SWIMMING SCIENCE BULLETIN

Number 39

Produced, edited, and copyrighted by

Professor Emeritus Brent S. Rushall, San Diego State University

[Revised July 16, 2015]

© SWIMMING ENERGY TRAINING IN THE 21ST CENTURY: THE JUSTIFICATION FOR RADICAL CHANGES (Second Edition)

Brent S. Rushall, Ph.D.

TABLE OF CONTENTS

© Brent S. Rushall, 4225 Orchard Drive, Spring Valley, California 91977.

PREFACE TO THE SECOND EDITION

July 16, 2015

With such a long paper as this, one often finds statements that could be worded better, sequencing of ideas that could be improved, and additional information that needs to be added to increase the accuracy and reliability of the information presented. Improvements have been recognized and are included in this revised edition.

The major change has been the added recognition of stored oxygen (oxyhemoglobin and oxymyoglobin) as a source of aerobic support at the commencement of ultra-short work intervals.

The designation of Ultra-short Race-pace Training (USRPT) really alludes to race-pace work being completed in the ultra-short interval training format. The ultra-short structure promotes swimmers to complete the greatest volume of high-intensity work, and in this case race-specific work, at training. As well, it prevents the development of degrading exhaustion which is a hallmark of most traditional training formats. There are many benefits that USRPT has over traditional training. When they are reviewed it is a wonder that anyone would ever try traditional training again (Rushall, 2013a).

There is one more feature of USRPT that needs stressing. For USRPT to be complete there has to be an equal emphasis on conditioning and technique. To only use it for conditioning is to miss the main point about race-pace training. The possible benefits of the training program will not be fully realized if technique is neglected. To assist coaches with integrating technique instruction into ultra-short conditioning, the coaching manual *A Swimming Technique Macrocycle* (Rushall, 2013b) was produced.

References

Rushall, B. S. (2013a). Ultra-short race-pace training and traditional training compared. *Swimming Science Bulletin, 43*, http://coachsci.sdsu.edu/swim/bullets/Comparison43.pdf.

Rushall, B. S. (2013b). *A swimming technique macrocycle*. Spring Valley, CA: Sports Science Associates. [http://brentrushall.com/macro/]

Abstract

For a variety of reasons, the accurate understanding of the energy requirements of swimming races has been absent from swimming coaching circles. The programming reasons and implementations of conditioning stimuli at training have largely been irrelevant for stimulating improvements in race performances. The traditional physiology of swimming energy use should be discarded.

Swimming is a fully supported, partially-intense activity. That sets its energy demands apart from non-supported, total-body activities such as running and cross-country skiing. Research implications gained from those activities should not be used as guidelines for physiological responses in competitive swimming.

Recent swimming research has indicated that in single races, stored oxygen and the alactacid and aerobic energy systems are dominant while a considerable amount of Type IIa fibers developed through specific training add to the oxidative energy pool for racing. The physiology of traditional swimming practices is discretely different to that of racing. Thus, traditional practices are largely irrelevant for racing and do not provide an avenue for race improvements.

By revising what is known about human physiology and neuromuscular patterning, the case was made for race-specific techniques and their energizing as being inextricably yoked and represented as discrete brain activation patterns. The result is that the only way to improve swimming velocities for specific races is to practice swimming at those velocities or slightly faster. The term "ultra-short training at race-pace" is appropriate.

Traditional practice programs and items do not accommodate much high-intensity work. Yet, the physiological and mechanical benefits of high-intensity (race-pace) training are more than any other form can provide, particularly those commonly seen in swimming practices.

Research has shown how to complete large amounts of race-pace training without incurring exhausting fatigue. It is proposed that ultra-short training at race-pace is the format upon which all race-pace training should be patterned. The benefits of race-pace training in swimming exceed those of other forms of interval, repetition, and continuous training.

The physiology, neuromuscular patterning, and implementation strategies for race-pace training are explained in some depth. Several factors that maximize the training effects of race-pace sets and that are contrary to common coaching practices are also explained.

