Swimming Needs Radical Change: Rationale for a Second Scientific Era

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Swimming world records have improved very little in the past 40 years - about one-quarter of a second per 100 meters per Olympiad (Figure 1). The current rate of improvement suggests that swimmers are “approaching the limits of human performance” (Kilgore & Gimbalvo, 2024), which may be true if there is no intervention. However, “scientific developments . . . have allowed for an almost complete picture of the complex network of factors that explain swimming performance” (Vilas-Boas, 2023) and can provide the needed intervention.

For example, from 1956 to 1980 (the first scientific era), records improved by almost two seconds per 100 meters per Olympiad. More recently, in the Olympiads of 2008 and 2012, world record improvements were noticeably above the mean of the last 40 years - and swimmers wore the now illegal, buoyant swimsuits - developed using science.

During this same period, there have been many scientific advancements that are legal - although unused or rarely used. Incorporating these advancements into a training program could have a very substantial impact on performance. Swimming needs a second scientific era where using science-based advancements is prioritized.

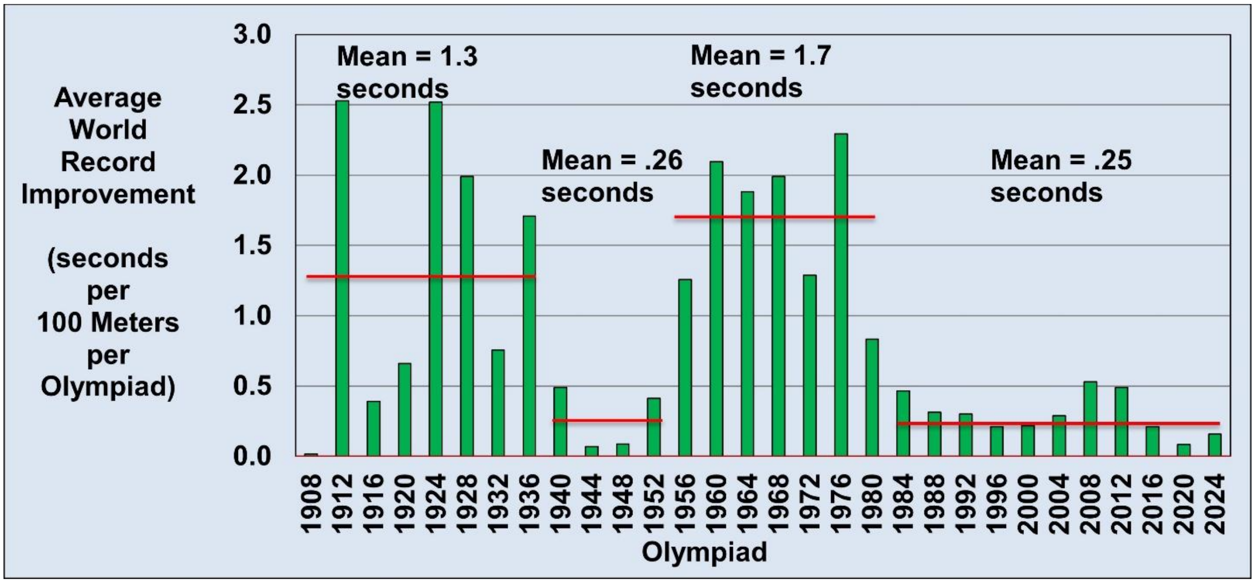


Figure 1. The graph shows the improvement in world records for all events per 100 meters per Olympiad.

Example of the Men’s 100 Meter Freestyle

The men’s 100 meter freestyle is an example of the slowing rate of improvement and the need for change (Figure 2). In the preface to his 1968 *Science of Swimming*, Doc

Counsilman suggested that a 40 second 100 meter freestyle was possible. (As a scientist, Doc knew how science could improve swimming performance.) If a regression line is drawn through the men's 100 meter freestyle world record data points, it shows a swimmer could achieve Counsilman's prediction. However, with the current approach to training, a swimmer will not achieve Doc's prediction for over 200 years. Science, specifically advancements in strategies for teaching technique and methods for measuring technique can improve world records much sooner.

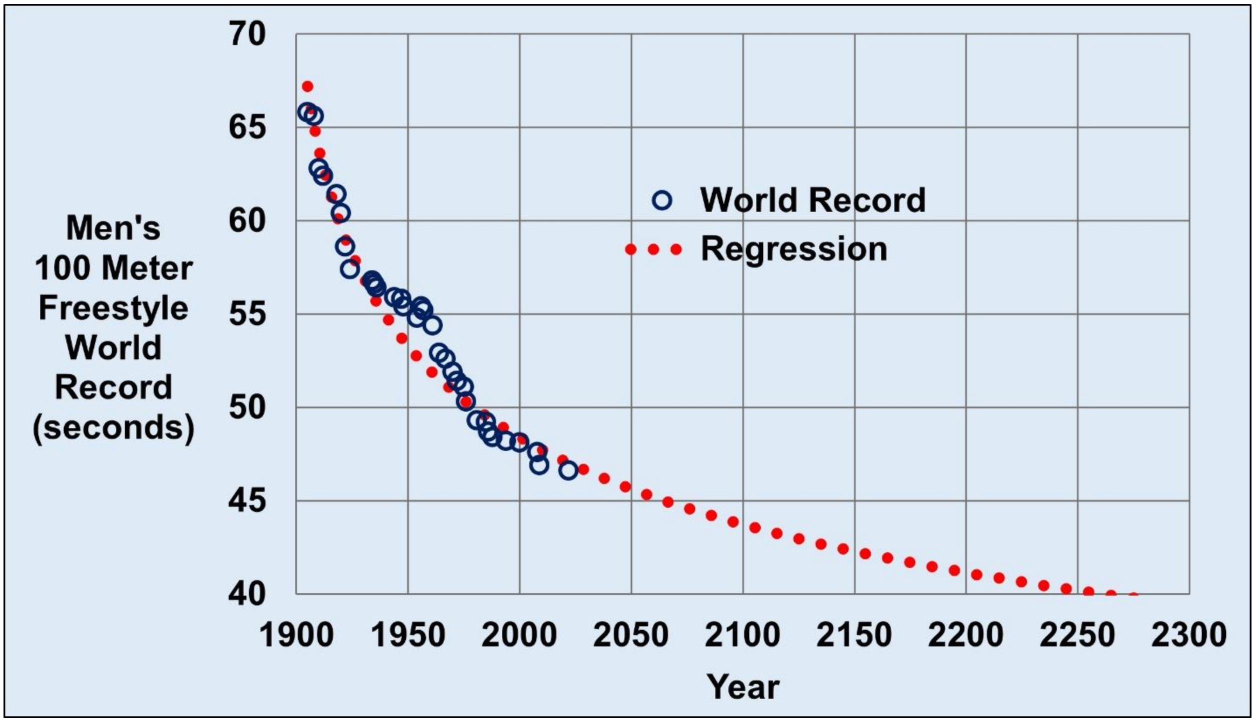


Figure 2. The graph shows the men's 100 meter freestyle world records (blue circles). The regression line (red) shows that rate of improvement has slowed considerably.

Strategies for Teaching Technique

Swimming could benefit greatly from advancements in strategies for teaching technique. One major advancement is attributed to psychologist Dr. Anders Ericsson. He found that experts use "deliberate practice" to become experts (Ericsson, et al., 1993). There are ten components to deliberate practice:

1. **Identification of technique elements to improve**

A coach must first identify technique elements that are most critical for the improvement of each individual.

2. Clear instructions

If the instructions are clear, there will be less chance that a swimmer will misinterpret the information. Instructions can be made clear with:

- Images and videos of an optimal model of technique
- Precise wording of specific visual and kinesthetic cues for each technique element that complement the model

Due to the necessity to maintain a fixed head position, a swimmer must rely on kinesthetic information for most of the stroke cycle, as shown in Figure 3. However, during the time that the arm is within a swimmer's field of view, visual cues are extremely helpful.

