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©THE FUTURE OF SWIMMING: “MYTHS AND SCIENCE”[1]

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Abstract

A brief description of what are and are not acceptable knowledge criteria for swimming coaches is offered. Concern is expressed about the growing magnitude of belief-based coaching principles and advice which have the potential to depreciate coaching quality further. When information is limited to evidence-based research, a rich source of valid and reliable coaching knowledge is available. A sample of the implications of that knowledge is presented and covers the following topics: A physiological emphasis, altitude, lactate, pacing, whole-arm propulsion, and stretching/flexibility. Because of the dissonance between established opinions and the implications of data-based research, mixed reactions in the audience are expected.

The purposes of this presentation are firstly, to discuss briefly scientific information and the types of reasoning frequently exhibited within swimming coaching that lead to misinformation. Recommendations will be made. Secondly, some commonly discussed pseudo-scientific concepts involved in swimming coaching will be reviewed and the latest implications for them from published research will be presented. That is intended to demonstrate the wealth of scientific information that is available on swimming matters but rarely accessed by swimming coaches.

Scientific Information

The quality of any information should be a major concern when deciding on coaching methods and content. It is popular to discuss coaching information in terms of *"science"* but what is often called that actually should be termed *"pseudo-science"*. Elsewhere, this writer has made an in-depth delineation between evidence-based and belief-based coaching knowledge (Rushall, 2003c). Belief-based reasoning is one of the major paths for misinformation and pseudo-science.

For simplicity sake, four sources of information that are often employed when structuring coaching knowledge are listed below. Three methods pertain to *"armchair theorizing*" and are likely to yield both true and mostly false information. The other employs scientific methods to gather data which are analyzed and likely to yield truths.

1. *Appeal to authority*. When *"experts"*, *"respected scientists"*, etc. offer opinions on matters, it is expedient to accept their postulations as truths. Unfortunately, when a scientist (i.e., usually someone who has established a reputation in a specialty) strays outside the area of reputable expertise, opinions offered depreciate very quickly in truthfulness and are often manifested as dogma. Perhaps the best current example of the influence of dogma sweeping

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[1] An invited presentation on September 12, 2009 at the ASCA World Clinic 2009 held in Fort Lauderdale, Florida.

the sports world is the drugs-in-sport movement. Although it is considered rarely, there is no conclusive evidence that shows most banned substances are performance-enhancing[2]. In swimming, we have often relied upon *"experts"* to cast their opinions as a means of determining coaching actions and principles which have eventually been shown to be false (e.g., lift theory, altitude training, lactate testing, straight-arm crawl stroke). This method yields dogma and misinformation, and only occasionally, truths.

2. *Self-evident truths*. There are coaching matters that are so obvious to many that it is determined there is no need to evaluate their reliability or accuracy. This blind acceptance has led to false coaching directions (e.g., kicking must be propulsive in crawl stroke; the more training that is done, the better one must become; going out fast establishes a lead that is easier to maintain). This method yields dogma, misinformation, and resistance to objective analyses.
3. *Intellectual tenacity*. When individuals publicly commit themselves to opinions/beliefs, it is a rare individual that is willing to alter that position. Holding steadfastly to beliefs is a feature of many coaches, particularly when original or distinguishing *"coaching methods"* are promoted to *"sell"* a program as having a unique benefit not offered by competitors' programs. This method yields dogma, misinformation, and aggressive resistance to objective analyses. An example of the rare individual who admits being in error occurred at one of these ASCA presentations in the 1990s – Dr. Ernie Maglischo admitted an erroneous emphasis and reliance on lift theory when explaining propulsion in swimming.

The above methods of pseudo-science produce dogma, misinformation, and mostly erroneous knowledge. They are unacceptable methods for sports science. Only one method can be considered as scientific.

4. *Verification by objective data*. Real science relies on observable and measurable phenomena. Interpretations must be based on replicated valid, reliable, and accurate data. For a true phenomenon to exist, there must be evidence of its presence. While some forms of common scientific methods can yield Type I and II errors, the added criterion of replication of measured phenomena generally promotes coaching principles that are reliable and true. It is this writer's opinion that there is sufficient evidence-based sports science research available to satisfy coaching inquiries about important principles for effective coaching. This is as true for swimming as it is for many other sports.

Armchair theorizing, while easy and popular, is unacceptable in all circumstances. In this presentation, scientific information will be restricted to evidence-based phenomena. However, even that criterion is insufficient for determining scientific information that is useful for swimming coaching. There are further threats to obtaining valuable and useful information.

The *"Information Age"* has spawned a remarkable increase in the number of self-appointed *"authorities"* in sport; individuals and organizations that make assertive claims about research, product effects, etc., and make unabashed claims about what to do to improve performance. The Internet and search engines have made these sources conveniently accessible. Rarely are independent data-based affirmations provided at those sources. The aggradations of these web sites amount to a virtual tsunami of misinformation. A conscientious practitioner has to be able to discern

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[2] To be considered for the banned-substance list, a substance must satisfy two of three criteria: the potential to enhance performance; significant risk to the athlete; and contravention of the spirit of sport (meaning it is illegal or could be construed as cheating). There is no consideration of data. The process involves only speculation and cannot be considered *"scientific"*.

good from bad information. Unfortunately, technologies have fostered the circumstance where misinformation, already in a major proportion of sources, is increasing at a much faster rate than valid and reliable (scientific) information. The media have not helped form a distinction between the two. A serious coach has to be able to distinguish between misinformation and scientific information. The best that one can do is to develop criteria for scientific (data-based) information and exclude all other forms. To aid in this endeavor, this writer has been producing the *Coaching Science Abstracts* (http://coachschi.sdsu.edu/index.htm) and the *Swimming Science Journal* (http://coachsci.sdsu.edu/swimming/index.htm). Accessing those sources is hardly a total solution for this problem. Not only does a coach need to know how to discern scientific information, it is necessary that the skill of discerning between deceptive misinformation and acceptable information be developed.

There is yet a further major obstacle confronting those who wish to gather valid and reliable information about swimming coaching. The number of professional journals claiming to publish scientific information continues to increase. In this writer's opinion[3], the volume of submitted and published articles below acceptable scientific standards is increasing at an alarming rate. Errors in interpretation, incomplete literature reviews, and less than rigorous editorial standards are some of the reasons for the decline.[4] This phenomenon further muddies the information to which coaches are exposed.

In these modern times, the discernment of good (scientific) information from poor (erroneous or deceptive) information continues to increase in complexity and difficulty. Within coaching, of which swimming is a good example, the criteria for the acceptance of information continue to erode and be distorted or irrelevant.

In this presentation, principles and conclusions that are stated are supported by evidence-based research papers that conform to high standards of structure and are available for public viewing. It is contended that those papers serve as true premises upon which the generalizations offered are based.

As the recent implications of acceptable sport science research are contemplated, one further moderator of reasoning should be considered. Many coaches believe that if one training principle works with a group of swimmers, it will work with all swimmers. Unfortunately, that belief is naïve. Hetelid, Herold, & Seiler (2009) showed that even the well-trained and recreationally trained differ in their respiratory responses to extended high-effort tasks. It is this writer's opinion that sufficient acceptable sports science research is available to justify specific coaching expertise for at least pre-pubertal (Bar-Or, 1996), adolescent, and gender-specific swimmers[5]. The implication is clear, even with scientific evidence, it is only valid to apply the meanings of such evidence to like groups that served as subjects in the original investigations. Assuming any valid finding is useful information for training swimmers is naïve and potentially erroneous. In other domains, the illustration of what

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[3] That opinion is formed by having functioned consistently as an article reviewer for established reputable journals as well as new publications for most of the past 50 years. A good example of poor standards in publication and among *"qualified"* individuals is provided in Rushall (2006, 2009a), although in books about baseball.

[4] Publications with very questionable content continue to be published (e.g., Callaway, Cobb, & Jones, 2009). Cartoons from yesteryear were presented as valid representations of video [which actually should have been termed "filmed"] analysis of swimming strokes. That misappropriation continues to propagate the errors of the past in a veil of pseudo-respectability. This example serves as a warning that accepting the written word in a "research journal" often is as treacherous as giving credence to a popular non-critically appraised article.

[5] This list can be modified further if the athletes are unfit or fit, aged, or experienced in other like sports. The coaching procedures and program contents would have a large proportion of distinct principles that are inappropriate across one or more target-training groups.

works for one group of athletes not working with others have been discussed in depth (Mills & Rushall, 2006; Rushall, 2006; Rushall, 2009b; Rushall 2009c) and labeled *"paradoxes"*. Some examples of paradoxes are:

- Drills and swimming equipment are helpful in developing the swimming skills of very young swimmers in instructional settings, but are harmful or irrelevant for training serious swimmers. The implication from this is that instructional procedures are different between two distinct classes of swimmer (Rushall, 2006).
- The requirements for conditioning swimmers differ between mature and immature athletes (Bar-Or, 1996; Mercier, Vago, Ramonatxo, Bauer, & Prefaut, 1987) and genders (Rocha, Matsudo, Figueira, & Matsudo, 1997).
- The technical aspects of skills differ between the genders (Cappaert, Kolmogorov, Walker, Skinner, Rodriguez, & Gordon, 1996; Dutto & Cappaert, 1994) and swimmers of different maturational ages (Cappaert, Pease, & Troup, 1996; Chatard, Collomp, Maglischo, & Maglischo, 1990; Watanabe & Takai, 2005).

It is contended that there is at least a science of the maturing and mature female and male athletes/swimmers. The justification for that generalization is in the different data-bases of research findings presented in the *Coaching Science Abstracts*.

One further complication concerns the fitness status of athletes. The principles of conditioning athletes undergoing *"change training"* from an unfit to fit status usually are different to those required to train those already with a high level of fitness (*"maintenance training"*; Rushall & Pyke, 1991; Rushall, 2003a). To apply the implications of scientific research concerning change training to swimmers who are in 12-month training programs likely would result in inappropriate and probably detrimental training.

