

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

THE RELATIONSHIP OF SPRINT PERFORMANCE TO KINETIC AND  
KINEMATIC VARIABLES DURING RESISTED SWIMMING

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Human Performance

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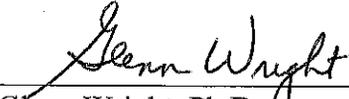
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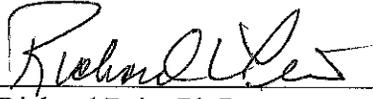
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We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Human Performance

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## ABSTRACT

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Sport-specific resistance training relies on applying resistance to the same motions used in a sport's competition movements. Resisted swimming offers the opportunity to measure training variables used by coaches under an optimal force-velocity relationship. The purpose of this study was to determine the relationship between kinetic and kinematic variables observed during resisted swimming and sprint performance. Three trials were conducted during weeks 1, 6, and 12 (T1, T2, and T3) of the competitive season. During each trial week, a 45.72-m maximal effort freestyle sprint was used as a performance test. Two days later, 22.86-m resisted swim trials were performed against a predetermined resistance while recording and averaging time, stroke count, and stroke rate. A tethered swim test was used to determine peak force, average force, and the fatigue index of a maximal 30-sec maximum swim effort. A product-movement correlation determined the relationships of all variables to performance. The results show that peak and mean force were most strongly correlated to performance across all trials and genders. For coaches and athletes using resisted swimming, taking simple measurements of common training variables may provide some insight into the performance enhancing value of the training program being implemented.

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## INTRODUCTION

The ultimate goal of training in collegiate athletics is to improve performance. In competitive swimming, this means lowering times by swimming faster. In order to produce faster times, swimmers can modify a number of things. Their stroke techniques can be altered to become more efficient. Swimmers can wear the latest swimsuit technology to minimize the drag imposed on the body as it moves through the water. More intuitively, swimmers can adjust their training methods to optimize the body's physiological responses to the intense demands of the sport. Technique modification for already trained athletes can provide limited benefits in performance. Further, low-drag swimsuits present an ethical dilemma in the swimming community and restrictions have been put in place on how efficient a swimsuit can be. Therefore, biological adaptation from training is the ideal primary factor to produce the faster times desired by swimmers and their coaches.

Recently, revelations in training theory have led to a move towards sport-specific resistance training, in which athletes train in their competitive environment at a high intensity under the influence of resistance. Several studies have looked at various factors that are currently utilized in sport-specific resistance training and how these factors may link training variables produced during resistance training to performance (3, 4, 7, 13, 17, 18, 19, 21). Observing these variables during resisted swimming may shed light on the benefits of this training modality for overall improvements in performance. Resisted swimming offers the opportunity to slow a swimmer down to optimize the force-velocity

relationship (20) and to test the kinetic and kinematic variables used by coaches. Therefore the purpose of this study is to observe these variables during resisted swimming and determine their relationship to sprint performance over time.

## **METHODS**

### **Experimental Approach to the Problem**

Tests of mean differences and correlations were used to examine the relationships between sprint freestyle swimming performance and the kinetic and kinematic variables associated with resisted swimming in a NCAA Division III swimming team. Performance time was measured during a 45.72-meter (50-yard) freestyle sprint three times during a 12-week training program beginning the first day of official practice in mid-September, and ending at the end of the semester in December. Assessments were performed on the same day of the week and time of day to assess performance under similar environmental and physiological conditions during weeks 1 (T1), 6 (T2), and 12 (T3). Familiarization trials of swim testing procedures testing procedures were performed one week prior to T1. Four different types of testing were performed: performance testing, resisted swim testing, tethered swim testing, and body composition measurements.

### **Subjects**

A group of 26 men and 30 women of the University of Wisconsin-La Crosse swimming team participated in the study. These swimmers were in a training program designed by the swim coaching staff. It was not the intent of this investigation to modify the normal team training, only to analyze the kinetic and kinematic variables over the course of the first 12 weeks of the season. Men and women were analyzed separately since the objective was not to compare men and women. Table 1 shows anthropometric data for each gender at the beginning of the season.

Table 1. Subject Characteristics.

	Men	Women
Age (yrs)	19.5±1.2	19.0±1.1
Height (m)	1.82±0.07	1.69±0.05
Weight (kg)	77.6±8.2	65.3±7.6
Body Fat %	7.9±3.6	26.9±5.0

Anthropometric values are expressed as mean ± SD.

Approval from the university's Institutional Review Board for the Protection of Human Subjects was obtained prior to any subject testing. The subjects participated voluntarily and signed an informed consent form prior to testing. All swimmers who volunteered were included in the study, thus there was a variety of freestylers, non-freestylers, sprinters, and distance swimmers.

### **Procedures**

During testing weeks, a 45.72-m (50-yd) freestyle sprint performance test and 22.86-m (25-yd) resisted swimming test were performed in a 22.86-m pool on the same day, separated by at least 15 minutes. A tethered swim test was then performed 48 hours later to allow for a more thorough recovery. The day between testing sessions involved low-to-moderate intensity, moderate volume swimming.

### **Performance Test**

A single, maximal effort, 45.72-m freestyle time-trial from the starting blocks was chosen as the performance test. During these time-trials, performance time was recorded as the dependent variable. Timing was performed by two assistant coaches with handheld stopwatches. The two times (in seconds) were averaged and rounded to the nearest 0.01 sec. A 45.72-m time trial was chosen as the indicator of sprint performance as it is the shortest legal event in collegiate swimming.

## **Resisted Swim Test**

During the first week of practice, three unresisted 22.86-m time-trials from an in-water start with five minutes recovery between efforts were performed to determine a suitable resistance for the resisted swim (RS) test. Performance times of the three trials were averaged and 20% of the averaged time was added, resulting in a time 120% of the original averaged time-trials. At least 48-hours following the unresisted 22.86-m time-trial, the swimmers performed repeated all-out 22.86-m resisted swimming efforts on a pulley system attached to a plastic bucket that weight can be added to on one end and a belt that fit around the swimmers waist on the other end (Power Tower, Total Performance Inc., Mansfield, OH). Recovery between the repeated efforts consisted of five minutes of passive recovery. Water was added in 0.45-kg increments prior to each trial until the swimmer's time reached the pre-calculated 120% time. The load was established at 120% time to ensure that the swimmers' performance was affected by the weight, but not so much that their stroke mechanics were altered in a meaningful way as recommended by previous studies using resisted and unresisted swimming (1, 13). This same load was used during the RS test during T1, T2, and T3.

