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Effectiveness of Biokinetic Training on Swimming Performance in Collegiate Swimmers

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Abstract

Resistance training is often recommended to competitive swimmers. Studies have demonstrated a relationship between stroke mechanics, biokinetic power and endurance, anaerobic power, and swimming performance. The purpose of the present study was to determine the effect of adding biokinetic resistance training to high velocity swim training in collegiate swimmers. Freestyle swimmers (n = 16) were randomly divided into swim only and swim plus biokinetic resistance training groups. The data from both groups indicated that maximal work (at 0 resistance) and endurance improved on the biokinetic swim bench (about 50%). Maximal isokinetic shoulder flexion increased (about 25%), maximal distance per stroke increased (about 20%, Control group only), and competitive times (100 yds) decreased (3.5 sec). There were no improvements in anaerobic power, isokinetic shoulder flexion, maximal velocity, or stroke frequency. The improvements in the two groups were not significantly different from each other. Based on these data, in-season biokinetic resistance training did not add to the improvement obtained from high velocity swim training alone. High velocity swim training would appear to be sufficient to improve performance.

Introduction

Maximal swimming speed is, in part, determined by the capability of the swimmer to develop propulsive forces to overcome water resistance. The propulsive force is determined by the force the muscles involved in swimming can generate and the effective application of this force through stroke mechanics. In previous studies, the maximial distance per stroke, distance per stroke at maximal speed, and maximal stroke frequency have been related to maximal speed and performance time (7,8,15). The maximal distance per stroke could be influenced by muscular strength, while the maximal stroke frequency could be influenced by muscular speed and power.

Previous studies have suggested strong relationships between arm muscle power, determined on a biokinetic swim bench, and sprint freestyle swimming performance (3-5,13,14,22). It was also shown that swimmers with a higher optimal speed during the biokinetic testing had greater swimming speed (23). Another study reported that there was no relationship between swimming performance and isokinetic strength, power, or endurance of shoulder, elbow, wrist, hip, knee, or ankle (16), while biokinetic power has been demonstrated to be related (19,22). In another study of elite freestyle swimmers, there was no relationship between power measured biokinetically and swimming performance (18,22). A summary of these data would imply that lower power (biokinetic) values relate to swimming performance, while once power exceeds a critical value, it is no longer related to performance.

We are unaware of data relating biokinetic muscle function to stroke mechanics; however, isokinetic data for arm or leg muscle function appear not to be related to stroke mechanics (16). It should be noted that the speed of contractions and the paths of movement were different in the biokinetic and the isokinetic studies.

These studies raise the question if resistance training,

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particularly on the biokinetic swim bench, would improve swimming performance. Resistance training is routine in swim training and increased muscle mass has been suggested as important in recent practical swimming journals (18). Other studies (15) have suggested that increased body density may increase the energy cost of swimming. It has been reported, in a small group of detrained swimmers, that biokinetic resistance training increased muscle power by about 20% and performance by 4%. Controlled studies where larger groups of resistance trained swimmers were compared to non-resistance trained swimmers are not available.

The present study evaluated the effectiveness of high velocity resistance training on a biokinetic swim bench on the stroke mechanics; biokinetic power; isokinetic strength, power, and endurance; anaerobic power; swimming speed; and performance (100, 200 and 400 m freestyle) of collegiate swimmers.

Methods

The 16 subjects were members of a men's university Division II swimming team that was ranked nationally in the top ten at the time of the study. All swimmers completed a medical history and were given a physical examination, then signed an informed consent form which followed the guidelines of the American College of Sports Medicine. The subjects averaged 19.1 ± 2.1 years of age, 183.1 ± 7.6 cm in height, 75.67 ± 10.06 kg in weight, $12.1 \pm 2.3\%$ body fat (underwater densiometry), and 3.85 ± 0.02 $l \cdot min^{-1}$ peak $\dot{V}O_2$ while swimming.

The swimmers competed in sprint and/or middle distance freestyle events and were randomly divided into Control and biokinetic resistance training groups (Experimental). This study was conducted in the first half (10 weeks) of the competitive season. All swimmers participated in the normal swim training, the results of which were previously published (5).

