physical fitness and performance

Dry-land resistance training for competitive swimming

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ABSTRACT

TANAKA, H., D. L. COSTILL, R. THOMAS, W. J. FINK, and J. J. WIDRICK. Dry-land resistance training for competitive swimming. *Med. Sci. Sports Exerc.*, Vol. 25, No. 8, pp. 952–959, 1993. To determine the value of dry-land resistance training on front crawl swimming performance, two groups of 12 intercollegiate male swimmers were equated based upon preswimming performance, swim power values, and stroke specialties. Throughout the 14 wk of their competitive swimming season, both swim training group (SWIM, $N = 12$) and combined swim and resistance training group (COMBO, $N = 12$) swam together 6 d a week. In addition, the COMBO engaged in a 8-wk resistance training program 3 d a week. The resistance training was intended to simulate the muscle and swimming actions employed during front crawl swimming. Both COMBO and SWIM had significant ($P < 0.05$) but similar power gains as measured on the biokinetic swim bench and during a tethered swim over the 14-wk period. No change in distance per stroke was observed throughout the course of this investigation. No significant differences were found between the groups in any of the swim power and swimming performance tests. In this investigation, dry-land resistance training did not improve swimming performance despite the fact that the COMBO was able to increase the resistance used during strength training by 25–35%. The lack of a positive transfer between dry-land strength gains and swimming propulsive force may be due to the specificity of training.

SWIM PERFORMANCE, SWIM POWER, SWIM BENCH STRENGTH, DISTANCE PER STROKE, TESTOSTERONE, CORTISOL, BLOOD LACTATE

Muscular strength and power are major determinants of success in competitive swimming (3,5,10,21). With a variety of testing equipment, upper body strength and swimming power have been demonstrated to be highly correlated with swimming performance time (3,5,10,21,23). Therefore, improvements in arm strength following resistance training may result in higher maximum stroke force and, in turn, improved sprint swim performance.

Previous research has shown that concurrent resistance and endurance training may result in less than optimal strength development (11). In addition, swim power as measured on the biokinetic swim bench and during a tethered swim has been reported to decrease during an intensified period of swim training (6). Local muscle fatigue produced from an intensified period of training may decrease the propulsive force, resulting in poorer performance. However, it is unclear whether the heavy demands of combined swim and resistance training may suppress the athlete's ability to improve sprinting performance, or if resistance training might be beneficial in preventing local muscle fatigue by enhancing muscular strength.

Modern swim training is characterized by a large training volume and dry-land resistance training. Previous research (6,12) has questioned the necessity for increased swim training volume. However, in light of the limited amount of research available and the lack of agreement among published research, conclusions regarding the effect of resistance training on swimming performance remain uncertain. Very few studies have been conducted to determine if the improvement in muscular strength gained from resistance training results in faster sprint swimming (3,20). Due to the principles of specificity of training, additive effects of dry-land training to ongoing swim training have been controversial. At the present time, it is not certain if the strength gained on land can positively transfer to propulsive force used in the water. Therefore, the purpose of this study was to examine the contribution of swimming-specific resistance training on swimming performance in male competitive swimmers.

METHODS

Subjects. Twenty-four male collegiate swimmers on a varsity swimming team (NCAA Division I) served as subjects for this study. Prior to participation, a verbal and written explanation of the procedure and potential risks was administered and, in turn, the swimmers gave their written consent to participate in this investigation. The men were then divided into two matched groups: a swim training group (SWIM, $N = 12$) and a concurrent swim and resistance training group (COMBO,

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$N = 12$). The assignments into each group were systematically determined according to swim performance ability, swim power values, swim bench strength values, previous experience in weight training, and stroke specialties. Since freshmen tend to increase their swim abilities more than other classes, collegiate swimming experience was also considered for group selection. Despite the fact that various criteria were established for group selection, the two training groups were similar not only in swimming abilities but also in anthropometric and physiological measurements. As can be seen in Table 1, at the start of a swimming season there were no significant differences between the COMBO and SWIM groups in any of the variables measured, thus allowing a fair comparison to be made between groups. The only difference detected as statistically significant ($P < 0.05$) was mean blood lactate values, with the swimmers in COMBO being higher (Fig. 6). The majority of the swimmers were familiar with most of the testing procedures from testing conducted during the preceding year.

TABLE 1. Comparison of the two groups at the beginning of a swimming season.