Implications from Sports Science for Swimming Coaches

Physiology/Conditioning

The scientific bases of sports training have been changing in emphasis. For several decades, and still persisting to this day, there was a major focus on the physiological functions of the human body, and in particular exercise physiology and three metabolic energy systems. Much ado was made about developing those energy systems and at various times emphasized their measurement through indexes such as heart rates and lactate values derived from a variety of testing protocols. They were seen as the programming avenue for performance improvement. The structure of session content was often dominated by the consideration of how much aerobic or anaerobic work was to be performed. Complex divisions of training were formed to provide impressive labels, zones, systems, etc. of practice to further "*refine*" training applications. The conditioning of physiological factors has dominated the content of swimming training programs at all levels of competition.

The limited focus on physiological training emphases was reinforced by a number of phenomena including the following.

- Most physiological schemes are simple and easy to understand but possibly a little more difficult to implement. Unfortunately, the presentation in the competitive swimming world largely has been based on theory and a level of simplified vagueness that has fostered many irrelevant or incorrect training applications.
- National organizations (e.g., USA Swimming, American Swimming Coaches Association), swimming experts (e.g., Bar-Or, 1996; Madsen, 1983; the World Wide Web lists many claiming to offer valuable and authoritative advice), and coaches propagated training systems

and provided belief-based literature and coaching aids for implementing physiological conditioning.

- Coaches of many high-profile and successful swimmers attempted to explain swimmers' achievements in "*scientific*" terms and usually resorted to physiological descriptions of training programs that were based largely on belief and never on data.
- Coaches educated at the tertiary level in physical education, human movement studies, exercise science, or kinesiology degrees most often were exposed to courses of study that emphasized exercise physiology to a much greater degree than any other scientific factor involved in movement. That emphasis reinforced a perception of exercise physiology being the most important path for altering human movement.

Studies have demonstrated deficiencies in a physiological/conditioning emphasis on swimming training and training in general (Myburgh, Lindsay, Hawley, Dennis, & Noakes, 1995; Noakes, 2000). The combined weight of many data-based research publications and their implications has shown many facets of physiological irrelevancy for established coaching practices. [A disturbing feature is that many evidence-based studies have existed for a considerable time only to be disregarded by belief-based constructions which themselves were proposed without a basis of proof.] Some examples of disproved facets of the physiological training emphases in swimming follow.

- Prescribed training intensities are not followed by athletes (Stewart & Hopkins, 1997). [What a coach says is completed at training is not necessarily what actually is done by the swimmers.]
- High-yardage training and dryland training demands are unrelated to or negatively impact male elite swimming performances (Sokolovas, 2000). [Current training theory is unrelated to male competitive performances.]
- Muscle fiber use and energy delivery differs between sprint events (Ring, Mader, & Mougious, 1999). [There is no single energy-oriented method for training sprinters.]
- Training effects vary greatly and depend upon the actual set swum (Avalos, Hellard, & Chatard, 2003; Olbrecht, Madsen, Mader, Liesen, & Hollmann, 1985). [Just what is achieved through a program with training "*variety*" is unknown but is more than likely unrelated to a competitive swimming event.]
- Anaerobic work capacity and factors/indices are unrelated to swimming performances (Papoti, Zagatto, Cunha, Martins, Manchado, Freitas, Araujol, & Gobatto, 2006; Rohrs, Mayhew, Arabas, & Shelton, 1990; Zoeller, Nagle, Moyna, Goss, Lephart, & Robertson, 1998) and are difficult to determine in swimming (Almeidal, Gobatto, Lenta, & Kokubun, 1999).
- Physiological capacities have limited (ceiling) levels of adaptation and after they have been achieved no further benefits are possible (Bonifazi, Bela, Lupo, Martelli, Zhu, & Carli, 1998; Costill, Thomas, Robergs, Pascoe, Lambert, Barr, & Fink, 1991). [The coaching belief that performance improvements will occur if more or harder training is experienced has no basis in physiology.] The potential to improve through conditioning effects stops once growth has stopped (Novitsky, 1998).
- Swimmers within a group exposed to the same training program respond with varied and different physiological adaptations (Howat & Robson, 1992[6]). [It is erroneous to assume that

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[6] This study is not refereed. However, it is credible because it has confirmatory authors, is data based, and within the observational environment, two distinct subsets of subjects yielded similar results. Pre-experimental work of this type is worthy of expansive replication under true experimental strictures.

a swimmer will change in a particular physiological way because of a coach's intentions and program content.]

- Aerobic measures are unrelated to training and competitive swimming performances (Montpetit, Duvallet, Serveth, & Cazorla, 1981; Pyne, Lee, & Swanwick, 2001; Rowbottom, Maw, Raspotnik, Morley, & Hamilton, 2001). However, some physiological tests performed during taper are moderately related to ensuing competitive performances[7] (Anderson, Hopkins, Roberts, & Pyne, 2003). [Physiological testing during training yields no predictive value for competitive performances and could yield irrelevant directions for training alterations.]
- Alternative forms of training (e.g., tethered swimming, swimming with paddles) use different proportions of energy systems when compared to free-swimming (Payne & Lemon, 1982; Maglischo, Maglischo, Zier, & Santos, 1985; Ogita, Onodera, & Izumi, 1999; Sexsmith, Oliver, & Johnson-Bos, 1992). [Because of specific training effects, non-specific activities will have no potential for transferring any form of conditioning to swimming performances, which normally is the justification for their use.]
- Strength/land training is a false avenue for swimmer improvement (Bulgakova, Vorontsov, & Fomichenko, 1987; Breed, Young, & McElroy, 2000; Costill, King, Holdren, & Hargreaves, 1983; Crowe, Babington, Tanner, & Stager, 1999; Tanaka, Costill, D. Thomas, Fink, & Widrick, 1993). [There still is an emphasis on developing "*strength*" in swimmers, despite its irrelevance.] Occasionally, a report of the value of strength training emerges (e.g., Hsu, Hsu, & Hsieh, 1997).
- Significant gender differences exist in physiological factors associated with training (Bonifazi, Martelli, Marugo, Sardella, & Carli, 1993; Rocha, Matsudo, Figueira, & Matsudo, 1997; Simmons, Tanner, & Stager, 2000; Sokolovas, 2000). [Mixed gender training groups will produce less than optimal training responses for both genders.]
- The meaningfulness of physiological test results varies depending upon the performance standard of the swimmer (e.g., for Power Rack results - Boelk, Norton, Freeman, & Walker, 1997). [Such tests are irrelevant for guiding training program content or swimmer progress.]
- Blood factors are not associated with swimming training effects (e.g., Hickson, Koziris, Chatterton, Groseth, Christie, & Unterman, 1998; Mackinnon, Hooper, Jones, Gordon, & Bachmann, 1997; VanHeest & Ratliff, 1998) but have a moderate relationship in tapered states (Mujika, Padilla, Geyssantm, & Chatard, 1998).
- The various forms of physiological thresholds measure different factors in swimmers (Johnson, Battista, Pein, Dodge, & Foster, 2009).
- Noakes (2000) evaluated several models of physiological adaptation that are presented in sports in general. He stated ". . . *until the factors determining both fatigue and athletic performance are established definitely, it remains difficult to define which training adaptations are the most important for enhancing athletic performance, or how training should be structured to maximize those adaptations*." (p. 141)

Many performance physiology findings are incompatible with the predictions of specific physiological models. The traditional tenets of physiology should be challenged until universal predictive validity is established irrespective of any limited model used mostly mistakenly to guide training. New interpretations of training structures and content are warranted. The limited reasons and implications from the restricted models described in Noakes' review will not result in the best form of training. The following are implied [training adaptations are considered to be responses that

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[7] However, during taper it is too late to take any corrective steps to re-train physiological functions.

will transfer to competitive performances] from Noakes' considerations and those of others cited in this paper.

- Laboratory measurements, which are only partially related to laboratory performance, are useless for predicting competitive performances.
- Training programs based on oxygen and substrate supply theories are likely to result in incorrect stimulation and will not yield maximal fitness adaptation for a specific sport, such as swimming.
- Training that emphasizes the reaction of muscles in the replicated activities of the sport is likely to produce beneficial fitness adaptation.
- It should be noted that training with auxiliary activities, such as weight training, will not produce adaptations that transfer to competitive performances in experienced athletes.
- The physiological responses to complicated sporting activities such as swimming are likely to be caused by a complicated set of physiological processes. Limiting training *"theory"* to one incomplete physiological model will not result in maximal fitness adaptation for a specific sport.
- It is likely that training programs developed by incorporating principles from psychology, biomechanics, and physiology will stimulate the best training adaptations for a particular sport.

Billat (1996) was particularly critical of the uncritical use of exercise physiology principles and function for designing training programs. Because of the variation in concepts and measurement techniques governing a physiological label (e.g., lactate threshold, maximum oxygen uptake), it is particularly spurious to apply controversial laboratory techniques and concepts to the ever more variable practical arena of sports [swimming]. Sport scientists are ethically bound to represent the worth of testing and the inferences that are commonly proposed.

The above items are presented as a sampling of factors that over time have shown there has been a gradual whittling away of the confidence and trust that has been placed on the training of physiological factors in swimming. The emphasis on physiological adaptation through conditioning has been too restrictive and largely irrelevant for competitive swimming (Kame, Pendergast, & Termin, 1990). Savage, Brown, Savage, and Bannister (1981) implied the following:

- Swimmers have different levels of physiological capacities, different reactivity to training stimuli, and different patterns of physiological response to standard training programs. That individuality guarantees that under a group training formula, quite a number of swimmers will not benefit fully from the training because it is inappropriate for their needs (Howat & Robson, 1992). Individual training programs are essential for maximizing individuals' swimming performances.
- There are serious implications for coaching groups, particularly at the higher levels. Unless individual programming can be provided, a considerable number of swimmers are destined to not perform their best despite the intentions of the coaching staff.
- Unless representative teams are measured and trained according to their specific requirements, the performance of representative teams will always include disappointments and *"unexplained"* performances.
- Modern coaching requires the greatest amount of individualized training and programming possible.