The RS test consisted of three resisted time-trials at their established load with five minutes passive rest between attempts to allow for adequate recovery. Time was measured in similar fashion to the performance test. Each trial was timed and recorded by two assistant coaches. The average of these times were then used as a dependent variable. Then the three resisted time-trials were averaged, resulting in a resisted swim time, which was used to calculate velocity. In addition, stroke rate (SR) was also determined using the pre-programmed three-stroke rate program on the stopwatch (Ultrak 495, CEI, Gardena,

CA). The stopwatch was started as the swimmer's right hand entered the water and stopped after the right hand entered the water for the fourth time (following three stroke cycles). This measurement was taken between the five-yard markers at either end of the pool to ensure an established, rhythmic stroke was being measured (1). In order to calculate stroke length (SL), the swimmer's average velocity was divided by SR (5). The interclass correlation coefficient (ICC) for SR and SL was 0.95.

### **Tethered Swim Test**

To assess the force produced during the freestyle swim stroke, a 30-second maximal effort freestyle tethered swim test was performed 48 hours following the performance and RS tests. Force produced by the swim stroke was measured by a load cell (H2O Power Meter, Macungie, PA) connected to a tether system attached to the wall of the pool. Data was sent from the load cell to the manufacturer's software on a laptop computer.

Performance data for peak force (PF), mean force (MF), and fatigue index (FI) were collected. Thirty seconds was chosen for the test duration since all the swimmers' 45.72-m freestyle performance trials fell within this time frame and changes in force output could be interpreted similar to Wingate anaerobic testing on a cycle ergometer (11).

Familiarization trials were performed so that the swimmers could become acquainted with maximal effort swimming in place. High ICC for PF and MF ( $r > 0.98$ ) and FI ( $r = 0.89$ ) were found.

### **Body Composition Test**

Anthropometric data for each swimmer was collected during T1, T2, and T3 over the course of the 12-week period. Body mass was measured using a physicians scale (Continental Scale Corp., Bridgeview, IL) and height was measured using a wall-

mounted stadiometer (Genentech Inc., San Francisco, CA). Body fat percentage was estimated using a three-site skinfold analysis. Men's body density was determined using skinfolds at the chest, abdomen, and thigh. The women were tested at the triceps, suprailiac, and the thigh. All Skinfold measurements were conducted using a Lange skinfold caliper (Cambridge Scientific Instruments, Cambridge, MD) by the same qualified investigator. Body density was determined using the gender-specific Jackson and Pollack three-site formulas and percent body fat was determined from the Siri equation (12).

### **Training**

The swim coaching staff set up general microcycles so that Monday, Wednesday, and Friday practices were aerobic in nature. These days were designed to be unresisted and with brief rest periods between sets allowing heart rate to remain elevated (30-40 beats below each swimmer's maximum heart rate) for an extended period of time (>45 mins). Each aerobic practice varied in difficulty, length, and set structure. Also, after a base conditioning was established (~6 weeks, mostly freestyle swimming), the focus of aerobic practices became event- and stroke-specific as the competition season began.

Tuesday and Thursdays however, were designed to be anaerobic sprint practices in which resisted swim training occurred. This involved a loaded pulley system at each end of the pool. The swimmer was belted to a tether around the waist while swimming 22.86-m of resisted swimming at a time (one length of the pool). When the swimmers reached the end of the pool, they were required to unclip and then clip into a second pulley system before returning to the starting end of the pool for a total of 45.72-m of

resisted swimming. The swimmers could complete this transition process in approximately 7-10 seconds.

Anaerobic practices were designed to be different from one microcycle to the next. There were planned variations in rest, distance, and load in the resisted swimming sets. During anaerobic sprint practices, the swimmers were informed that all resisted sprint efforts were to be of maximal effort. Thus the training resembled repeated, high-intensity sprint training, which recent research suggests can improve both aerobic and anaerobic metabolism (9). In addition to resisted swim training, unresisted sprinting was also incorporated into practice on anaerobic training days. As with the aerobic training, the focus of anaerobic swim training after six weeks became event- and stroke- specific. Figure 1 shows the approximate distances by week of aerobic, anaerobic, and sport-specific resistance training.