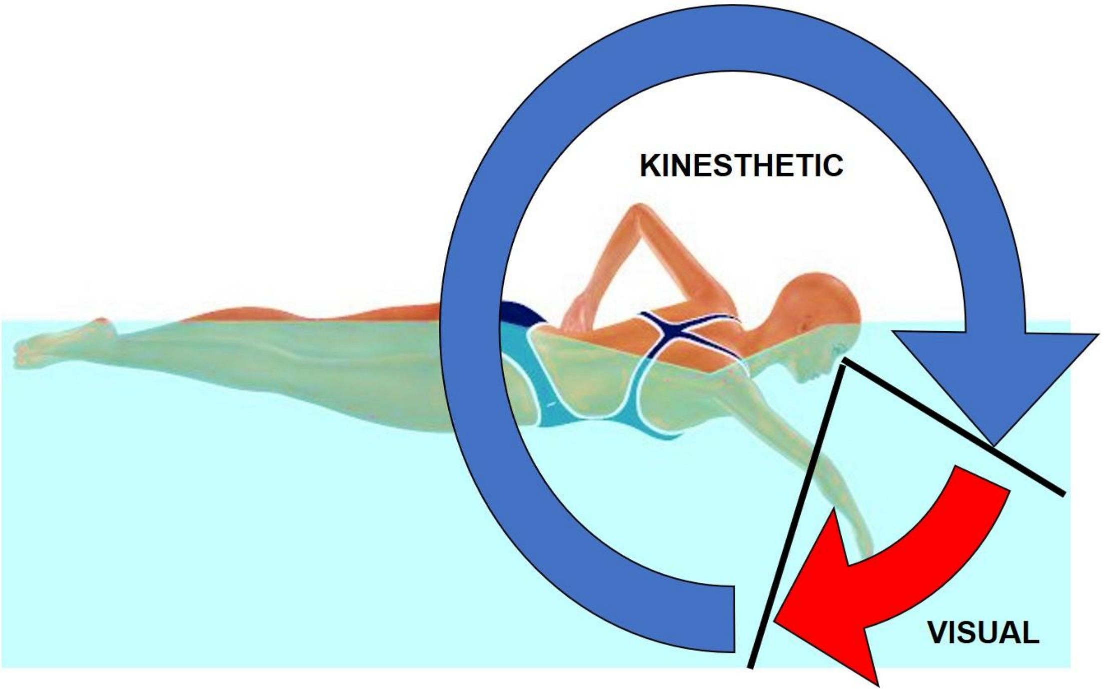


Figure 3. Visual and kinesthetic cues are a clear way to present information to swimmers. Most of the information must be kinesthetic, as a swimmer can only see a small fraction of a stroke cycle.

3. Appropriate task difficulty

The design of the task must be appropriate to each swimmer's skill level. For example, a younger or less-skilled swimmer might only be able to replicate a skill on a non-breathing stroke. The coach can moderate the task difficulty by:

- Adjusting the course distance in a competition pool or by using a non-competition pool (Figure 4)
- Simplifying the skill to isolate specific body parts, such as the arms

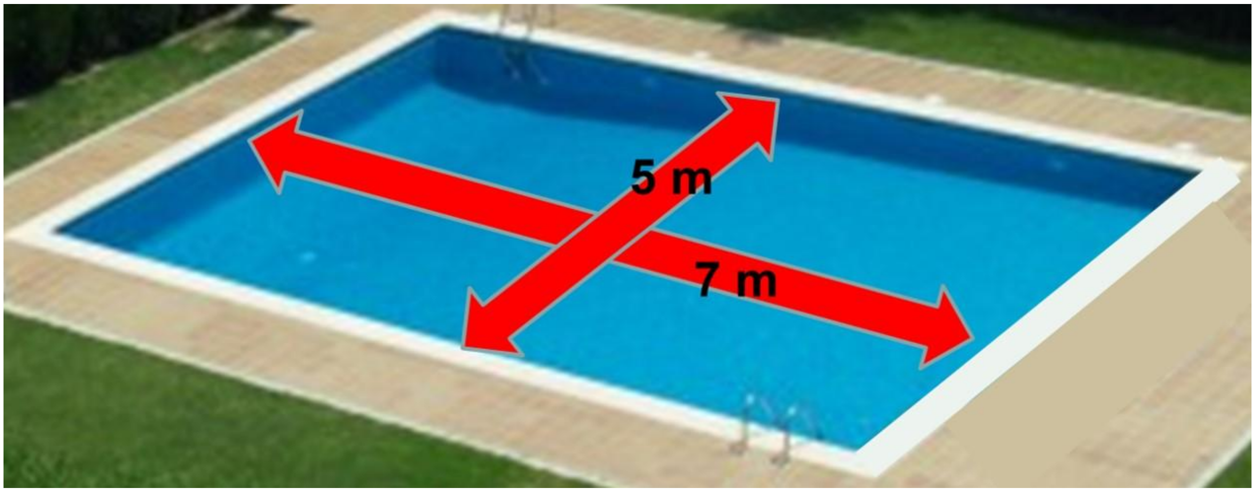


Figure 4. The course distance for the most appropriate task difficulty may be much shorter than a standard competition course for some younger and less-skilled swimmers.

4. A sufficient number of skill repetitions

A swimmer must repeat a specific skill many thousands of times to develop permanency (so that a he/she maintains the skill when racing). There are guidelines to increase the chances of maintaining a specific technique element, including:

- Short-distance swims at a slow stroke rate
- Limited breathing to sustain focus on effective technique
- Swims at increasingly faster stroke rates

5. Immediate feedback

The necessity for immediate feedback is an additional reason for short-distance swims. Options for feedback include:

- Swimmer self-generated feedback about technique while swimming
- Group feedback from coach immediately after swims
- Individual feedback from coach immediately after swims

6. Individualized supervision

As a coach is usually training a group of 20 or more swimmers, it is a challenge to provide individual supervision. However, it remains a critical component of deliberate practice. There are occasional opportunities for a coach to communicate with a swimmer during a swim. However, most of the coach-swimmer communication must occur before or after a swim, such as:

- Reminders before swims about specific cues
- Reinforcement after swims about compliance with cues
- Feedback after swims about non-compliance with cues

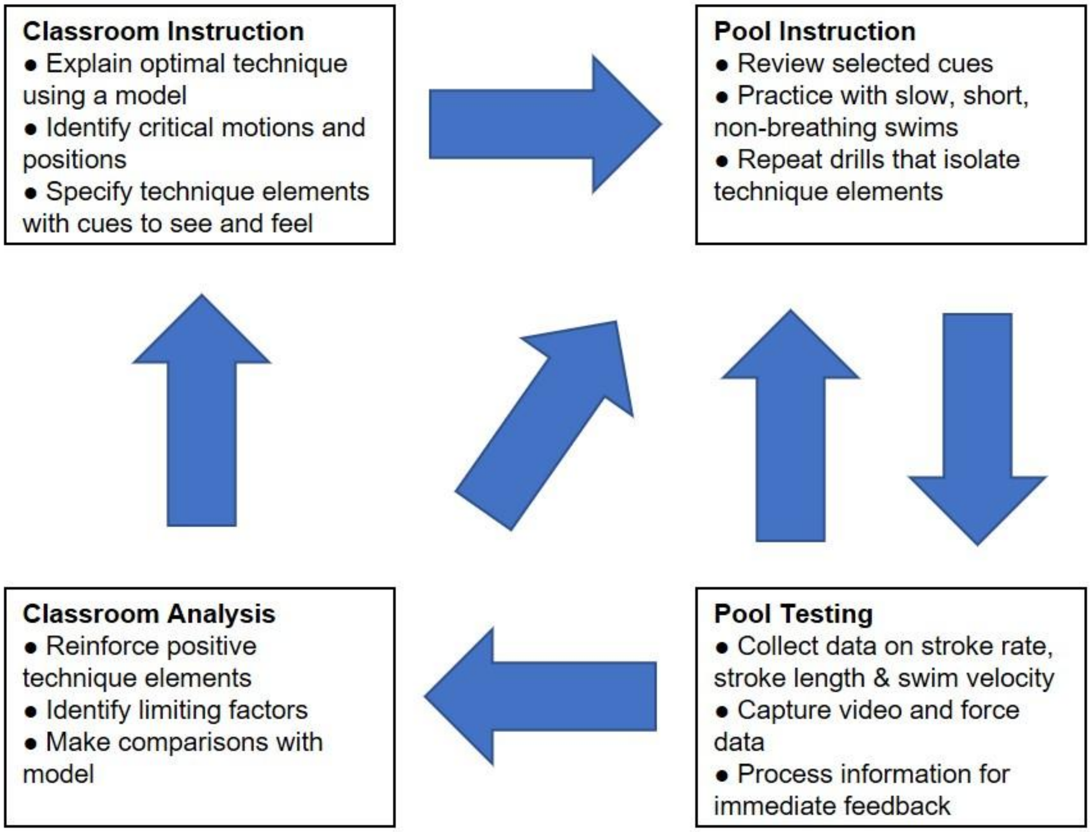
- Assessment of ability to swim with correct technique at faster speeds and greater fatigue
- Decision of when to introduce new technique refinement

7. A variety of learning strategies

A classroom offers an environment with less distractions than a pool and using a classroom might be the most underutilized strategy in competitive swimming. A combination of classroom and pool activities presents the most options for improving technique.

- Classroom instruction using images of optimal technique
- Pool instruction, including drills that isolate focus on select cues
- Pool testing (video, force, velocity, etc)
- Classroom analysis of qualitative and quantitative measures

The diagram in Figure 5 provides details for each strategy.



Classroom Instruction
- Explain optimal technique using a model
- Identify critical motions and positions
- Specify technique elements with cues to see and feel

Pool Instruction
- Review selected cues
- Practice with slow, short, non-breathing swims
- Repeat drills that isolate technique elements

Classroom Analysis
- Reinforce positive technique elements
- Identify limiting factors
- Make comparisons with model

Pool Testing
- Collect data on stroke rate, stroke length & swim velocity
- Capture video and force data
- Process information for immediate feedback

Figure 5. A variety of learning strategies includes pool and classroom instruction and analysis. The blue arrows show different possible strategy progressions.

