divers. It is conceivable that a more intense training protocol, that would require less time, could be beneficial in enhancing performance, however, training at approximately 85% of $\dot{V}_{O2max}$ that keeps the individual near, but not over, the intensity where lactate is increased significantly in blood has been suggested to be the upper limit for optimal endurance training (5,6). Recent studies of terrestrial locomotion have suggested, however, if the exercise intensity is high, which requires intermittent exercise, training 2 days/week may be as beneficial as training 4 days/week and the overall time commitment may be less (6). Previous studies in surface swimming (7,8) have shown the benefits of HIIT in competitive swimming performance. High intensity intermittent training (HIIT) may be ideal for divers, however, a comparison of the two training methods during fin-swimming, to our knowledge, has not been conducted. The hypothesis of the present study was that HIIT during surface fin-swimming for 4 weeks would reduce the $\dot{V}_{O2max}$ at all investigated velocities and improve $\dot{V}_{O2max}$ and endurance fin-swim time of subjects more than MICT for the same training period.

METHODS AND PROCEDURES

This study was approved by the institutional review board of the University, the subjects were cleared medically to participate and they signed an informed consent after the protocols were explained to them.

Subjects

Twenty male competitive swimmers were recruited from the local community to participate in this study. Subjects did not have previous underwater swimming experience but underwent SCUBA certification concurrent with fin training. The average age of the subjects was 25 ± 5 yrs., average height 180 ± 6 cm, and average weight 82.57 ± 10.38 kg. The pre-training maximal $\dot{V}_{O2max}$ expressed per unit body weight, retrospectively separated into training groups, was 30 ± 5 ml/kg/min for MICT and 27 ± 7 ml/kg/min for HIIT.

Protocol

Subjects were randomly assigned after the pre-test to one of two surface fin-swimming protocols; high intensity interval training (HIIT) or moderate intensity continuous training (MICT). All fin training and testing was conducted in an annular pool (60m circumference, 2.5 m wide and 2.5 m deep) equipped with a computerized underwater light system on the pool bottom that paced the swimmer's training sessions (8). Both training types were conducted three days per week for 4 weeks. Subjects in the MICT protocol swam continuously for 45 minutes, maintaining a pace requiring an effort of approximately 65% of their individual maximum heart rate. The HIIT group performed three maximal 10-minute fin-swim sets at the same velocity, interspersed with 10-minute rest intervals (50 min), which was set a 90% HRmax as determined from the pre-testing. Heart rate was monitored with Polar® heart rate monitors (Polar Electro Inc., Lake Success, NY) during all training sessions to insure compliance.

Before and after completion of fin-training the $\dot{V}_{O2max}$ and endurance fin-swim tests were administered. During $\dot{V}_{O2max}$ testing, subjects swam behind a platform that bridges and circulates over the circumference of the pool. The platform moved at incremental speeds; starting at 0.4m/sec, remaining at each speed for 3 min, and increasing in speed by 0.1m/sec until the subject could no longer maintain his position behind the platform. Expired gas was collected in Douglas bags during the final minute at each speed. Expired gas volume was measured using a dry gas meter (Harvard Model #AH-50-6164) and CO_2

and O_2 concentrations were analyzed with a mass spectrometer (MGA 1100 Medical Gas Analyzer, Perkin-Elmer Corp., Pomona, CA). Standard equations were used to calculate $\dot{V}_{O2}$ and $\dot{V}_{CO2}$. As most underwater swimming is sustained, lactate measurements were taken only during the training sessions and endurance swims and not after the maximal swim.

During the endurance swim, subjects were paced by the underwater light pacing system at a pace requiring an effort of approximately 70% $\dot{V}_{O2max}$ determined during pre-testing, and the time was measured until they could no longer maintain the pace of the lights. Heart rate was measured continuously during the swim and venous blood lactate was measured 5-7 min after the subject stopped swimming (Accusport, Boehringer Manheim Corp. Indianapolis, IN).

Statistical Analysis

All data are represented as mean ± standard deviation. The data were compared using analysis of variance between the two groups for each variable as a function of speed. Post-swim lactate and endurance swim times were compared between the two groups by a "Students t Test". SigmaStat (SPSS v 3.0) was used to perform all statistics and a level of probability ≤ 0.05 accepted as significant.

RESULTS

Training Data

The training velocities during the first week of training were 0.78 ± 0.04 m/sec for the MICT group and significantly higher at 0.87 ± 0.14 m/sec for the HIIT group. Over the four weeks of the training the velocities increased to 0.79 ± 0.04 m/sec and 0.92 ± 0.15 m/sec for the MICT and HIIT groups, respectively. On average, the HIIT group's velocity was 14 ± 3% faster than that of the MICT group over the four weeks of training and increased more over the 4 weeks. During the first week of training, the overall distance covered in each individual training session averaged 1,722 ± 265 m for the MICT group compared to an average distance of 2093 ± 95 m for the HIIT group. Over the course of the 4 week training period, the distance covered in each individual training session increased to 1,878 ± 177 m and 2133 ± 111m for the MICT and HIIT groups, respectively.

