Generating Power in the Pool: An Analysis of Strength Conditioning and its Effect on Athlete Performance

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Abstract

There are many things that affect the speed of a swimmer in the water, from size of the individual to their technique and strength. This study tracked a group of NCAA Division III athletes across their season to see how their capacity for power generation changed over the course of three months, and whether or not time drops at the end of the season could be reasonably attributed to gains in power production. This was done by collecting data from a commonly used training apparatus called a Power Rack. Along the way, different models for looking at the forces in play while moving through the water were developed and tested to see if they predicted realistic outcomes that are observed in the sport. In the end, a statistically significant increase in power was found across the group of Carthage College swimmers from the month of November to the month of January. In addition, power ratios were plotted against times in the 100 yard freestyle event for all the swimmers, and a significant correlation was found between the power ratios and swim speeds.

1 Introduction

Modern Competitive Swimming is something that would be unrecognizable to the world of 100 years ago. People have been swimming for ages- the first Olympic Games to include swimming occurred in 1896, which consisted of only men swimming the freestyle stroke. The earliest accounts of swimming competitions that we have only date back to the early 19th century, although it probably fair to assume that swim races occurred before that. However, 1844 was a turning point for the sport on a global scale. Two Native American men named Flying Gull and Tobacco were visiting England for a race against Englishmen Harold Kenworthy according to England's "The Times" newspaper. Both the Native Americans crushed Kenworthy, swimming in a style that was "totally un-european". While Kenworthy swam the breaststroke, the Native American's swam what we now call the Front Crawl, or Freestyle stroke. Power generation during this specific stroke will be the main focus of this paper, along with observing how the overloading principle is applied to training in order to produce faster and more powerful swimmers. In 1908, the Federation Internationale de Natation, or FINA, was formed. FINA was and still currently is the top authority for competitive swimming worldwide. Over the next 50 years the sport grew in popularity and in diversity. The Olympic competition's first only consisted of men swimming freestyle, backstroke and breaststroke, with women only swimming in freestyle events. In 1924 backstroke and breaststroke events were added to the women's competition, and in 1952 FINA added butterfly events to both gender line ups.

Despite all this progress, the swimming world of the early 20th century was surprisingly slow compared to modernity. Even as late as 1952, world record times are now typical of some age group swimmers, and even the average division III college team of today would handily beat the Olympic squads that came out compete just 60 years ago. So what has changed? The short answer is the steady inclusion of lifting weights and strength conditioning. Before the 1960's, weight training of any kind was highly discouraged, as it was thought to lead to decreased flexibility and bulky muscles. However, attitudes toward weight training have changed completely since then, with the general consensus being that swimmers *must* engage in some kind of resistance training in order to be successful in the water.

The basics of resistance training for swimming are fairly simple, and focus on one specific principle called "overload". Overload is the increasing of resistive elements against which swimmers are swimming. To the swimmer, this is usually viewed and felt as an increased load to the muscles. They are being forced to generate greater force than normal swimming for shorter bursts. Many professional coaches believe however that training at overload capacity does not just target the muscle groups involved, but the central nervous system as well. As athletes try to move through the water with increased resistance, their body and mind must adapt to find ways to generate more power. The consistent existence of this element in training regimens is cited by most professionals in the sport as the number one source of the dramatically increasing performance levels observed leading into the 21st century.

This study focuses on one specific tool that is widely used in high schools, swim clubs, and colleges nationwide and even globally called a Power Rack. The Power Rack is a training tool that is designed to target and train an athlete's overload capacity. A typical power rack is a metal tower about 7.5' high, with a square base that flares out to provide stability to a central column, about 1.5'x1'. This column has a stack of weights ranging from 10-100 pounds at the bottom, similar to any kind of weight lifting machine you would see at your local gym. These weights are attached to a pulley system that runs out the top of the tower and ends in a belt that the swimmer attaches around their waist. When the Power Rack is set up on the edge of the pool, this allows the swimmer to push of the wall and swim a distance of 12.5 yards before the cord ends and the weights hit the top of the rack, all while being resisted by whatever weight is set. The swimmer is then pulled back by the weight to the wall, and repeats the exercise for a given amount of times. Each attempt is timed by someone on the pool deck with a stopwatch, and for each stroke there is an optimal time window that they should be in for peak training capacity. If they are going faster then there is not enough weight and if they are going slower the weight is too much and causing their stroke technique to deteriorate. In this study, the times are recorded and divided by the weight carried in order to obtain a "power ratio". It is this power ratio that we are most interested. This study will graph power ratios against swim times over the course of the season to see if there is an increase in power throughout the season, and whether or not that increase in power can be reasonably connected to a drop in swim race times.