8. Stay in cognitive and associative learning stages until skill mastery

It is very easy - and very natural - for most competitive swimmers to swim “automatically” (in the autonomous learning stage), which makes it impossible to practice deliberately. Some strategies that will help swimmers maintain focus are:

- Reminders before swims to focus on cues on every stroke
- Mental rehearsal of cues following swims
- Frequent dialog between the coach and swimmers about the use of cues and the focus on technique

9. Replicate superior performance

It is extremely difficult for a swimmer to replicate superior technique when swimming fast or when fatigued. Swimming many strokes at a slow stroke rate will help, but fatigue and fast swimming are unavoidable. Strategies to help replicate superior performance include:

- Maintaining continual control of movements as stroke rate gradually increases
- Maintaining focus when swimming fast or when fatigued

10. Engage in solo practice

Solo practice removes many of the distractions of a typical team training session, as shown in Figure 6. Some tips to benefit the most from solo practice are:

- Do not include a conditioning component
- Swim a short distance at a slow stroke rate with minimal breathing and complete focus on technique
- Rest after each swim until fully recovered and ready to focus

Figure 6. Traditional practice (left) and solo practice (right).

Unfortunately, the components of deliberate practice are generally not applied to a sufficient extent, if at all. However, the potential benefit is considerable.

Impact of Strategies for Teaching Technique

The impact of deliberate practice was determined by comparing the active drag coefficient (the overall best measure of technique) of several studies (Figure 3). The results show that a short-term deliberate practice session (as short as 2 or 4 weeks, red bars) is comparable to a long-term traditional practice session (as long as 2 years, yellow bars).

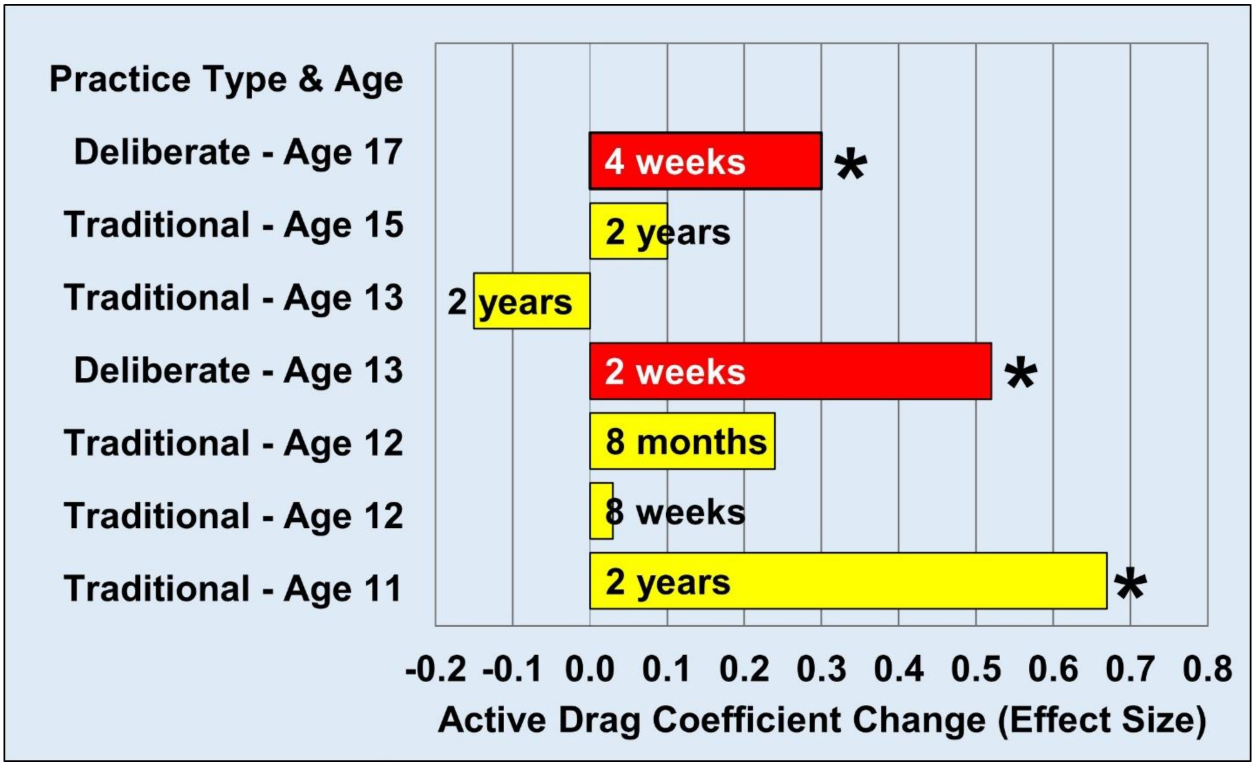


Figure 7. The results from several studies show that a short-term deliberate practice treatment (red bars) is comparable to a long-term traditional treatment (yellow bars). (The active drag coefficient changes are standardized as effect sizes).

Methods for Measuring Technique

Similar to the benefits of applying new teaching strategies, swimmers can benefit from many advancements in measuring technique. Each measurement (in bold) can identify technique limitations and has a particular value:

- **Stroke counts** can determine technique changes (if the swimming velocity is constant).
- The **Index of Coordination** indicates the gap or overlap in arm propulsion (in freestyle and backstroke).
- **Exposure time to shoulder stress** prevents shoulder injury and improves performance (in freestyle and butterfly).
- **Intracycle hand force variations** identify specific technique limitations.
- The **active drag coefficient** is the best overall measure of technique.
- **Stroke cycle phase times** identify general technique limitations when the arm is both in and out of the water.

- **Intracycle velocity variations** pinpoint phases of the stroke cycle with technique limitations.
- The **symmetry index** quantifies bilateral imbalances.

1. Stroke Counts

Stroke counts can provide a crude measure of technique. Usually, a stroke count decreases with a more effective technique, as shown by the difference between regression lines in Figure 8. Usually, a stroke count increases with an increase in swimming velocity, as shown by the increase in both regression lines in Figure 8.

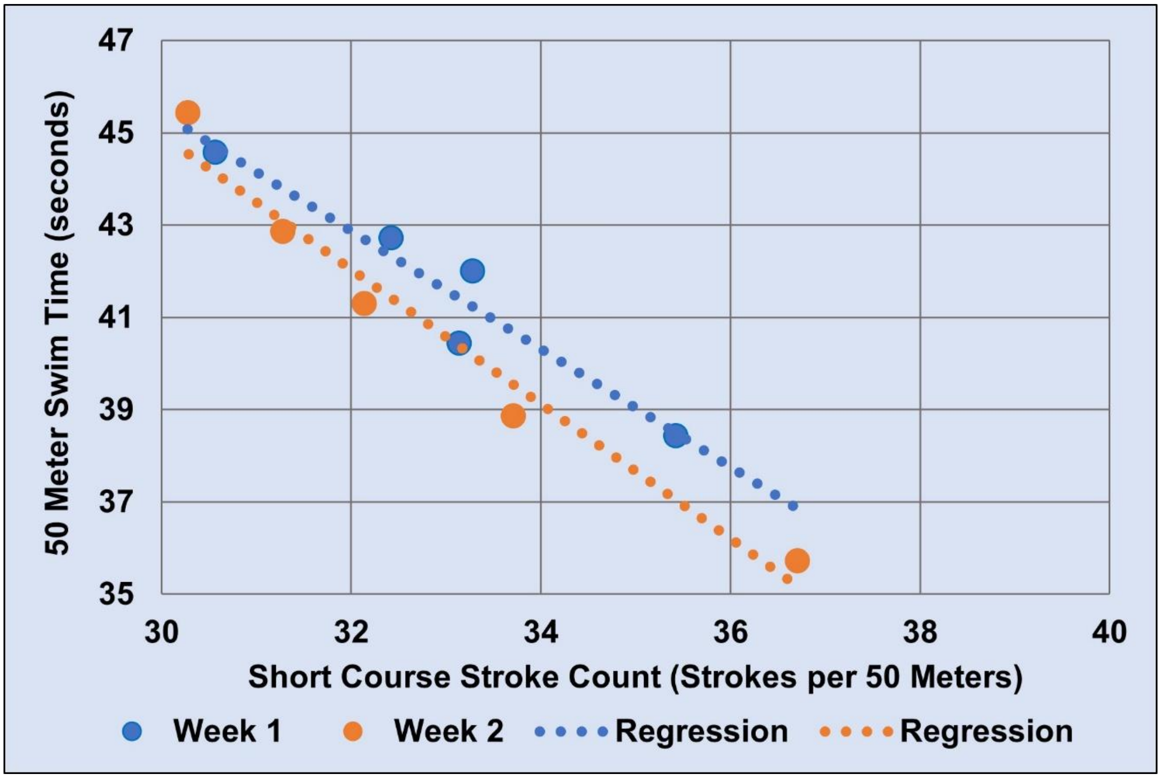


Figure 8. In a two-week study, swimmers decreased their stroke count by about one stroke.