This far-reaching paper attempts to make the case for drastic changes in the programs and behaviors of swimming coaches. Increasing relevant and decreasing irrelevant training is proposed. It is evidence-based with extensive references to support most of the premises in its arguments. Consequently, it is hard to argue against as it is more defensible than current belief-based coaching behaviors and practices.

Radical changes in swimming coaching are in order!

Introduction

This paper concerns matters that are appropriate and important for coaching serious dedicated swimmers who seek performance improvements.

Over the past 60 years in competitive swimming, the interest in associated science has grown. For a major portion of that period, theories of human function, limited science, and extensive dogma from other sports migrated into swimming. A major share of swimming research developed in the domain of applied physiology. As more good research is completed, many popular and historical beliefs about swimming physiology have not been corroborated no matter how powerful the reasoning behind the beliefs of the former swimming "science".

The extent of valid and reliable swimming research grows. More dogma has been disproven while it is reasonable to assert that new dogma has arisen, somewhat alarmingly. Still, old beliefs die hard leading to increases in the difficulty of promoting scientific data as the basis for altering beliefs and habits that have existed often to the detriment of swimmers' performances and experiences. Recent research has promoted the need to radically change a considerable number of the beliefs concerning the use of energy systems in swimming races.

Some enduring factors that have continued to hinder change in this area are listed below.

- A failure to distinguish between the different demands and effects of repetitious training and the single-performance nature of swimming races.
- Adherence to false, bad, or misunderstood principles of the physiology of single races that lead to largely irrelevant-for-racing training experiences.
- The canon that "if hard work leads to good performances, harder work will lead to better performances." The number of young people who have been turned-off by swimming training following that tenet, is likely to be much greater than one might care to admit.
- The conditioned state of swimmers can always be improved. Physiological factors have finite levels of development and no matter what occurs cannot pass an individual's genetic ceiling.
- Resistance to behavior change is in the nature of humans. Once comfortable with publicly committed behaviors, resistance to altering behavior becomes active no matter what contrary evidence is presented. [Such a reaction is likely in many who care to read this treatise.]

No matter how great the dogma, entrenched practices, lore, and the dubious logic underlying the reasoning to maintain the status quo, it is important to indicate how the swimming experiences of training and competing might improve. This paper focuses on the energizing of single swimming races and how training should be altered to relate to the appropriate energetics.

Traditional Physiology-inspired Training Programs[1]

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[2]. 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

[1] This introductory section is taken largely from this author's keynote address, *The Future of Swimming: "Myths and Science"*, presented at the ASCA World Clinic 2009 in Fort Lauderdale, Florida on September 12, 2009. That address was reproduced as *Swimming Science Bulletin #37* in the *Swimming Science Journal* (http://coachsci.sdsu.edu/swim/bullets/table.htm).

[2] Unfortunately, possibly the most important energy system for powerful human performance, the elastic energy system, is rarely mentioned, let alone discussed in swimming circles.

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.[3]

- 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 and/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 propagate training systems and provide belief-based literature and coaching aids for implementing physiological conditioning (e.g., Greyson et al., 2010) .
- Coaches of many high-profile and successful swimmers attempt to provide explanations of swimmers' achievements in "pseudo-scientific" terms, which usually resort to physiological descriptions of training programs that are based largely on belief and seldom 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 reinforces 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 et al., 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 in favor of 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 was completed at training is not necessarily what actually was 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 elite 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 et al., 1985). [Just what is achieved through a program with training "variety" is unknown but is more than likely unrelated to a competitive swimming event.]

[3] The supportive references throughout this paper are not exhaustive. A deliberate attempt has been made to represent the published literature, particularly when research results have been equivocal.