2 Definitions and Development

When a swimmer enters the pool, there are many factors that determine the speed at which they swim. Therefore, any correct model for the power generated by a swimmer will be taking into account a large number of variables. When researching this topic, many different models were found which ranged from basic to complex. The basic equations were a good place to start, however more information was needed to produce an accurate working model. The complex models involved fluid dynamics and equations which included variables that were often not defined within the paper itself. This led to difficulties in following their approach, but a few key pieces of information were found. These pieces of information allowed for the production of a model for the velocity of a swimmer which is dependent on a measure of power produced. The first key piece of information is that when a swimmer has reached a constant speed in the water, their propulsive force must be equal to the resistive force of the water. If the velocity of is constant, that means that acceleration must equal zero and therefore the forces must be in balance. It then follows that if models for propulsive and resistant forces could be found, they could be set equal to each other. This condition of zero acceleration is useful when dealing with power racks, because the propulsive and resistive forces reach equilibrium very quickly when training at overload capacity [1], and therefore is an accurate representation of the environment in which the study took place. After settling on a model that was developed with help from a paper from NIU [3], the function that outputs force is as follows in Equation 1:

$$F = L^{3/2} G^{1/2} \mu \emptyset \left(\frac{P}{G \mu L^2}, n\sqrt{\frac{L}{G}} \right) \qquad \text{[Equation 1]}$$

Where L is the length of the swimmer in meters and G is the gravitational constant which is measured in m/s^2. The viscosity of the water μ is measured in $kg\ /\ (m * s)$, while P is the power of the swimmer in watts. Finally, n is the stroke rate in strokes per second, and ∅ is a function which returns a dimensionless constant. Dimensional Analysis can show that the units work out for this model in the following way:

$$m^{3/2} * \frac{m^{1/2}}{s} * \frac{kg}{m * s} * \emptyset \left(\frac{\frac{kg * m^2}{s^3}}{\frac{m}{s^2} * \frac{kg}{m * s} * m^2}, \frac{1}{s} * \sqrt{\frac{m}{\frac{m}{s^2}}} \right) \Rightarrow \frac{m^2 * kg}{m * s^2} * \emptyset \left(\frac{\frac{kg * m^2}{s^3}}{\frac{kg * m^3}{m * s^3}}, \frac{1}{s} * s \right) = \frac{kg * m}{s^2}$$

Similarly, a model for the resistive force of the water on the swimmer was found here in equation 2:

$$R = k \mu v \sqrt{A} \qquad \text{[Equation 2]}$$

Where k is a dimensionless constant similar in function to ∅, μ is still the viscosity, v is the velocity of the swimmer and A is the cross sectional area of their body. Just like with the function for force, we can verify this result using dimensional analysis:

$$R = k \mu v \sqrt{A} \Rightarrow \frac{kg * m}{s^2} = \frac{kg}{m * s} * \frac{m}{s} * \sqrt{m^2} = \frac{kg * m}{s^2}$$

After setting force equal to resistance and solving the equation for velocity, we obtain the following velocity function which is dependent on all previous variables:

$$v = \frac{L^{3/2} G^{1/2} \emptyset \left(\frac{P}{g * \mu * L^2}, n\sqrt{\frac{L}{G}} \right)}{k \sqrt{A}} \qquad \text{[Equation 3]}$$

Only two of these variables are in the control of the swimmer- P and n. In this study, we looked to see if there was a relationship between P and v at several different points throughout the semester. The driving study is to see if there is a significant difference in power throughout the season. If there is, it would point to power increases from weight training like the power rack being a significant contributor to end of season time drops.