Rather than focusing on conditioning/physiology, what is required is an alternative emphasis on variables that better reflect the matrix of factors involved in the movements and racing sequences of competitive swimmers. A case has been made for technique to be the primary emphasis of coaching (Rushall, 2006). Mental skills training should also be stressed before physiological conditioning is emphasized.

Altitude

Altitude training has been attractive to swimming coaches since the USOC Training Center opened in Colorado Springs. That site was determined by adventitious events rather than some rationale justifying situating a site there and gaining *"altitude training benefits"*. That fact seems to have been lost on many coaches. Other altitude training centers have opened (e.g., Flagstaff, AZ) and been patronized by national and international swimmers. Over time, there have been many interpretations about the values derived from altitude training offered mainly through armchair theorizing (e.g., Pyne, 1998) or poorly controlled research. Not only has living and training at altitude been promoted as a positive training/performance experience but the relatively recent phenomena of contrived hypoxia (e.g., living-high—training-low (Rushall & Pyke, 1991)), and nitrogen houses and tents (*"hypoxic living"*), have been promoted as either improving altitude effects or making up for altitude shortcomings.

Early in this decade, US Swimming promoted altitude training, live-high—train-low, and nitrogen tents as valuable training and recovery stimuli. This writer offered a comprehensive analysis of such a position (Rushall, 2002) that was contrary to the association's recommendations. That action was based on the available evidence at that time including a review by Rushall, Buono, Sucec, and Roberts (1998).

For swimming, the following conclusions have been supported.

- Intermittent hypoxia (residing in an altitude tent) does not improve swimming performance economy (Truijens, Rodriguez, Palmer, Townsend, Gore, Stray-Gundersen, & Levine, 2004) or produce any beneficial effects (Truijens, Dow, Cabayo, Palmer, Witkowski, Chase, Toussaint, & Levine, 2002; Truijens, Palmer, Witkowski, Chase, van Asseldonk, Toussaint, & Levine, 2003).
- Erythropoietin (EPO) changes due to altitude and intermittent hypoxia are not associated with total hemoglobin mass [and therefore do not have the potential to influence swimming performance] (Friedmann, Frese, Menold, Kauper, Jost, & Bartsch, 2005). Elevated EPO augmentation is likely of little benefit to conditioned athletes (Spivak, 2001).
- Swimmers' sea level performances are not associated with total hemoglobin mass (Friedmann et al.).
- Swimmers' ventilatory responses are not improved by intermittent hypoxia although sedentary individuals do exhibit improvements (Townsend, Gore, Truijens, Rodriguez, Stray-Gundersen, & Levine, 2004).
- Altitude residence does not affect the ventricular structure of swimmers (Haykowsky, Smith, Malley, Norris, & Smith, 1998).
- Simulated altitude conditions reduce both swimming performances and physiological factors (Toussaint, Truijens, van Asseldone, & Levine, 2004).
- Altitude residents improve swimming times when they compete at sea level (D'Acquisto, Tran, Jackson, & Troup, 1996).

Recently, Bonetti and Hopkins (2009) conducted a meta-analysis of altitude and performance research. They concluded that non- or low-level athletes are benefitted by some forms of hypoxic training. However, elite athletes are not benefitted. [This is one example of a paradox of training effects across different classes of athlete.] Their analysis showed that the live-high—train-low experience did produce some marginal benefits in elite athletes. Their conclusion was qualified by the indication that unintended confounding variables (e.g., placebo, training-camp effects) are likely to be responsible for any observed performance changes (Rushall, 1993). In another meta-analysis, Salgado, Parker, and Quintana (2009) seemingly pooled all studies to determine effects of hypoxic exposure on VO_{2max} and performance. Without differentiating the treatment or subject groups, they determined that hypoxia does not affect VO_{2max} but does improve performance. The potential problems with that analysis should be obvious.

A phenomenon that happens often with sweeping research topics occurred with altitude research. Initially, research and armchair theorizing were positive about definite beneficial effects on performance of altitude/contrived-hypoxia. After some time, the promoted effects were not so evident with the emergence of non-confirmatory studies. So the experience was modified with the introduction of contrived-hypoxia that provided devices and manipulations that were purported to enhance performance and make up for the shortcomings of living and training at altitude. After some time, those modifications were gradually shown not to be as effective as initially promoted. Good research has caught up with the dogma and initial poor research surrounding altitude/hypoxic training and shown it to be a waste of time and expense for improving performance at sea level. Holiday/placebo/reduced-workload effects (the uncontrolled unconsidered causal factors in many *"positive altitude studies"*) can be achieved more pleasantly and probably less expensively in other environments. Lynn (no date) recently provided a pointed denial of any beneficial effects of altitude training for swimmers.

For swimming, altitude training camps and experiences are expensive follies[8]. Pleasant/positive camp situations and/or reduced workloads are better avenues for improving competitive and training performances of serious swimmers irrespective of being at altitude or sea level.

Lactate/Lactic Acid

Lactic acid is a term used frequently by swimming coaches. It is attributed as being the cause of several swimmer problems. This topic is presented to correct the misinformation that surrounds the substance. Swimming coaches perpetuate a number of errors about the role of lactic acid in the sport.

Error #1: It is lactic acid. The term *"lactic acid"* is incorrect for the phenomenon it is supposed to encompass. Lactic acid does not exist as an acid in the body but in another form called *"lactate"*, which actually is measured in the blood when *"lactic acid concentration"* is determined. This distinction is important for the sake of correctness, and more importantly, because lactate and lactic acid would have different physiological effects (Time-to-Run, no date). Therefore, any individual talking about lactic acid pooling or accumulating in muscles is wrong.

Error #2: Increases in lactate measures are indicative of muscles working without oxygen. The higher the measure, the greater the "anaerobic capability" of the athlete. Most swimmers and coaches believe that lactic acid is released during hard or unaccustomed exercise and that it limits

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[8] Swimming Australia (Thompson, 2009) published an account of intended pseudo-science with regard to altitude training effects on swimming performances. The expensive venture entails many design flaws that would not allow it to be classed as research despite its attribution to a Swimming Australia sports science expert who wanted to find better ways to tailor altitude training to swimming. *"Altitude training has been around for a long time and there's been a fair bit of research done around that . . . But what we are trying to do is get some more specific answers out of it for swimming. There's a general acceptance altitude training is beneficial, but we want to get some more answers on the sort of work that is done, which kind of athlete gets more benefit out of it and also the timing of racing off altitude"* (Williams, 2009). Statements and activities such as these illustrate the knowledge gulf between belief-based swimming practitioners and evidence-based scientific researchers.

performance. Lactate accumulated in exercise does not only come from working muscles. The amount of lactate in the blood is not an indication of how much anaerobic work has been completed in exercise. It is a result of: (a) processes which produce and contribute to its appearance, and (b) processes which catabolize it after its removal from the blood. *". . . the concentration of lactate in the blood provides minimal information"* about its rate of production (Brooks, 1985). Lactate measures cannot be inferred to indicate only exercise production (Brooks, Wolfel, Groves, Bender, Butterfield, Cymerman, Mazzeo, Sutton, Wolfe, & Reeves, 1992).

Brooks (1991) clarified some misconceptions about lactate.

- Coaches and many sport scientists consider lactate as a representation of oxygen-limited exercise metabolism (anaerobic glycolysis). That is too simplistic. The formation, exchange, and utilization of lactate represents an important means of distributing carbohydrate energy sources after a carbohydrate meal and during sustained physical exercise. Lactate is now considered a beneficial intermediary metabolite between carbohydrate storage forms (glucose and glycogen) and metabolic end products (CO_2 and H_2O). The advantage of lactate as an intermediary is that it exchanges rapidly between tissue compartments.
- Skeletal muscle, once considered to be the major site of lactate formation, in some circumstances is responsible for significant net lactate removal from the blood. The liver, once thought to be a primary site of lactate removal through its role in the Cori cycle, can contribute in a major way to a rise in arterial lactate, particularly at the onset of strenuous exercise. During exercise, lactate is the predominant fuel for the heart. Other tissues and organs (e.g., skin, intestines) are also involved in blood lactate kinematics during exercise.
- Lactate can be formed in fully aerobic tissue, such as the heart, and used within those same tissues. As well, lactate production has been found in fully oxygenated muscles. Thus, muscle lactate level is an unsuitable indicator of lack of oxygen (anaerobic work).
- Net lactate output from contracting muscles is related to the intensity of stimulation, not oxygen deprivation.

Working muscles are a significant source of lactate removal. Since not all fibers in a muscle are elicited to work excessively during exercise, and therefore do not produce lactate, those non-lactate-producing fibers are one site of lactate extraction. Other muscle groups which perform work during exercise, but do not contribute markedly to power or movement production, extract more lactate than they produce (Stanley, Gertz, Wisneski, Neese, Morris, & Brooks, 1986). Given the limited maximum working muscles in swimmers, much muscle mass would be removing lactate during high-effort swims.

Lactate production occurs in muscle for reasons other than an oxygen limitation or mitochondrial ATP production (Brooks, 1985). Lactate levels sampled in worked or working muscles show the balance between the production of waste products from glycolysis and their removal in the mitochondria (Stainsby, Brechue, & O’Drobinak, 1991). Most coaches have traditionally ascribed villainous attributes to lactate but it should now be recognized that it does not hinder but helps exercise (Hasimoto, Hussien, & Brooks, January 24, 2006).

Error #3: Sore muscles are caused by lactic acid pooling and not being cleared. Excessive lactate is removed from the blood and muscles usually within one hour after exhaustive exercise. Active recovery usually accelerates the clearance process (Rushall, 1967). In swimming, recovery can be achieved in as little as 15 minutes (McMaster, Stoddard, & Duncan, 1989). During recovery from sustained exhausting exercise, most of the accumulated lactate will continue to be removed by direct oxidation (Brooks, 1986).

The usual reason for soreness and stiffness in the body after strenuous exercise is not a *"pooling and retention of lactic acid."* Rather, it stems from muscle cell damage caused by the intensity of the performance, a level of intensity that previously has not been experienced, or a modification of style that causes muscle fibers to be used and loaded in an unfamiliar manner.