- Anaerobic work capacity and factors/indices are unrelated to swimming performances (Papoti et al., 2006; Rohrs et al., 1990; Zoeller et al., 1998) and are difficult to determine in swimming (Almeidal et al., 1999).
- Physiological capacities have limited (ceiling) levels of adaptation and after they have been achieved no further benefits are possible (Bonifazi et al., 1998; Costill et al., 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[4]). [It is erroneous to assume that 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 et al., 1981; Pyne, Lee, & Swanwick, 2001; Rowbottom et al., 2001). However, some physiological tests performed during taper are moderately related to ensuing competitive performances[5] (Anderson et al., 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 (Maglischo et al., 1985; Ogita, Onodera, & Izumi, 1999; Payne & Lemon, 1982; Sexsmith, Oliver, & Johnson-Bos, 1992). [Because of specific training effects, non-specific activities will have little 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 (Breed, Young, & McElroy, 2000; Bulgakova, Vorontsov, & Fomichenko, 1987; Costill et al., 1983; Crowe et al., 1999; Tanaka et al., 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 et al., 1993; Rocha et al., 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 et al., 1997). [Such tests are irrelevant for guiding training program content or swimmer progress.]
- Blood factors are not associated with swimming training effects (Hickson et al., 1998; Mackinnon et al., 1997; VanHeest & Ratliff, 1998) but have a moderate relationship in tapered states (Mujika et al., 1998).
- The various forms of physiological thresholds measure different factors in swimmers (Johnson et al., 2009).

---

[4] 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.

[5] However, during taper it is too late to take any corrective steps to re-train physiological functions if those functions are important for racing.

- 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) [This paper attempts to satisfy the implications contained in that quote.]

Many performance physiology findings are incompatible with the predictions of specific physiological models. The traditional dogma of swimming 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. This paper attempts to satisfy that need.

The limited reasons and implications from the restricted models described in Noakes' review will not result in the best form of swimming training. The following are implied [training adaptations are considered to be responses that 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.
- 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 programs that lead to maximal fitness adaptation for a specific sport's events, in this case, swimming races.
- Training that emphasizes the reaction of muscles in the replicated activities of the sport is likely to produce beneficial fitness adaptation.
- It is likely that training programs developed by incorporating scientific 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 inferences that are commonly proposed. However, this ethic is not commonly observed.

The above items are presented as a sample of factors that over time have shown there has been a gradual exposition of some of the misinformation perpetuated in most educational ventures in the sport of swimming. The emphasis on physiological adaptation through conditioning has been too restrictive and largely irrelevant for competitive swimming (Kame, Pendergast, & Termin, 1990). Savage et al. (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 deficiencies when 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. [A strategy for accommodating individual differences within a training group is prescribed toward the end of this paper.]
- Unless representative teams are measured and trained according to their specific requirements, the performance of representative teams will always include disappointments and "unexplained" poor performances.
- Modern coaching requires the greatest amount of individualized training and programming possible.

The purpose of this long exposition is to illustrate the number of research findings in physiology that are contrary to the existing dogma of swimming coaching. Since many coaches follow a pseudo-scientific path and plan training around misinformation and myths, it is not hard to assert that current training practices and theory do not lead to the best forms of training experience and effects. It is time for new thinking. It possibly would be best to start from basic science rather than only altering some of the incorrect training theory that abounds in the sport.

Considerations of physiological functioning in swimming that are contrary to the entrenched dogma of swimming coaching, often ill-attributed as being scientific, have met with considerable resistance. Individuals presenting alternative, scientifically verified concepts and applications are rarely presented to swimming bodies and gatherings. The behavior of the "powers that be" in swimming coaching and swimming in general, is a common trend in human functioning. It is but one piece of evidence that substantiates Machiavelli's (1446-1507) astute commentary on human behavior in his enduring documentary, *The Prince*:

> *"There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain its success, than to take the lead in the introduction of a new order of things, because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new".*

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, 2011b). Mental skills training should also be emphasized before physiological conditioning is stressed. However, physical conditioning is an important facet of the training of serious athletes. The correct application of sound, evidence-based principles in training and competing is an important aspect of beneficial training. Relevant-for-competition training stimuli should be provided and irrelevant-for-competition stimuli disregarded or presented solely as intriguing activities for physical recovery from fatiguing relevant overload experiences and program content.