However, there are reasons that stroke counts can be inaccurate or confusing. For example, a stroke count may increase with a more effective technique that has a greater IdC. A stroke count may decrease with an increase in swimming velocity because the technique is more effective.

The advantage of stroke counts is that they are a measurement that swimmers can capture frequently and on their own. The disadvantage is that they may not be accurate. Consequently, stroke counts are recommended but must be monitored to ensure their accuracy.

2. Index of Coordination

There is great potential in adjusting arm coordination, as measured by the Index of Coordination (IdC). Research shows that as the IdC increases so does swimming velocity (Figure 9). However, when the fastest swimmers are swimming their fastest, their IdC is only slightly above zero (1-3 %). An IdC of +20% is possible. The current world record holder swam his world record with a negative IdC (about -10%). If 100 meters can be swum in 46 seconds with a -10% IdC, Counsilman's prediction is certainly possible with a +20% IdC.

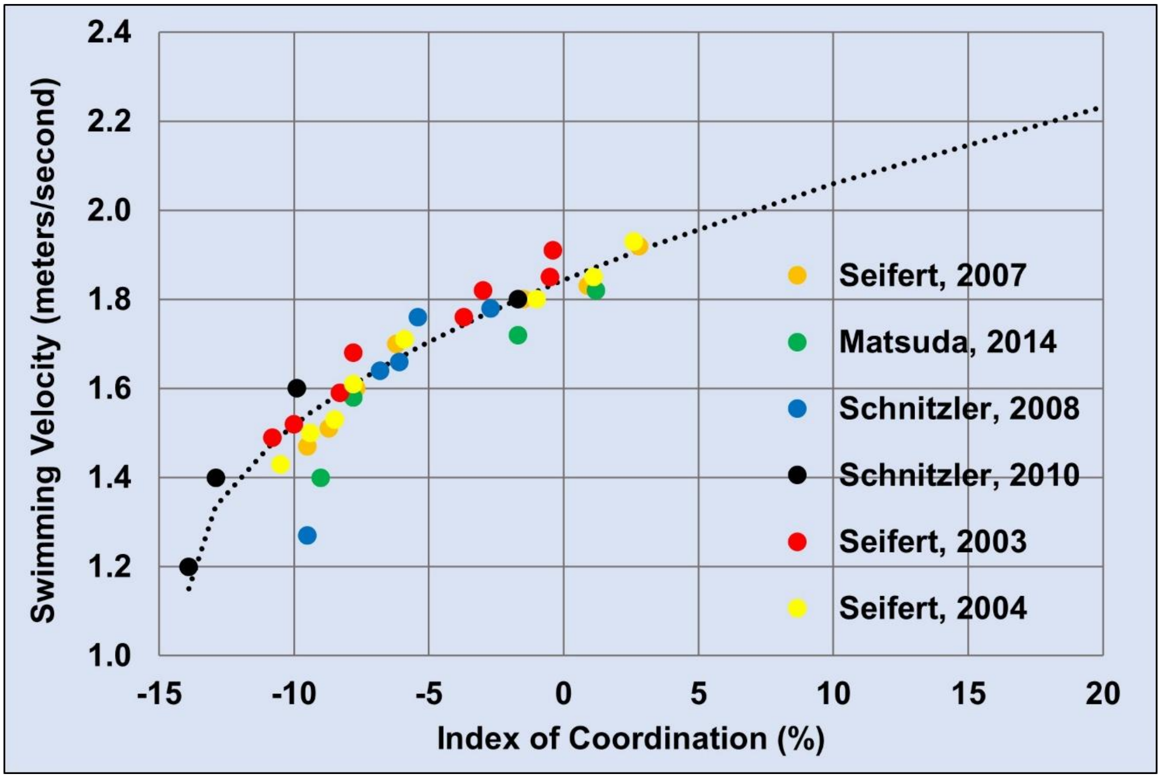


Figure 9. The results of several studies shows that as the Index of Coordination increases, swimming velocity increases.

3. Exposure Time to Shoulder Stress

Exposure time to shoulder stress is important to increase swimming velocity but also to decrease injury rate. University swimmers (70 male and 38 female) were for their exposure time to shoulder stress, Index of Coordination, and swimming velocity (Becker & Havriluk, 2014). The swimmers were divided into two groups based on whether their arm entered the water level with their shoulder (LS) or above their shoulder (AS).

The LS group had a significantly shorter ET and higher IdC for both males and females ($p < .05$). The LS group had a faster SV for both males ($p < .05$) and females (ns). The results show that swimmers benefit from an LS arm entry with a shorter ET (to minimize the risk of shoulder injury) and a higher IdC that can increase SV (Figure 10).

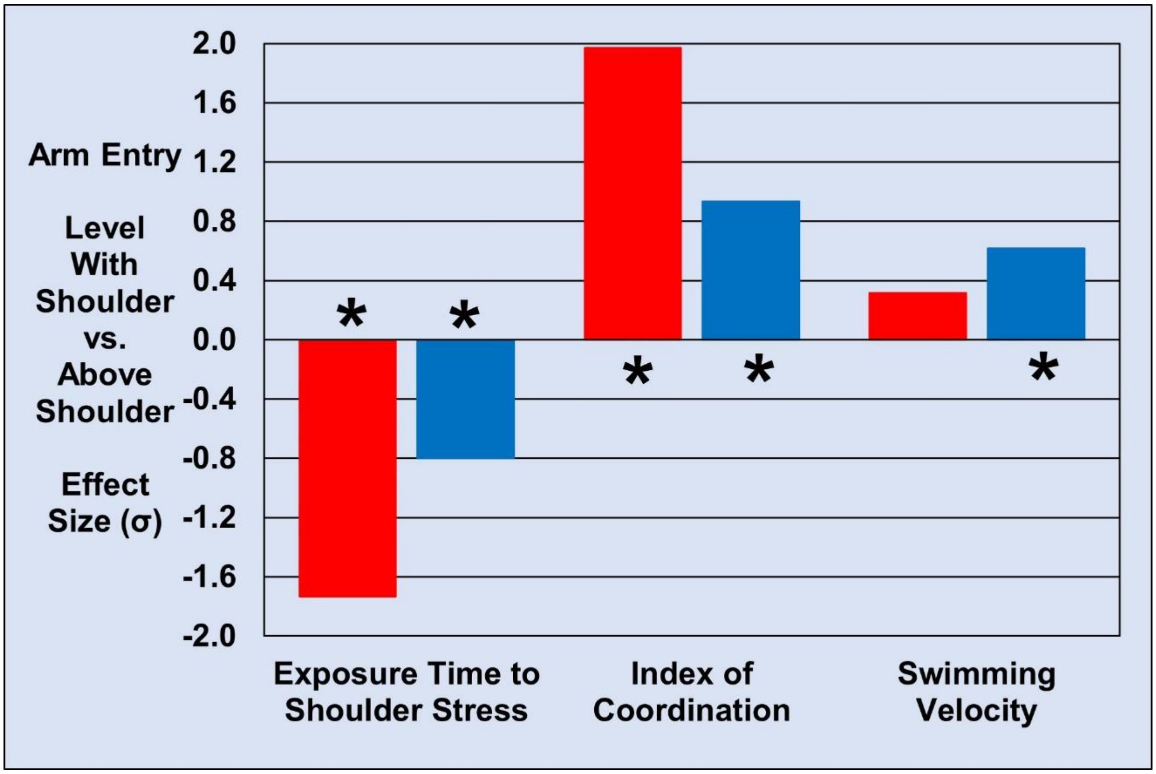


Figure 10. The graph shows the difference between the group of swimmers that entered the water with their arm level with the shoulder and the group of swimmers that entered the water above their shoulder in exposure time to shoulder stress, Index of Coordination, and swimming velocity.

4. Intracycle Hand Force Variations

Research shows that an increase in hand force is consistent with an increase in swimming velocity (Figure 11). However, increasing strength is not the only way to generate more force. Intracycle hand force variations often show that swimmers often fail to increase force at the beginning of the stroke and often lose force in the middle of the stroke (Figure 12). Intracycle hand force variations can often identify technique limitations.