3 Results

The sample size of this study was 23, with 12 male swimmers and 11 female swimmers. Each week the athlete performed a certain number of repetitions on the power rack, and the weight and times of each repetition were recorded. Then once the average power ratios for the first and last month of the season were calculated, they were arranged in Table 1.

Table 1- Average Power Ratios and Races Times

Power Ratios			Race Times (100 Free)	
Swimmers	µ of Nov.	µ of Jan.	µ of Nov.	µ of Jan.
1	2.54	4.69	61.70	57.65
2	2.67	4.53	60.83	56.87
3	3.12	5.89	58.51	55.32
4	2.78	4.98	57.87	55.26
5	3.33	5.42	58.41	55.41
6	2.9	5.19	60.18	56.95
7	4.1	6.45	58.03	53.78
8	2.76	4.87	60.27	58.02
9	2.92	5.2	59.34	56.75
10	3.56	5.74	59.03	55.32
11	3.43	5.21	57.32	55.29
12	2.79	4.51	61.24	58.23
13	7.2	7.83	52.20	49.6
14	8.23	9.56	52.06	48.12
15	6.98	7.59	51.90	49.19
16	6.77	7.4	51.27	48.91
17	7.45	8.91	50.89	48.87
18	9.16	11.83	49.20	47.09
19	10.12	13.58	49.93	46.73
20	8	10.2	50.73	47.4
21	8.83	10.57	50.72	48.45
22	9.4	11.9	51.29	47.43
23	8.07	11.04	50.69	47.71

We want to test the hypothesis that the average power ratio for a swimmer on the Carthage Swim Team in November (μ_N) is less than the average power ratio for a Carthage swimmer in January (μ_J). Therefore, if H_0 is the null hypothesis and H_a is the alternative hypothesis, we have

$$H_0: \mu_N = \mu_J$$

$$H_a: \mu_N < \mu_J$$

With $n = 21$ for a sample size, a one-tailed 2 sample T-test was used with a significance level of .05. The resulting t-score is -2.50, and the p-value is .0081$< .05$. Therefore, with a p-value less than the alpha level, we must reject the null hypothesis. We cannot say that there is no change in power throughout the season for Carthage College swimmers.

The second test performed was a regression slope test. If there is a relationship between power ratios and race times, then when plotted against each other the slope of the regression line will be significantly far away from zero at the .05 level. Average power ratios and 100 free times from Table 1 were graphed against each other in two separate scatterplots. Least squares regression lines (LSRL) were calculated for both Figure 1 and Figure 2 and the equations of the LSRL and the R^2 values are displayed on the figures as well.