Sore muscles are related incorrectly to the stinging sensations experienced in muscles upon the cessation of intense exercise. Often that *"pain"* is described as being caused by *"lactic acid"*. To the contrary, several factors, such as glycolytic flux, NADH hydrogenase + H+ accumulation, and ATP hydrolysis contribute to acidosis while lactate accumulation does not. Robergs and Ghiasvand (2001) concluded: *". . . metabolic acidosis is not caused by lactate production, and the terms 'lactic acid', and 'lactic acidosis' should not be used. The explanation of metabolic acidosis in the classroom, as well as in biochemistry, physiology, and exercise physiology textbooks should better identify the multifaceted determinants of skeletal muscle acidosis during exercise."*

Error #4: Lactic acid causes fatigue. Although somewhat related to the second error above, another misconception is that lactate is responsible for acidifying the blood, thereby causing fatigue. To the contrary, lactate is actually an important fuel that is used by the muscles during prolonged exercise (Time-to-run, no date) and mitigates fatigue.

Error #5: Anaerobic threshold is a valuable criterion for programming training activities. Swimmers have blood taken from various sites to measure *“lactic acid”*. The usual rationale is that as swimming speed increases, a point is reached where insufficient oxygen is available to the muscles and energy sources that do not require oxygen are mobilized. That causes a disproportionate increase in the blood lactate concentration, a point identified as the anaerobic threshold (a.k.a. lactate threshold or lactate *"turnpoint"*). That reasoning is false because 1) the muscle never becomes anaerobic (there are other reasons for the supposed disproportionate increase in blood lactate concentration) and 2) the so-called disproportionate increase causing a *"turnpoint"* is incorrect because the increase is actually smooth and incremental.

The concept of anaerobic threshold and its being caused by a few processes is unsupported. Factor analysis showed that disproportionate changes were the result of increased work intensity and metabolic rate. Wide variations in specific threshold variables (e.g., lactate, ventilatory, work output, catecholamine, respiratory exchange ratio, heart rate) indicate inflections are influenced more by glycolytic rate than anaerobic conditions. The body has a variety of response mechanisms, many of which are redundant, with which to cope with exercise stress. However, an individual reacts to increased workload that produces a level of metabolic demand through increased glycolysis that induces fatigue at an accelerated rate. This appears to be better described as the *"inflection point of metabolic acceleration."* That point is best described as a particular level of work intensity for a particular activity. It is specific to each activity and will vary between trained and untrained states. No specific and limited physiological test is adequate for measuring this phenomenon. *"Anaerobic threshold"* is an inappropriate term (Wyatt, Jackson, & Tran, 1997).

The problem of threshold determination is complicated one-step further in that different protocols and criteria yield different lactate threshold values (Johnson, Battista, Pein, Dodge, & Foster, 2009; Santos & Gomes, 1998; Watts, Jensen, Gannon, Harney, & Kobienia, 1998). Comparing the findings of one protocol, and often the results from one laboratory, with another is nonsensical.

Lactate concentration measured after a performance gives no information about when it appeared in the performance. Thus, knowing the lactate level tells you nothing about how it was formed in a performance (Roth, 1991). That weakness prompted the formation of controlled incremental protocols to arbitrarily and occasionally form turnpoints in a manner that never exists in competitive swimming. There is no validity for such *"dances"* for competitive swimming; only for lactate measurement, a point that has been ignored by many coaches.

Lactate or ventilatory threshold tests as measures of training adaptation are best suited for assessing the progress of individuals from untrained to trained states (e.g., those states achieved through 8-12 weeks of endurance training). Once a moderate level of fitness is achieved, either test is unlikely to be sensitive to further training adaptations, if any occur (Londeree, 1997).

It was once thought that much of training should be completed at or below the anaerobic threshold. It is now recognized that the lactate threshold is not intense enough for appropriate stimulating training (Kenefick, Mahood, Mattern, & Quinn, 2000). Intensive training at or above the anaerobic threshold is the most effective work level for improving VO_{2max}. Low-intensity continuous training is a better method for improving the anaerobic threshold (Rusko, 1987),which would be irrelevant to racing demands.

Lactate testing is meaningless for predicting competitive swimming performances (Gomes-Pereira & Alves, 1998; Pyne, Lee, & Swanwick, 2001, Rushall & King, 1994a, 1994b). For example, peak post-exercise blood lactate (La_{peak}) and accumulated oxygen deficit (AOD) are not related to 50- or 500-yard swimming performances (Zoeller, Nagle, Moyna, Goss, Lephart, & Robertson, 1998).

Error #6: Anaerobic training is an important aspect of swimming programs. The utility of this concept is doubtful. There are no medals given for the greatest increase in anaerobic or for that matter aerobic capacities. That the focus of training should be on changing physiological functions that have low to no relevance for competitive performances is baffling. The capacity of females to do anaerobic training is less than in males (Esbjornsson, Bodin, & Jansson, 1995).

The following are implications of research for sport practitioners. Sport scientists are ethically bound to represent the worth of lactate testing and the inferences that are commonly proposed.

- Lactate concepts and measures are limited/specific to each testing protocol.
- Results from one protocol cannot be used to generalize or infer values to other testing protocols.
- If one cannot infer from one lactate testing protocol to another then it is illogical to generalize lactate testing results to competitive performances.
- It is a greater stretch of the imagination to leap conceptually from an inferentially-limited measure under controlled conditions to the dynamic circumstances of a competitive or practice setting.
- At most, lactate and lactate threshold measurements reveal changes but have limited to possibly non-existent inferential qualities about future performances (even training performances let alone competitive performances).
- In some cases, lactate and lactate threshold measurements can reveal that they have changed as a result of training, but, if those changes are unrelated to competitive performances what is their value?
- There are no national or international competitive events that reward medals for physiological changes, levels, or testing protocols.

" . . lactic acid, while still important from the exercise physiologist's viewpoint, now is known to contribute much less than originally believed to the regulation of man's physiological responses to exercise" (Hagberg, 1984; p. 106). When someone attributes *"bad"* phenomena, experiences, or results in swimming to lactic acid or lactate, they clearly do not know what they are talking about.

Pacing

Around competitions when coaches instruct swimmers as to how to race, statements such as *"get out ahead and hold it"*, *"take it out to lead at the end of the second lap"*, *"take it out fast"*, etc. are commonplace. Among many coaches, *"taking it out"* somehow is meant to give a swimmer a racing advantage. Swimmers who lead after the first length do not necessarily win, as was so frequently exhibited in the sprint swimming events at the Beijing Olympics and the recent Rome World Championships. There are some features of pacing that should be seriously considered by coaches to facilitate their swimmers performing the best times of which they are capable.

The pacing strategies for short duration (less than one minute) and longer duration events are slightly different. In terms of absolute split times, the first race segment should always be faster than succeeding segments because of the dive. To all intents and purposes the available anaerobic and aerobic energy in a race is fixed and limited (de Konig, Hettinga, Mulleman, & Foster, 2008; Hettinga, de Konig, Emierl, Teunissen, & Foster, 2007). Using too much of one energy resource, particularly anaerobic energy, too soon will cost a swimmer later in a race. The judicious allocation of these energy sources should result in the best time possible on any given day.

Cyclists were able to accomplish significantly more mechanical work when employing an even-paced strategy than under conservative or aggressive strategies when performing a ~2-minute time-trial. The pacing strategy was clearly identifiable in the pattern of anaerobic energy expenditure, though total anaerobic work did not differ between strategies. No differences in aerobic work or pattern of aerobic energy expenditure were evident between the conditions. Pacing strategy affected finish time, that is, the even-paced strategy was superior to going out fast or holding back in the early stages of a performance (Hettinga et al., 2007).

Dutto and Smith (1999) evaluated the pacing characteristics of Olympic and World Championship 5,000 m speed skaters. For women, lap variations were much less in the medalists than in the rest of the field. For men, there was little difference in lap variation between the field and medalists. Men tended to drop-off velocity throughout the event more than women. This suggests a gender difference for pacing in that it is particularly important for females to maintain close to constant velocities over distance events that contain a greater demand for aerobic energy than anaerobic energy. Females intrinsically have a better feeling for more consistent pacing than males (Hoops, Vanderburgh, & March 2009). Since many males coach females, the potential is high to advise the females to perform with more variable *"male-appropriate"* strategies which could result in reduced performances.

By systematically varying anaerobic energy distribution over ~2-minute time-trials and keeping total energy constant, performance outcomes of different pacing strategies were determined. For each S, the fastest and slowest time trials were compared and the relative importance of the measured differences in anaerobic power output and pacing strategy was determined. The fastest trials were performed with a higher anaerobic peak power, combined with a relatively high, but statistically unchanged anaerobic rate constant. The most successful pacing strategy was characterized by a short and faster start. The variation in mean anaerobic power output accounted for 70% of the difference in final time between the fastest and slowest trials. The remaining 30% was attributable to differences in pacing strategy. Thus, a short fast start (not an extended fast start) followed by a constant level of anaerobic power output (an evenly-paced performance) produces the best time over events lasting about two minutes (de Konig et al., 2008).

Zacharogiannis, Paradisis, Tziortzis, and Smirniotou (2006) compared two strategies over 5-12 minute treadmill runs. After having determined the VO_{2peak} velocity, one run covered the first half of the run at 1% faster than vVO_{2peak} and the second half at 1% slower. The other trial reversed the velocities. The slightly faster pace in the first half of the run produced the better performance. It should be noted that the paces differed from the average velocity by ±1%. That is much less than is often exhibited in championship races, particularly when a swimmer obviously sprints out early to *"establish a lead"*. However, Kenefick, DeCamp, Edwards, and Quinn (2004) reported better running times in trained females by covering the first mile of a ~3-mile run at a pace 3-6% faster than the average velocity for the previous best time-trial. Because of the different metabolic demands of running and swimming, conclusions from running should be tamped down for swimming. Thus, conservative *"fast-outs"* would be preferable to aggressive velocities in the first elements of races.