The average heart rate over the 45 minute training session represented 66% of the average maximum heart rate (mean 113 ± 8 b/min) for all subjects in the MICT protocol and 86% (139 ± 9 b/min) for the three 10 min exercise periods for the HIIT protocol.

The blood lactate levels were obtained after one of the three training session per week 5-7 min after the 45 minute continuous training sessions for the MICT group and were averaged for the four weeks and the value was 2.57 ± 0.48 mMol. Using a similar protocol following the final 10-minute swim interval in a session, the HIIT subjects' average blood lactate levels were significantly higher than MICT and their average was 5.13 ± 1.1 mMol.

Energy cost of swimming

Sub-maximal values: The energy cost of swimming as a function of velocity (Fig. 1) was not significantly different between groups and their expression was $\dot{V}_{O2} = 1.02 + (-1.65V) + 2.89V^2$ ($r^2 = 0.99$). For the post test the data, as shown in Fig 1, the post-training expressions were $\dot{V}_{O2} = 1.92 + (-4.96V) + 5.53V^2$ ($r^2 = 0.99$) for the HIIT and $\dot{V}_{O2} = 2.42 + (-6.64V) + 6.80V^2$ ($r^2 = 0.98$) for MICT. The $\dot{V}_{O2}$ at sub-maximal speeds between pre- and post-training, or between MICT and HIIT, did not achieve statistical significance.

Sub-maximal minute ventilations increased exponentially with velocity and were not significantly different among the tests (Fig

2) and the plots in the figure can be expressed as $\dot{V}_E = 54.19 + (-119.48V) + 129.89V^2$ ($r^2 = 0.99$) for pre-training and $\dot{V}_E = 41.54 + (-78.38V) + 93.76V^2$ ($r^2 = 0.99$) for the HIIT post-test and $\dot{V}_E = 79.73 + (-223.11V) + 212.80V^2$ ($r^2 = 0.99$) for MICT post-test.. During sub-maximal steady state swimming the $\dot{V}_E/\dot{V}_{O2}$ ratios were not statistically different among velocities and were therefore averaged for all sub-maximal velocities and the values were 27.0 ± 1.0 L $\dot{V}_E$/L$\dot{V}_{O2.}$

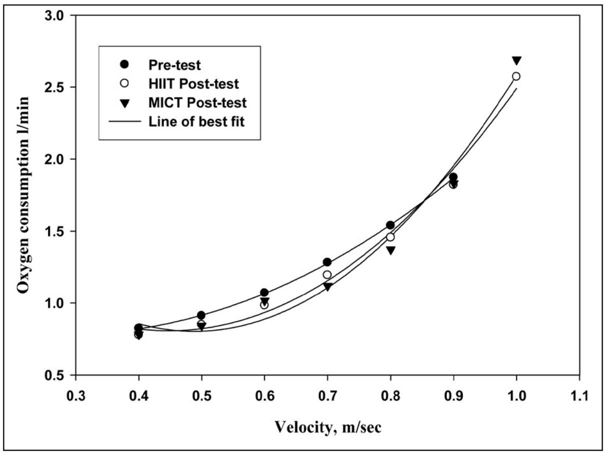

Fig. 1 Oxygen consumption (mean values) is plotted as a function of swimming velocity for Pre-fin training, HIIT and MICT. The sub-maximal values were not significantly different.

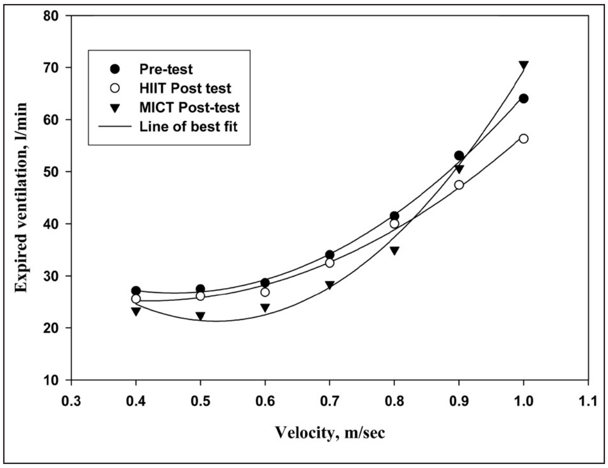

Fig. 2 Minute ventilation is plotted as a function of swimming velocity for pre-fin training, HIIT, and MICT. There were no significant differences between groups at sub-maximal velocities.