Traditional Conceptualizations of Energy Systems and Exercise

The metabolic energy[6] required for short explosive activities is provided by the breakdown of high-energy phosphate compounds in the muscles. One of these, adenosine triphosphate (ATP), must be present before a muscle will contract. ATP could be called the "chemical of contraction", as the body-machine will not work if it is absent. ATP is stored in small amounts in the muscles and can only sustain activity for one to two seconds unless some other additional or restorative interaction occurs. If activity is to continue, ATP can be replenished from other energy sources in the muscle. This occurs when another high-energy phosphate compound found in the muscle, creatine phosphate (CP), is degraded to produce ATP and provide the energy for continued activity. CP too can be restored during exercise. Only very short recovery periods are required for these energy sources to be sufficiently replenished to provide for a repeat effort. Restoration also can occur within an exercise when a very brief relaxation period follows an equally brief effort phase. After a total exercise, any alactacid deficit is restored extremely fast and in unusual circumstances of depletion could take up to 30 seconds (unlikely to occur after swimming races). Oxygen is the main restorative chemical for this category of energy provision. Improvements in the supply of restorative oxygen during exercise can be the result of specific training that stimulates that functional need.

The activity of the ATP-CP energy system does not require the presence of oxygen and is considered to be part of the anaerobic (without oxygen) energy system. Since lactic acid is not produced by this system it is also called the "alactacid" system. It uses both Type II and Type I muscles fibers when executing a rapid response to a stimulus. However, oxygen is required for this system's recovery/restoration. Traditionally, the alactacid energy system is considered to be used in short-duration total-body speed and strength activities. However, as is explained below, it has a most important role in swimming races. The functioning of this energy system can be prolonged by training stimuli of appropriate intensity and activity.

A rarely mentioned feature of the sources of energy for exercise is stored oxygen. Myoglobin (also called myohemoglobin) and hemoglobin are proteins that are structurally different but functionally similar in that they combine with oxygen and serve as stores for readily available oxygen. Their distribution throughout the body differs (e.g., myoglobin is dominant in the muscles and hemoglobin travels primarily in the circulation). When combined with oxygen, they are referred to as oxyhemoglobin and oxymyoglobin. In the grand scheme of work physiology, their similar functionality does not need them to be differentiated and they serve as the body's cache of stored oxygen that is readily available at the outset for high-intensity exercise. For the remainder of this paper alactacid energy potential will be yoked with stored oxygen as the endogenous substances[7] available for use in high-intensity exercise.

Other forms of fuel are also stored and made available in the muscles for more sustained bouts of work. These are stored sugar (glycogen) and fat, which are degraded by different mechanisms to again produce the chemical of contraction, ATP. During a sustained total-body high-powered sprint,

[6] Rarely, if ever, is energy derived from the elastic properties of the connective tissues mentioned in swimming circles. However, it is very likely to be the most important energizing factor in explosive and/or powerful actions, movements that abound in the arm and leg actions of competitive swimming strokes. Unfortunately, this essential factor is often depleted by abusive, ill-advised, and/or ill-conceived stretching routines (Rushall, 2009) that are still popular in swimming.

[7] It is common to consider stored oxygen as part of the aerobic system. However, for this paper it will be considered as an endogenous resource that exists along with the alactacid system as available resources at the onset of exercise. Exogenous oxygen is used to replenish the endogenous oxygen stores.

when both stored ATP and CP and the delivery of oxygen are insufficient to meet the demands of the effort, the high-energy carbohydrate compound glycogen can be broken down by enzyme reactions to glucose ("glycogenolysis"), then to lactic acid, which finally dissociates to lactate and hydrogen ions. The production of lactic acid, called "glycolysis", produces limited quantities of ATP, which, along with stored ATP and CP, can maintain high-effort total-body muscular contractions for between 30 and 40 seconds. The system that produces energy from this source is called the "lactacid" or "glycolytic" energy system. It is used in sustained total-body sprint or muscular endurance activities of relatively short duration. Ultimately, the presence of large amounts of lactate and hydrogen ions interferes with the mechanical events associated with muscle shortening and neural conductance and a person is forced to decrease the exercise intensity or cease activity altogether. While the subsequent removal of lactate is facilitated by oxygen and exercise that does not promote lactate accumulation during recovery, it still takes considerable time. In continuous activities that have cyclic use and non-use of the lactacid system, restoration of some of the system deficit occurs within the exercise. The functioning of this energy system can be prolonged by training stimuli of appropriate intensity and activity.