	COMBO ($N = 12$)	SWIM ($N = 12$)
Age (yr)	19.17 ± 0.32	19.50 ± 0.26
Height (cm)	181.17 ± 1.47	182.25 ± 2.12
Weight (kg)	77.05 ± 1.93	76.39 ± 2.16
LBM (kg)	68.02 ± 1.46	67.62 ± 1.86
% Body fat*	11.60 ± 0.93	11.44 ± 0.63
22.9-m swim time (s)	11.01 ± 0.15	11.34 ± 0.23
365.8-m swim time (s)	258.10 ± 4.15	264.71 ± 5.31
Freshmen (*N*)	4	3
Previous strength training experience (*N*)	3	3
Stroke specialities (*N*)		
Front crawl	4	4
Butterfly	1	2
Breast stroke	3	2
Back stroke	3	2
Individual medley	1	2
Distance specialities (*N*)		
Sprint	4	2
Middle distance	5	7
Long distance	2	3

Anthropometric values and swim performance times are expressed as mean ± SE. There were no significant differences between groups.

* Estimated from skinfold measurements (18).

Training. Both groups of subjects swam together for the 14 wk of their competitive swimming season (Fig. 1). All of the swim training was performed as intermittent exercise. As shown in Figure 1, swim training volume was gradually increased from the start of the season, attained a peak (6000 $m \cdot d^{-1}$) at the 9th week, and then gradually decreased. In addition to the swim training, the COMBO group engaged in a resistance training program 3 d per week, on alternate days, over the 8 wk between weeks 3 and 10 of the competitive swimming season. Following the resistance training period, both groups tapered for approximately 2 wk prior to an important competition on week 14 (Fig. 1).

The resistance training program was intended to simulate the muscle and swimming actions employed during front crawl swimming and utilized weight lifting machines and free weights. This resistance training program consisted of dips, chin-ups, lat pull-downs, elbow extensions, and bent arm flys. The swimmers performed between 8 and 12 repetitions of each exercise bout. Each subject performed three sets of each exercise. Swimmers were instructed to increase the weight as they adapted in order to maximize the resistance training effect. All resistance training was conducted under the direct supervision of a strength training coach, and

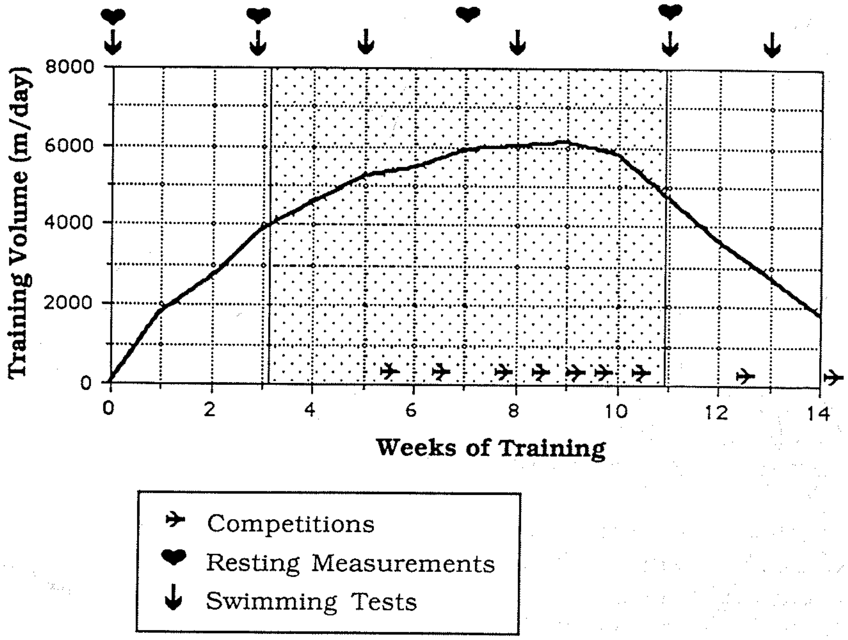

Figure 1—Experimental design and daily swim training volume over the period of this investigation. The rectangular shaded area represents the period of resistance training.

each subject's strength training record was closely monitored throughout the resistance training period.