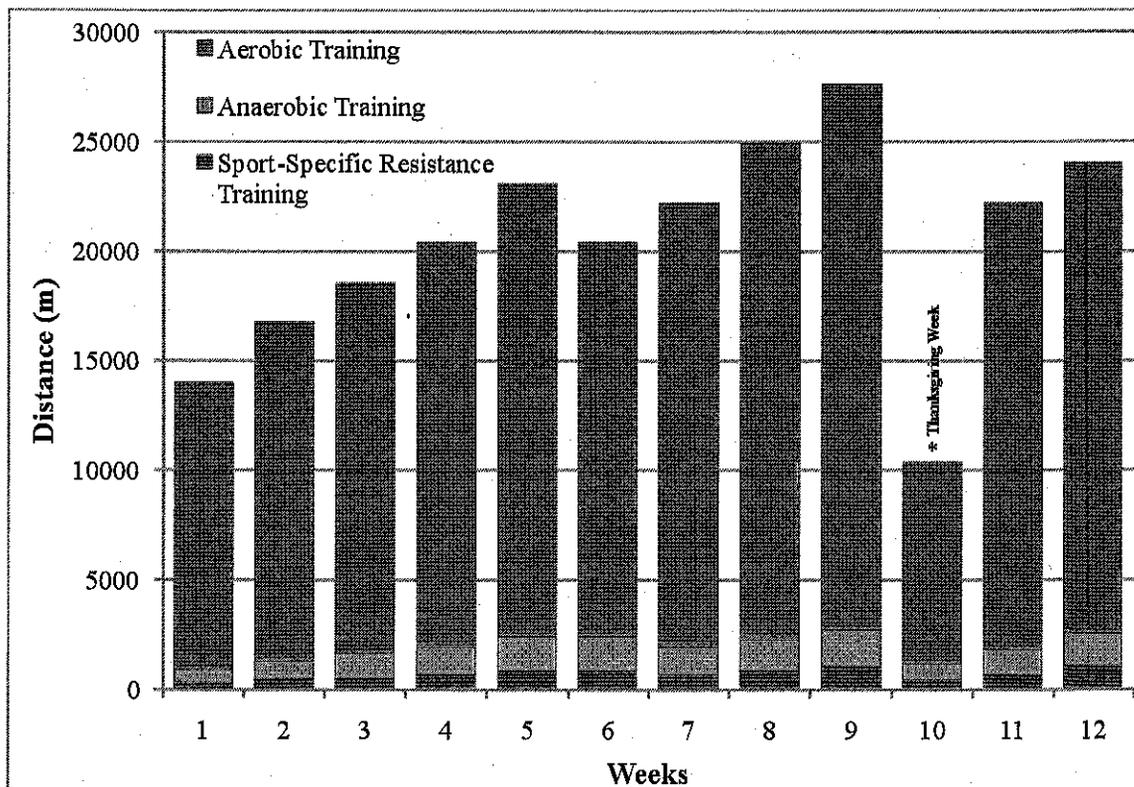


Figure 1. Breakdown of Training Distance per Week for Weeks 1-12.

### Statistical Analyses

Data were reported as mean values with standard deviation (mean  $\pm$  SD).

Performance time in the 45.72-m freestyle sprint, SL and SR in the RS test, PF, MF, and FI from the tethered swim test, and body fat percentage and mass were analyzed using ANOVA with repeated measures on the 3 trials (T1, T2, T3). Product-moment correlations were also performed between these same variables within each trial. Cohen (2) and Hopkins (10) have ranked the meaningfulness of correlations as  $r$  = trivial (0.0), small (0.1), moderate (0.3), strong (0.5), very strong (0.7), nearly perfect (0.9) and perfect (1.0). Men and women were analyzed separately for all statistical analyses. Level of significance was set at 0.05.

## RESULTS

A repeated measures ANOVA revealed that the men had significant improvements in sprint freestyle performance time from T1 to T2, and from T2 to T3. Significant changes were found in SR from T1 to T2 and T2 to T3, but in SL, PF, MF and body fat percentage from T1 to T2 only (Table 2). A Pearson product-moment correlation analysis found strong significant correlations of PF and MF with performance during all three trials. Additionally, FI had a moderate correlation during T1 and a strong correlation during T3. No other observed variables were significantly associated with performance (Table 3).

Women significantly improved sprint freestyle performance between T1 and T2. Similar to performance, significant changes were only observed in PF, MF, and FI between T1 and T2. However, women did show significant changes from T1 to T2 and T2 to T3 in SR, SL, body fat percentage, and weight (Table 2). The correlation analysis for women revealed strong to very strong significant correlations of PF and MF with performance during T1 and T2. No other variables were significantly correlated during T1 and T2. No variable had a significant relationship to performance during T3 (Table 3).

Table 2. Repeated Measures ANOVA for Measured Variables During T1-T3.

		T1	T2	T3
Men	Performance (sec)	24.72 ± 1.35	24.34 ± 1.24*	23.96 ± 1.07*†
	Stroke Rate (stroke·min <sup>-1</sup> )	50.0 ± 4.5	52.7 ± 4.9*	55.40 ± 4.3*†
	Stroke Length (m·stroke <sup>-1</sup> )	1.87 ± 0.16	1.95 ± 0.19*	1.86 ± 0.14†
	Peak Force (N)	175.0 ± 30.1	192.4 ± 17.3*	192.8 ± 23.7*
	Mean Force (N)	117.9 ± 8.8	128.0 ± 9.1*	129.0 ± 13.3*
	Fatigue Index %	41.1 ± 10.7	45.5 ± 5.5	44.4 ± 4.5
	Body Fat %	7.9 ± 3.6	9.4 ± 3.3*	9.1 ± 2.6*
	Weight (kg)	77.6 ± 8.2	78.0 ± 6.6	77.5 ± 7.3
Women	Performance (sec)	28.13 ± 1.41	27.16 ± 1.21*	27.00 ± 1.28*
	Stroke Rate (stroke·min <sup>-1</sup> )	45.7 ± 4.5	48.8 ± 5.5*	51.6 ± 5.7*†
	Stroke Length (m·stroke <sup>-1</sup> )	1.79 ± 0.18	1.80 ± 0.21	1.73 ± 0.18*†
	Peak Force (N)	109.2 ± 9.2	134.1 ± 12.7*	134.9 ± 18.6*
	Mean Force (N)	82.4 ± 6.7	88.0 ± 7.7*	88.2 ± 9.3*
	Fatigue Index %	32.7 ± 4.7	44.6 ± 6.1*	44.4 ± 8.9*
	Body Fat %	27.1 ± 4.9	26.2 ± 4.7*	24.6 ± 4.2*†
	Weight (kg)	65.3 ± 7.6	65.1 ± 7.4	64.6 ± 7.4*†

\* Significant difference from T1, † Significant difference from T2. Significance levels were set at  $p < 0.05$ .

Table 3. Correlations of Dependent Variables with Performance During T1-T3.

		T1	T2	T3
Men	Stroke Rate	-0.358	-0.263	-0.304
	Stroke Length	-0.130	-0.275	-0.305
	Peak Force	-0.519**	-0.627**	-0.578**
	Mean Force	-0.585**	-0.610**	-0.490*
	Fatigue Index	-0.467*	-0.311	-0.574**
	Body Fat %	0.303	0.268	0.362
	Mass	-0.126	-0.369	-0.228
Women	Stroke Rate	-0.306	-0.095	-0.086
	Stroke Length	-0.137	-0.301	-0.316
	Peak Force	-0.675**	-0.496**	-0.264
	Mean Force	-0.776**	-0.597**	-0.353
	Fatigue Index	0.217	0.052	-0.114
	Body Fat %	0.060	0.034	0.155
	Mass	-0.210	-0.064	0.007

\* Significant at  $p < 0.05$ , \*\* Significant at  $p < 0.01$ .

## DISCUSSION

The purpose of this study was to observe technical, kinematic, and physical variables of swimmers during trials using resisted swimming and determine the relationship to swimming performance over time. While other studies have observed these predictive variables during a single testing session (3, 4, 5, 13), this study is the first known to monitor these variables in competitive swimmers over the course of a 12-week training period. Only noninvasive variables that have previously been shown to predict performance were included in the correlation analyses allowing coaches to monitor training effects and train their swimmers to improve those variables. Since the study was conducted within the confines of an in-season, competing collegiate team, no modifications were made to the training program, which already consisted of high-intensity, sport-specific resistance training, sprint training, and aerobic swim training. While men and women are not being compared in this study, the most highly correlated dependent variables were observed to be similar for both genders despite the fact that there were differences in performance improvements between the genders.

