

## Resistance to Fatigue and Success in Competitive Swimming

Steven C. Myers, Los Alamos High School  
Jake A. Bailey, University of Northern Colorado

### Introduction

Developing and training successful competitive swimmers presents a variety of challenges to the modern day coach. The various elements that must be addressed in order to develop a quality swimmer include the following: endurance, speed, stroke technique, strength and flexibility, starts, turns, race pacing strategies, nutrition, and mental preparation. One indicator of an athlete's readiness to compete is their ability to resist excess fatigue as a race progresses (i.e., endurance). Many coaches spend a significant fraction of their training time on developing this important training parameter, and they often feel it is the single most important factor that has contributed to their swimmers success. During the 1970's and 1980's the world witnessed a constant onslaught on world records that appeared to go hand in hand with increases in training yardage, training time, and intensity relative to the methods commonly used by coaches in the 1950's and 1960's.

Several questions arise when one ponders the importance of developing endurance as an aspect of successful swimming. How capable are the best in the world in resisting fatigue as they swim their best times ever? Is there a fundamental difference in the ability of world class swimmers to resist fatigue compared to less accomplished swimmers with similar training histories? Is there a difference between males and females? How much difference is there between the top athletes of the last decade compared to the top swimmers from 35 to 40 years ago?

### Methods

A definition of the notion "resistance to fatigue" is in order. The shortest race in swimming is the 50. The best time any swimmer could hope for in their 100 event is their 50 time multiplied by two. Of course this never happens as there is always some element of fatigue that occurs and the average velocity of a 100 is less than the average velocity of the 50. The same concept applies when comparing a swimmers 100 effort to their 200. Once again, the best that could be hoped for is to achieve a 200 time that is equal to the 100 time multiplied by two. However, an element of fatigue causes the athlete to reduce their average velocity (relative to their 100 velocity) so they can cope with the additional physiological stresses of the longer event. Therefore, physiological fatigue will occur as race distances increase, and resistance to fatigue is the ability to maintain the mean velocity in the longer event as close as possible to the mean velocity of the shorter race. The equation to determine % fatigue is provided below.

$$\% \text{ Fatigue} = \left( \frac{200 \text{ Time} - 2 \times 100 \text{ Time}}{2 \times 100 \text{ Time}} \right) \times 100$$

(Note: 500 to 1650 freestyle comparisons were performed by multiplying the 500 time by a factor of 3.3)

Thanks to the internet there is a huge amount of data that is readily available to help examine these concepts. We decided to compare short course yard data from three classes of swimmers: 1) world class swimmers with the top times ever recorded, 2) NCAA Division III national championship competitors (2001 - 2003), and 3) New Mexico Senior age group state meet

competitors (2001 - 2003). On the USA Swimming website we downloaded the fastest 50 times ever recorded in all events for men and women. Naturally, some of the individuals with the fastest 50 freestyle of all time were also included on the list of those who recorded one of the fastest 100 freestyles of all time. The same is true when we examined the individuals in the 100's and 200's of each stroke. In order to remain unbiased in our approach, we used every data point from each individual that was listed in both events. We computed the percent change in the mean velocity from the shorter race to the longer race for the following pairs of data: 1) the 50 and 100 freestyles, 2) the 100's and 200's of each stroke, and 3) the 500 yard and 1650 yard freestyles. All of our comparisons reported here are from the fastest times in 25 yard pools although we have made a few comparisons from 50 meter pools just to convince ourselves that the results are not substantially different between yards and meters.