The lactacid energy system is associated with muscle fibers that have the distinct quality of contractile speed, being labeled "fast-twitch" fibers (Type II fibers). In an untrained state, those fibers function anaerobically. However, when the body is exposed to much high-intensity training, some of the fibers switch and become oxidative, using inspired air in much the same way as aerobic fibers but still maintaining the fast-twitch characteristic. In the oxidative process, glycogen is converted to water and carbon dioxide, not lactic acid. Fibers that remain glycolytic are labeled Type IIb fibers while the oxidative fibers are Type IIa. The absence of lactate after an exercise does not mean that fast-twitch fibers were not used. It could indicate they were used, but in an oxidative manner, which is not evident in lactate analyses. Thus, the portion of the lactacid system conversion that is oxidative adds to the ability of muscles to function with speed and endurance.

In exercise, oxygen is used in varying degrees of importance depending on the level of effort. If exercise is not very intense, performance can be prolonged. The process of oxidation, which provides much larger quantities of ATP, can then maintain the rate of energy release in the muscles. For oxidation to occur, oxygen must be transported from air to the muscles by the cardiorespiratory system and then used for the production of energy. This process is termed "aerobic" metabolism, and can occur with the oxidation of both the glycogen and fat stores contained in the body. The oxidation of glycogen through the aerobic system is much more efficient than through the lactacid system and therefore, is preferred. The muscle fibers associated with untrained aerobic metabolism are Type I or "slow-twitch" fibers. For swimming races, glycogen is preferred to fat as the fuel for high-effort levels because it yields energy more efficiently. For all swimming pool events, the limited supply of glycogen is not a problem. The functioning of this energy system can be prolonged by training stimuli of appropriate intensity and activity. Such stimuli are rarely programmed in swimming training, although many coaches claim such is the case.

In extended practice sessions, both glycogen and fat are used as fuel. Fat use spares the limited resource of muscle glycogen and allows a training session to be completed without depletion. The ability to exercise for long periods at a moderate intensity is related to what has been termed the anaerobic threshold, or sometimes the "lactate" threshold among other labels. This is the effort level that if exceeded requires some energy supplementation from anaerobic energy sources, particularly the splitting of glycogen to form lactic acid. The use of glycogen is dependent on the aerobic qualities of the muscles and usually is high in swimmers who complete large training volumes without reaching an overtrained state.

One aspect of the aerobic system is its capability to pay-back anaerobic energy use while recovering. Reviewing the nature of oxygen consumption during recovery provides a window into some of the non-aerobic energy functions that occurred during a performance. Post-performance oxygen consumption restores the portion of anaerobic processes used while exercising that was not restored/cleared during the exercise. The post-performance consumption curve has two parts. First, the "fast-component" is used to restore muscle phosphagen compounds (ATP-CP) and to oxygenate myoglobin and hemoglobin. That restoration occurs very rapidly and rarely exceeds 30 seconds. Second, the "slow-component" occurs during recovery and initially overlaps with the fast-component. It removes lactate and other compounds associated with the use of glycogen as well as restoring temperature, hormonal balance, etc. The degree that post-exercise oxygen consumption remains notably above normal suggests the extent of anaerobic energy production during the performance. The traditional interpretation of aerobic energy use is only within exercise. It is a position of this paper that the role of oxygen in recovery directs attention to how energy is used in swimming events as well as indicating some capabilities of swimmers which until now have been largely ignored.

Respiratory rate, oxygen consumption, and metabolism can remain above normal for considerable time after the restoration of energy systems has finished. If the exercise was demanding and fatiguing, recovery continues to re-establish body temperature, bathe damaged muscle cells, and attend to the biochemical and hydration statuses, among other functions.