The results showed that the men's sprint performance significantly improved through all three trials and that this was primarily due to improvements in the power and force variables of swimming performance. This agrees with similar findings by Costill et al. (3) and Johnson et al. (13) who only used male subjects in their studies. Results of those studies also found peak power to be highly correlated to sprint freestyle performance with  $r = 0.82$  and  $r = 0.87$  respectively. The results of the present study for

men showed strong correlations between peak force and performance of  $r = 0.52$ ,  $r = 0.63$ , and  $r = 0.58$  for T1-T3, respectively. The higher correlations in the previous studies may be attributed to the fact that a 22.86-m sprint was used as a measure of performance, while this study used a 45.72-m sprint, which included a block start and turn. The present study's tethered swim test measured the force of the swim stroke since the swimmer is tethered to the wall, with no horizontal displacement while Costill et al. (3) and Johnson et al. (13) used partial tether systems to determine stroke power. The partial tether system allows the swimmer to swim a measurable distance while recording time and force on the tether so power can be calculated. Thus no direct comparison can be made to the power findings of those previous studies. However, since force is an underlying component of power, the force and strength variables found to be correlated to the men's performance in this study are also likely related to power and compare favorably with the findings of Costill et al. (3) and Johnson et al. (13).

Additionally, MF showed strong correlations to performance during T1 and T2 and a moderate, but significant, correlation in T3. These results were similar to the correlation findings of Johnson et al. (13) who found power values at 1.5 and 7.8-kg of resistance were strongly associated with swim performance. The fact that MF and PF were most highly correlated to performance in all three trials of the present study may imply that the application of force on the water is more important than the biomechanical technique in which it is applied (3). Since the highest correlation shifted from MF to PF from within the first six weeks of sport-specific resistance training (T1 to T2), it may be deduced that the resulting performance improvements were neurological in nature. Neurological improvements as a result of resistance training have been shown to be the

main contributor to strength gains in the first ~eight weeks of training (22), especially in improving peak strength. Interestingly, the correlations of the men fell for both PF and MF during the latter six weeks. It has been shown that maximal and explosive strength, similar to what was tested with the tethered swim test, can decline in as little as 2-3 weeks during constant high-intensity strength training (6) or detraining (17).

While resistance training induces neurological adaptations to increase muscle strength, the application of high-intensity training, in conjunction with sport-specific resistance training, leads to anaerobic as well as aerobic metabolic adaptations in the trained muscles. This may be the reason FI had a strong correlation to performance in the men at T3. A higher resistance to fatigue may be a suitable reason for significantly faster performance times from trial to trial. Studies have shown that high-intensity sprints not only improve anaerobic, but aerobic capacities as well (23), including resistance to fatigue (9). While PF was the most highly correlated variable to performance at T3, the strong correlation of FI in conjunction with a moderate relationship MF to performance suggests that metabolic adaptations in the muscle may be the reason for a strong correlation to FI (15). Thus, the repeated sprint and resisted swim training may have maintained sport-specific strength and metabolic conditioning in the men toward the end of the study. As a result, resisted testing seems to reflect that men's sprint performance may be the direct result of swimming-specific strength and metabolic adaptations rather than kinematic stroke variables.

Women, on the other hand, only improved their sprint performance times from T1 to T2 and did not significantly improve from T2 to T3. This may be because the women showed less physical adaptation from the resistance training than the men and that their

primary improvements (T1 to T2) were mostly neural in nature as a result of resisted swimming. Since women have much less testosterone than men, structural adaptations to the muscle due to resistance training may not be as extensive as men, limiting the amount of strength increase in women following the initial neural improvements (8).

The initial performance improvements are echoed by the correlational findings, which show PF had strong correlations with performance during T1 and T2, while MF had a very strong correlation during T1 and a strong correlation during T2. No significant correlations were seen between performance and in any variables observed during T3, which may explain the lower than expected improvement of performance during that testing session. Thus, similar to the men, performance appears to be mostly related to swimming-specific strength rather than the technical stroke variables.

It was surprising to discover that neither stroke variable had significant correlations to performance in either gender despite the relationship of SL, SR, and velocity (5). The correlations of both SL and SR were trivial to moderate for all three trials. Neither gender showed significant correlations between SL, SR, and performance. However, the ANOVA analysis in Table 2 confirms that SR does increase along with faster performance, similar to the observations of Craig and Pendergast (5). This may reflect the level of swimming ability exhibited at the collegiate level and indicate that minute technique changes are minimal in affecting performance at an advanced level.

It is interesting to note that during T3, the women had a significantly lower average weight than T1 and a significantly lower body fat percentage than T1 or T2. It was unclear how these changes affected performance, but the lack of a significant correlation signifies these variables did not have a meaningful influence on performances

in this study. Though it has been shown that leaner swimmers have improved performance times (16), with less buoyancy, technique alterations might have been made to keep the body hydrodynamic and level in the water, which may have affected the women's performance during T3. It is also intriguing that the men's body fat percentage was significantly higher in T2 and T3 when compared to T1. This may shed light on why fatigue index had a higher correlation during T3. During this time, the men were likely more buoyant which may have improved their hydrodynamics. This would allow for more energy to be focused on forward propulsion, though it has been argued that increase in body fat percentage also increases drag (14).

This study had a number of limitations which may have had an effect on the results observed. After approximately six weeks of training (shortly after T2), the focus of practice shifted from a general base-conditioning to specific event and stroke preparation for both men and women as the competition season began. Since all swimmers were included in the study, distance swimmers, middle-distance swimmers, sprinters, and non-freestylers began diversifying their training sets and loads. This likely had an effect on the results of the correlation analysis in T3, such as the lower correlations of PF and MF to performance. Another limitation is that given the free-living nature of the athletes in this study, there was no way to control the athlete's eating, drinking, and sleeping habits. There were also instances of sickness that may have affected training and testing days. Though it has been shown not to have any significant effect on in-water performance (13, 24), a weight-training program was available (but not be mandated in accordance with University policy), and lifting was at each swimmer's discretion. Additionally, since the team was comprised of nearly 60 male and female

athletes combined, training and testing attempted to replicate as close as possible the conditions from practice to practice and testing week to testing week. However, differences such as time of day, class schedule, and minor injuries affected the order and protocol of some testing days as the researchers were working within the confines of an in-season practicing and competing collegiate team.