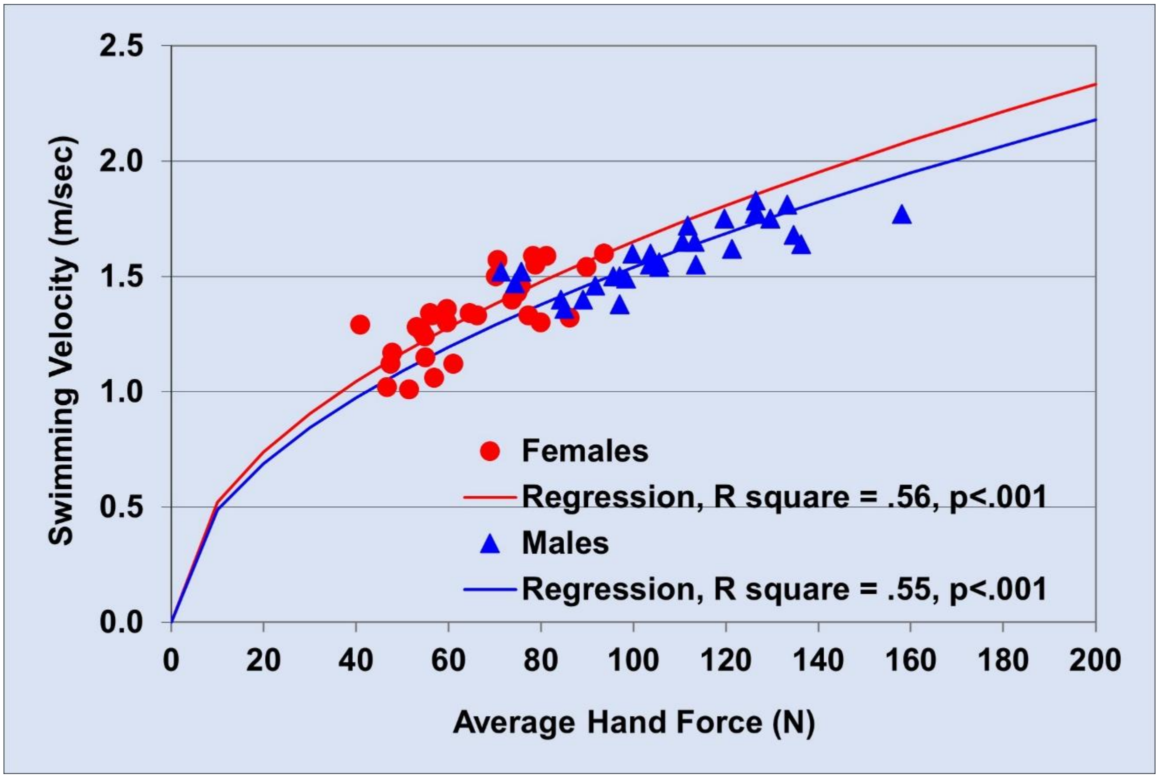


Figure 11. Research shows that an increase in hand force is consistent with an increase in swimming velocity

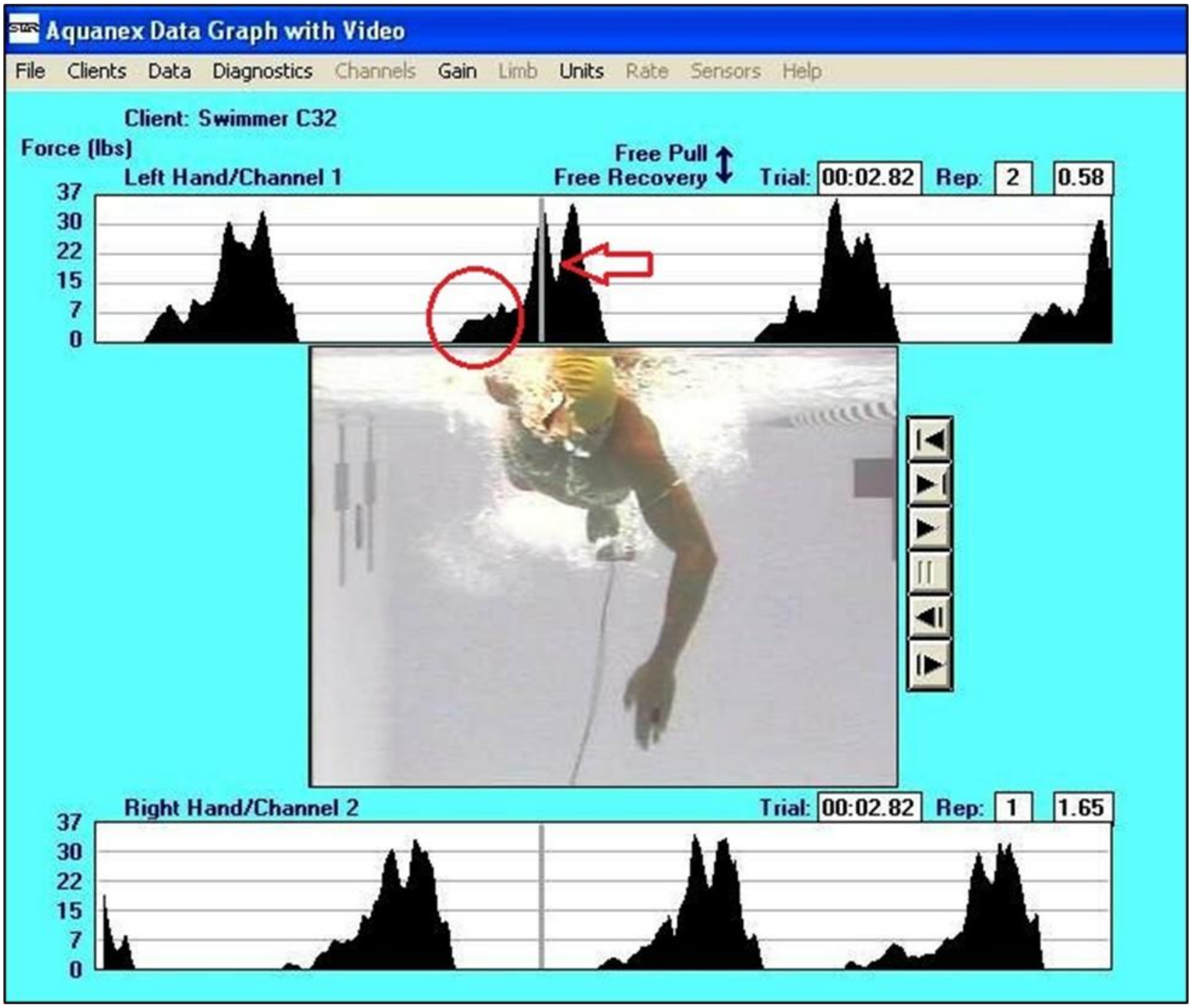


Figure 12. Intracycle hand force variations often show that swimmers often fail to increase force at the beginning of the stroke (red circle) and often lose force in the middle of the stroke (red arrow).

5. Active Drag Coefficient

The active drag coefficient (Cd) is the overall best measure of technique. Research shows that 9 and 10 year old swimmers improve their technique (decrease their Cd), but there is a much smaller change for 11 and 12 year old swimmers (Figure 13). The data shows no technique improvement for teenagers. Measuring the Cd is essential, especially by the time a swimmer approaches the teenage years.

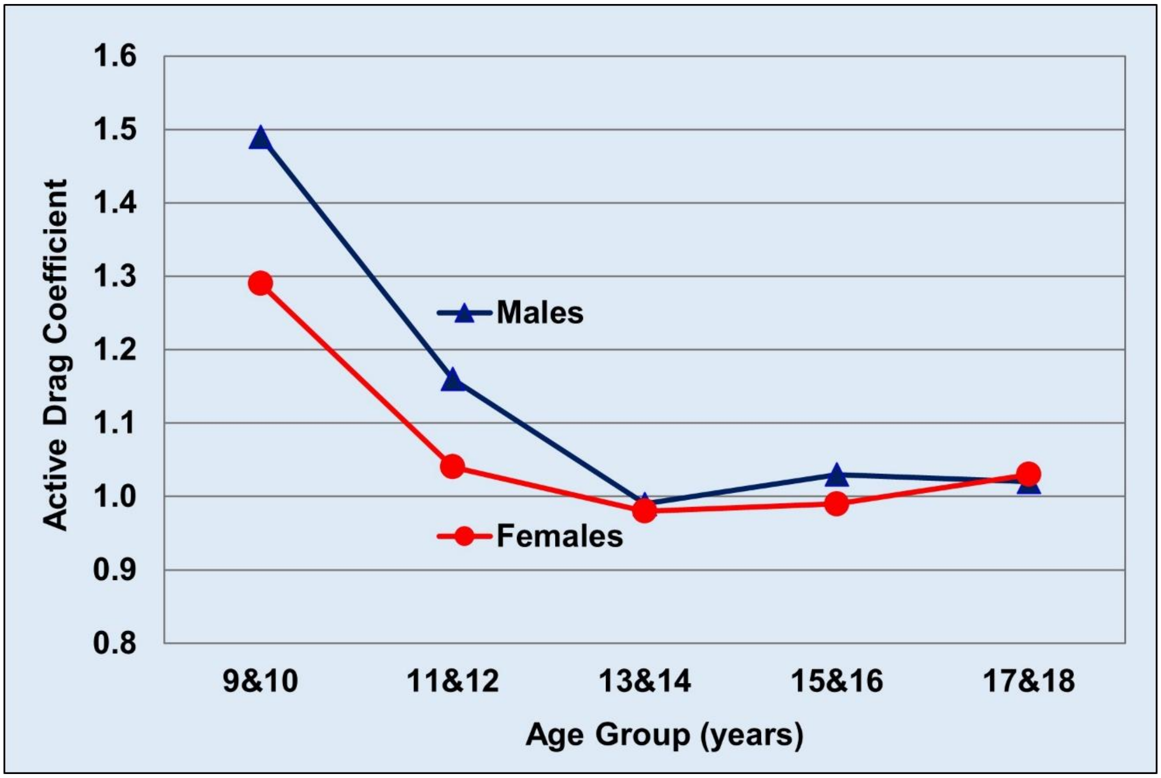


Figure 13. The graph shows the active drag coefficient for males and females of five age groups.