The sensations used to govern a pacing strategy affect the ultimate performance. Streeper, Peiffer, Faria, Quintana, and Parker (2006) compared developing pacing efforts by heart rate, power output, and rating of perceived exertion on simulated stage-cycle time trials (~15 minutes). Pacing by concentrating on output power produced superior performances to those that focused on heart rate or rating of perceived exertion (effort). It would appear to be best to have athletes concentrate on their perception of power production when stipulating the content of a pacing strategy. In swimming, power production could be described as *"perceived stroking effectiveness"* (i.e., strokes per lap at constant velocity).

Vesbach, de Konig, Lucia, Porcari, and Foster (2009) showed that traditional lap-split times used to indicate race-pacing are perhaps too simple. Within a pool length, the times for the first and second half are significantly different. The increased velocity off the dive and turn produces a faster first half than second half. Across the course of a race, if the skill effectiveness off the turns deteriorates early and the latter half swimming velocity remains relatively constant then the overall conclusion that lap times were slowing due to swimming velocity would be erroneous. Analyzing lap performances at least in two halves would indicate the consistency of both swimming velocity and turn/dive skill executions. It is possible that deterioration in both segment emphases could vary and would therefore indicate areas requiring improvement if analyzed accordingly. In lap lengths where skill executions are increasingly important (e.g., 25 yards and 25 m) the usual assumption that lap time deteriorations come from only stroking effectiveness changes likely would be wrong. When contemplating pacing, swimming coaches need to heed this phenomenon and cast aside the overly-simplified current method of analyzing only lap times when contemplating pacing

The imposition of coach-determined pacing strategies and race-segment times might not be the best way to improve swimmers' race performances. Hettinga, de Konig, Schmidt, Wind, MacIntosh, and Foster (2009) showed that theoretically justified imposed race paces (in speed skating) produced slower overall times than athletes' self-imposed pacing strategies. Because of the individual variations in optimal pacing between swimmers, it would be advisable for coaches to work with swimmers across several competitive performances to analyze what is the best personal approach to pacing. Such analyses should be performed after observing and measuring the self-imposed pacing strategies of each individual. While aerobically dominant swimming events (i.e., events >100 m) should exhibit largely even pacing due to the judicious application of consistent stroking power, the amount of the early slight velocity increase most likely would remain a very individual quantity. As well, inter-individual differences in skill executions (i.e., dive, turns, and finish) would also influence overall times. Their interactions across the transitions from skill velocities to swimming velocities would also influence the production of optimal strategies.

The research papers exhibited here do not provide a clear answer about what is the ideal pacing strategy. It is likely there will be some individual variations around a central premise (e.g., Kenefick et al. reported 3-6% variations in the first mile of a three-mile run). However, among these papers are samples that involve the very best athletes in the world (e.g., Dutto and Smith, 1999) while others involve experimental manipulations of selected subjects in experimental settings (e.g., Zacharogiannis et al., and Kenefick et al.). In this instance, this writer recommends being swayed more by what the world's best athletes do than what is exhibited in laboratory settings. Consequently, recommendations made here will be weighted more heavily on the world champion athletes than on the limited and possibly not maximal performances in laboratories.

Swimming races use both anaerobic and aerobic energy to fuel optimal performances. The shorter the event, the higher is the anaerobic to aerobic energy ratio (Troup, 1990). In theory, the best pacing strategy would be even-pacing for the total event. That would be true if the same energy kinetics were available throughout an entire race. However, they are not. In the early stages, aerobic energy is supplied but not in the most efficient or optimal manner (e.g., Janes, Foster, deKoning, Lucia, Esten, Kernovek, & Pocari, 2004; Smith, Kjeisers, Kanteebeen, Williams, Hughes, & Hill, 1998). [This partially is caused by the loss of warm-up effects due to official organization that precedes a race.] It takes time after the onset of an event for aerobic energy to proceed to maximally efficient function and performance contribution. Consequently, early in a race, the initial diminution of aerobic inadequacy/inefficiency has to be compensated with extra anaerobic energy. At the outset of a race, the swimming velocity and technique that uses higher levels of anaerobic energy optimally is different to that which uses fully functional aerobic energy supported by anaerobic energy (Wakayoshi, D'Acquisto, Cappaert, & Troup, 1996). For efficient utilization of the finite anaerobic and aerobic energy resources in a race, the initial component that uses *"extra"* anaerobic energy would be swum slightly faster than the remaining fully-functioning-energy part of the race. Gauging the proportion of the race that should be slightly faster than the majority of a race is a challenge and at this time there is no scientific procedure for determining the volume and quality of augmented anaerobic swimming early in a race. As with most performances, there is likely to be great individual variations in what would be suitable among factors such as stroke, gender, age, time of day, form of preceding training, volume of appropriate training experienced, etc.

A major feature of the early swimming in a race is that aerobic kinetics improve gradually and the demand for augmented anaerobic energy decreases reciprocally. Translated into performance, there would be no sudden change/stage from one swimming velocity to another. That is why gauging swimming velocity in terms of power production is more important than absolute times. Discounting the dive and underwater swimming effects, the early *"slightly-faster"* swimming split would really be at an incremental slowing velocity until optimal aerobic energy supply for the majority of the event was possible. The difficulty of governing that demand should not be underestimated. Given that obstacle, it would be best initially to swim too slow than too fast because the *"saved"* anaerobic energy would be available for the remainder of the race. In accordance with the popular myth *"to get out there"* espoused by many coaches and swimming commentators, too much anaerobic energy use early would result and that which would be available later would be diminished. The concomitant complications of glycolytic energy production caused by that initial excessive use would also have to be accommodated, reducing further the efficiency of energy production in the remainder of a race.

This description of factors that influence swimming velocities early in a race also accounts for the de Konig et al. (2008) finding of shorter faster starting phases, when absolute time is considered. A cautionary consideration would be to not deliberately emphasize or extend any marginally faster swimming initially in a race. An important factor to be considered is that when swimmers are performing near maximal levels, minor absolute performance-time improvements have to be achieved through relatively much greater expenditures of energy, those costs being far in excess of the performance benefits that might result.[9] A few tenths of a second gained in the early stage of a race could cost many tenths of a second later in the event. In general, attempts to gain better performance through increased effort seldom yield the intended benefits (Capelli, Pendergast, & Termin, 1998). The energy demands of swimming races are so critical that even-pacing is a major determinant of success in the sport.

An acceptable over-simplified practical application of pacing would be to perform even lap times for all but the first and last laps of events that require a major focus on energy apportionment. The time for the first lap would have to accommodate the start and its underwater transition. The last lap should accommodate a minor improvement in lap time as the anaerobic resources available should be depleted as the finish-pad touch is executed. Awareness of the swimming velocity to achieve even-lap swimming is likely to be influenced by the volume of race-pace swimming performed at training.

This sampling of recent studies on pacing suggests that it is time to re-focus on sane pacing strategies for all race distances in competitive swimming. No medals are given to swimmers who lead at the quarter-distance mark in a race. The point that the amount of anaerobic energy and aerobic available for use in a race is fixed is paramount. The judicious expenditure of anaerobic energy is of greatest importance and it suggests that strategies that tax that capacity early in a race are recipes for disappointment. Since children (Billat, 2001) and women (Byrnes & Kearney, 1997) have less anaerobic capability than men, its use in races is even more important for age-groupers and females and explains the findings of Dutto and Smith described above (females [and children] need to be exquisite in their performance pacing when compared to men). Using the sensations of power (perceived stroking effectiveness) as the governor for swimming velocity, even-lapped performances guided by anaerobic exertion, no matter what the event (discounting starts), appears to be the best pacing option possible.

Race-pacing is not as simple as is often believed. It requires repeated cooperative efforts between the coach and swimmer on an individual basis and must consider 1) the duration and intensity of early increased velocity, 2) the consistency and effectiveness of the skills of turning, the dive, and finish across all race segments, 3) the overall stroking velocity in that part of the length where it is the dominant performance determinant, and 4) the optimization of the transition from high-velocity skills to lower-velocity stroking in each length throughout the duration of a race. A focus on these factors would like produce significant competitive improvements.

Whole-arm Propulsion

This topic is presented to illustrate acceptable research that is not reliant on publications. It involves the replication of objective, observable, and measurable phenomena.

For almost three decades, the majority of swimming coaches clung to the belief that lift forces derived from Bernoulli-Principle reasoning were responsible for propulsion. Only a minority clung to the assertion that drag forces were primarily involved in propulsion, as they always have been in rowing, kayaking, and canoeing. It was always a mystery to this writer why would the underlying

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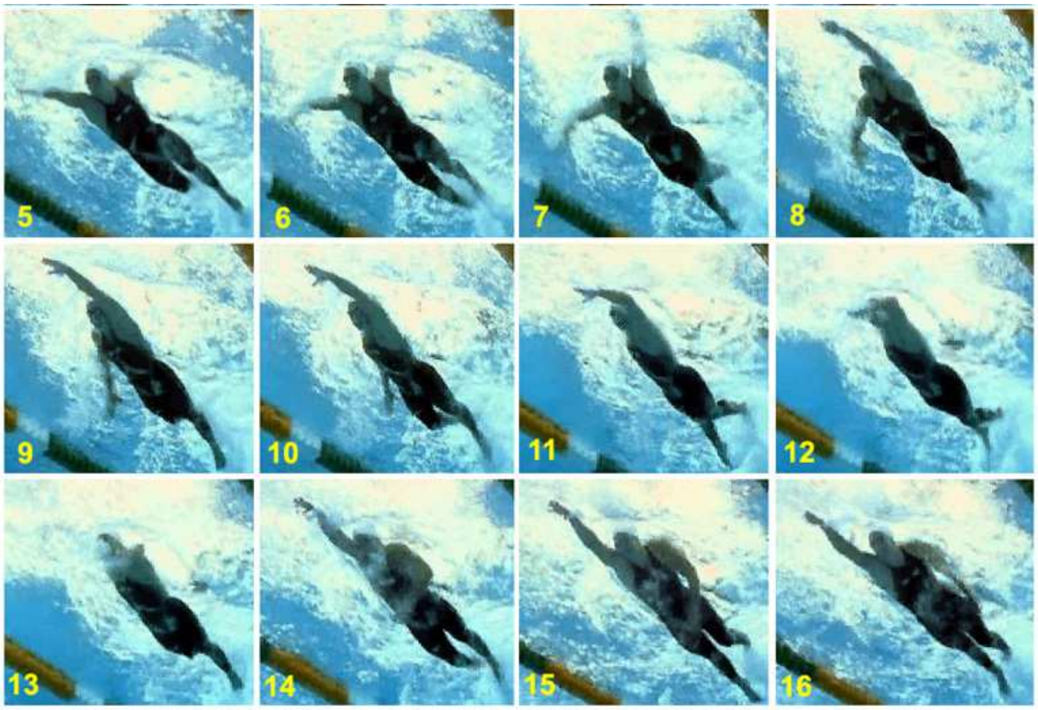
[9] As swimming velocity increases, the two major forms of water resistance increase. The relationship between frontal resistance and velocity is quadratic and between wave resistance and velocity is cubic. The musculature contractions required to overcome elevated resistances have to increase greatly to produce the forces to achieve any notable effect. A general index of the energy requirements for a change in effort is the *Theoretical Cube Law*, which states that the energy cost of a muscular contraction varies with the cube of the speed of the contraction. Since the allocation of anaerobic resources in a swimming race is a factor that governs the performance level achieved, even a slight change in effort (i.e., perceived performance change) would be at an extravagant cost in terms of energy resource utilization.