In summary, the findings of this study indicate that performance for men and women are most strongly correlated with peak and mean force and power. The focus of this study was solely to monitor changes in freestyle variables and find their relationship to performance for the first 12 weeks of a competitive season using resisted swimming for testing. Additional research could look at how these kinetic and kinematic variables correlate to middle-distance and distance performance, as well as observing the other three competitive strokes. Additionally, it would be ideal to follow the team's progress throughout a full 20-week season to determine how different phases of the training program affect testing. The ability to observe changes in technical and kinematic variables on sports-specific resistance machines may help coaches monitor the effectiveness and successfully adapt their training programs to their swimmers' needs based upon which variables do or don't correlate highly with successful performance.

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APPENDIX A  
INFORMED CONSENT

## **Informed Consent Form**

**Title:** The Relationship of Sprint Performance to Kinetic and Kinematic Variables During Resisted Swimming

**Investigator Name:** Nick Kuffel  
Human Performance graduate student  
University of Wisconsin-La Crosse

### **1. What is the purpose of this research?**

This study intends to implement a relatively new training technique in the sport of competitive swimming that involves pulling weighted buckets. The idea is to train swimmers to be faster without swimming as far which might make it less likely to get injured from training too much. This type of training is called sport-specific resistance training (SSRT) and is used to improve speed and endurance. Performance will be determined by a timed trial of 50 yards of front crawl at four instances during the 12-week study. A 25-yard time trial while resisted by the buckets will also be performed during those times. You will also be evaluated by stroke count, stroke frequency, stroke length, and power both during the time trial and while pulling the buckets. Additional information such as body weight, height, body fat percentage, and years of experience will be collected as supplementary variables to incorporate in the statistical analysis. A multiple regression analysis and ANOVA will be used to find correlations between the different training variables and the highest performance. The testing will take place at the Mitchell Hall pool and the program will last 12 weeks. You will be asked to swim 5 days a week for 2 hours, two days of which will be resistance training on the buckets. This will occur when you are already scheduled to practice, so no additional practice time will be required and the study won't interfere with your class schedule.

### **2. What are the possible risks of this study?**

It is possible you may be subject to any injuries commonly found in swimming training. Since the buckets are a form of resistance training, strains or pulls may develop as a result of this form of weighted training. A proper warm-up period will always be a part of practice so potential injuries from pulling the weighted buckets are decreased. A warm-down will also be a part of the practice to help prevent potential soreness that may result from training. Athletic trainers will be available to assess any injuries or soreness and tend to you as needed (i.e. massages, ice, injury treatment).

### **3. Are there any benefits to participating in this study?**

It is possible that you will see improvements in performance as indicated by faster times, decreased time till fatigue, or decreased stroke count per pool length. It is also possible you will not see any improvement in swimming efficiency.

### **4. What are my alternative options?**

You may choose at any time not to participate in the study.

### **5. How will my identity be kept confidential?**

Names will not be published in any form and the will only be used for the collection of data. Your name will not be associated in any way with the data you produce once it has been



APPENDIX B

REVIEW OF RELATED LITERATURE

## **REVIEW OF RELATED LITERATURE**

### **Introduction**

The ultimate goal of training in collegiate athletics is to improve performance. In competitive swimming, this means lowering times by swimming faster. In order to produce faster times, swimmers can modify a number of things. Their stroke (biomechanical) techniques can be altered to become more efficient. Swimmers can wear the latest in swimsuit technology to minimize the drag imposed on the body as it moves through the water. More intuitively, swimmers can adjust their training methods to optimize the body's physiological responses to the intense demands of the sport. Biomechanically, stroke techniques can only be modified to a certain degree to maximize efficiency. On the other hand, low-drag swimsuits present an ethical dilemma in the swimming community and restrictions have been put in place to determine how efficient a swimsuit can be. Therefore, alterations in swimming training become the ideal factor to produce the faster times desired by swimmers and their coaches.

It is important that new and improved methods of training be explored in the sport of swimming if the ultimate goal of faster times is to be met. In accordance with the principle of specificity of training, newer techniques utilized by cyclists and runners hybridize resistance and endurance training to simulate the intensity and duration of competition as near as possible to maximize the athlete's training (21). If this hybrid style of training is introduced into swim training and it leads to increasing fatigue resistance while also increasing swimming velocity, improvements in swimming performance will

be realized. Various authors have explored these concepts as they apply to athletics to show how this type of training could be implemented and the physiological, technical, and temporal results of these techniques.

Recently, revelations in training theory have led to a move towards sport-specific resistance training, in which athletes train in their competitive environment at a high intensity while applying some form of resistance. The following review highlights research that looks at various factors that are currently utilized in sport-specific resistance training and how these factors may link kinetic and kinematic variables produced during resistance training to performance. Observing these variables produced during resisted swimming may shed light on strengths and weaknesses of swim performance during competitive efforts. Resisted testing has the potential to slow an athlete's movement velocity so that variables related to force production (propulsion) could be singled out and measured. If current knowledge about sport-specific resistance swimming can be utilized to correlate training variables to performance, then the way in which coaches train swimmers may be revolutionized.

### **Sport-Specific Resistance in Cycling and Running**

Often times coaches and athletes observe training styles and exercises employed by other sports to potentially find a new training method for their own sport that will improve performance. Swimming is no exception to this concept. Much research has been done to determine the effects of resisted movements on performance in cycling and running since they can be easily controlled for in the laboratory setting.

Paton and Hopkins (16) demonstrated how sport-specific resistance training is more beneficial to a road cyclists' performance during the competitive season than

unresisted training. The control group maintained their prescheduled competition training plan while the experimental group added workouts consisting of resisted (magnetically braked) cycling sets. Performance tests were performed before and after the designated training phase and included mean power in a 1- and 4-km time trial, peak power in an incremental test, and lactate-profile power and oxygen cost during 2 fixed submaximal workloads. The results indicated that the control group showed little to no improvement in any variable of the performance tests. However, the experimental group that added sport-specific resistance training to their training program increased mean power during the 1- and 4-km time trials 9 and 8%, respectively, as well as in peak power in the incremental test, which differed by 7% over the control group. Improvements in both mean and peak power produced by the sport-specific training were found to almost certainly have a substantial benefit, while the control group was found to have no beneficial change in either variable. The effects on oxygen cost and lactate-power profile were less clear, but still deemed beneficial in the experimental group. The authors concluded that resisted cycling training produces positive gains in sprint and endurance performances of well-trained cyclists. However, the amount of resistance that could lead to improved performance was still unknown, an issue they attempted to clarify a few years later.