On the NCAA website we downloaded the results of the Division III national championships over the last three seasons. Once again, every athlete who competed in both events of a paired data set was included in the analysis. We went back three seasons in order to get a larger sample size for the comparisons to world class swimmers. However, we only included one set of results from athletes who competed in multiple nationals in order to eliminate bias from the data sets. Finally we also downloaded state championship meet results for New Mexico Senior swimmers from the New Mexico Swimming website. Once again we included data from three years in order to bolster our sample size and improve the statistical certainty of the analyses. However, as with the Division III results, we only included one set of results from athletes who competed in multiple state meets. Since these state meets in New Mexico occurred at elevations of 5,000 ft or more, an appropriate elevation correction factor was subtracted from the actual times in events of 200 yards or more (per USA Swimming guidelines). These corrections allow us to compare "apples to apples". New Mexico was chosen because it is the author's home state and because it is a small LSC. Being a small LSC (approximately 850 swimmers), the overall abilities of NM swimmers tend to be weaker than the abilities of world class and Division III athletes.

Finally we also obtained the results of the 1966 Short Course and Long Course AAU National Championships (the authors wish to acknowledge the ISHOF Library for their help in this matter). The year 1966 was pseudo-randomly chosen as a year in the mid-60's time frame which was not an Olympic year. These nationals seemed to be routine in nature as only a handful of new American and World records were established. Therefore, they represent a good snapshot of the abilities of world class swimmers at a point in time when training techniques were quite a bit different than they are today.

In order to draw inferences regarding the differences between two sets of data we performed T-tests on the sample data. The T-statistic is the appropriate statistical test when the samples sizes are relatively small (i.e.,  $< 30$ ). The results of the T-test provide us details about the likelihood that the differences between the two sample sets could have occurred strictly by chance. By convention, differences between two sets of data are considered statistically significant when the probability that they could have occurred by chance alone are less than 5 percent.

## Results

The first set of results include comparisons of the mean percentage of fatigue between world class swimmers and Division III swimmers, as well as comparing world class swimmers to New Mexico state meet competitors. These results are presented in Tables 1 and 2 below. Only one of the 12 comparisons between world class and Division III athletes yielded a significant difference (women's 100 to 200 Breast). This is a strong indication that Division III athletes on the whole have a comparable ability to resist fatigue as world class athletes.

**Table 1: Percent Fatigue in World Class and Division III Swimmers**

Paired Events	Mean % Fatigue: World Class (SD)	Mean % Fatigue: Division III (SD)	T-test Result	Sample Size (WC/D3)
W 50 to 100 Free	9.48% (1.17%)	9.09% (1.33%)	0.904	14/25
W 100 to 200 Free	8.55% (1.15%)	9.02% (1.30%)	-1.210	17/25
W 100 to 200 Back	7.67% (1.45%)	7.63% (1.97%)	0.077	22/25
W 100 to 200 Breast	7.75% (1.24%)	8.81% (1.62%)	-2.831	29/31
W 100 to 200 Fly	9.69% (1.19%)	9.89% (2.07%)	-0.290	11/21
W 500 to 1650 Free	3.88% (0.80%)	4.34% (1.05%)	-1.818	32/22
M 50 to 100 Free	10.44% (1.45%)	10.23% (1.54%)	0.420	18/30
M 100 to 200 Free	10.38% (1.29%)	9.49% (1.40%)	1.798	16/14
M 100 to 200 Back	9.31% (1.57%)	8.59% (1.43%)	1.573	24/20
M 100 to 200 Breast	8.58% (1.02%)	8.65% (1.39%)	-0.199	29/18
M 100 to 200 Fly	10.37% (0.97%)	10.99% (2.36%)	-0.736	9/13
M 500 to 1650 Free	5.08% (0.87%)	5.44% (1.32%)	-1.179	27/28

Notes: Shaded rows indicate a statistically significant difference between data sets. Values in parentheses are standard deviations for the data set.