principle for propulsion be different for swimming than for the other aquatic sports when they all relied on pressing against the water to move forward. The lift-force/Bernoulli Principle/Theorem was supported extensively by ASCA and most of its members. To ASCA's credit, an article by Rushall, Holt, Sprigings, and Cappaert (1994) was published in *Swimming Research*. It contradicted the lift theory emphasis/attribution and argued with evidence that drag forces were majorly responsible for propulsion. As often happens, there was initial negative reaction from people/members within ASCA but eventually, the wisdom of evidence was recognized (see the action by Dr. Ernie Maglischo mentioned above) and erroneous beliefs were cast aside by some. Since then, influenced by the work of Anderson and Eberhardt (2000), Rushall (2003b) showed that swimming's interpretation of the Bernoulli Principle had been wrong because it did not consider real fluid flow characteristics nor did it involve the ever-present existence of Newton's Third Law. As well, the preoccupation with the hand as being the principle propulsive surface was disputed (Cappaert in Troup, 1992) with clear evidence showing that the forearm provided more propulsion than the hand. The drag forces created by the hand + forearm propelling surface were superior to any lift forces. Drag force as the principal propulsive force component was promoted early on by Red Silvia at Springfield College and James *"Doc"* Counsilman at Indiana University. Attempts to promote drag-force propulsion in the early years of adoption of the Bernoulli Principle by members of ASCA were met with derision and hostility (Laurence E. Holt, personal communication, 1976).

It is now time to extend the concept of the propelling surface to include the upper arm. No refereed papers have been produced about the upper-arm contribution to total propulsive forces generated by parts of the arm. The replicated photographic evidence from champion international swimmers in races provides consistent evidence of the upper arms producing substantial drag forces, at least in crawl stroke and backstroke (see *How Champions Do It* in the *Swimming Science Journal*). This is a demonstration of how scientific information can be obtained when there are no refereed articles to reference.

The visual evidence of drag propulsion stemming from the upper arm is easiest to see in sprint freestylers and sprint backstrokers. At distances of 200 m or more, the exertion level of the swimmer usually is insufficient to produce an obvious turbulent pocket behind the arm. Depending on the angle from which video records are made, there are times when upper arm turbulence is obscured by turbulence formed by the lower arm and hand (see Figure 1 for one example). [In the actual ASCA presentation, three examples of crawl stroke and one of backstroke were provided to illustrate this feature.] Even when no drag pocket can be discerned, the unified movement of the whole arm in all strokes is noticeable among champion swimmers.

The distinguishing characteristic of upper-arm propulsion is in the biomechanics of the arm-pull action. The upper arm adducts and abducts with almost the same velocity as the lower arm and hand, that is, the whole arm moves as a unit and applies force backward. The elbow flexes and the upper arm medially rotates in the preparatory phase of the stroke to establish the largest propelling surface possible. What is remarkable in today's champions is the absence of S-shaped pulls and defined movement paths of the hand. Hand movements differ between arms within and among swimmers (Rushall, no date a; Rushall, no date b; see Figure 2 for an example) and usually do not move smoothly contrarily to what is normally drawn (cartooned) in many swimming books and instructional materials.



Libby Trickett at 40 m of Her World Record 100 m Freestyle Race at the 2008 Australian Olympic Games Swimming Trials

Figure 1. Frames 7 and 8 show turbulence in front of Libby Trickett's upper-right arm. It cannot be discerned if it is original or residual turbulence. Frame 14 shows a pocket of turbulence in front of the left bicep and elbow. That feature is best described as original turbulence. Both phenomena support the contention that the upper arm is responsible for considerable propulsion.

The movement of the total arm as the propelling surface requires particular actions of the internal shoulder-joint rotators (anterior deltoid, pectoralis major, and latissimus dorsi) and external humeral rotators (infraspinatus, teres minor, and supraspinatus) which control adduction and abduction. One would have to coach the attainment of the appropriate body position and the timing of the pull relative to the other arm [that requirement disputes any tolerance of an overtaking stroke pattern].

In all strokes, focusing on propelling with the upper arm and keeping the lower arm and hand fixed relative to the upper arm would seem to be an important instructional element when coaching serious swimmers.

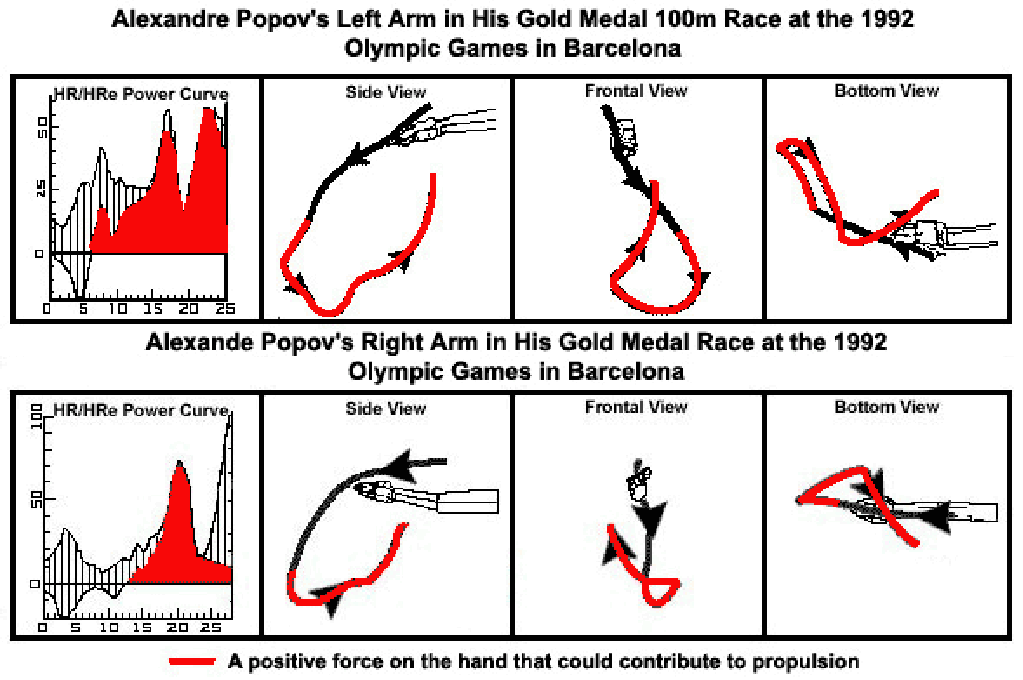


Figure 2. The disparity of hand-path patterns and forces produced by the hands of multiple-Olympic Champion Alexandre Popov (From Rushall, no date a).

Stretching/Flexibility

Swimming coaches have consistently expressed an interest in and the ascription of importance to stretching. It is common to see swimmers manipulating joints, particularly the shoulders, to what seem to be extreme ranges of movement. Some swimmers (e.g., Petria Thomas of Australia) have legendary status when ranges of movement are described. For years, coaches have contended that the greater the range of movement that is developed in a swimmer, the better will be performance. Consistent conscientious stretching also is supposed to reduce the occurrence of injuries, promote recovery from exercise fatigue, as well as increase performance potential.

The terms flexibility and stretching generally are used interchangeably, which is erroneous. Flexibility implies the range of movement that is accommodated by the physical structure (e.g., bones, tendons, cartilage, etc.) of an individual. Stretching refers to facilitating the achievement of natural flexibility, that is, the lengthening of soft tissues (i.e., muscles) to facilitate attaining one's flexibility. Thus, one can stretch sanely to accommodate the natural range of movement that resides in the athlete. However, if one attempts to alter flexibility by forcing rigid and compact tissues to change, the possibility of injury is heightened markedly without any valid evidence ever being shown that such strategies improve performances.

McMaster, Roberts, and Stoddard (1998) evaluated shoulder laxity and found it to be a very common denominator in swimmers' shoulder problems. Shoulder flexibility may be important for swimming, but if a shoulder becomes too flexible, that is the head of the *humerus* moves too much within the *glenoid capsule*, pain and injury usually result. Unrestrained (overtrained) shoulder flexibility allows the head of the humerus to *"rattle"* in the shoulder capsule. Over time and with the huge number of repetitious movements involved in swimming training, injury results. Usually or eventually, senior swimmers have to undergo surgery to repair the damage caused by a high number of small sub-luxations. Once excessive shoulder irritations (pain) have occurred, auxiliary training experiences (e.g., hand paddles, weight training, and kicking with a board) also exacerbate the problems (Pollard, 2001).