A correlating study conducted by Paton, Hopkins, and Cook (17) was developed to assess the effects of high- vs. low-cadence sprint workouts on performance in cyclists. While subjected to the same workloads, the high- and low-cadence groups differed by light and heavy magnetic resistance, respectively, in their sprint workouts. The high-cadence group maintained 110-120 rev min<sup>-1</sup> while the low-cadence group cycled with an

equated load that allowed pedaling at 60-70 rev min<sup>-1</sup>. The training ergometers were magnetically braked and the resistance could be manually adjusted by the participants to ensure the cyclist's cadence fell within the prescribed parameters. The results showed that the cyclists following the higher load, low-cadence training protocol had higher improvements in 60-second mean power, peak power, and power at 4mM lactate concentration (3, 4, and 7%, respectively) than their lower load, high-cadence counterparts. The improvements in the low-cadence group were found to have a likely benefit when compared to the high-cadence improvements. They also improved maximal oxygen uptake by 3% more (deemed likely beneficial) than the high-cadence group. They believed that the increased muscular forces needed to sustain the low-cadence, a higher resistance, attributed to the additional increases in power performance. Ultimately, the researchers concluded the need to overcome extra resistance during low-cadence training offered increased performance benefits over a similar workload, high-cadence training program.

Training to improve sprint running has also used sport-specific resistance methods. Ross et al. (19) developed a training program for runners on a treadmill to maximize sprinting velocity and power using resistance. The researchers varied the sprint repetitions (8-12), distance (40-60 meters), and rest between each sprint (2-3 minutes). In addition, as training progressed, the sprints were resisted using a tethered harness connected to a magnetic loading system while on a treadmill, which could provide sport-specific resistance anywhere from 10-25% of the subjects body mass. A control program followed a non-specific weight-training program that consisted of 2 upper-body and 2 lower-body strength training workouts per week. Pre- and posttesting was done to

determine 30-meter maximal sprint times, average velocity, and peak power produced during maximal sprinting. Posttesting revealed that those subjected to resisted-sprinting on the treadmill showed significant improvements in peak power, velocity, and time during a 30-m sprint. Those who participated in non-specific weight training only showed significant improvement in average velocity, but this was overshadowed by the fact that the resisted sprint group ran significantly faster. However, while the results of this sprint training program developed for runners contained valuable information, sport-specific resistance movements pose an interesting dilemma of altering movement mechanics. The authors conclude that monitoring technique during resisted-sprint running may also help enhance improvements.

The kinematics of sprint running while influenced by a different form of resistance, a weighted sled, were studied by Lockie, Murphy, and Spinks (13). A number of variables were measured including stride length, stride frequency, ground contact time, trunk lean, and hip flexion. The subjects performed sprints that were unloaded, as well as sprints that were loaded via the sled so the participants sprinted at 90% (Load 1) and 80% (Load 2) of their maximal 15-meter sprinting velocity. Lockie et al. (13) found that stride length decreased significantly ( $p < .05$ ) from the unloaded sprint to Load 1 (~10% reduction) and Load 2 (~24% reduction) was significantly different from both Load 1 and unloaded sprinting. They also discovered that stride frequency was significantly altered (decreased) from the unloaded to the loaded trials, but there was no difference between the loaded trials. Additionally, ground contact time significantly increased from unloaded to loaded sprinting as well as increasing from Load 1 to Load 2. This increase in ground contact time may allow for greater force production due to more time for cross-bridge

attachment in the muscles (3). The researchers also noticed technique alterations as hip flexion decreased as well as an increase in mean trunk lean with each successive load. The authors suggest that while resisted training via the sled may be good for improving performance, the resulting kinematic alterations from using resistance should be monitored and that lighter, rather than heavier, resistance should be used to minimize the changes in technique. These findings were confirmed by Alcaraz, Palao, Elvira, and Linthorne (1) and Cronin, Hansen, Kawamori, and McNair (8) who looked at similar kinematics in sled towing as well as parachutes and weight belts and vests. As with Lockie et al. (13), Alcaraz et al. (1) suggested using a weight that slows the athlete to approximately 90% of their unresisted sprinting speed. Any heavier weights might produce substantial changes in running technique not desirable for training.

However, can kinetic and kinematic variables measured under resistance be useful in determining relationships to performance? Harris, Cronin, Hopkins, and Hansen (11) investigated the relationship of sprint times to strength and power measurements taken from a weighted squat jump. They discovered that correlations of force, velocity, power, and impulse with short 10-m sprint times were positive and moderate to strong in magnitude ( $r = 0.32-0.53$ ). However, the correlation with work showed a negative relationship ( $r = -0.18$ ) though the magnitude was small. Longer sprints of 30 to 40-m produced similar correlations though work was positive and moderate in magnitude ( $r = 0.35$ ). The authors found it interesting that the stronger the athlete, as determined by the subjects' one repetition maximum, the slower their performance appeared to be. However, while the results show moderate to strong positive relationships between performance time and the independent variables, a lack of movement specificity of the

squat jump in comparison to sprint running may indicate why relationships to performance weren't stronger. However, the concept of measuring variables under resistance to correlate to performance is a relatively new concept that may have unforeseen advantages.

These studies (1, 8, 13, 16, 17, 19) have shown that sprint and sport-specific resistance training have proven beneficial to performance in cycling and running, provided the resistance isn't so great that technique is negatively altered. Harris et al. (11) and Ross et al. (19) took resistance a step further and applied it to testing for performance correlations. In the sport of swimming, this revelation has led to development and use of the Power Tower (Total Performance Inc., Mansfield, OH), an apparatus in which swimmers lift weighted buckets, by way of a pulley system, as they swim the length of the pool. An advantage of this training device allows coaches the potential freedom to implement both high intensity and resistance training into their programs. The potential benefits of such training include a reduced training volume, increased power production, higher efficiency, and metabolic adaptations to fatigue during high-intensity training. While the ideas of high-intensity and sport-specific resistance training are not new in athletics, little has been researched regarding their correlation to performance in competitive swimming. Using a training implement such as the Power Tower could have similar performance improvements as seen in cycling and running if resisted swimming is incorporated into a swim team's training schedule in a similar fashion. This device also has a high degree of specificity to swimming movements and thus would be a good tool to determine relationships between swimming performance and training variables. However, the effectiveness of using resisted swimming for training and testing in the

pool needs to be assessed before assuming that the Power Tower can be used to predict sprint performance.