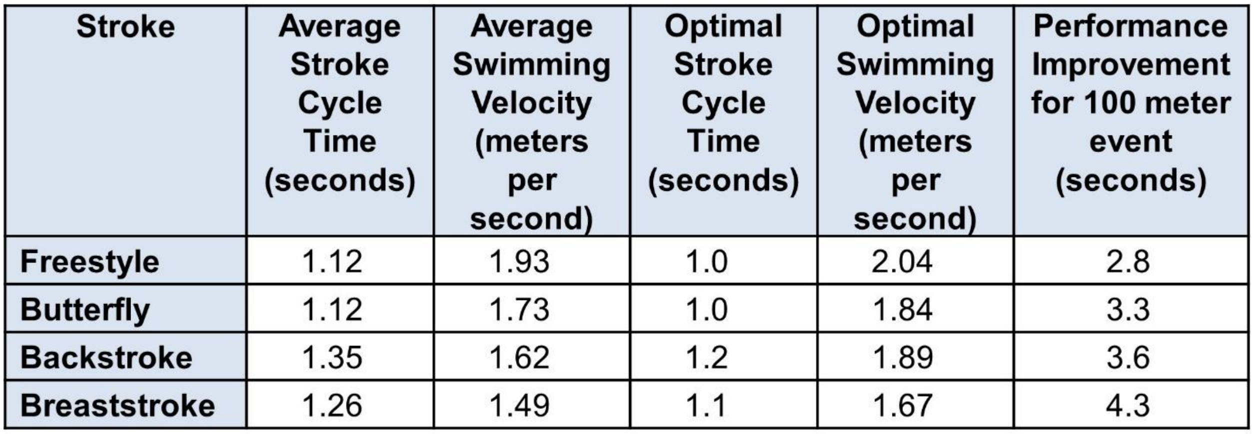
6. Stroke Cycle Phase Times

Stroke cycle phase times identify phases that are shorter or longer than optimal. In many cases, measurement of the recovery phase or entry phase identifies times that are longer than optimal. In many cases, measurement of the push phase identifies times that are shorter than optimal. Table 1 lists the optimal time for each phase of each stroke.

	Stroke Cycle Phase Times (seconds)				
Stroke	**Entry (Glide)**	**Pull (Outward Scull)**	**Push (Inward Scull)**	**Exit (Recovery)**	**Stroke Cycle**
Butterfly	.1	.3	.3	.3	1.0
Backstroke	.1	.3	.3	.5	1.2
Breaststroke	.3	.3	.2	.3	1.1
Freestyle	.1	.3	.3	.3	1.0

Table 1. The optimal stroke cycle phase times for all four strokes.

Table 2 lists the performance improvement using the average stroke cycle times and swimming velocities of college male swimmers and the optimal stroke cycle times and swimming velocities. There is considerable potential in measuring and adjusting stroke phase times.



Stroke	Average Stroke Cycle Time (seconds)	Average Swimming Velocity (meters per second)	Optimal Stroke Cycle Time (seconds)	Optimal Swimming Velocity (meters per second)	Performance Improvement for 100 meter event (seconds)
Freestyle	1.12	1.93	1.0	2.04	2.8
Butterfly	1.12	1.73	1.0	1.84	3.3
Backstroke	1.35	1.62	1.2	1.89	3.6
Breaststroke	1.26	1.49	1.1	1.67	4.3

Table 2. The average and optimal stroke cycle times and swimming velocity for all four strokes.

7. Intracycle Velocity Fluctuations

Research shows considerable variation in the intracycle velocity fluctuations. Usually, freestyle and backstroke velocity vary about .5 meters per second, butterfly varies about 1 meter per second, and breaststroke varies about 1.5 meters per second (Figure 14).

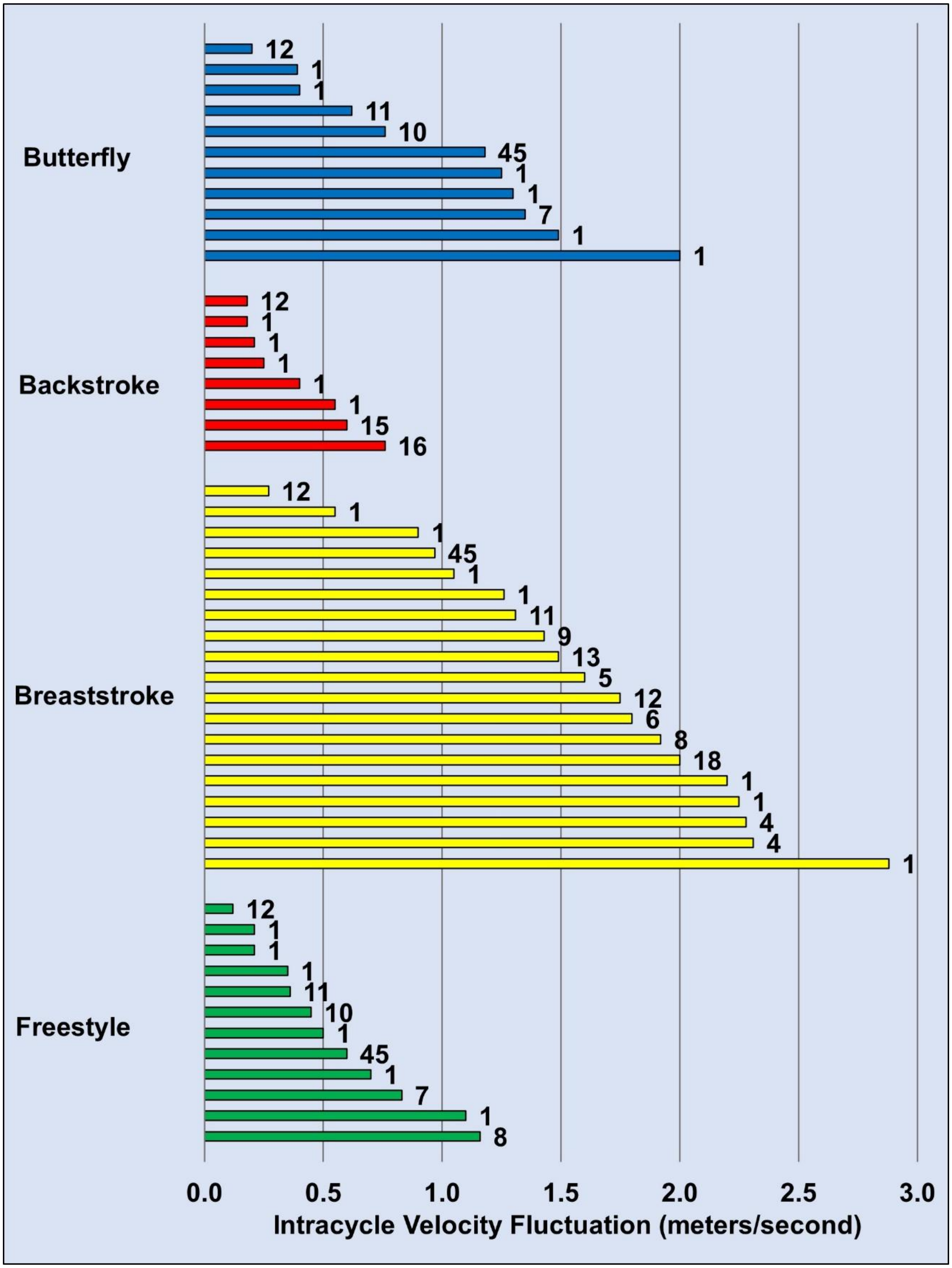


Figure 14. The intracycle velocity variation for all four strokes.

The extreme variations in breaststroke velocity are shown in Figure 15.