Measurements

Weight; percent body fat; biokinetic and isokinetic muscle function; anaerobic power; stroke frequency and velocity relationship; competitive times during meets; and the times and post-swim venous blood lactic acid for a 100 yard (91.44 m) "mock meet" were determined prior to and after the 10 week experiment. Body weight was determined on an electronic scale. The percentage of body fat was determined by underwater densiometry (9). Underwater weight was measured on a LVDT strain gauge which was calibrated prior to each determination.

Stroke Frequency

Methods previously described were used in this study (7,8,16). Swimmers swam at a constant stroke frequency over a 10 meter section after pushing off from the wall. The swimmers started at their minimal stroke frequency and progressed to their maximal in small increments (5 $strokes \cdot min^{-1}$). The time required to cover a specific number of strokes was measured with a stroke watch. Two to three minutes was allowed between swims.

Biokinetic

Methods similar to those previously published were used in this study (23). The swimmers were strapped to a biokinetic swim bench (Biokinetics Inc.) and allowed three practice pulls before they were tested. The best of three trials at speed settings of 0, 3, 6, and 9 were used for analysis. After five minutes of rest, a 45 second continuous test was performed at a setting of 0. The subjects pulled at their maximal frequency (speed). The work performed during each five second period was recorded.

Isokinetic

Isokinetic torque, work, and power were determined using a Cybex II and upper body extension table with a CDRC computer to record the data. The Cybex was calibrated prior to each testing. Shoulder flexion and extension were determined at speeds of 60 (strength), 180 (power), and 240 (endurance) $degrees \cdot sec^{-1}$ in accordance with Cybex testing procedures (Cybex manual, Lumex, Inc., Ronkonkoma, New York).

Anaerobic Power

The Wingate Anaerobic Power test was used as previously described (1). In practice, the swimmers arm cranked a mechanical brake ergometer placed on a table at shoulder height. Swimmers were allowed to use both arm and shoulders. The frequencies at five second intervals for 30 seconds were recorded and multiplied by the resistance to calculate power.

"Mock Meet"

A mock swimming competition was held for the 100 yard (91.44 m) freestyle. Swimmers were randomly assigned to participate in one of four heats, with four swimmers in each heat. The swims were conducted as a meet and the times determined electronically.

Competitive Time

The swimmers swam in two dual meets part way through the training (4-6 weeks) and one Invitational meet at the end of the training. Swimmers were electronically timed and were rested and shaved for the last meet. The Invitational meet times from this year were compared to the Invitational times from the previous year for those swimmers who competed in both meets.

Training

The normal swim training was followed by all swimmers (10). The swimmers trained for a single session three times per week and double sessions three times per week. The yardage was 5,500 and 9,000 for the single and double sessions, respectively. The interval training was carried out at splits that were 90%, 95%, 100%, 110%, and 120% of the peak speed (determined during pre-season testing) for distances of 1000, 500, 200, 100 and 50 yards, respectively, as determined from the stroke frequency analysis.

The biokinetic resistance training was carried out three times per week by the Experimental group. The shape of the pull simulated the freestyle, maintaining the stroke frequency where maximal velocity was observed during the stroke frequency analysis. All swimmers started at a setting of 7 on the swim bench. The subjects pulled for ten seconds and rested for ten seconds, for four repetitions. After a 30 second rest, this protocol was repeated for three more cycles. As the subject became adapted to the training, the biokinetic setting was reduced (increased resistance) as rapidly as possible, while insuring that the appropriate stroke frequency was maintained. During the period of resistance training, the settings on the swim bench were significantly reduced from the starting value of 7 to 3.0±0.8.

Data Analysis

Means ± standard deviations were calculated for all variables. The data for each variable between the two groups were compared by a multiple variance analysis of variance. The data within a group prior to and after the training were analyzed by a multi-variate analysis of variance for repeated measures. After both analyses, a Fisher Post-Hoc test was run to determine where differences in the data matrix were found. The 0.05 level of significance was used to interpret all analyses.