Resting measurements. Testing was conducted in the morning for resting measurements and in the afternoon for swimming tests. Resting measurements were obtained during weeks 0, 3, 7, 11, and 13 of the competitive swimming season (Fig. 1). Early in the morning (06:30 h) on the testing day, a blood sample was drawn from an antecubital vein. These resting samples were used to determine total testosterone and serum cortisol concentrations. In consideration of the diurnal changes of cortisol and testosterone, the blood sampling was taken at the same time of day in subsequent testing. Serum cortisol and testosterone were determined by a solid-phase radioimmunoassay using a commercially available test kit (Diagnostic Products Corporation, CA.). All samples from an individual subject were assayed in duplicate in the same assay. Blood samples taken on weeks 0 and 13 were not analyzed for cortisol or testosterone.

In addition to the blood samples, height, weight, and seven-site skinfold measurements were obtained in the morning testing session. All the skinfold measurements were performed by the same investigator over the course of the experimental period. Percent body fat (% fat) and lean body mass (LBM) were subsequently estimated from the skinfold measurements (18).

Swimming tests. In the afternoon of weeks 0, 3, 5, 8, 11, and 13, the swimmers performed the following tests: swim bench strength, swim power, a 22.9-m (25-yard) front crawl sprint, and a standardized 365.8-m (400-yard) front crawl swim (Fig. 1). Every swimming test was always conducted between 15:30 to 17:00 h in consideration of circadian changes in swimming performance.

For the biokinetic swim bench testing (Biokinetic, Inc., Albany, CA), velocities were set at 3, 6, and 9. The mean velocities at these settings correspond to approximately 2.05, 2.66, and 3.28 $m \cdot s^{-1}$, respectively (21). The best value, out of three trials at each velocity setting, for the double arm pull were averaged and used in analysis. After completing the swim bench power test, swimmers performed a 365.8-m (400-yard) warm-up swim. Swimming power during a tethered swim was then measured with an isokinetic system (5). In this system the force generated during the swim was converted to an analog voltage output that was then converted to a digital signal. The peak values recorded 2 s after the start were used for analysis. Prior to each testing session both the swim bench and swim power apparatus were carefully calibrated by dropping known weights.

After the tethered swim power test, swimmers performed two sets of a 22.9-m front crawl sprint swim from a push-off start in the water. They were allowed a 3- to 5-min rest period between the two trials. Times for the 22.9-m swim were recorded by two independent observers, and these two values were averaged. The faster value of the two trials was used to represent 22.9-m front crawl sprint time. Next, a standardized 365.8-m front crawl swim was performed at maximal effort (5). During subsequent tests, the subjects swam at the same pace as they achieved during the first maximal effort testing session by following pace lights (Pacer Products, Kankakee, IL) set on the bottom of the swimming pool. During the 365.8-m front crawl swim, time taken for four complete stroke cycles were measured at the 182.9 (200), 274.4 (300), and 365.8 m (400 yard) points. The mean swimming velocity and the time for four strokes were used for determination of the stroke rates (7,8). Distance per stroke was determined from velocity divided by the stroke rate. This parameter was used to monitor changes in stroke mechanics over the season. Within 1 min following the 365.8-m swim, a blood sample was obtained from a hyperemerized earlobe for the determination of blood lactate concentration. Subsequently, the lactate was analyzed enzymatically from perchloric acid extracts.

Statistical analysis. Test data for the two groups were analyzed with a two-way analysis of variance with repeated measures. When a significant interaction was attained, Tukey's *post-hoc* test was used to identify significant differences among mean values. The level of statistical significance was set at $P < 0.05$ in all comparisons. Descriptive statistics are expressed as means ± SE.

RESULTS

Resting measurements. As shown in Table 1, prior to resistance training there were no significant differences between the groups in any anthropometric measures. The 8 wk of resistance training did not result in a significant change in body weight or LBM throughout the course of this investigation. The changes in LBM during the resistance training period (from week 3 to week 11) were 67.42 ± 1.69 to 68.72 ± 1.49 kg in COMBO and 68.24 ± 1.84 to 67.94 ± 1.71 kg in SWIM. Percent body fat, estimated from skinfold measurements, declined significantly ($P < 0.05$) at weeks 7 and 11 in both groups. However, there was no significant difference between the COMBO and SWIM groups.