In summary, stored oxygen and high-energy phosphates are the predominant energy sources for brief total-body efforts. The splitting of glycogen into lactic acid provides the major energy resources for sustained sprints and feats of muscular endurance lasting between 10 and 60 seconds. Both these energy sources are *anaerobic* in their provision of energy but require oxygen for recovery/restoration. Estimates of duration of time limits usually are associated with high-power total-body activities. Those estimates can be extended significantly when the activity form is not total-body and does not have to completely combat the effects of gravity. The totally-supported and partial-effort nature of swimming stamps it as one of those activities. The energy for lower-power efforts over longer periods of time is provided by the oxidation of glycogen and fat and requires a supply of oxygen to the working muscles via the cardiorespiratory system. However, the ability to use oxygen to sustain exercise is limited within the individual with considerable inter-individual variance. In swimming, that variability usually produces some swimmers who can absorb a lot of training while others breakdown more easily and can only tolerate smaller volumes of training stimuli.

Total-body sports in which high-power efforts are made intermittently, such as many individual sports (e.g., tennis, squash, boxing, etc.) and team sports (e.g., rugby, cricket, volleyball, etc.); rely on the continual breakdown and restoration of anaerobic energy sources during a contest. The process of resynthesis during recovery periods within training or games requires the provision of oxygen. Hence, athletes in these sports require both aerobic and anaerobic training, but not necessarily as discrete entities. That also is what is required at swimming practices. The traditional interpretations of the actions of various energy systems are restricted to total-body continuous or intermittent exercises. Even in total-body exercises, there are modifications of muscular efforts. For example, in a 200 m run, the arms and legs work as hard as each other and both draw upon energy sources to sustain their high-intensity effort levels. In longer running races, such as 10,000 m and marathons, the intensity of the leg work is reduced as it is for the arms, but the latter to a much greater degree. That results in some body actions minimizing their exercise intensity while those that are directly productive in generating functional forces are sustained at a higher intensity. The balance within a human of all these functions and energy requirements results in activity that uses oxygen maximally within the activity while saving (sparing) the available energy sources (particularly glycogen).

Open-water swimming is likely to require much aerobic energy system use. However, since the sport is totally supported and relies on only partial-body intense work, there is the possibility that the active but below-lactate-threshold non-functionally productive exercise elements (legs and in particular the trunk) provide a large platform for within-exercise recovery of anaerobic functions[8]. That interaction allows for the functionally performing muscles to endure working for longer periods of time than is usually attributed to total-body unsupported exercise forms. The functional modifications of energy supply caused by swimming being totally supported rarely, if ever, are considered in the theoretical postulations about energy supply and functions. Further considerations about the nature of swimming and its interactions with energy supply mechanisms are discussed below. The main point though, is that the supported nature of swimming alters its energy use from that described for unsupported exercises, which in turn requires a filtering of research findings to discover those that are valid and invalid for understanding swimming energy requirements.

Energy Use in Swimming

Few people understand the nature of energy provision that happens in a swimming race. As the activity is initiated, the greater amount of energy comes from stored oxygen and the alactacid system. After the start of a race, lactate is increasingly produced until oxygen consumption also increases to a level where lactate production and removal are balanced. Lactic acid (eventually lactate) is produced not only in active muscles but also in inactive or low-demand muscles, the kidneys, and the liver. [Consequently, lactate sampled from blood does not indicate the source of or time since production of the substance.] Finally, the aerobic system becomes fully functional. If an individual is untrained and not "warmed-up" (in a race-specific metabolic sense) it could be 90 seconds before full aerobic functioning occurs. That might be the scenario in the first repetition of an 8 x 100 m set on 1:30 at 800 m race-pace. As the set progresses, stored oxygen and the alactacid system always initiate each repetition but activation of both the lactacid and aerobic energy provision occur earlier and earlier in each succeeding repetition. If the rest interval is too long, the activation level of the aerobic energy system decreases, making it necessary to endure more alactacid and lactacid energy provision at the start before the aerobic system is fully functional.

With the specific parameters of each training set (swimming velocity, duration of rest, number of repetitions, form of stroke), the brain establishes a network of activation centers that are associated only with a consistent pattern of exercise stimulation experienced in the set (if indeed it is performed that way). That patterning will not be established if the quality of repetitions within a set varies (e.g., as in ascending and descending sets). With each constant repetition in the training set, the brain learns what is required to complete the familiar task and codes that constancy as a set of neuromuscular patterns that are closely associated[9]. There is a critical time between the re-exposure

---

[8] Lactate does not accumulate much when its clearance during exercise closely matches its production, which happens often in swimming races and at training. Lactate is cleared by the heart, brain, liver, and muscles. Lactate formed by heavy working muscles (arms, shoulders, upper torso) can be used by less active muscles (legs, lower trunk, the heart). The less active muscles use oxygen to convert lactate to pyruvate to glucose ("gluconeogenesis") when it can be stored or reused as fuel.