Results

There were no significant differences in the pre-training values for all biokinetic, isokinetic, and anaerobic power parameters between the two groups. There were no significant differences in the stroke frequency analysis between the two groups. Based on this analysis, the pre data (with the exception of stroke frequency) has been combined for graphic presentation.

Muscle Function

Over the period of this study, the subject's body weight, or percent body fat, did not change significantly. The work (W) performed as a function of swim bench speed settings are presented in Figure 1. The pre data for the two groups were not different from each other. There was a significant increase in work at a setting of 0 in all groups. The values for the Control and Experimental groups were not significantly different from each other. The post work values for settings of

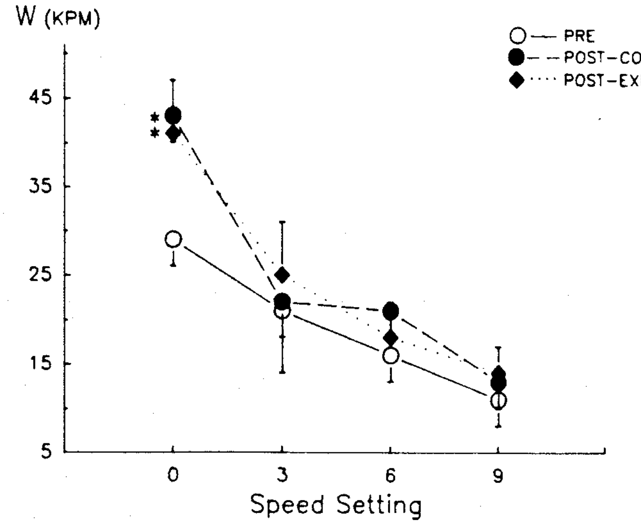

Figure 1. Mean ± for peak work achieved at biokinetic swim bench settings of 0, 3, 6, and 9. The values are for the combined pre and the post tests for both groups. The * indicates significantly different from the Control values.

3, 6, and 9 were not significantly greater than the pre values for either group.

The work on the swim bench at a setting of 0 is plotted as a function of time in Figure 2. The work decreased as a function of time in both groups. There was a significant increase in work at all times when the post data were compared to the pre data. The post values for the two groups at all times were not different from each other. The magnitude of the increase in work was greater at five seconds (60%) than it was after 45 seconds (45%) of sustained exercise.

Isokinetic torque for shoulder flexion at the three speeds were not significantly different between the two

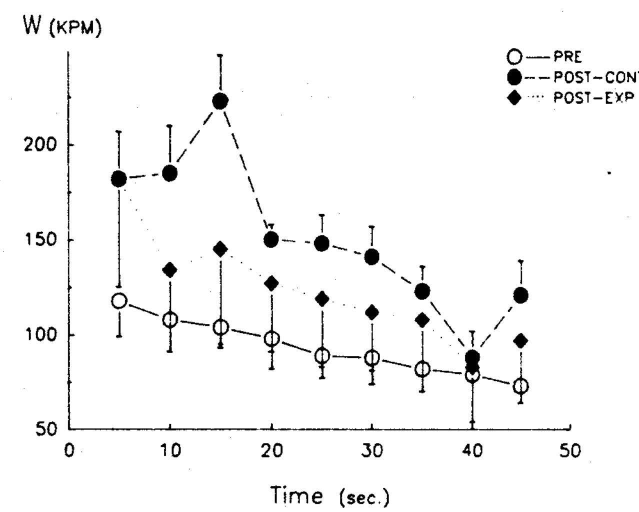

Figure 2. Mean ± SD for work performed on the biokinetic swim bench at a setting of 0 accomplished at five second intervals during a 45 second endurance test. The values are for the combined pre and the post tests for both groups. The post values of the two groups are significantly elevated over the pre values; however, they are not different from each other.