Mean blood testosterone concentrations were not significantly altered during the period of resistance training in either group (Table 2). The changes in testosterone were 22.3 ± 2.0 to 19.7 ± 1.3 $nmol \cdot l^{-1}$ in COMBO and 20.2 ± 1.3 to 21.6 ± 1.0 $nmol \cdot l^{-1}$ in SWIM. Serum cortisol decreased from 469.6 ± 20.3 to 425.3 ± 21.3 $nmol \cdot l^{-1}$ in the COMBO group ($P > 0.05$). Cortisol concentrations in the SWIM group, however, increased in the middle and decreased at the end

TABLE 2. Changes in total testosterone, cortisol, and the ratio of testosterone and cortisol over the resistance training period.

Hormones	Group	Resistance Training Period Start (Week 3)	 Middle (Week 7)	 End (Week 11)
Testosterone (nmol·l^{-1})	COMBO	22.3 ± 2.0	19.5 ± 1.5	19.7 ± 1.3
	SWIM	20.2 ± 1.3	20.4 ± 1.2	21.6 ± 1.0
Cortisol (nmol·l^{-1})	COMBO	469.6 ± 20.3	442.7 ± 38.4*	425.3 ± 21.3
	SWIM	501.1 ± 45.1	543.2 ± 27.2	486.7 ± 44.4
Ratio	COMBO	0.0481 ± 0.0042	0.0501 ± 0.0080	0.0472 ± 0.0033
	SWIM	0.0470 ± 0.0082	0.0391 ± 0.0038	0.0489 ± 0.0050

All values are expressed as mean ± SE.
* Significantly different ($P < 0.05$) from SWIM.

of strength training. These changes were not statistically significant ($P > 0.05$). In the middle of the resistance training period (week 7), there was a significant difference ($P < 0.05$) in cortisol concentrations between the groups, with the swimmers in COMBO being lower. The ratio of testosterone to cortisol did not change throughout the resistance training period. No significant differences in the ratio of testosterone to cortisol were detected between the groups.

It is important to note that the swimmers in the COMBO group increased the resistance used during strength training by 31.0 ± 4.0%.

Swimming tests. Figure 2 shows the seasonal changes in the mean biokinetic swim bench strength obtained at settings of 3, 6, and 9. At the start of the swim season, the mean swim bench strength values were 196.10 ± 8.62 and 198.01 ± 6.42 W in COMBO and in SWIM, respectively. Similar percent changes in mean strength on the biokinetic swim bench were observed in both groups. The strength values tended to increase toward the end of the swimming season. Compared with the start of the swim season, a significant increase ($P < 0.05$) in swim bench strength was found at weeks 11 and 13. However, there was no significant difference between the two groups. In this investigation, a significant correlation between performance time and swim bench strength was not detected.

Percent changes in mean swim power during a tethered swim are presented in Figure 3. At the start of the swim season the mean swim power values in the COMBO and SWIM group were 110.94 ± 6.72 and 101.66 ± 4.17 W, respectively. As noted in Figure 3, swim power increased significantly ($P < 0.05$) following the tapering period (from week 8 to 13) in both groups. No significant differences in swim power were found between the groups throughout the course of this investigation.

At week 1 mean values for sprint swimming velocity, measured in the 22.9-m front crawl swim, were 11.01 ± 0.15 and 11.34 ± 0.23 s in the COMBO and SWIM group, respectively. Mean values for sprinting performance tended to decrease from the beginning of the season in both groups ($P > 0.05$). Throughout the swim training period, the sprinting velocity was always slower