### **Sport-Specific Resistance in Swimming**

Resistance training is often used outside the pool in the forms of dry-land and strength training to increase a swimmer's strength. However, this should not be considered sport-specific since the movements of exercises on land do not mimic those in the pool to a high degree of specificity. Thus, the effectiveness of using dry-land strength programs to measure in-water performance should be assessed to determine if their implementation actually yields any significant correlations to performance.

Tanaka, Costill, Thomas, Fink, and Widrick (20) set out to evaluate the efficacy of incorporating weight training into a swimming program and its effects on performance. Twenty-four consenting male collegiate (NCAA Division I) swimmers participated in the 14-week training program. The swimmers were randomly and evenly divided into a swim group (SWIM) and a simultaneous swim and resistance-training group (COMBO). Both groups swam the same practices in the pool together for the entire 14 weeks. The COMBO group additionally participated in a dry-land training regimen 3 days a week for 8 weeks during weeks 3 through 10 of the entire training period. The strength training program consisted of dips, chin-ups, lat pull-downs, elbow extensions, and bent arm flys and each subject of the COMBO group performed between 8 and 12 repetitions per set for three sets. Swimming tests were performed during weeks 1, 4, 6, 9, 12, and 14 to record power via a tethered swim test, strength by a Biokinetic Swim Bench (Biokinetic Inc., Albany, CA), and velocity in a 25-yard and 400-yard swim.

The results showed significant increases in strength, power, and velocity in both the SWIM and COMBO groups, but no significant differences were found between the groups. According to the authors, the dry-land strength training program does not improve swimming performance despite the fact that the swimmers in the COMBO group were able to increase their strength training loads 25-35% from pre-training. These findings imply that there is little relationship between dry-land strength gains and swimming propulsive force, possibly due to a lack of specificity of training.

The concept of lack of specificity between dry-land and actual swimming motions is further exemplified by Neuffer, Costill, Fielding, Flynn, and Kirwan (14). In this detraining study, the authors showed that over 4 weeks of reduced or minimal training, no strength decrements were measured using a Biokinetic Swim Bench, an apparatus that emulates swimming out of the water. However, over the same period, significant decreases in swimming power in the pool were measured. This further illustrates the need for in-water swimming tests to make correlations to performance.

Johnson, Sharp, and Hedrick (12) investigated the relationship of dry-land power, swimming power, and strength to freestyle performance. An additional purpose of this study was to formulate a prediction equation using a multiple regression analysis for estimating sprint freestyle performance using power/strength variables. Dry-land power was determined by a test on a Biokinetic Swim Bench (Biokinetic Inc., Albany, CA) while swimming power was calculated using a Power Rack (Total Performance Inc., Mansfield, OH) at various loads. The Power Rack is a form of resistance on a pulley system, but does not allow the swimmer to lift the weight stack over the full length of the pool. Peak power was determined as the highest power observed regardless of load. A

1RM bench press test was used as the assessment for upper-body strength, and the maximum mean velocity from a 45.72-m front-crawl sprint served as the performance test.

The results of the multiple regression analysis show that peak power, power at 1.5 kg resistance, and power at 7.8 kg resistance on the Power Rack most accurately predicted sprint velocity. The ultimate conclusion from this study, in agreement with Tanaka et al. (20) and Neuffer et al. (14), was that swimming power, and not dry-land power or strength, was the best predictor of swim performance. This begs the question: can resisted swimming help predict swim performance? The Power Tower is an ideal apparatus to answer that question since, unlike the Power Rack, variables can be measured over the entire length of the pool allowing for additional variables to be measured. There are certain stroke parameters used by researchers and coaches alike that would be ideal to relate to performance.

Stroke variables such as stroke length (distance per stroke) and stroke rate lead to velocity and as a result, are valuable contributors to swimming performance, similar to the way stride length and stride rate are in running. Craig and Pendergast (6) set out to determine how these variables are related in competition. The researchers constructed a 'swim-meter,' which had the capability of measuring distance, time, and velocity and could begin recording at any point of a stroke cycle and for as many stroke cycles as the researchers deemed necessary. Swimmers of varying ability participated in the study, though several were collegiate athletes of national rank. The swim-meter consisted of a collar worn by the swimmers attached to a fine, stainless steel, wire, which was fixed to the end of the pool. The wire passed through two wheels that could discern distance and

velocity and record electrical signals. The swimmers swam several lengths of the pool while wearing the device, slowly at first trying to maximize stroke length, and then progressing to the fastest maximal velocity that could be sustained for one pool length.

The results showed that the males and females who had the longest stroke length also had the highest velocity at submaximal efforts. However, as velocity increased, they found that increased stroke rate (and subsequent decrease in stroke length) accounted for the achievements of maximal velocity. This was one of the first studies emphasizing the essential importance that stroke length and stroke rate play in producing a swimmer's velocity. The interaction between stroke rate and stroke length with increased velocity has also been observed in elite swimmers during the 1976 and 1984 U.S. Olympic Swimming Trials (7). However, these variables need to be assessed in relation to velocity to further understand the role they play in stroke mechanics and force propulsion.

Barden and Kell (2) used these same parameters to assess the effectiveness of sprint training in the pool. Eight female (mean age  $17.3 \pm 1.5$  years) and three male (mean age  $18.4 \pm 0.2$  years) elite competitive swimmers consented to the study. In pretesting, each swimmer's critical speed, the speed that can theoretically be maintained without exhaustion (also thought to correlate with the maximal lactate steady state) was determined through a series of swims of 200-meter, 400-meter, and 1000-meters at maximal effort. Critical speed was determined by measuring the slope of a regression line for distance versus time of these efforts. This speed was determined to be the mean velocity at approximately 80% of each swimmer's prior best 100-meter performance. A training set was devised, based on the critical speed calculations, that progressed to faster swim velocities through 8 x 100-meter repetitions starting at 65% and finishing at 100%.

of each swimmer's best performance. The rest allotted was individualized to a 1:1 work-to-rest ratio. The authors gave no instruction to the swimmers regarding technique and only indicated when the next repetition should start.