groups prior to or after the experiment. The average values increased significantly from 57 ± 12 ft·lbs to 72 ± 21 ft·lbs, 55 ± 11 ft·lbs to 63 ± 13 ft·lbs, and 53 ± 12 ft·lbs to 61 ± 10 ft·lbs for speeds of 60, 180, and 240 degrees·sec^{-1}, respectively. The values for shoulder extension work did not increase in either group. The pre values were 1011 ± 361 ft·lbs, 1894 ± 595 ft·lbs, and 1716 ± 629 ft·lbs for 60, 180, and 240 degrees·sec^{-1}, respectively. The average power for the two groups did not increase significantly. The pre values were 60 ± 23 watts, 122 ± 39 watts, and 136 ± 49 watts for speeds of 60, 180, and 240 degrees·sec^{-1}, respectively. There were no significant differences in isokinetic shoulder flexion between the two groups, prior to or after the experiment. The average pre values for torque were 73 ± 13 ft·lbs, *64 ± 11 ft·lbs, and 60* ± 11 ft·lbs; for work 1190 ± 490 ft·lbs, 2122 ± 744 ft·lbs, and 1791 ± 766 ft·lbs; and for power 77 ± 29 watts, 144 ± 56 watts, and 155 ± 67 watts for speeds of 60, 180, and 240 degrees·sec^{-1}, respectively.

In summary, there was a similar increase in strength for isokinetic shoulder extension at the fastest speed (240 degrees·sec^{-1}) for both groups. The fatigue test on the swim bench revealed increases that were similar between the two groups. The other measures of strength, power, or endurance did not increase significantly in either group. From these data, it would appear that the addition of resistance training, emphasizing high velocity, did not improve muscle function any more than high velocity swim training alone.

Stroke Frequency Analysis

The data for the stroke frequency analysis for the two groups are presented in Table 1. The data at the speed where maximal distance per stroke was observed revealed that the stroke frequency decreased significantly after swim training in the Control group. However, it did not change significantly in the Experimental group. The distance per stroke at this speed increased significantly in the Control group. However, it did not change significantly in the Experimental group. Although there was a tendency for a decreased velocity to be achieved at the maximal distance per stroke, the differences were not significant.

There were no statistically significant differences between the stroke frequency, distance per stroke at maximal velocity, or maximal velocity prior to or after the intervention in the Control or Experimental group.

In summary, high velocity swim training alone resulted in improvements in the distance per stroke. However, when biokinetic resistance training was added to high velocity swim training, there were no significant improvements for the values prior to training.

Table 1

Mean ± SD values from the stroke frequency analysis. The data for stroke frequency, velocity, and distance per stroke are given at the maximal distance per stroke and at maximal velocity. The data are shown for the Control and Experimental groups prior to and after the training program.

Group	At Maximal Distance/Stroke			At Maximal Velocity		
	S	V	D/S	S	V	D/S
Control						
Pre	24.4	1.15	2.86	62.6	1.83	1.77
	3.6	0.12	0.29	4.6	0.04	0.14
Post	19.4*	1.09	3.40*	61.0	1.81	1.79
	1.8	0.10	0.22	3.9	0.04	0.12
Experimental						
Pre	23.7	1.14	3.05	60.3	1.76	1.87
	3.5	0.12	0.56	5.2	0.08	0.37
Post	21.5	1.11	3.2	58.3	1.81	1.9
	4.9	0.12	0.55	8.2	0.06	0.31

Metabolic

Maximal anaerobic power (W) is plotted as a function of time in Figure 3. The values for the two groups were not significantly different from each other prior to or after the experiment. In fact, there were no significant improvements in either group as a result of the experiment. The peak lactic acid values determined after an all-out swim were systematically lower after the experiment in the Control and Experimental groups (14 ± mM to 11 ± 2 mM and 12 ± 4 mM to 11 ± mM, respectively). There were no significantly effects of swim training alone or when it was coupled with biokinetic