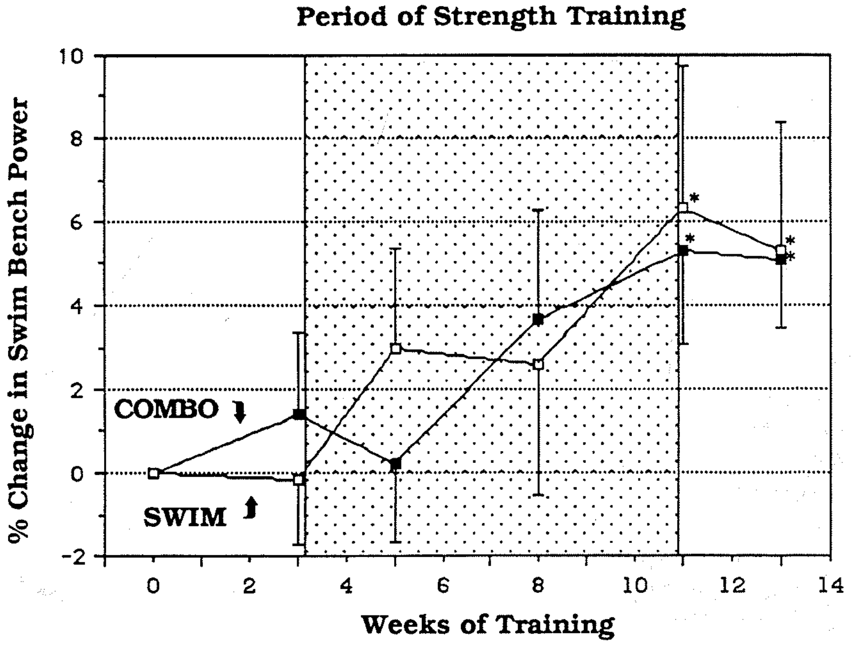

Figure 2—Percent change in mean (±SE) values for the biokinetic swim bench strength during the course of the 13-wk experimental period. * denotes a significant difference ($P < 0.05$) from pretraining values (week 0 and 3).

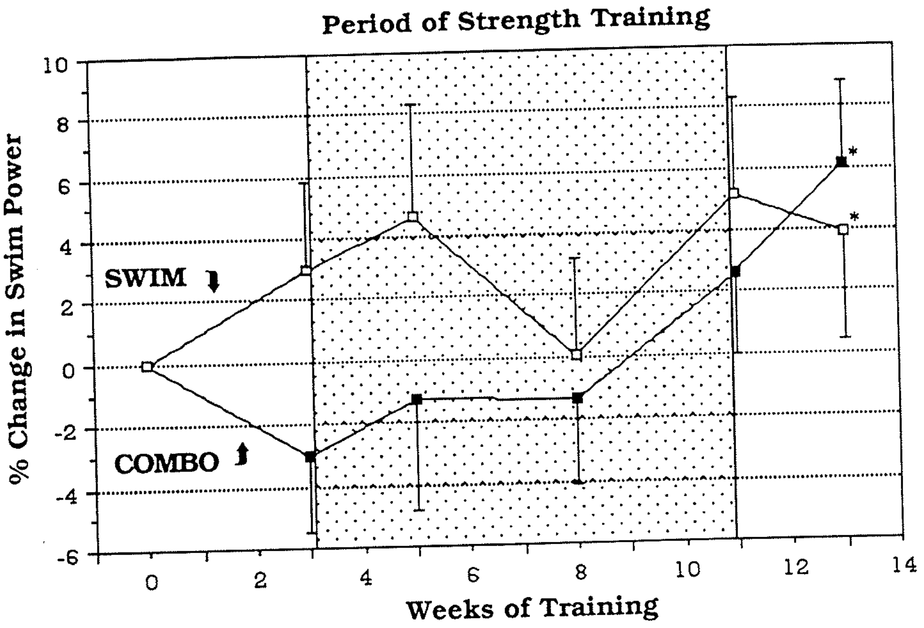

Figure 3—Percent change in mean (±SE) values for swim power recorded during a tethered swim over the period of this investigation. * denotes a significant difference ($P < 0.05$) from week 8.

than the pretraining values obtained at week 1 (Fig. 4). No significant differences in sprint swimming velocity were found between the two groups.

In an attempt to examine the effects of resistance training on stroke mechanics, the distance per stroke was recorded at three points (182.9, 274.4, and 365.8 m) in the standardized 365.8-m front crawl swim. The training-associated change at the three points are averaged and shown in Figure 5. As evidenced in the figure, both groups showed similar responses in distance per stroke. Following the tapering period, both groups showed a tendency to increase the average distance per stroke ($P > 0.05$). Between the 182.9-m and the 365.8-m points, a significant decline ($P < 0.05$) in the distance per stroke was noted for both groups (data not shown). This decrease in the distance per stroke was compensated for by increasing the stroke rate so that swimming velocity was kept constant throughout the course of this investigation.