After determining the average swimming velocity, stroke rate, and stroke length for each repetition, Barden and Kell (2) found that once critical speed was reached in the fourth repetition (80% of each swimmer's best 100-meter performance), unpredictable changes in stroke parameters occurred. While velocity increased with each repetition of the set, stroke rate increased and stroke length decreased significantly, suggesting deterioration in efficiency during the higher intensity sprint training.

According to the force-velocity relationship, the faster a movement is made, the less force can be produced (18). At a lower velocity, a longer stroke length provides the force and power necessary to provide propulsion. However, this force decreases gradually as velocity increases and thus a proportional increase in stroke rate must occur to maintain high speeds in spite of propulsion loss. Practically speaking, the authors concluded that swimmers have two sets of stroking parameters: one for high velocity anaerobic performance and one for lower velocity aerobic swimming.

If the goal of maximizing efficiency is to be realized in sprint swimming, then use of a resistance to test for the relationships between power, force, and stroking variables might prove to be highly valuable. Resistance may be used to slow a swimmer so that kinetic and kinematic variables can be tested with an optimal force/velocity/power relationship. Care must be taken to ensure that only enough resistance is applied to slow the movements down to allow for optimal time to complete the cross-bridge cycle at the sarcomere. If too much resistance is used, then unwanted technique changes may occur

that may be detrimental to the athlete's ability to perform efficient movements (12). Additionally, other studies that observed swimming-specific resistance (9, 10) suggest resistance in swimming's natural environment has a higher correlation in developing swim-specific strength and thus might provide positive biomechanical adaptations to technique. Due to the resistance, a swimmer might be forced, out of necessity, to become more efficient in the water by altering their technique in minute ways. Resisted swimming can provide the means to purposely decrease stroke rate and hopefully increase force production by providing more time to allow the cross bridge cycle in the muscle to take place, producing greater force during each stroke.

On the other hand, stroke rate, stroke length, and velocity are not necessarily the only measurable variables that may play a role in performance. Costill, King, Holdren, and Hargreaves (4) sought to measure swimming power directly, as opposed to detecting power on land via a swim bench, to determine its relationship to sprint speed. Thus they deconstructed a Biokinetic Swim Bench and adapted the control mechanism with a stainless steel cable that could be attached to a swimmer with a harness belt. The recoil mechanism was fitted so that the line could be let out at certain speed settings, thus controlling the swimmers velocity. The participating swimmers swam several 25-yard trials at  $\sim 1\text{-meter}\cdot\text{sec}^{-1}$  while power and force values were recorded by the Biokinetic control box. This was then compared to an average of several unrestrained 25-yard time trials from which maximal sprinting velocity was calculated.

Costill et al. (4) discovered from the results that even small differences in sprinting speed are related to measurable differences in power and force. They also found that average velocity of the 25-yard sprints were highly correlated with peak force

( $r=0.84$ ) and swimming power ( $r=0.82$ ). Beyond these correlations, the authors discovered discernable differences in force and power between a swimmer's arms within a single stroke cycle, indicating an inefficient mechanical flaw due to technique in only one arm. It was also observed that a swimmer's power changed in proportion to improvements or decrements over the course of a season. Thus it was concluded that swimming power was just as vital to analyzing a swimmer's performance as mechanical variables such as stroke length and stroke rate, with the added benefit that a machine that measures power could also aid in analyzing technique by detecting stroke defects.

While Costill et al. (4) controlled the swimmers velocity by the speed settings of the swim bench, resisted swimming could serve the same purpose for testing these kinetic and kinematic variables. Swimming force can now be measured with a new product, the H2O Power Meter (H2O Power Meter LLC, Macungie, PA), a commercialized load sensor with associated software that is anchored to the wall of the pool as a tether system. Other studies have used tethered systems to measure and track swimming force (5, 15, 20). If the resisted and/or tethered swimming can successfully predict performance and monitor training variables, then swim coaches may be able to understand better the effects of training on their athletes.

### **Summary**

These studies offer beneficial insight into developing a more efficient training program by using the Power Tower and the H2O Power Meter as instruments for predicting swim performance. It has been shown that use of sports-specific resistance has improved performance in cyclists and runners (16, 17, 19). Often times drawing on the experience and research from other sports is what drives progress in athletics. This

research also pointed out benefits of sprint training in conjunction with sports specific resistance training such as improved power, lower oxygen costs, and a lowered lactate-power profile. Ross et al. (19) provided evidence that high-intensity training affects not only the anaerobic energy systems, but the aerobic energy systems as well. It provides an impetus for the muscles and cardiovascular system to adapt rapidly in the face of exceedingly high-energy demands brought on by the intensity of the exercise. However, resistance training relies on proper technique in order to gain the desired benefits. The kinematics of sled towing were observed and found to alter several variables such as stride length and stride rate depending on the amount of resistance applied (1, 8, 13). Johnson et al. (12) cautioned that this may also take place with resisted swimming as the resistance load increases. Use of resistance has also been adapted to determine relationships of force, velocity, power, and impulse to sprint running performance (11). The introduction of the Power Tower as a means to provide sports-specific resistance to the competitive swimming community may be a valid assessment tool to monitor similar kinetic and kinematic variables in the pool.

It has long been thought that resistance training on land could benefit swimmers' performance in the water, but no correlation was found (20). An additional study showed that even replication of the swimming stroke on land using a Biokinetic Swim Bench had a low relationship to a swimmer's in-water power or performance measurements (14). This was further confirmed by using an apparatus called the Power Rack to measure in-water power and strength with had the highest correlations to swim performance in comparison to bench press and swim bench tests (12). This supports use of sport-specific resistance to assess variables of swimming performance. It has also been observed that

there is a critical swimming speed at which stroke parameters are altered as a result of the force-velocity relationship (2). Resisted swimming offers the opportunity to slow a swimmer down to optimize this relationship and test and observe kinematic variables used by coaches that may aid in predicting swim performance.

Stroke length and stroke rate have been shown to be the essential variables that quantify swim velocity (6, 7), which is essential to performance. However, it has also been shown that swimming-specific force and power can be predictive of performance (4). Hopefully, by narrowing down the sport-specific resistance tests to observe variables shown to be related to performance, a better way to monitor swimming training and more accurately predict performance can be found.

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