Figure 1

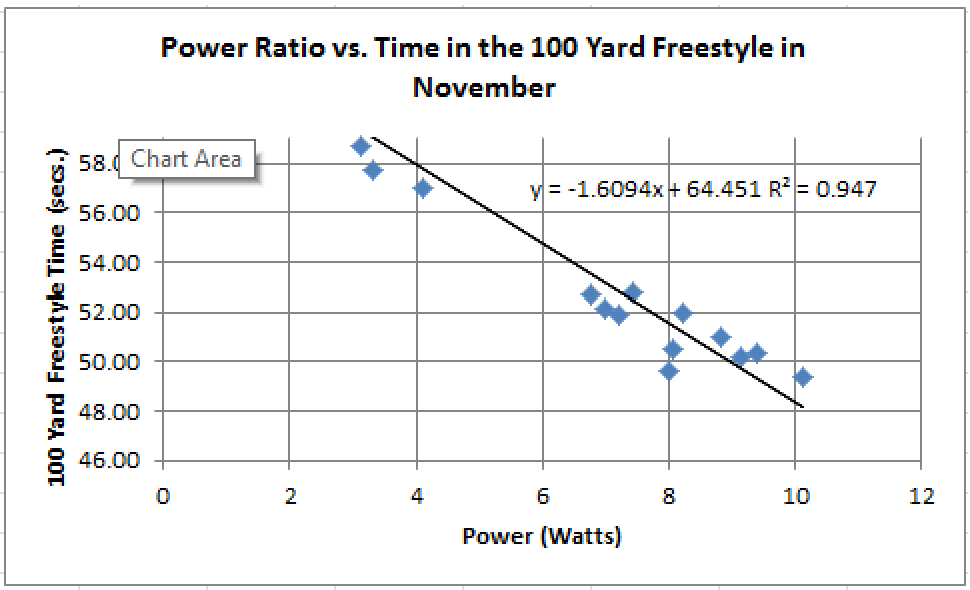
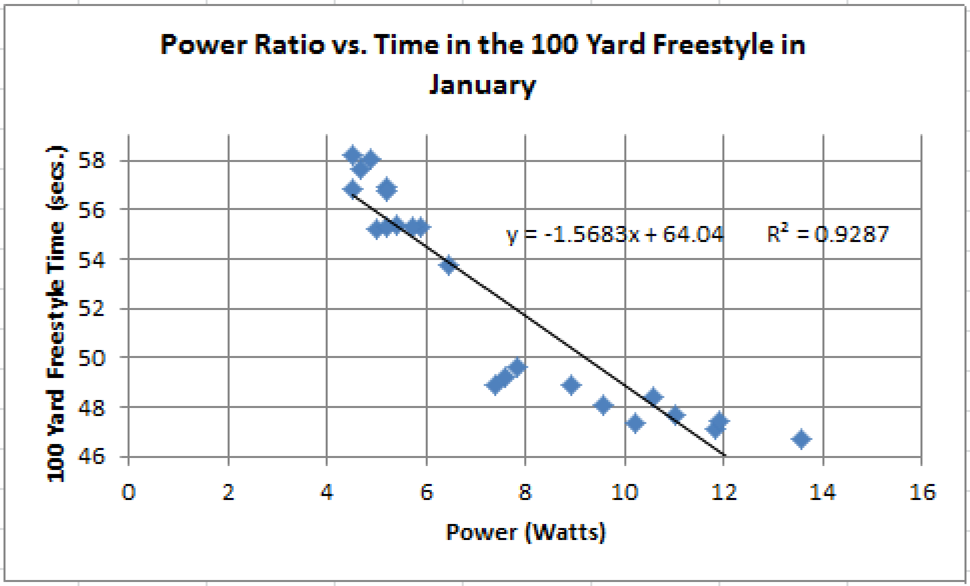


Figure 2



A linear regression T-test was run on both of the data sets, to see if there is significant evidence for an association between power ratios and swim times. Both of the T-tests returned p-values less than $1 * 10^{-10}$, so the null hypothesis must be rejected. It cannot be said that power ratios and swim times in the 100 yard freestyle for Carthage swimmers are not related.

4 Conclusion and Directions for Further Research

Swimming is an activity that has been necessary for the survival of our species since our ancestors crawled out of the ocean depths. In that spirit, the sport of swimming for competition has been equally susceptible to evolution. Due to changing prospective on weight training, the athletes competing in the pool are vastly superior to their peers just a century ago. There are many factors that go into generating power in the pool, but models can be made to approximate the forces at work and give accurate predictions for change.

After collecting power rack data on 23 swimmers participating in the NCAA Division III Swimming Program at Carthage College, it can be concluded that those athletes had significant increases in power from the beginning of the season to the end of the season, and that these increases in power helped them to drop time at the end of the season in a significant capacity.

This study was done on sprint athletes, who use all their energy very quickly on short burst races. It would be very interesting to try this study on long distance swimmers to see if similar conclusions could be drawn about the connection between power and race times. One obstacle to that is that distance swimmers do not typically use power racks for training purposes, so another method of data collection would have to be used. Another interesting area of study would be to try this out on different caliber groups of swimmers. Division I athletes might find ways to translate power gains to the pool better than their age group counterparts, or maybe power would have less effect due to most of their skill coming from near perfect technique and physiology.

References

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[2] Daniel A. Marinho, Tiago M. Barbosa, Vishveshar R. Mantha, Abel I. Rouboa and Antonia J. Silva (2012). Modeling Propelling Force in Swimming Using Numerical Simulations, Fluid Dynamics, Computational Modeling and Applications, Dr. L. Hector Juarez (ed.)