**Table 2: Percent Fatigue in World Class and New Mexico Senior Swimmers**

Paired Events	Mean % Fatigue: World Class (SD)	Mean % Fatigue: New Mexico (SD)	T-test Result	Sample Size (WC/NM)
W 50 to 100 Free	9.48% (1.17%)	9.15% (1.53%)	0.657	14/17
W 100 to 200 Free	8.55% (1.15%)	6.70% (1.56%)	3.605	17/11
W 100 to 200 Back	7.67% (1.45%)	6.67% (2.27%)	1.732	22/21
W 100 to 200 Breast	7.75% (1.24%)	7.48% (2.04%)	0.574	29/19
W 100 to 200 Fly	9.69% (1.19%)	11.18% (3.06%)	-1.487	11/9
W 500 to 1650 Free	3.88% (0.80%)	5.14% (1.18%)	-4.142	32/13
M 50 to 100 Free	10.44% (1.45%)	9.43% (1.39%)	1.474	18/6
M 100 to 200 Free	10.38% (1.29%)	8.85% (2.45%)	2.196	16/15
M 100 to 200 Back	9.31% (1.57%)	7.96% (2.38%)	2.284	24/22
M 100 to 200 Breast	8.58% (1.02%)	9.68% (2.16%)	-2.327	29/16
M 100 to 200 Fly	10.37% (0.97%)	10.67% (4.30%)	-0.202	9/12
M 500 to 1650 Free	5.08% (0.87%)	5.48% (1.33%)	-1.250	27/20

Notes: Shaded rows indicate a statistically significant difference between data sets. Values in parentheses are standard deviations for the data set.

The comparisons of world class swimmers to New Mexico Senior swimmers yielded five statistically significant results (two of six for the women and three of six for the men). However,

three of the five significant results suggest New Mexico swimmers have a greater resistance to fatigue, while two of the five results suggest the opposite. Taken as a whole the results do not point to a significant trend in either direction. Possible reasons for these inconsistencies could be include both psychological and tactical differences between senior athletes at the New Mexico Short Course Championships and world class swimmers involved in national or international championships. The short course state meet in New Mexico is rarely the ‘premier’ event for these athletes during their short course season. Furthermore, most of the senior swimmers at these meets are prompted to swim six events over the three-day affair. Therefore, they frequently choose additional events that they would not normally consider swimming at their top competitive meets. That includes 100 yard events for distance swimmers and 200 yard events for sprinters. World class distance swimmers rarely appear on the top 50 list in 100 yard events, and true sprinters only appear infrequently on the top 50 lists in the 200 yard events. However, these are common occurrences at the New Mexico short course championships.

Our next group of results compares the mean percentage of fatigue between world class men and world class women. The results of these six comparisons are presented in Table 3. There is a statistically significant difference in four out of the six comparisons, with the women consistently exhibiting a lower percentage of fatigue than the men. This is a strong indication that women are better able than men to maintain relatively high racing velocities as the distance of the race increases.

**Table 3: Percent Fatigue in World Class Men and World Class Women**

<b>Paired Events</b>	<b>Mean % Fatigue: World Class Men (SD)</b>	<b>Mean % Fatigue: World Class Women (SD)</b>	<b>T-test Result</b>	<b>Sample Size (Men/Women)</b>
50 to 100 Free	10.44% (1.45%)	9.48% (1.17%)	2.004	18/14
100 to 200 Free	10.38% (1.29%)	8.55% (1.15%)	4.309	16/17
100 to 200 Back	9.31% (1.57%)	7.67% (1.45%)	3.672	24/22
100 to 200 Breast	8.58% (1.02%)	7.75% (1.24%)	2.802	29/29
100 to 200 Fly	10.37% (0.97%)	9.69% (1.19%)	1.378	9/11
500 to 1650 Free	5.08% (0.87%)	3.88% (0.80%)	5.507	27/32

Notes: Shaded rows indicate a statistically significant difference between data sets. Values in parentheses are standard deviations for the data set.