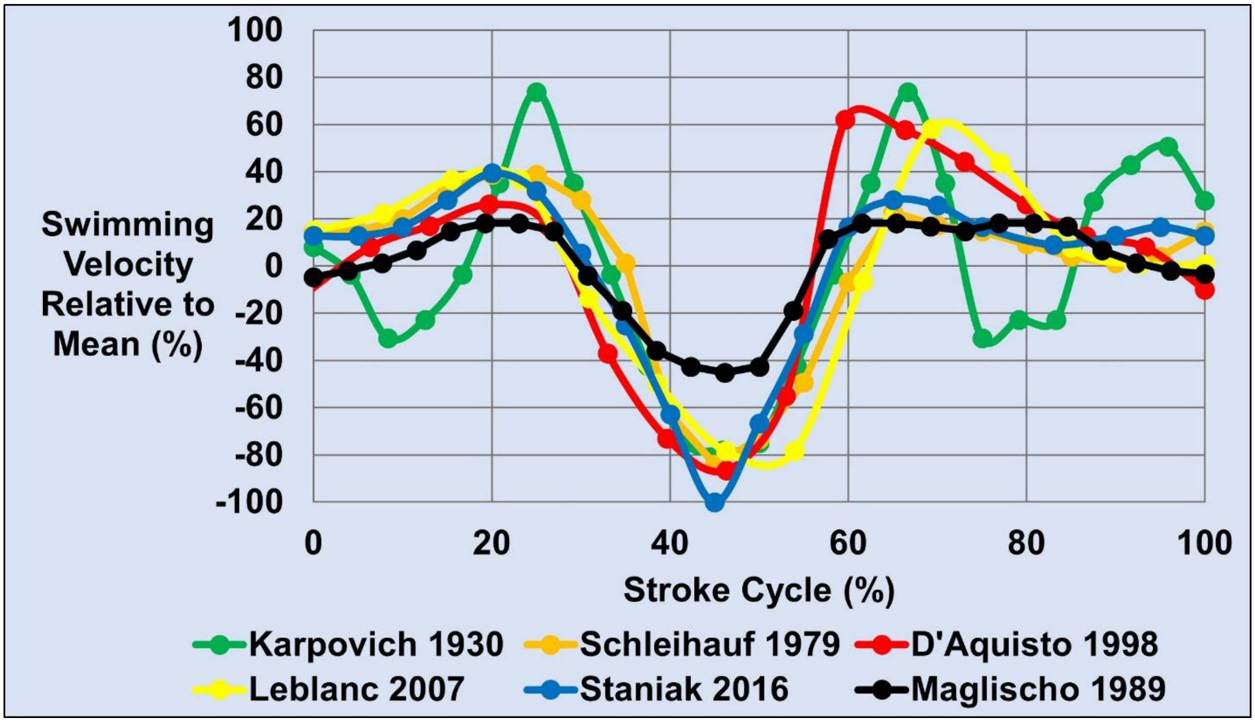


Figure 15. The intracycle velocity variation for breaststroke from 6 studies.

8. Symmetry Index

Bilateral symmetry in hand force was measured by a symmetry index (SI) in butterfly (Pereira, Schutz, Ruschel, Roesler, & Pereira, 2015) and breaststroke (Werlang, Pereira, Ruschel, Pereira, Prado, Schütz, & Roesler, 2017). The SI is the difference between the left and right hand force divided by the average and expressed as a percent. Both studies included adult male and female swimmers. There were 14 swimmers in the butterfly study and 17 swimmers in the breaststroke study.

An SI using the peak force for each hand was calculated in both studies. About one-third of the swimmers had an SI that was more than 10% and classified them as unsymmetrical (Figure 16). Three swimmers had an SI in excess of 30%. While any asymmetry can limit performance, swimmers with the larger SI values must find ways to correct asymmetries to improve performance.

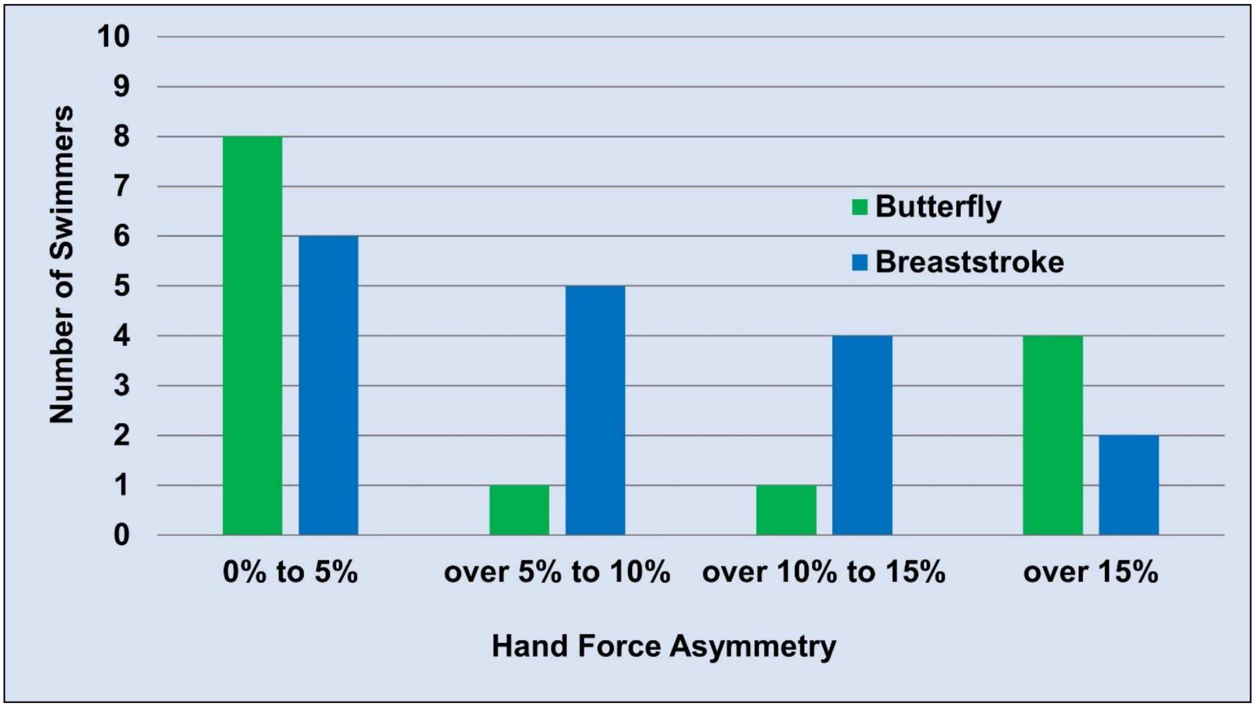


Figure 16. The number of butterfly and breaststroke swimmers by their symmetry index.

The impact of bilateral symmetry on force is shown in Figure 17. The swimmer's left hand is in a stronger position (beneath the thigh and close to the body midline) than the right hand. Consequently, the swimmer averaged about 10 lbs more of peak force with the left hand than the right hand.

