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Physiologic Responses to High Intensity Training in Competitive University Swimmers

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Abstract

A season long high intensity training program was performed by 17 male competitive collegiate swimmers. Data collected for the study were maximal and submaximal oxygen consumption ($\dot{V}O_2$) and assessment of stroke frequency ($\dot{S}$) vs. velocity (v). Each subject was tested pre-season, mid-season and post-season while performing the front crawl. $\dot{V}O_2$ was determined during a tethered swim to exhaustion, while $\dot{S}$ and v were taken during successive free swims of one length of a 22 meter pool. The training program was individually based and focused on swimming at or near maximum v and the corresponding $\dot{S}$ for relatively short distances. There were significant ($p \leq 0.05$) increases in $\dot{V}O_2$ peak, $\dot{S}$ max and v max when post-season was compared to pre-season. The implications of the work are to alter training programs toward increased intensity quality rather than low intensity quantity training for optimal in-season improvement.

Introduction

In swimming, performance is limited by the metabolic capability as well as the skill of the athlete. Craig and Pendergast (3) showed that velocity is a product of stroke frequency and distance per stroke, with velocity increasing with an increasing stroke frequency and a decreasing distance per stroke. In addition, it has been shown that the distance traveled per stroke correlated with actual swimming performance (2). Maximum velocity has also been related to metabolic capability of the athlete (4). The present study was designed to test a new type of training program which focused on training the athlete at high stroke frequency, velocity and level of metabolic demand. It was hoped this would bring about maximum benefits and improvements in the variables which limit performance.

Methods

The subjects for this study were college age males (n = 17) who were members of a University Division II swimming team whose characteristics are presented in table 1. Each underwent a pre-season physical exam according to the university's guidelines. The subjects competed in one of the four primary strokes, however, all participated in at least one free style event, and therefore the front crawl was used for all tests. Each subject was tested for all parameters before, at the mid-point and after a full season of training and competition. Pre-season testing was performed during the initial period of training over a two week span, mid-season testing was performed after an invitational competition and

Table 1
Physical characteristics of subjects

Age years	Height cm	Pre-Season Weight Kg	Post-Season Weight Kg
19.06	181.0	75.02	74.97
0.22	1.28	1.26	1.27

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Table 2
Protocol for oxygen consumption testing

TIME	(min)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20
DRAG	(Kg)	2	3	4	4.5	5	5.5	6	6.5	7	7.5

before a month long break before any further competition, and post-season testing was performed immediately after the season was complete during a similar two week period.

Data collected were maximal and submaximal oxygen consumption ($\dot{V}O_2$), and stroke frequency ($\dot{S}$) vs. velocity (v) relationships. Oxygen consumption was determined using the open circuit spirometry method during tethered swimming until exhaustion. Workloads were increased every two minutes in either 1kg or 0.5kg increments (see table 2).

In order to measure the relationship between stroke frequency and velocity (1) each subject was instructed to push off a wall of a 22 m pool and swim one length maintaining constant velocity with a very slow arm rate. The subject was then instructed to increase $\dot{S}$ during subsequent trials until the subject was swimming at what they perceived was their maximum velocity. It was then necessary to instruct the subject to perform at higher $\dot{S}$ than what they associated with maximal v in order to ensure that a true maximal v was established. On each trial the subject was timed during a 10 m portion of the swim so that v could be determined.

In order to determine the effects of a season utilizing this type of training $\dot{V}O_2$ peak, $\dot{S}$ max and v max were compared pre-season vs. post-season using a Students t-test with the results being considered significant if $p \leq .05$. In addition to this the slopes of the linear portions of the $\dot{V}O_2$ vs. Tethered Drag as well as the $\dot{S}$ vs. v graphs were analyzed to determine the training effect on the efficiency of the swimming. The latter results were also be considered significant at the $p \leq .05$ level.

The training method employed concentrated on high intensity quality work over relatively short total distances. Traditionally a swimming workout consisted of 8-12 thousand meters of work at considerable lower intensities than the athlete would utilize during competition (5,7). This method, however, was designed to train the swimmer at or above the muscular and metabolic intensity the competition would demand. For each practice a goal v and corresponding $\dot{S}$ was identified for each swimmer and this was monitored for each swimmer. This goal v and $\dot{S}$ was at an higher than standard intensity and one which corresponded to near peak v. The determination of $\dot{S}$ and v were important aspects of the training program because it allowed for specific monitoring of the swimmer's training intensity and quality of work. The mid-season testing was used to alter the training based on improvements during the first half of the season. A typical workout consisted of a 1 hour period of high intensity work broken up into bouts which were somewhat shorter than the actual event itself for a given swimmer. A schedule of two consecutive days intensity work followed by two days light work was employed to allow for maximal glycogen depletion and replenishment between sets of high intensity workouts. The pattern of exercise and rest was utilized to avoid chronic fatigue and the resultant decline in training performance.