Mean blood lactate concentrations showed a similar pattern of change for both groups over the course of this investigation (Fig. 6). Both groups experienced steady and significant declines ($P < 0.05$) in blood lactate values from week 0 to week 13 during the standardized 365.8-m swim. The mean blood lactate values in the COMBO group were 14.38 ± 0.80 $\text{mmol}\cdot\text{l}^{-1}$ at the start of the season compared with 11.81 ± 0.74 $\text{mmol}\cdot\text{l}^{-1}$ at the end. Corresponding mean blood lactate values in the SWIM group were 11.93 ± 0.62 and 9.51 ± 0.68 $\text{mmol}\cdot\text{l}^{-1}$, respectively. There were

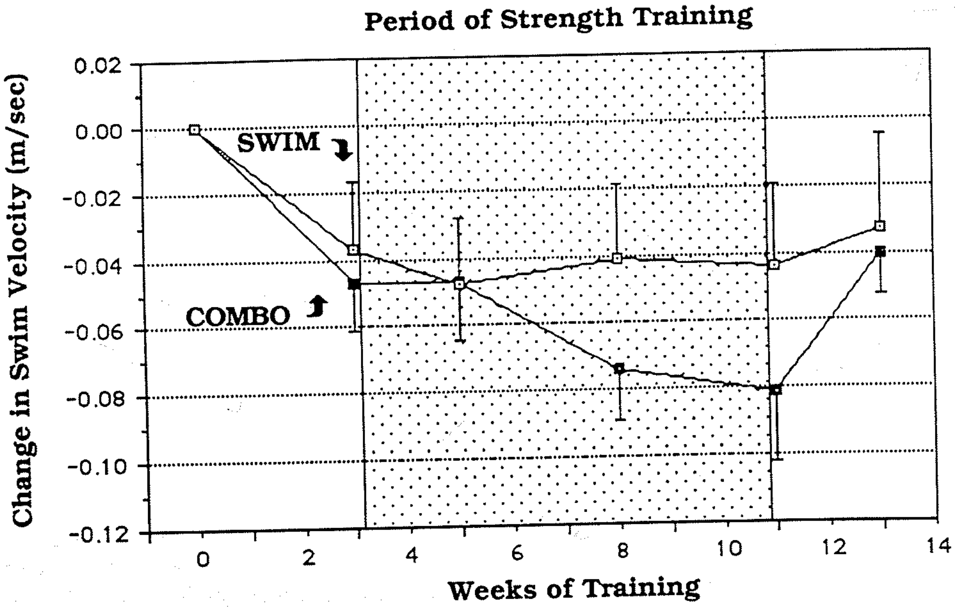

Figure 4—Change in mean (±SE) swim velocity recorded in 22.9-m front crawl sprint swim over the course of the 13-wk experimental period.

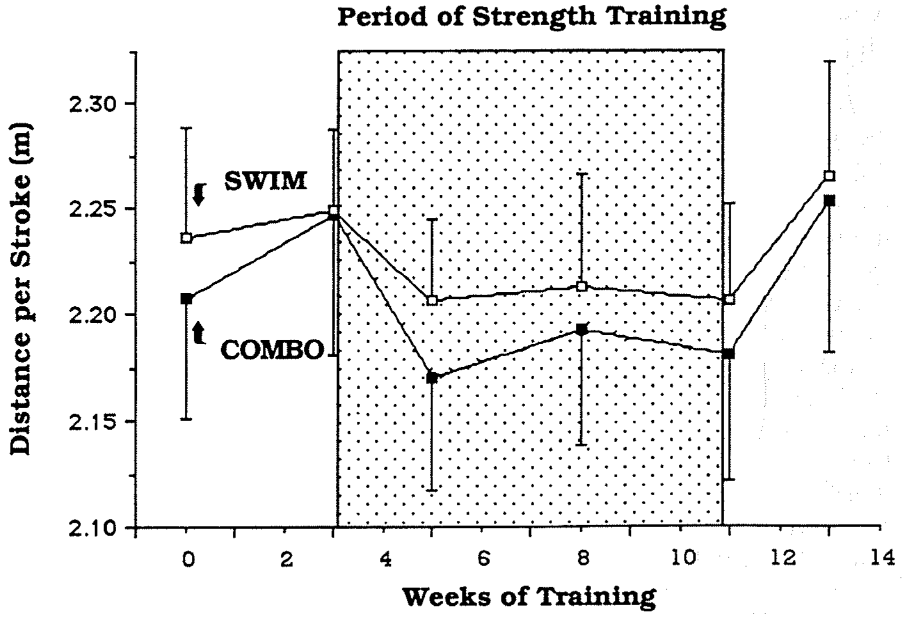

Figure 5—Change in mean (±SE) distance per stroke during the course of the 13-wk experimental period.