Finally, Table 4 presents results comparing world class athletes from the all-time top 50 list to the swimmers at the 1966 AAU national championships. Modern day world class athletes exhibit a lower percentage of fatigue in eight out of the 10 comparisons, but only four of those results are statistically significant (Note: The 50 free was not an event at the national championships in 1966, so 50 to 100 freestyle comparisons could not be performed). There is virtually no difference between the groups in their resistance to fatigue when we examine the change in velocity from the 500 free to the 1650 free. Considering all results together, the mean percent difference between these two groups was just 0.92 percent. This is a very small difference considering the relatively large improvements in swimming times between 1966 and today (see Table 5 below). In general, the US Open records have improved between 10-20%, yet only 1% of that improvement has come from an enhanced ability to resist fatigue. It is also worth pointing out that the enhanced ability of female swimmers to resist fatigue better than males was apparent even back in 1966. Furthermore, the percent improvement in women’s US

Open records is consistently better than the percent improvement in the men's records. There are a few potential reasons for this result.

**Table 4: Percent Fatigue in World Class Swimmers and 1966 National Competitors**

Paired Events	Mean % Fatigue: Present World Class Swimmers (SD)	Mean % Fatigue: 1966 Nationals Competitors (SD)	T-test Result	Sample Size (WC/1966)
W 100 to 200 Free	8.55% (1.15%)	9.41% (2.47%)	-1.347	17/29
W 100 to 200 Back	7.67% (1.45%)	8.90% (2.00%)	-2.425	22/28
W 100 to 200 Breast	7.75% (1.24%)	9.66% (2.30%)	-3.961	29/32
W 100 to 200 Fly	9.69% (1.19%)	10.31% (1.97%)	-0.940	11/18
W 500 to 1650 Free	3.88% (0.80%)	3.75% (1.75%)	0.364	32/23
M 100 to 200 Free	10.38% (1.29%)	10.78% (2.11%)	-0.680	16/21
M 100 to 200 Back	9.31% (1.57%)	9.72% (2.18%)	-0.761	24/27
M 100 to 200 Breast	8.58% (1.02%)	9.62% (1.64%)	-2.765	29/22
M 100 to 200 Fly	10.37% (0.97%)	13.33% (3.28%)	-2.611	9/12
M 500 to 1650 Free	5.08% (0.87%)	5.00% (2.38%)	0.156	27/20

**Table 5: Percent Improvement in the US Open Records from 1966 to Present\***

Stroke	100 Yards	200 Yards	500 Yards	1650 Yards
Free (W)	13.03	12.13	16.11	16.16
Free (M)	9.56	9.32	13.01	13.93
Back (W)	21.47	20.34		
Back (M)	16.43	15.83		
Breast (W)	15.05	13.85		
Breast (M)	12.80	15.08		
Fly (W)	15.98	16.61		
Fly (M)	10.48	9.45		

\* Records as of May, 2003.

### **Discussion**

The results in Tables 1 and 2 indicate that there are no substantial differences in the ability to resist fatigue between world class swimmers, Division III swimmers, and New Mexico Senior swimmers. One could conclude that the relative endurance of these different levels of athletes is comparable. However, there is a sizable difference in the velocity at which these different classes of swimmers complete their events. World class swimmers are generally 7 to 10 percent faster than Division III national competitors and approximately 20 percent faster than the average New Mexico Senior swimmer.