The competitive effects of the high intensity training were evaluated by comparing the improvement in swimming times during competition for distances of 50, 100, 200, 500, 1000 and 1650 yards between the season utilizing high intensity training and the previous season where lower intensity and longer duration training was used. The lower intensity training consisted of two workouts per day with a total distance of 10-12,000 yards made up of 10 x 100 yards on one minute 15 seconds and long sets of 200 yards with short rest periods for sprinters. The training for distance swimmers consisted of 2 x 2000 yards or 10 x 500 yards with short rest periods. The specifics of the high intensity training included dividing the race distances into thirds and having the swimmer complete these at race pace with 45 seconds rest between each trial. Once the swimmer failed to maintain race intensity for a trial, he was given 90 seconds rest and then resumed training. When the athlete could achieve 10-15 repeats at race intensity, the rest interval was decreased by 5 seconds until the race could be completed at the selected goal time. Once this was accomplished a new and faster goal was selected and the process was repeated. The swimmers trained once daily for 1 hour covering a distance of approximately 3,000 yards. A cycle of two consecutive days of intensity work and two rest days with technique work was used for reasons stated above.

Results

There was a statistically significant increase ($t = -5.87$, $p = 0.000$) in peak oxygen consumption ($\dot{V}O_2$) from 3.12 ± 0.11 to $3.91 \pm .01$ L/min pre-season vs. post-season. This 20 percent increase was accomplished without a change in the relationship between $\dot{V}O_2$ and workload, as determined by the similarity in the slopes of the $\dot{V}O_2$ vs. tethered drag pre-season vs. post-season (Figure 1).

Maximum velocity, determined during the stroke frequency analysis, increased from 1.62 ± 0.01 m/sec pre-

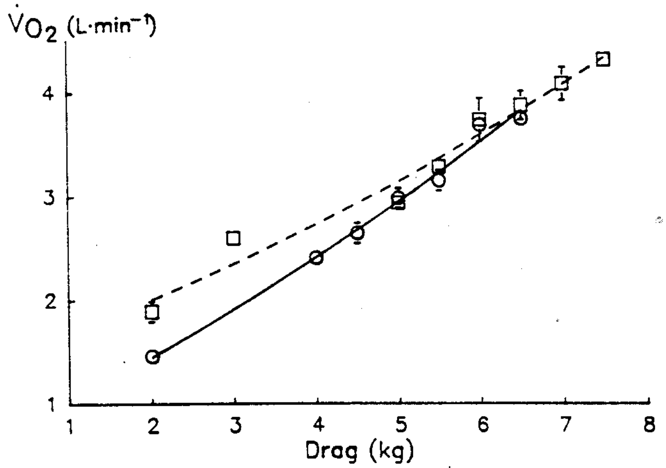

Figure 1.
Relationship between oxygen consumption ($\dot{V}O_2$) in L•min⁻¹ and tethered drag in Kg.
Pre-season and ——
Post-season and - - -

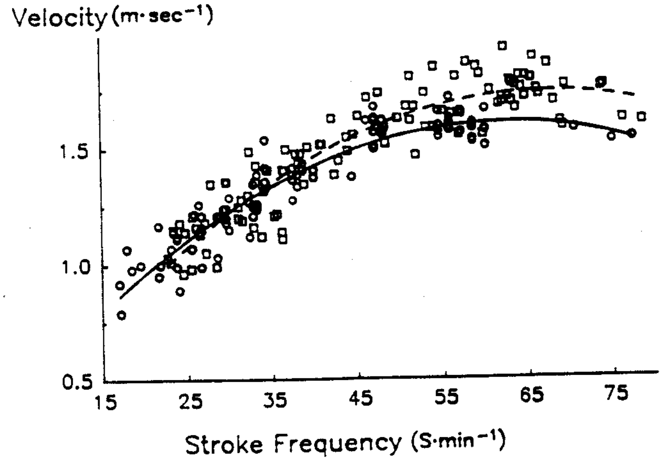

Figure 2.
Relationship between velocity in m•sec⁻¹ and stroke frequency in s•min⁻¹.
Pre-season and ——
Post-season and - - -
A stroke is 1 complete arm cycle.

season to 1.78 ± 0.02 m/sec post-season. This increase was statistically significant (t = -6.01, p = 0.000) and was due to a significant increase in the maximal stroke frequency (t = -4.45, p = 0.001) without a reduction in v. The distance traveled per stroke between the two points in training was not altered (see table 3, Figure 2) as described by the slope of the linear portion of the $\dot{S}$ vs. v graph.

The competitive swimming times for free style between 50 and 1650 yards for the experimental and the previous season, which was used as a control, were compared to evaluate performance changes. The improvements in times for 50 to 1650 yards were significantly greater during the experimental than the control season. Improvements ranged from 0.86 to 34.9 seconds (2.6 ± 0.5%) and 0.38 to 21.85 seconds (2.2 ± 0.7%) for the two seasons respectively.