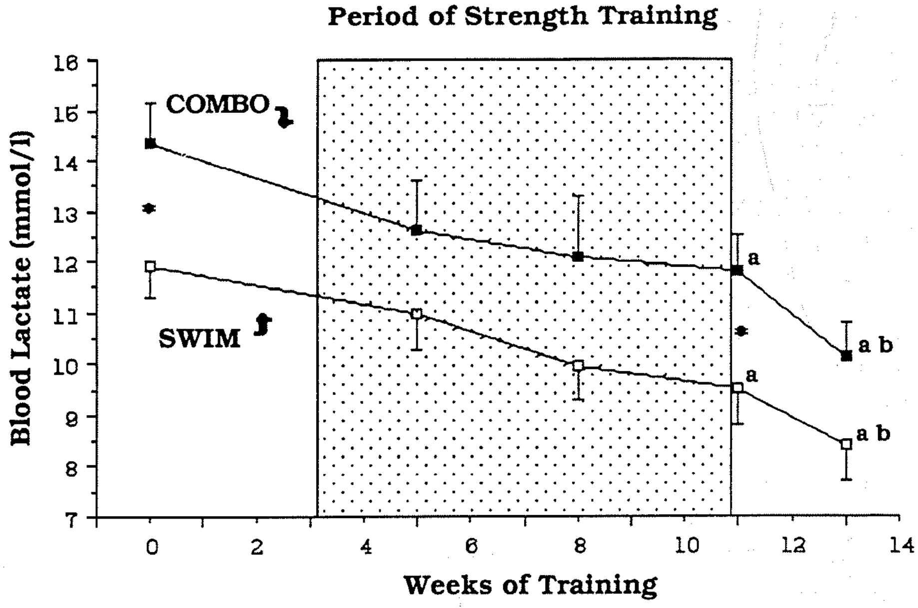

Figure 6—Change in mean (±SE) blood lactate concentrations during the course of the 13-wk experimental period. * denotes a significant difference ($P < 0.05$) between the groups. "a" denotes a significant difference ($P < 0.05$) from week 0. "b" denotes a significant difference ($P < 0.05$) from week 3.

significant differences ($P < 0.05$) in mean blood lactate values at weeks 0 and 11 between the two groups.

DISCUSSION

The primary findings of the present study differ from those of previous studies (3,9,15,21), which reported beneficial effects of dry-land resistance training. However, insufficient information and the lack of a control group in these previous studies (3,9,15,21) make their interpretation difficult. Conversely, the present study is in agreement with better controlled studies (13,17,22). Although Thompson and Stull (22) reported a significant improvement in swimming performance as a result of concurrent swim and resistance training, the swim training group increased performance more than the combined group, and there was no significant difference between the groups. These results are supported by Jensen (13), who reported that different combinations of swim training and weight training improved swim performance on the 100-yard swim. In his study, however, swim training or weight training alone also caused significant improvements in swimming performance, and no significant differences were observed among these groups. These previous studies along with the present study suggest that dry-land resistance training does not benefit swimming performance.

Dry-land resistance training is intended to overload the muscles used in swimming and to increase maximal power outputs. Resistance training similar to that currently used is known to produce an increase in phosphagen stores, an increase in contractile proteins in exercising muscle, selective hypertrophy of fast twitch fibers, and an increase in anaerobic power output (19). It is reasonable to assume that these adaptations may improve sprint swim performance. In addition, it is important to keep in mind that swimmers in COMBO were able to increase the resistance used during resistance training by 31.0 ± 4.0%. However, resistance training did not produce an improvement in swim performance in this investigation.

The principle of specificity of resistance training states that the training should be specific to the event to produce optimal gains in performance. Based upon the high correlation reported between upper body strength/power and sprint swim performance (5,10,14,21,23), the resistance training regimen used in the present study was designed to improve upper body strength. The major reliance on the upper body in swimming has been supported by muscle recruitment patterns measured by EMG (2) and enzymatic adaptations (12). In addition, a gain in muscle mass in the legs may elevate body density, thereby causing negative effects on swim performance. Preliminary study conducted in our laboratory showed that overall resistance training did not contribute to swim performance. For these reasons, no resistance training for lower body was performed in this study. However, it should be noted that the crawl flutter kick is an important element to faster swimming, and the leg is of primary use in turning. Moreover, in a recent review on the EMG in swimming (2), Clarys argues that trunk muscles such as gluteus maximus may have a more important activity than the upper arm muscles.