The respiratory exchange ratio (RER) during the pre-tests at the lowest $\dot{V}_{O2}$ was 1.22 ± 0.20 and 1.17 ± 0.17 for the continuous and intermittent training, suggesting hyperventilation. As $\dot{V}_{O2}$ increased during the pre-test, RER decreased significantly (0.97 ± 0.03 and 1.02 ± 0.08, MICT and HIIT, respectively); and then increased significantly to 1.13 ± 0.07 and 1.11 ± 0.08 for MICT and HIIT, respectively. The post-training values of RER were not significantly different from the pre-training values for either group at the lowest $\dot{V}_{O2}$ values (1.18 ± 0.18 and 1.16 ± 0.17), at intermediate sub-maximal $\dot{V}_{O2}$ values (0.99 ± 0.05 and 1.00 ± 0.09) and at the highest sub-maximal $\dot{V}_{O2}$ values (1.18 ± 0.08 and 1.08 ± 0.08) for MICT and HIIT groups, respectively.

Maximal values: The maximal velocity on the pre-test was 1.10 ± 0.12 m/sec and did not change significantly (1.1 ± 0.11 m/sec) during MICT post-testing. For the HIIT group, pre-test maximal velocity was 1.01 ± 0.19 m/sec and it increased significantly to 1.10 ± 0.13 post-fin training.

Maximal $\dot{V}_{O2}$ increased significantly from 2.53 ± 0.39 to 2.69 ± 0.45 L/min (6%) following MICT, and from 2.17 ± 0.61 to 2.57 ± 0.55 L/min (18%) following participation in the HIIT protocol. Both protocols were effective in improving $\dot{V}_{O2max}$, however, the improvement was significantly greater following HIIT than MICT.

The maximal heart rates during the progressive velocity test were not significantly different between pre- and post-training or MICT and HIIT and their average value was 161 ± 3 b/min.

The maximal minute ventilation prior to fin-training was not different between groups and therefore was averaged and the value was 80.80 L/min. There were significant differences between the post-training groups and they increased to 84.95 L/min after MICT and to 103.95 L/min following HIIT. The $\dot{V}_E/\dot{V}_{O2}$ ratios at maximal $\dot{V}_{O2}$ were not significantly different for all subjects during the pre-test and were 35.16 L$\dot{V}_E$/L$\dot{V}_{O2}$ pre-training, while post-training there were significant differences and they were 31.6 L$\dot{V}_E$/L$\dot{V}_{O2}$ and 40.45 L$\dot{V}_E$/L$\dot{V}_{O2}$ following MICT and HIIT, respectively.

The RER at maximal $\dot{V}_{O2}$ pre-fin training was 1.32 ± 0.10 and 1.24 ± 0.10 for the MICT and HIIT groups respectively, and post-fin training these values were essentially unchanged at 1.32 ± 0.08 and 1.24 ± 0.11 for MICT and HIIT groups respectively.

Compared to sub-maximal swimming values, the elevated post-training maximal values of RER and $\dot{V}_E/\dot{V}_{O2}$ indicate substantial respiratory compensation for metabolic acidosis, and the likelihood that maximal $\dot{V}_{O2}$ was observed in all conditions and that the higher values for MICT and HIIT post-training were due to the faster velocity in HIIT and increased aerobic contribution at maximal speed in MICT.

Endurance performance

The time to exhaustion at 70% of $\dot{V}_{O2max}$ was 10.61 ± 5.70 min pre-fin training for subjects assigned to the MICT protocol, and 13.62 ± 6.76 min for subjects assigned to the HIIT protocol. Improvement was noted following both protocols, 78% (18.84 ± 6.88 min) following MICT, and 131% (31.39 ± 9.93 min) following HIIT. The improvement in endurance swimming time was significantly greater following the HIIT protocol than following the MICT regimen.

The maximal lactic acid measured after the endurance swim was not significantly affected by either method of training for pre-training and averaged 4.01 ± 1.53 mM. The post training values were not different from pre-training or between MICT and HIIT and were 4.69 ± 1.10 mM averaged for both groups. However after both MICT and HITT the swim times were significantly longer than pre-training and HIIT longer than MICT.

DISCUSSION

In an aquatic environment, divers utilize fins in an effort to overcome drag forces (9) and improve the fraction of thrust useful to forward propulsion (2,3,10,11,12,13). Variations in diver kicking technique as well as variations in fin type have been shown to impact the energy cost of swimming (3,13), and alterations in the energy cost of an activity are known to impact $\dot{V}_{O2max}$ and endurance performance (1). As seen in Figure 1, $\dot{V}_{O2}$ is velocity dependent. The reduced $\dot{V}_{O2}$ observed post-training was not significant as our subjects were skilled swimmers prior to fin training and had previously perfected leg kicking without fins which is a similar motion to kicking with fins. Hoff et al (14) demonstrated that endurance performance can be improved by reducing $\dot{V}_{O2}$ through strength and rate of force development via neural adaptation. If divers whom are less proficient swimmers undergo the training used in this study, greater reduction in $\dot{V}_{O2}$ would be expected (1,3).