Discussion

Exercise training causes changes in the body's ability to deliver blood and oxygen to the working musculature and allows for increases in the amount of work performed. It has been shown that endurance training increases cardiac output via an increase in stroke volume as maximal heart rate is decreased (14). Peripheral adaptations include an increase in the muscle's oxidative as well as anaerobic capacity. Peripherally there is an increase in oxidative capacity which results in better extraction of oxygen from the blood delivered as well as an increase in the regional blood flow (6, 11, 14).

Numerous studies have shown that increases in swimming capabilities can only be facilitated via a program of swim training (8, 11, 12). These studies have consistently demonstrated that increases in $\dot{V}O_2$ max resulting from other forms of exercise training are not reflected when the subjects were tested swimming. Because swimming has shown such a high degree of specificity to training, this training program was designed to condition the athlete to the specific intensities that competition would demand rather than simply specific to swimming.

Mean peak pre-season $\dot{V}O_2$ was within the range associated with recreational swimmers (11, 12). The post-season value (3.91 ± 0.01) was slightly lower than Magel and Faulkner obtained during tethered swimming with college swimmers. This can be explained due to the fact that the above study was performed on Division I athletes. Among these were 7 All-Americas and 2 Olympians (10). The metabolic increases observed during this study were greater than those reported by others using a more traditional method. Neufer et al. (13) reported a 14.3 percent increase in $\dot{V}O_2$ over an entire season of training at approximately 9,000 meters per day. In addition to this, Costill et al. (1) and Kirwan et al. (9) showed no improvement in either physiologic tests or swimming performance when the training distance was doubled and intensity kept constant.

Although there were increases in $\dot{V}O_2$ peak, this was not reflected in any increases in the swimming efficiency of the subjects. If efficiency increased, one would ex-

Table 3
Relationship between stroke frequency and velocity

Pre-Season Max V m/sec	Pre-Season S At Max V strokes/min	Pre-Season Slope	Post-Season Max V m/sec	Post-Season S At Max V strokes/min	Post-Season Slope
1.622	53.56	0.019	1.785*	61.5*	0.019
0.012	1.7	0.001	0.023	1.85	0.001

pect a decrease slope of the $\dot{V}O_2$ vs. tethered drag line after training that would represent an increased ability to swim more efficiently at any given workload. However, in this study there was no decrease in the slope even though $\dot{V}O_2$ peak increased significantly (see figure 1).

The stroke frequency and velocity data (Table 3) agree well with that generated by Craig and Pendergast (3). The data suggest that the increase in $\dot{V}O_2$ allowed for maintenance of stroke mechanics at higher $\dot{S}$, which resulted in an increased v (see figure 2). Velocity could have also been increased by an increase in the skill level of the athlete. If there was an increase in the distance per stroke, the athlete could attain a higher v at any given $\dot{S}$. This does not appear to be the case in this study due to the similarity of the slopes of the linear portion of the $\dot{S}$ vs. v graph pre and post training (Figure 2).

The physiologic improvements made during this type of training, specifically the increased $\dot{V}O_2$ peak as well as v max, were reflected in the performance of the athletes during competition. This can be observed by the significant increase in time improvements during the experimental season when compared to a season where a lower intensity type training was used.

Conclusion

The unique aspect of high intensity training is the use of shorter distances and higher velocities during the workouts than are typically associated with the standard program. The daily sets consisted of swimming at a prescribed pace for each individual which was at optimal race velocity determined from the relationship between stroke frequency and velocity. The distance per set, rest interval between sets and the training intensity are the parameters regulated during the workouts. As the athlete's physical condition and/or technical ability improves he will be able to sustain his velocity and stroke frequency at proper levels for a longer period of time and require shorter rest intervals before he can resume swimming at the desired intensity.

During the workout the coach monitors the velocity and stroke frequency of each swimmer periodically. Velocity can be easily recorded by using the split time, and stroke frequency can be determined by timing a selected number of strokes. It is important that the athlete maintain the optimal position on his individual stroke frequency vs. velocity relationship for maximal benefits. A program of this type is very individualized and the athlete must bear some responsibility for improvement by maintaining the proper intensity during the workout.

This program succeeded in increasing $\dot{V}O_2$ peak, $\dot{S}$ and v maximum, resulting in improved performance. It did not, however, result in improved skill. The present program was designed to be an in-season program employed to increase metabolic factors which limit performance, and specifically did not address skill. An out of season program focusing on reducing stroke rate for a given velocity is being employed in order to increase efficiency and distance per stroke. The data suggest that high intensity training brings about optimal changes in physiologic parameters, but other factors, such as skill of the athlete must be addressed to facilitate maximal performance.

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