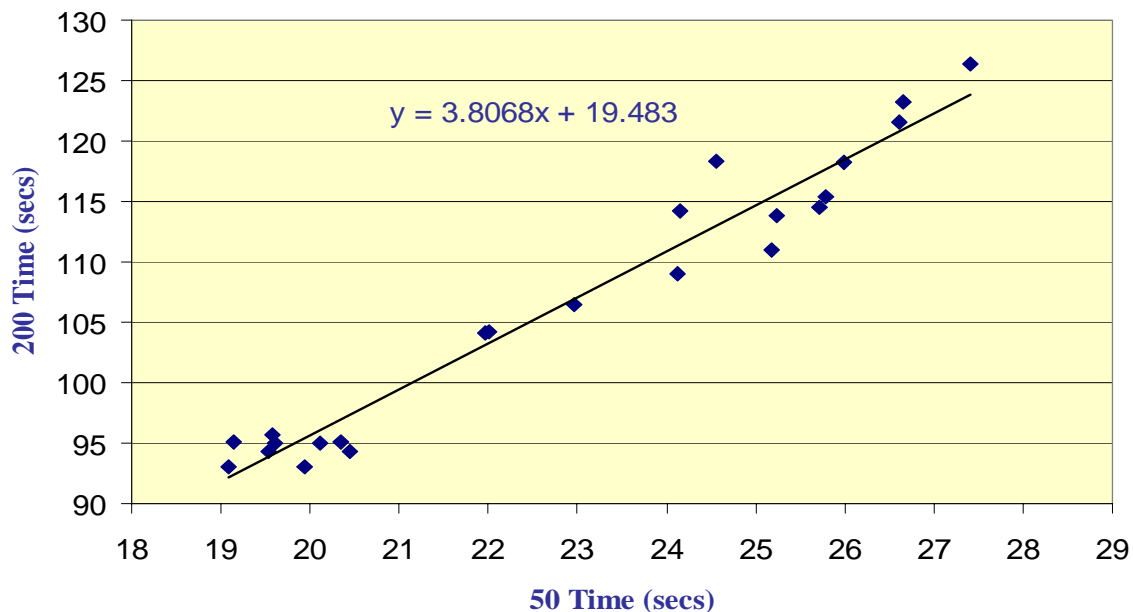
A similar result was obtained while examining the resistance to fatigue between national caliber swimmers in 1966 and the best swimmers of the last decade. There is only a slight trend that athletes of this era can resist fatigue better than athletes from 1966. However, a quick look back at table 5 reminds us that swimmers today are going a lot faster than they were in 1966. The fact that the ability to resist fatigue has only improved a small amount (~ 1%) between now and then is particularly intriguing given the fact that modern training regimes tend to involve more

training time and swimming volumes than the methods of the mid-1960's. Perhaps there are limits to our ability to resist fatigue that cannot be influenced by additional training.

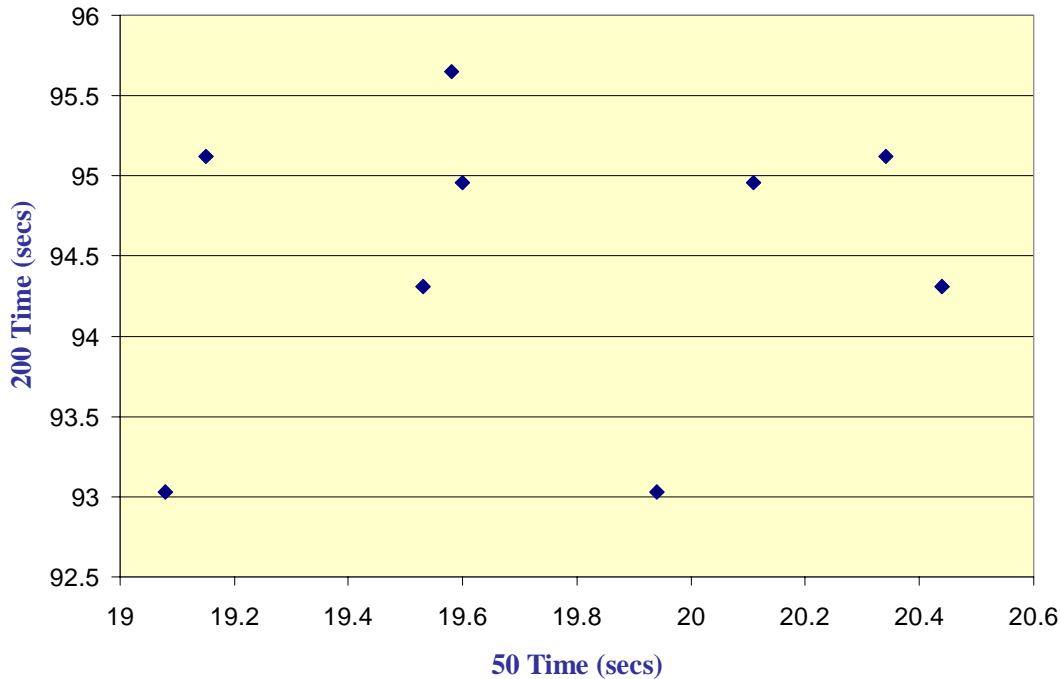
Taken as a whole, our results offer strong evidence that the best in the world today are faster than their slower counterparts because they can generate significantly higher velocities, not because they can maintain a higher percentage of their maximum velocity over the duration of their events. It is most likely that if you race two swimmers with the same velocity the one with greater endurance will usually prevail. However, if you race two swimmers with the same endurance, the one with a heightened ability to generate velocity will usually win. And it is the quality of velocity that separates world class swimmers from Division III swimmers and Division III swimmers from New Mexico swimmers, not the quality of endurance. We have examined a small subset of data from the 10 and under category in New Mexico and found that even young swimmers are sometimes able to maintain a similar percentage of their 100 free velocity in a 200 free event as world class swimmers.