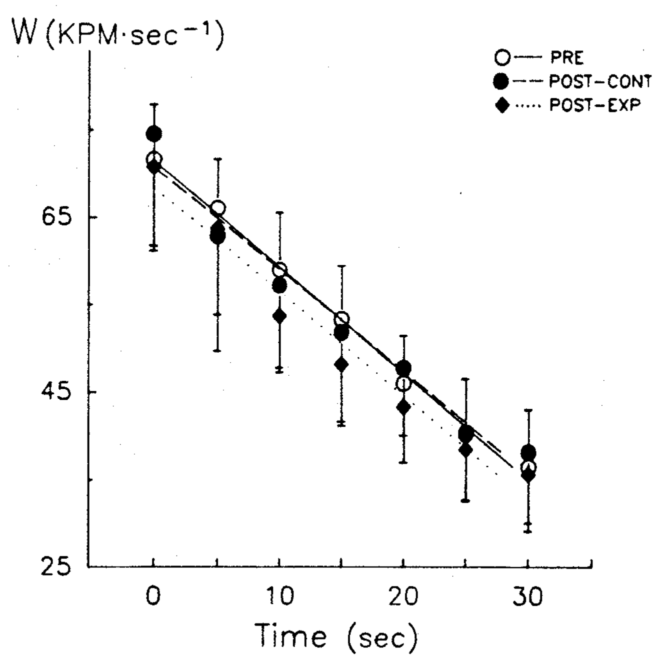

Figure 3. Mean ± SD for maximal power output for arm cranking at five second intervals during a 30 second test. The values are for the combined pre and the post tests for both groups. There were no significant differences at any time interval, pre to post, between the two groups.

resistance training on the anaerobic power of these swimmers.

Performance

The effects of swim training and biokinetic resistance training added to swim training on performance were evaluated by a "mock meet" and by a comparison of the times from competitive meets during the season. The "mock meet" was conducted as a 100 yard (91.44 m) swim with the freestyle. The summary data appear in Figure 4. There was a significant reduction in the time of the event in both groups. The average speed for the distance increased from 93% to 99% and 92% to 97% of the peak speed (stroke analysis) in the Control and Experimental groups, respectively. The stroke frequency for the first 50 yards and the second 50 yards were not significantly lower in either group.

Competitive times were used to examine the relative improvement in performance of biokinetic resistance training and swim training, as compared to swim training alone. The times from two dual meets and an Invitational meet this season were compared to values for the same distances from the previous season. These values for the Control group were not significantly lower than the same values for the Experimental group. The values were 2.7±0.8% and 2.3±0.7% for the dual meets and 1.6±0.1% and 1.6±0.1% for the Invitational for the Control and Experimental groups, respectively.

Discussion

Swimming performance is, to a degree, dependent upon natural ability. However, optimal swim training maximizes the use of natural ability and is, therefore, of critical concern to coaches. Furthermore, due to the importance of the relationship between technical ability and metabolic power in swimming (15), incorrect training can reduce performance (3,4,6).

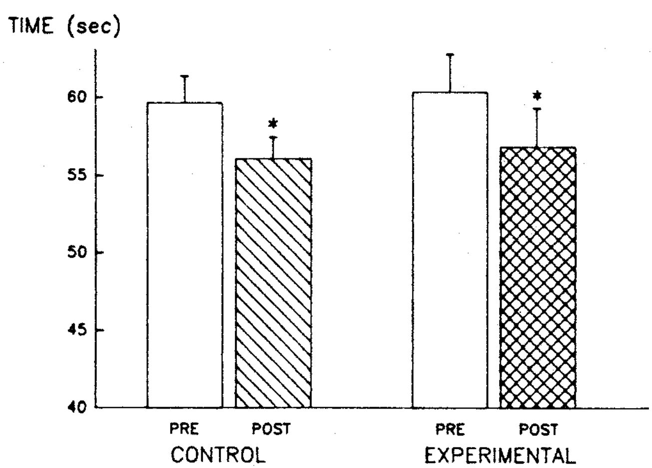

Figure 4. Mean ± SD for competitive times to complete a 100 yard (91.44 m) freestyle, for pre and post training "mock meets". The post times were significantly less (*) than the pre times for both groups. The pre and post times were not different between the two groups.

Recent trends in swim training have emphasized high intensity training (3,4,19,20,21) to improve performance and reduce fatigue (6). Other studies have demonstrated a strong relationship between stroke frequency, velocity relationships, and competitive swimming performance (2,7,8). A recent popular paper has suggested utilizing stroke frequency in training (13). In a previous study, we demonstrated that high velocity swimming, controlling stroke frequency, resulted in significant improvements in $\dot{V}O_2max$, distance covered per stroke, stroke frequency at maximal speed, maximal speed, and competitie performance (10).