Stretching is the one area of sport conditioning that has changed direction markedly over the last decade. Previously, much of what was involved with flexibility training or "*stretching*" was belief-based. While it still is considered important because it governs the range of movement that could be used in a technique and the length of movement over which forces can be generated, it only relates to the range of movement about a joint, not the ability to perform extreme activities. Today, the reasons for performing considerable stretching are questioned based on the evidence available. Swimming coaches will have to re-think their positions on stretching work.

Flexibility has limitations. In a very sane approach to flexibility training, Holt, Pelham, and Holt (2005) defined and limited flexibility training (stretching). A major concern was the avoidance of injury. Their work stimulated this writer to categorize the commonly observed phenomenon of a support person, coach, or other swimmer using his/her body weight to apply extra force to one or more joints to produce a movement range that could never be achieved through self-controlled swimming. It is best termed "*abusive stretching*" because it does pre-dispose athletes to injuries by interfering with the tissues that support joint integrity (Yang, Im, & Wang, 2005).

Two general categories of structures are involved in joints (Holt et al.). First are the joint tissues and structures themselves (cartilage, capsule, ligament, and bone). These elements are responsible for joint integrity and stability and should not be changed by any deliberate exercise (as is often the outcome of abusive stretching). Second are the soft tissues associated with a joint (muscle, tendon, and fascia). Stretching and flexibility training should target those soft tissues without involving the joint structure tissues. Thus, the difference between sane stretching/flexibility training (e.g., *3S* or *Proprioceptive Neuromuscular Facilitation*, Holt, 1973) and its abusive forms is the involvement of joint structures in the activities, something that should be avoided at all costs.

Joint mobility is restricted by bony and fleshy masses that block movement in the end position and by the skin, muscles, tendons, ligaments, and capsules that act as ties and are put on stretch in the limiting position. The shape of bones, the elasticity of ligaments and muscles, the strength of the antagonist muscles, and the effort of movement also determine the maximum range of movement. A variety of external factors also affect flexibility: heat treatment (Grobaker & Stull, 1975), preliminary exercise, short-wave diathermy (Asmussen & Boje, 1945), hot showers (Carlile, 1956), muscle soreness, tolerance for pain, ability to relax, and room temperature (Scott & French, 1959). These factors could cause day-to-day variations in flexibility in swimmers and need to be considered before exercising. Extended sports participation over a considerable period, produces an habituation of movement ranges that facilitate the actions in the sport. Specific physical activities, such as weight-training and calisthenics (Denk, 1971, de Vries, 1962), dance (Campbell, 1944), yoga (Meyers, 1971), basketball (Turner, 1977), and ice-hockey (Chevrier, 1981) produce changes in flexibility because of long-term habituation. Conscientious training and participation in a sport, and in particular swimming with its enormous number of movement repetitions from a pre-pubertal age, will eventually produce an habituated level of flexibility that will meet most of the usual demands of the sport. Adaptations alter the sensitivity of the joints (Dover, Kaminski, Meister, Powers, & Horodyski, 2003). Joint position sense is affected most in the shoulder. It is reduced even further when the shoulder is sore or injured (Safran, Borsa, Lephart, Fu, & Warner, 2001). Habituation would be specific to a stroke if one stroke was emphasized more than the others by the swimmer. As a swimmer's career develops, joint problems should be anticipated because of overuse (Ellenbecker, Mattalino, Elam, & Caplinger, 1998; Pomianowski, O'Driscoll, Neale, Park, Morrey, & An, 2001). Someone who has swum for a number of years, and particularly during the maturing years of adolescence, will "*grow*" the range of movement that facilitates swimming. Any attempts to develop greater ranges of movement are unlikely to yield benefits because the actual range of movement needed for effective performance has been developed through specific swimming activities. Rarely, if ever, will there be an experienced swimmer, who has participated in high school and club swimming and entered the college ranks, with a performance-limiting restricted range of movement in the important swimming joints.

Most athletes develop two approaches to stretching. One is that which is developed through trial-and-error over years of participation. Activities such as pulling the arms, flexing and extending the shoulders, touching the toes, and doing calisthenics exercises, usually promote mobility to the satisfaction of the performer. On the other hand, abusive partner-stretching, for example that which is observed in college and professional sports, yields sensations and movement ranges that are only possible with the extra forces supplied by the partner. Such activities are superfluous and irrelevant for swimming. They have the potential to produce much more harm than benefit. The prescription of Holt (1973; Holt et al., 2005) that only soft tissue stretching should be entertained limits the types of allowable formal stretching to either slow-dynamic stretching or correctly executed *3S* (*PNF*) stretching. Informal stretching has been displayed by most athletes for many years. They do the activities of their sport in an incrementally progressive manner. That is why incremental swimming remains popular with swimmers. Because of individual variations and needs, swimmers should be encouraged to perform the amount of warm-up stretching they feel they need and to notify the coach when they are "*ready*". A swimmer's perception of readiness usually involves a set of feelings in the swimmer that suggests he/she is "*right*" to perform. A swimmer most likely cannot describe the complete set of those feelings. Leaving the determination of readiness to the wisdom of the swimmer and his/her body is a correct decision.

Proprioceptive Neuromuscular Facilitation (*3S - PNF*) stretching (see Holt 1973; Holt et al., 2005) is the preferable form of stretching program, but only if executed correctly (Conley, Belt, Hochstein, Evetovich, Engebretsen, & Todd, 2006; Conley, Fertig, Huot, Jacobsen, Villwok, Evetovich, Engerbretsen, & Todd, 2007; Ryan, Lopez, Rossi, Doherty, & Jacobs, 2006). When done correctly in a sport setting it is known as "*3S*" stretching (Holt, 1973). Despite warnings and explicit instructions about the role of the partner, "*assisted*" flexibility exercises have been implemented incorrectly to the point of posing severe injury threats to the athletes being stretched. That problematic implementation comprises most of the "*abusive stretching*" programs (see Figure 3) that exist because they "*stretch* [injure]" the joint structures beyond the beneficial effects that can be achieved with the soft tissues alone. They in no way reflect the value and possibilities of an exact *3S* stretching program. When *3S* (*PNF*) partners or *3S*-specific machines are not available or when extreme ranges of movement, such as those needed in gymnastics, dancing, etc. are not needed, slow-active stretching (SAS)[10] can be substituted. It allows the athlete to protect the joint structures and only work the soft tissues. For swimming, initially slow-active stretching would probably suffice if a knowledgeable *3S* (*PNF*) partner is not available.

For some reason athletic trainers and conditioning "*experts*" develop methods of stretching that are excessive and injurious, despite the wealth of information that is available as to what exercises and stretching methods are and are not beneficial. This is probably due to the misguided belief, that when exercises are performed in exceptionally increased volumes and intensities they are more beneficial, which is a violation of the *Roux Principle*[11]. That false belief is extended further with stretching

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[10] The athlete-alone analog of the *3S (PNF)* stretching procedure.

[11] *Roux Principle*: *Small stimuli are useless, moderate stimuli are useful, and excessive stimuli are harmful* (Stegemann, 1981, p. 266).

when a second person applies high external forces to movements at their extremes. Muscles and joint structures in those positions are subjected to forces that damage the tissues and result in injuries.

Extreme hamstring stretching is a common activity in many sports. Askling, Tengvar, Saartok, and Thorstensson (2008) studied the injuries incurred in activities that forced the hamstrings to function in extremely lengthened positions. All injuries occurred during movements reaching a position with combined extensive hip flexion and knee extension.

Figure 3 illustrates a very common stretching exercise that places the hamstring muscles in the region of consideration in the above cited article. It is an instance of what is now termed "*abusive stretching*". The trainer forces the player into a position that could never be achieved voluntarily (i.e., without outside force). It should be easy to imagine what this exercise is doing to the player's groin and hamstring muscles' origins. The athlete has even put his hand on the muscle origins as an involuntary reaction to potential or actual harm being caused by the exercise and the way it is implemented.

Figure 3. Abusive stretching of a professional player's hamstrings and hip joints.

Dr. Larry Holt of Dalhousie University (personal communication, 2007) offered the following comments.

> *There are a number of things wrong with the picture. The most important observation for me is that by pushing on both legs the partner is creating something analogous to the 'rack'. Simply by forcing the left hip extensor attachments apart, the trainer is creating excessive tension and will either cause or predispose this athlete to a possible tear.*
>
> *Neither the athlete nor partner is in a correct position. The athlete is not lying flat, the non-exercised leg is off the ground (a protective maneuver), and the head and upper trunk should be against the ground without tension. I believe that the flexed right hip and tendency toward posterior pelvic tilt is the athlete's way of trying to minimize the tension on the left hamstrings created by the trainer.*
>
> *The entire protocol is unacceptable.*

One has to ask; *How many injuries in sports are caused by trainers and their stretching routines that entail the type of dangerous and nonsensical activities like that pictured above?* Not only are the exercises wrong but usually they involve static holding in the extreme positions. Consequently, the detrimental aspects of extreme static stretching are added to the injurious effects of forcing athletes into unnatural positions. Abusive stretching might well be a very common source of musculoskeletal injury in professional and serious sports, particularly when individuals attempt to justify their importance to an organization through overt activities that depend upon their [questionable] function. There is no research or scientific evidence that supports any procedure whereby the added partner in the stretching exercise contributes force to what should be a *PNF*-like resistive function.

Sufficient research has been published over the last decade to warrant a serious reappraisal of the value of stretching for sports performance.

Kokkonen and Lauritzen (1995) found that when performing *PNF* stretching, strength gains were also stimulated. Further, Kokkonen, Nelson, Tarawhiti, Buckingham, and Glickman-Weiss (2000) reported that strength gains were greater in a stretching plus weight-training condition than in a weight-training-only group. However, there is considerably more evidence about the negative effects of incorrect stretching on strength. Kokkonen, Nelson and Arnall (2001) found that extensive partner-assisted stretching (holding for 30 seconds which is construed as abusive) caused a significant decrease in the number of repetitions in a hamstring strength endurance test. It was recommended that heavy static stretching[12] of a muscle group intended for activity should be avoided before performances requiring a maximal strength endurance effort. In a later study, Nelson, Kokkonen, and Arnall (2005) found that static-stretching reduced muscle strength endurance. Force loss after prolonged static and passive stretching was shown (Behm, Button, & Butt, 2001). It was suggested that too much stretching decreases the capability for force production. Another study (Power, Behm, Cahill, Carroll, & Young, 2004) showed similar results and a negative association between increase in range of movement and maximal force and muscle inactivation. A thorough bout of ballistic stretching reduced the strength of the muscles stretched (Nelson & Kokkonen, 2001). Fry, McLellan, Weiss, and Rosato (2003) reported that static stretching in close proximity to maximum power and strength activities has a detrimental effect on performance.