The HIIT conducted at 77-92% of HRmax resulted in significantly greater improvements in $\dot{V}_{O2max}$ than the MICT that was conducted at 65.7%$\dot{V}_{O2max}$. Although the distance swum was slightly greater in the HIIT than MICT the training times were similar between the two groups so these factors should not have accounted for the differences observed between the two groups. Previous studies in terrestrial activities have shown that training intensity is a more important factor in the improvement of $\dot{V}_{O2max}$ than is training duration (15,16). Previous studies using terrestrial locomotion (17,18,19,20) have shown that high intensity type training improves $\dot{V}_{O2max}$ to a greater extent than traditional aerobic training. The benefit of high intensity training has also been shown for competitive swimmers who used a protocol similar to the one used in the present study and had similar increases in $\dot{V}_{O2max}$ (7,8). The subjects in the present study were competitive swimmers, although inexperienced surface fin-swimmers, and as the percentage improvement in aerobic fitness has been shown to be inversely related to the initial fitness level of the individual (6), greater improvements than observed in the present study may thus be seen with un-fit divers.

The high intensity training demands both, maximal aerobic power and anaerobic metabolism and leads to lactic acid accumulation in muscle and blood (21). Lactate levels during HIIT training were significantly higher than in MICT in the present study. During HIIT lactate accumulates in muscle and blood during the 10 min swim, and then it is washed out and metabolized during recovery, with this cycle repeated three times. Higher intensity training has been shown to improve lactate transport by increasing monocarboxylate transporters (MCT1) in skeletal muscle, whereas, no change in MCT1 occurs at the lower training intensities (22). Previous studies (17,22) demonstrated that six weeks of high intensity training not only increased $\dot{V}_{O2max}$ more than traditional aerobic training, but it increased anaerobic capacity more than traditional aerobic training. Although lactate after the endurance test was not decreased post-training in either group, the lactate levels were sustained significantly longer prior to cessation of swimming.

Endurance performance is correlated with $\dot{V}_{O2max,}$ however, the association is not strong and improvements in endurance have been shown without improved $\dot{V}_{O2max}$. The improvements in endurance in the present study after MICT (78%) were not as great as after HIIT (131%), and these increases were related to the increased $\dot{V}_{O2max}$ and the capacity to sustain high lactate levels for longer swim times. Previous studies have shown that higher intensity training resulted in a 23% greater running time to exhaustion than lower intensity training (23), in agreement with the present study.

The maximal swimming speed increased more in HIIT than MICT in the present study, presumably due to the combination of increased metabolic power ($\dot{V}_{O2max}$ and anaerobic) and reduced $\dot{V}_{O2}$/velocity. Another study (19,20) demonstrated a similar finding for terrestrial locomotion, in spite of an absence of changes in oxidative or glycolytic enzyme activity, suggesting that pH buffering capacity in skeletal muscle may be one mechanism contributing the enhanced endurance performance.

The improvements in metabolic power in the present study were achieved in 4 weeks, while traditional aerobic training takes at least 12 weeks to produce similar results (5,6). Other studies of terrestrial locomotion have also shown that 2 – 4 weeks of intense training can improve metabolic power (14,16,19,22, 24,25,26,27,28,29). The data for competitive swimming also agree with the data from the present study (7,8).

The results of the present investigation demonstrate that for purposes of maximizing metabolic power (oxygen consumption and anaerobic) and endurance performance, the high intensity interval program (HIIT) used in this study was more effective than a continuous, moderate-intensity approach with similar time commitments (3 times per week for 4 weeks). Although training decreased the $\dot{V}_{O2}$ at all velocities, the differences did not achieve statistical significance; however if divers with less swimming experience use this training program a significant improvement could be expected in $\dot{V}_{O2max}$ and endurance, as well as reduced $\dot{V}_{O2}$ at all swimming velocities. It has been shown that adding high intensity training to a base of lower intensity training improves metabolic power (19) so the HIIT would be beneficial for fit divers as well. The training programs investigated in the present study did not improve respiration, which previous studies have shown may limit maximal and endurance fin-swimming due to the increased work of breathing (30,31). Surface and underwater swim endurance performance is improved by respiratory muscle training employing static and resistive loads (RRMT) for 4 weeks (30). Thus RRMT could be added to the HIIT to optimize fin swimming capabilities in divers. Previous studies would suggest that this improved fin-swimming fitness (30) and respiratory fitness (32) could be maintained by 2 days per week of HIIT, but not MICT (6).

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