Figure 1 below presents a pairing of individual swimmers 50 free times to their 200 free time. The relationship established by this "macro-view" is nearly linear and the conclusions from it are clear; swimmers who have the fastest 50 times also have the fastest 200 times. However, if you were to take a small clustered subset of this data (see Figure 2) the relationship breaks down. Freestylers with 50 times between 19.0 and 20.5 all have very fast 200 times, but one cannot predict the ranking in the 200 free by their rank in the 50 free. But the point to be made is that if you wish to be competitive with the best 200 freestylers of all time, then you need to be able to generate velocities of 20 seconds or better in the 50 free. A male who can only swim a 22.0 in the 50 free will never be competitive with the fastest 200 free swimmers in the world.

**Figure 1: Relationship Between 50 Free and 200 Free**



**Figure 2: World Class Men: 50 Free Vs 200 Free**



Other elements besides raw velocity can influence the success a swimmer achieves in a 200 yard event: race pacing strategies, start and turn transitions, physiologic endurance, and stroke technique efficiency come to mind. However, in the “macro-view” we present in Figure 1, their impact on the final result does not appear to be as profound as the simple ability to produce high velocities in a shorter time frame. Given this information it behooves the modern day coach to ask specifically, “What are the qualities of velocity?” and “How do I train/coach in order to have the greatest impact on those qualities?” In swimming, velocity can be easily expressed as the product of the stroke rate times the distance per stroke ( $SR \times DPS$ ). Previous research has consistently demonstrated that increasing DPS is most likely to lead to improvements in velocity than increases in SR (Craig, et al 1985 and Kennedy, et al 1990). Indeed, even young age group swimmers can often swim at the same stroke rates of Olympic caliber swimmers (Myers, 1981). The ability to swim at greater distance per stroke is usually the quality that separates the most successful swimmers from the rest.

Another fundamental way to express velocity is as force divided by drag ( $F \div D$ ). One can easily recite a number of common methods used by coaches today that will enhance the athlete’s ability to generate force: hand paddles, fins, drag suits, parachutes, tethered swimming, and a huge variety of dryland strength routines, to name a few. Although some of these methods were used by coaches in the 1960’s, their use was not nearly as widespread as today (Colwin, 2001). The ability to reduce drag should also have a profound effect on increasing velocity as well. The design of competitive swim suits today clearly offers less friction drag than the suits of the 1960’s. However, frontal alignment and wave drag are also major components of the total amount of drag experienced by the swimmer. Stroke techniques that reduce these elements of drag are currently being investigated by many of our top coaches today. The evidence is strong

that once a swimmer can generate forces adequate to produce high velocities, that substantial increases in velocity are limited by the ability to reduce drag. Professional engineers will attest that this is also true of a variety of vehicles that attempt to move through a fluid medium (e.g., boats, cars, airplanes). Ultimately, drag becomes the limiting factor on further increases at very high velocities.