Various forms of weight training have been recommended for swim training without adequate scientific support (12,22). A recent paper in a practical journal has suggested that increased muscle mass is an important factor to swimmers (18). However, a previous report has suggested that increased muscle mass may increase the energy cost of swimming (15). Maximal isokinetic strength, power, and endurance do not relate to $\dot{V}O_2max$, distance traveled per stroke, or competitive performance (16). Other studies using biokinetic analysis on a swim bench have demonstrated strong correlations between swimming performance, biokinetic power, and work; however, this relationship does not appear to hold true for elite swimmers with high power (18,22). These correlations do not demonstrate a causal relationship between muscle performance and competitive performance. In a training study using four non-competitive swimmers, it has been shown that biokinetic training improved biokinetic power and work by 20% and swimming speed by 3%. It is difficult to transfer these data to highly competitive swimmers. However, the absence of a relationship between power and performance in this group may suggest that resistance training may not be beneficial (18,22,23).

The present study was designed to determine the effects of a previously developed high velocity swim training program on the isokinetic and biokinetic strength, endurance, and power, as well as on anaerobic power and competitive times. The primary purpose of this study, however, was to determine if the addition of biokinetic resistance training to the high velocity swim training improved the dependent variables. This study was unique, as all freestylers from an elite swimming team were randomly assigned to a swim only group and a swim plus biokinetic resistance training group. The study was conducted in the first half of the season, as participation did not risk the final tournament performance. However, there was an important Invitational meet at the end of the first half of the season. Data from the previous year, when no strength training was performed (10), was available for most of the swimmers. The results of this study clearly indicate that the addition of biokinetic resistance training to high velocity swim training did not significantly improve isokinetic strength, power, or endurance; biokinetic power or work; anaerobic power; distance per stroke; maximal speed; or competitive performance when compared to swim training alone. It is interesting to note that the competitive performance of the Experimental group was not statistically different from the Control group or their performance the previous year. The Control swimmers swam 0.57 ± 0.65 seconds faster than in their previous dual meet performances, while the Experimental swimmers swam 1.46 ± 0.75 seconds slower at the same meet (during resistance training). All groups improved similarly during the mid-season Invitational meet, which was after the taper from the resistance training. This suggests that biokinetic resistance training did not facilitate performance in the rested states. These data would suggest that biokinetic resistance training, perhaps strength training in general, should be avoided during competition in elite swimmers. This may be due to the highly developed power resulting from swim training, as has been previously suggested (22). These data do not necessarily apply to out of season training, training in less accomplished swimmers, or swimmers using low intensity training.

The improvements in the two groups were significant in the maximal distance per stroke, stroke frequency at maximal speed, isokinetic shoulder extension strength, and biokinetic power. There was relatively little improvement in muscle endurance (isokinetic or biokinetic) or isokinetic shoulder flexion. The observation that improvements from the program effected only shoulder extension suggests that this movement is the most important in swimming or simulated swimming in air. The absence of improvement in endurance, coupled with an absence of improvement in anaerobic power, would appear to impede performance. However, performance did improve in both groups of subjects. The post lactic acid values, after the all-out swim during the "mock meet", were lower than the pre values, in spite of the faster times. It can be concluded that the training in the first half of the season was primarily on the biomechanics of the stroke and maximal $\dot{V}O_2$. This conclusion is in agreement with a previous study (10). The training during the second half of the season concentrated more on high stroke turn over, anaerobic power and endurance, and further improvements in performance. This type of training may be important as anaerobic power has been related to swimming performance (17). It was impossible to continue this controlled study into the second half of the season, as times would have been compromised and the success of the team would have been at risk.

This study confirmed that high velocity swim training can improve stroke mechanics, as well as muscle strength. The addition of biokinetic resistance training did not improve the success of the training. Swim training, if high enough in intensity, would appear to be the optimal training method during this phase of swim training.

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