The most prevalent dry-land training device for swimming is the biokinetic swim bench. Costill et al. (3) reported that following resistance training on the biokinetic swim bench, swimmers increased their power output by 28% with a concomitant improvement in sprinting performance of 3.6% (3). In their study, however, a small number of subjects were used, and swim training was discontinued during the resistance training period. In addition, the specificity of the swim bench has been controversial (2,20). On the swim bench, the legs and trunk are inactive, and shoulder does not roll as it does in the free swimming. EMG evidence suggests that the time course, amplitude, and frequencies of muscles employed on the bench may be different from that in swimming (2). Schleihauf (20) reported a biomechanical drawback for specificity of swim testing. On the bench, the pulling path traveled by the hand is longer. The distribution of pulling force at various joint angles were not similar for swim bench exercise and swimming. In addition, the three-dimensional movement pattern in the water cannot be reproduced on the swim bench (20). In this investigation, no significant correlation was found between swim bench strength and swim performance.

Swimming is a highly specific sport, and reproduction of complex swimming movements is difficult on land as suggested by biomechanical studies (2,20). Moreover, the velocity of muscle contraction used in the weight room is well below those in the water. Recently, Bulgakova et al. (1) reported that although a dry-land resistance training group produced greater increases in swim power and pulling force, an in-water resistance training group recorded larger increases in sprint swim performance. Neufer et al. (16) reported that 10 d of reduced swim training induced a significant decline in swim power in water whereas swim bench strength on land was maintained. These results imply a lack of specificity when resistance training was performed on land. Recently, Toussaint and Vervoorn (23) investigated the effects of a more specific resistance training device on the MAD system (system to Measure Active Drag). The resistance training group significantly increased swim performance by 3.4% accompanied with a significant increase in swim power output of 7%. In the present study, the strength gained on land did not transfer to propulsive force used in the water despite the fact that the resistance training was intended to simulate arm actions and muscle actions similar to those used during front crawl swimming. Thus, it seems to be that a resistance training effect may not appear unless highly specific training is prescribed for swimmers.

It is interesting to note that the mean values for sprinting velocities were always slower than the pretraining values obtained at week 1. This is in line with Costill et al. (6). It appears from Figure 4 that swim velocity might have continued to slow in the COMBO group if resistance training had continued. Although statistical significance was not reached, certain training responses that have practical applications are evident. During a heavy period of swim training, muscular power and sprint front crawl swim performance are known to be depressed (6). Previous research (11) has shown that concurrent resistance and endurance training caused similar increases in endurance capacity compared with the endurance-only trained group, but a reduced improvement in strength when compared with the resistance-only trained group. Therefore, it is possible that the heavy demand of both swim and resistance training in COMBO may have caused a local muscular fatigue and inhibited the development of swim power and performance resulting from dry-land resistance training. However, swimmers in COMBO increased the resistance used in resistance training as well as swim bench strength. In addition, serum cortisol concentrations, one of the indicators for overwork, did not change during the swim season. Therefore, we are inclined to think that overwork is not a mechanism behind the lack of beneficial effects from the resistance training.

The primary stroke investigated in this investigation was the front crawl stroke. It can be expected that the results would have been different if the swimmers had been composed entirely of front crawl specialists. However, a separate analysis performed with four front crawl specialists from each group supported the present results obtained from the entire swimmers.

Complex mechanics in swimming may be responsible for enhancing swimming performance (4,7,8). Craig et al. (8) showed that improved swimming performance over the period from 1976–1984 was attributed to greater distance per stroke. Costill et al. (5) has reported that the single best predictor of 365.8-m front crawl swim performance in collegiate swimmers was the distance per stroke (r = 0.88). Resistance training may increase power outputs but also may alter stroke mechanics. A greater distance per stroke can be achieved by strengthening the muscular force of the upper body since distance per stroke depends upon propulsive lift and drag force. However, no modulation in distance per stroke nor swim sprint performance was found in either group. It is concluded that muscular strength gained in resistance training did not transfer to propulsive force needed for a greater distance per stroke.

In conclusion, the major finding of this investigation was that dry-land resistance training did not improve swimming performance in male collegiate swimmers despite the fact that the combined swim and resistance training group was able to increase the resistance used during resistance training by 25–35%. These results imply that muscular strength was improved by resistance training, but did not transfer to improved swimming performance. The lack of positive transfer between dry-land strength gains and swimming propulsive force may be due to the specificity of training. The results of this study indicate that competitive swimmers did not experience performance benefit from dry-land resistance training in conjunction with swim training.

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