Although it doesn't appear that modern training methods have significantly enhanced the ability to resist fatigue compared to methods of the 1960's, one cannot deny that we are doing something that is enabling our athletes to swim considerably faster than they used to. Perhaps the net effect of additional practice yardage and training time is that there is a correspondingly greater adaptation to the qualities that enhance velocity. Other practices that have probably enhanced our athlete's level of performance over the last several decades also include the teaching of modern stroke techniques, improved swim suit design, and dryland training. The modern coach's greatest challenge is to identify the training methods that will have the greatest impact on developing velocity. We are not proposing that endurance training is unimportant - it may in fact have a significant side benefit of increasing overall swimming velocity. However, it appears prudent to question whether endurance oriented training is the best way to enhance swimming velocity. It's also possible that there may be a variety of "correct" answers from one swimmer to the next.

Another interesting result of this study is the evidence that women swimmers can resist fatigue better than men. There are a couple possible explanations for this: 1) men are less likely to have the physiologic characteristics to resist fatigue, or 2) women are more efficient swimmers than men. The results of previous research by Pendergast, et al (1979) indicate that the second explanation is more plausible. Their study concluded that females are more efficient swimmers than males largely because of the higher distribution of body fat in the hips and legs which enables the lower half of the body to maintain a streamlined body position at the surface with less energy expended. Furthermore, the percent improvement in women's US Open records is consistently better than the percent improvement in the men's records. One plausible explanation is that women swimmers are currently doing a lot more dryland training than their 1966 counterparts. Physical strength is a more of a natural quality for men than for women, but it is an important component in order to generate adequate forces for fast swimming. It is possible that women have improved more than men because they have improved their abilities to apply force more than men. It is also possible that the improvements in swim suit design have impacted women's swimming more than men's simply because of the greater amount of fabric involved in a women's suit.

### **Summary**

There appears to be no substantial differences in the ability to resist fatigue between world class swimmers, Division III collegiate swimmers, and New Mexico senior swimmers. Given that there are large differences in their competitive times in all events, we propose that the ability to generate velocity is the quality that separates these groups from one another. Furthermore, the ability to resist fatigue has only improved a small amount since 1966, although US Open records have improved considerably. It appears that the net effect of modern training routines has been to improve the velocity abilities of modern swimmers more than endurance characteristics compared to the mid-60's. We also conclude that female swimmers can resist fatigue better than males. The likely reason is that females have a higher level of mechanical efficiency (that they come by naturally) than males. Females have also reduced the US Open records more than

males since 1966. We project that this is due to potential improvements in force production as well as enhancements in drag reduction from modern swim suit designs.

## **References**

1. *Quantitative analysis of the front crawl in men and women*, Pendergast, D.R., Di Prampero, P.E., Craig, A.B. Jr, Wilson, D.R., and Rennie, D.W., 1979, *Journal of Applied Physiology*, Vol 43, Issue 3 475-479.
2. *Analysis of male and female Olympic swimmers in the 100-meter events*. Kennedy, P., Brown, P., Chengalur, S. N., & Nelson, R. C. (1990). *International Journal of Sport Biomechanics*, 6, 187-197.
3. *Breakthrough Swimming*, Colwin, C. March, 2002, Human Kinetics Publishers, Inc., Champaign, IL.
4. *Velocity, stroke rate, and distance per stroke during elite swimming competition*. Craig, A., Skehan, P.L., Pawelczyk, J.A. and Boomer, W.L. (1985). *Medicine and Science in Sports and Exercise*. 17 (6): 625-634.
5. *Stroke Rate, Distance Per Stroke, and Velocity Relationships in Male and Female Age Group Swimmers*. Myers, S.C. Master's Thesis submitted in 1981, State University of New York at Buffalo, Buffalo, NY.
6. *Probability and Statistics for Engineers*, Miller, I., Freund, J.E., and Johnson, R.A. 1990 by Prentice-Hall, Inc., Englewood Cliffs, NJ.