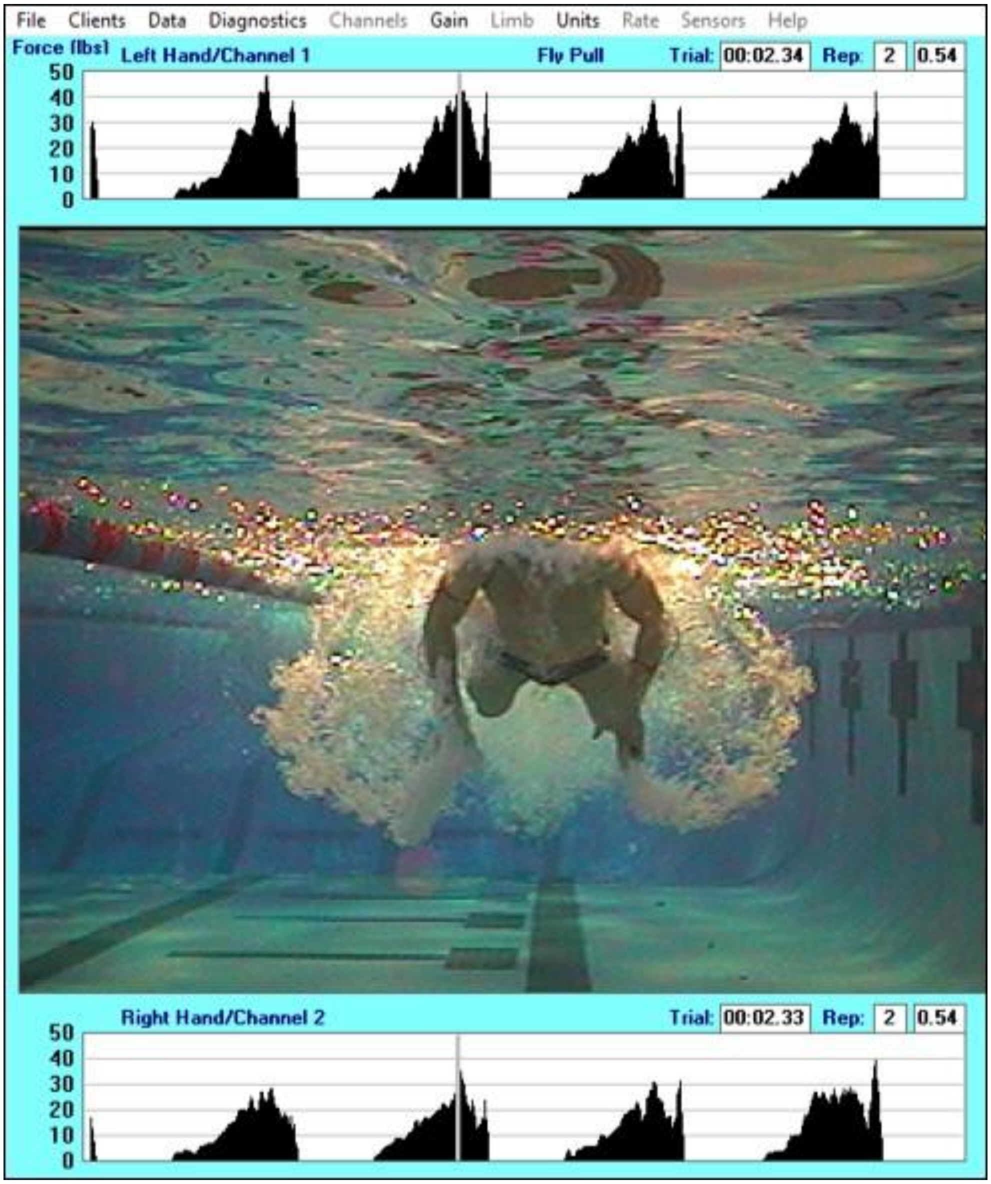


Figure 17. A hand force analysis shows a bilateral difference.

Swimmers need a much greater focus on measuring technique so that:

- they know they need to improve,
- they know what to improve, and
- they know if they improve.

Impact of Methods for Measuring Technique

The need for technique measurement is probably best exemplified by the results of a study on the active drag coefficient (Figure 13). The graph shows that only the youngest swimmers make substantial technique improvement (i.e., decrease their active drag coefficient). However, teenagers show no significant improvement.

Incorporating Scientific Advancements into a Training Program

Most training programs utilize every minute of training time. It is only reasonable to question how the scientific advancements (ten strategies and eight measurements) can be incorporated into an already full training program. The answer often depends on whether the coach is willing to "risk" a radical change. (There is no actual "risk" as the scientific concepts are all well supported by research. However, a coach is likely to see any program change as risky, just because it's different.) Alternatively, a team that doesn't incorporate scientific advancements is not likely to be as competitive.

To make training time available for scientific concepts requires abandoning the conventional wisdom of "more laps means faster swimming." One suggestion is to incorporate Ultra-Short Race Pace Training (USRPT) with the scientific concepts. USRPT requires "race pace" conditioning. Therefore, swimmers should swim a suitable distance in a relatively short amount of time, making available a considerable amount of time for teaching strategies and measuring methods.

An example of time allocation for a week of two-hour training sessions with a 15-18 age group is shown in Table 3. A schedule for the analysis time (technique measurements) is shown in Table 4. The strategies for teaching technique and methods for measuring technique should increase the number of effective repetitions and produce faster swimming.

Activity Time Allocation for the 15-18 Age Group		Daily Training Time (minutes)						
#	**Activity**	**Total**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**
1	Classroom or Studio Sessions	50	20			10		20
2	Deck drills	30	10		10		10	
3	Vertical kicks	20	10		10			
4	Kicks without kickboard	20		10				10
5	Kicks with kickboard	60	20		20		20	
6	Swims of 5 yds	N/A						
7	Swims of 7 yds	N/A						
8	Swims of 12 yds	60	20		20		10	
9	Swims of 25 yds	130		20		90		20
10	Swims at specified distance	100		30		20		50
11	Swims with hand paddles	60	20		20		20	
12	Swims at race pace	60	20		20		20	
13	Swims of race distance	40		20				20
14	Swims at race pace & distance	40		20			20	
15	Starts	20			20			
16	Turns	20		20				
17	Relay exchanges	10					20	
	Total	**720**	**120**	**120**	**120**	**120**	**120**	**120**
18	Analysis*	90				90		
19	Solo Practice**	40		20				20

Table 3. Activity time allocation for a week of 15-18 age group training sessions.
*The analysis is scheduled during the “Swims of 25 yds.”
**Solo practice is scheduled separately from team training.

	Age Group				
Analysis	**7-8**	**9-10**	**11-12**	**13-14**	**15-18**
Stroke Counts	Daily	Daily	Daily	Daily	Daily
Index of Coordination	Weekly	Weekly	Weekly	Weekly	Weekly
Intracycle Hand Force Variations		Monthly	Weekly	Weekly	Weekly
Exposure Time to Shoulder Stress			Monthly	Weekly	Weekly
Stroke Cycle Phase Times			Monthly	Monthly	Monthly
Active Drag Coefficient				Monthly	Monthly
Intracycle Velocity Variations					Quarterly
Symmetry Index					Quarterly

Table 4. Schedule for methods for measuring technqe for each age group.

Summary

There are many science-based advancements in strategies for teaching technique and methods for measuring technique that are unused or rarely used and can greatly improve performance. Swimming needs radical change - a second scientific era - to benefit from these advancements.

Author Notes

Dr. Rod Havriluk, a longtime contributor to *Swimming World*, is a sport scientist who specializes in swimming technique instruction and analysis. He consults in-person and remotely, year-round and worldwide. His ebooks, courses, software and videos are available at swimmingtechnology.com. Contact Rod through info@swimmingtechnology.com.

References

Becker, T., & Havriluk, R. (2014). Freestyle arm entry effects on shoulder stress, force generation, and arm synchronization. In B. Mason (Ed.), *Proceedings of the XIIth International Symposium on Biomechanics and Medicine in Swimming*. Australian Institute of Sport, Canberra.

Counsilman, J. E. (1968). Science of Swimming. Prentice Hall.

D'Aquisto, L. J., Costill, D. L., Gehlson, G. M., Wong-Tai Young, M. A., & Ang, G. L. (1988). Breaststroke swimming economy, skill and performance: study of breaststroke mechanics using a computer based" velocity video" system. *J Swim Res*, *4*, 9-13.

Kilgore, A. & Gimbalvo, E. (2024). Fastest, Highest, Strongest. Washington Post.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*(3), 363-406.

Karpovich, P. (1930). Swimming Speed Analyzed. *Scientific American*, *142*, 224.

Leblanc, H., Seifert, L., Baudry, L., & Chollet, D. (2005). Arm-leg coordination in flat breaststroke: a comparative study between elite and non-elite swimmers. *International Journal of Sports Medicine*, 787-797.

Maglischo, E. W., Maglischo, C. W., & Santos, T. R. (1989). Patterns of forward velocity in the four competitive swimming strokes. In *ISBS-Conference Proceedings Archive*.

Matsuda, Y., Yamada, Y., Ikuta, Y., Nomura, T., & Oda, S. (2014). Intracyclic velocity variation and arm coordination for different skilled swimmers in the front crawl. *Journal of human kinetics*, *44*, 67.

Pereira, G. S., Schut, G. R., Ruschel, C., Roesler, H., & Pereira, S. M. (2015). Propulsive force symmetry generated during butterfly swimming. *Revista Brasileira de Cineantropometria & Desempenho Humano*, *17*(6), 704-712.

Schleihauf, R. E., Jr. (1979). A hydrodynamic analysis of swimming propulsion. In J. Terauds & E. W. Bedingfield (Eds.), *Swimming III* (pp. 70-109). Baltimore: University Park Press.

Schnitzler, C., Seifert, L., Ernwein, V., & Chollet, D. (2008). Arm coordination adaptations assessment in swimming. *International journal of sports medicine*, *29*(06), 480-486.

Schnitzler, C., Seifert, L., Alberty, M., & Chollet, D. (2010). Hip velocity and arm coordination in front crawl swimming. *International Journal of Sports Medicine*, 875-881.

Seifert, L., Boulesteix, L., & Chollet, D. (2003). Effect of gender on the adaptation of arm coordination in front crawl. *International Journal of Sports Medicine*, *25*(03), 217-223.

Seifert, L., Chollet, D., & Bardy, B. G. (2004). Effect of swimming velocity on arm coordination in the front crawl: a dynamic analysis. *Journal of sports sciences*, *22*(7), 651-660.

Seifert, L., Chollet, D., & Rouard, A. (2007). Swimming constraints and arm coordination. *Human movement science*, *26*(1), 68-86.

Staniak, Z., Buśko, K., Górski, M., & Pastuszak, A. (2016). Accelerometer profile of motion of the pelvic girdle in breaststroke swimming. *Journal of human kinetics*, *52*(1), 147-156.

Vilas-Boas, J. P. (2023). Swimming biomechanics: from the pool to the lab… and back. *Sports Biomechanics*, 1-23.

Werlang, R. G., Pereira, S. M., Ruschel, C., Pereira, G. S., Prado, A. P. M., Schütz, G. R., & Roesler, H. (2017). Hand force symmetry during breaststroke swimming. *Revista Brasileira de Educação Física e Esporte*, *31*(1), 41-50.