The current literature supports the contention that extensive stretching and in particular long static holding, reduces the strength generating capabilities of the muscles stretched. Explosive activity is also compromised. Since sprint-swimming is explosive, the performance of considerable formal stretching as a preparatory activity for racing should be re-considered. A conservative interpretation of the evidence suggests that excessive stretching programs should not be entertained before competing and their value for training should also be reconsidered.

Evetovich, Nauman, Conley, and Todd (2003) proposed the loss of strength capabilities after stretching is as follows:

> "*. . . a greater ability to produce torque without prior stretching is related to the musculotendinous stiffness of the muscle rather than the number of motor units activated. This suggests that performing activities that reduce muscle stiffness (such as stretching or warming up) may be detrimental to performance*" (p. 370).

Running economy is actually improved when muscles are acceptably stiff. Craib, Mitchell, Fields, Cooper, Hopewell, & Morgan (1996) concluded running economy (and any explosive action) needs natural tightness in lower leg muscles and connective tissues to maximize the storage and return of elastic energy, and reduce the need for stabilizing activity. Continuing with the theme that the elasticity of muscles needs to be preserved for high performances, Jones (2002) attributed running

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[12] Current static stretching appears to refer to and involve extended hold positions in aberrations of *PNF* and *SAS* stretching. In *SAS*, 10 seconds was advised originally but has risen to as much as 30 seconds in most of the recent investigations. In *PNF* work, the isometric contraction of ~6 seconds has also been extended to as much as 30 seconds. It is possible that 30 seconds is too long and could be the cause of detrimental effects on activity performance. The lower boundary of abusive stretching could be holds that are too extensive.

performance to metabolism in the muscles and stiffer musculotendinous structures that facilitate a greater elastic energy return during the shortening phase of the stretch-shortening cycle. A certain level of muscle stiffness preserves the storage and return properties of elastic energy that can be used to generate energy in an activity. The contribution of elastic energy to overall muscle performance is as much as 25-40% (Cavagna & Margaria, 1966; Cavagna, Saibene, & Margaria, 1964). Nelson, Driscoll, Landin, Young, and Schexnayder, (2005) found that stretching before sprinting, slowed 20-meter sprint times. A review of data-based investigations led to the conclusion that stretching did not improve performance capability (Ingraham, 2003).

The consideration that performance results from metabolism and elastic properties in the muscles and connective tissues is rarely discussed. However, many of the factors associated with running exist in swimming, particularly where high velocities are sought as well as in explosive actions at the start and in turns.

Stretching has been used as an important ingredient for post-activity recovery. Exactly how it might assist in recovery rarely has been described. However, recent evidence has shown benefits from stretching in recovery are questionable. Herbert and Gabriel (2002) concluded:

> "*The results of five studies . . . imply that stretching reduces soreness in the 72 hours after exercising by, on average, less than 2 mm on a 100 mm scale. Most athletes will consider effects of this magnitude too small to make stretching to prevent later muscle soreness worth while*" (p. 470).

Inappropriate stretching has been shown to actually increase muscle soreness rather than reduce it. Static stretching induced significantly more delayed onset muscle soreness (*DOMS*) than did ballistic stretching (Smith, Brunetz, Cheniere, McCammon, Hourmard, Franklin, & Israel, 1993). Stretching did not accelerate recovery from ankle surgery when the recovery involved exercise (Moseley, Herbert, Nightingale, Taylor, Evans, Robertson, Gupta, & Penn, 2005).

Until definitive research demonstrates a positive relationship between improved recovery and stretching routines, one should assume that stretching does not affect recovery in any beneficial manner. Other forms of activity, such as continuous moderate overall movements that are aerobic in nature, provide a better avenue for recovery. However, if stretching is to be performed, it should follow the *3S* (*PNF*) protocol rather than static stretching (Funk, Swank, Mikla, Fagan, & Farr, 2003).

The basic tenet of increasing flexibility needs to be reconsidered. What is the value of being able to move a joint through a greater range of movement than that which is endowed naturally or required for an activity?

Injury prevention is used frequently to justify deliberate stretching routines that cover particularly vulnerable joints (e.g., ankles, knees, hips, and shoulders) often as a part of training, warm-ups, and performed at appropriate opportunities during a competition. High frequency flexibility exercises reduce injuries (Hartig & Henderson, 1999). Contrarily, Ingraham (2003) proposed that stretching is dangerous and that supporting data-based research to the contrary position of it being beneficial does not exist. Thacker, Gilchrist, Stroup, and Kimsey (2004) concluded similarly noting that the research showed that stretching was not significantly associated with a reduction in injuries. Herbert and Gabriel (2002) concluded the following:

> "*On average, about 100 people stretched for 12 weeks to prevent one injury and (if the hazard reduction was constant) the average subject would need to stretch for 23 years to prevent one injury*" (p. 470).

In an attempt to clarify this confusing topic, the following are recommended principles for use when considering doing sane stretching for swimming training and competitions.

- Do not perform any stretching activities that stress the joint tissues or structures.
- Do no exercises that bounce or force a joint beyond a natural range of movement (the voluntary stretching limit).
- Only use a partner for stretching activities if the partner is knowledgeable about and adheres to the correct execution of *3S* (*PNF*) stretching.
- Slow stretching should follow a physical warm-up but precede any skill and intensity specific activities. [*3S* (*PNF*) stretching has been shown consistently to be the only protocol that produces beneficial effects. Coaches should be wary of individuals promoting any other form of stretching.]
- No stretched position should be held other than in the PNF procedure.
- Once specific race preparations begin after warm-up, no further formal and deliberate stretching should be performed. The stretching of soft tissues should be achieved through swimmer-directed activities that are performed to meet the particular needs of the moment.
- If any stretching produces pain or *DOMS* that keeps returning after each stretching session, cease stretching.

Just what is the dividing line between sane and abusive stretching has not been defined. One could speculate that it occurs when a sane procedure is altered by the introduction of one or more dangerous practices. As was developed throughout this topic, sane stretching procedures that involve static holding propose the length of the hold be ~6 seconds (*PNF*) and ~10 seconds (*SAS*). In most recent studies that do not support flexibility benefits, the introduction of holds of ~30 seconds, which could be construed as being excessive, could be one cause of negative results. Because of this lack of clarity, the best direction that can be offered is to follow the original procedures of *3S* (*PNF*) and *SAS* stretching for formal stretching as well as letting athletes stretch themselves using self-established methods and progressions in which they have confidence and are comfortable.

Closure

Six topics were discussed with implications drawn from research publications presented to clarify often observed misconceptions of many swimming coaches about their status. There likely is to be considerable dissonance in and understandable negative reactions from those who hold contrary belief-based views. It is contended that what has been presented here is typical of other topics in that there is a research/data-base that should be mined so that the coaching swimmers receive is founded on evidence-based truths rather than rationalized speculations, misinterpretations, or misinformation often developed through armchair-theorizing.

The 25-years Rule

This writer has often talked about the *"25-years Rule"*: An hypothesis/observation that it takes at least 25 years for a finding in human movement science to be accepted by coaches and incorporated into their practices. After 50+ years in this science-coaching business, that rule seems as valid today as it was in the 1950s (e.g., then interval training was being embraced as the *"new"* training paradigm although Gerschler wrote and published at length about it in the mid- to late-1930s).

- Emphasizing conditioning and physiology is so entrenched in swimming and educational curricula that complete understanding and re-emphasis within 25 years is unlikely. As such, most swimming experiences will be based on irrelevant guesswork, for which swimmers with potential that is not nurtured correctly, will not be able to enjoy success in the sport at a level to which they are entitled.

- The rejection of altitude/hypoxic training is likely to take less than 25 years because there appears to be a semblance of realization that expected benefits from this class of activity have not been forthcoming.
- Lactic acid will remain in the swimming coaches' lexicon until conscientious individuals change their understanding of the phenomena embraced by the term and transfer that realization to other coaches. Since this is a verbal content item and requires re-labeling to *"lactate"*, the change in the concept of lactate/lactic acid and its associated phenomena should occur in less than 25 years. However, unless educational courses also correct this *"misspeak"*, outside forces will prolong its existence, despite the errors being widely known since the early 1980s.
- Pacing will be paid lip-service because *"racing is all about taking a lead and holding it"*. The implication of swimming performances being limited to discrete energy quantities, and the requirement for their judicious use, will be thwarted by the common exhortation to swimmers to *"go out early"*. Unfortunately, because of the associated false premises of competing, many potential winners will be turned into losers over at least the next 25 years.
- The acceptance of whole-arm propulsion could take 25 years because sound technique instruction is still masked by the use of irrelevant training aids, basic flawed thinking (e.g., catch-up stroking), and the reliance on other dubious over-emphases such as nutrition and dryland training.
- Excessive and detrimental stretching will persist because it is a practice to which the current generation of swimmers have been indoctrinated and only when they have passed through the competitor and coaching ranks might alternative data-based implications be considered. This dubious practice should persist for 25 years. The role of support persons in the sport will exacerbate this problem.

Features that have been presented above are but a smattering of what is available and should be known by conscientious swimming coaches and indeed, coaches of any sport. It is possible that systems could be developed to provoke attitudinal changes in coaches but given the politics and power struggles that are commonplace in coaching organizations, that is unlikely.

The opportunity to present to this body is much appreciated. What was presented was an honest attempt to suggest some fruitful re-directions for swimming coaching. It is hoped that it will be accepted in that light. For those who feel disposed not to react in a positive manner, apologies are extended for the angst that was provoked.

With regard to the matters discussed here, changes are in order!

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