[9] The description here is of a restricted area of the brain containing neural activation patterns appropriate for a race, the constant training repetitions being replications of parts of the race. Because swimming is not an exact-skill sport, the neural patterns are more like a family of patterns that are activated at various stages in a race. When race-pace training sets stimulate this family of patterns, although to an observer the technique and pace of the swimmer seem consistent, the various contingencies and needs that arise in a race will have been suitably prepared through specific-race training.

to the set's parameters that allows learning/training to occur. If the time between exposures is too long, then forgetting occurs. [That period might be 36-48 hours but there will be considerable interindividual variation.] An effect of accurate training is that the activation of the slower-responding energy systems occurs earlier than when the set was first experienced. The amount of earlier activation of each system progresses up to a level where it will no longer improve. That occurs when a specific training effect is fully achieved. That is how specific activity training produces specific-activity adaptations.

However, if sets are never or rarely repeated or just too far apart, but the training program provides much variety in terms of set contents, the use of "useless toys" (e.g., kick boards, pull buoys, fins, etc.), and irrelevant "drills"[10], the brain does not establish specific patterns of activation related to a specific race. It develops a higher-order coping procedure that allows the body to perform in virtually novel tasks as best it can, but that will never be to the level of efficiency promoted by race-pace specific sets. "Variety training" gives rise to the notion that "mixed training produces mixed results".

Consequently, repeated exposure to constant specific training stimuli improves the initiation of energy function. That can only be fostered by familiarity with the training stimulus. When swimming velocity is race-pace specific, the familiarity is evoked in a race.

Much traditional and novel (as advocated in this paper) swimming training employs aerobic function. In time, those continual stimulations provoke some fast-twitch Type IIb fibers to become oxidative Type IIa fibers. It is generally accepted that the arms and shoulders contain a greater percentage of Type II fibers than do the hips, thighs, and legs. Consequently, swimming training should stimulate the conversion of the fast-twitch fibers to oxidative metabolism. Individuals with a high-capacity for conversion are likely to be more suited to swimming than those with a lesser capacity. After sufficient training, an appreciable number of fast-twitch and all slow-twitch fibers should function oxidatively. That could account for the absence of an association between anaerobic glycolytic activity and swimming racing. However, after a full training session, both forms of Type II fiber are likely to have been close to, if not fully, stimulated.

At the stroke cycle level, that is when an arm produces propulsive force for a very brief time and abruptly changes to a brief recovery phase, the energy activation is slightly different. The work level of the arms, shoulders, and upper torso is much higher than the remainder of the body. The energizing properties of the different intensity levels are dissimilar. As specific training and relevant learning experiences are encountered, the energizing of the lower-intensity body and legs is very likely to be mainly aerobic and to a lesser extent lactacid energy. However, the high-intensity force production of the arms and upper body occurs for such a short time that it mainly will be fueled by stored oxygen and the alactacid system, which is mostly repaid in the very lesser-intensive recovery phase. Even if glycogen is eventually used in a stroke-cycle, most lactic acid will be reconverted by the lower-intensity activated legs and body. In that role, in a race those portions of the body act just like active recovery which is promoted as a post-race activity. The reason one can be sure about the stored oxygen and alactacid demands of the propulsive phase in stroke cycles is that post-race aerobic kinetics only demonstrate the fast-component. The slow-component, which indicates use of the lactacid system, usually does not appear in post-race analyses. It may appear in many sets of repetitions at training which distinguishes irrelevant training stimuli from relevant training stimuli

[10] Not that there are any relevant drills for high-level or elite swimmers, no matter how popular they are in the dogma of swimming coaching. On the other hand, drills are useful for learn-to-swim programs and the early stages of learning specific skills (e.g., tumble turns, double-leg kicking, etc.). The paradox here is that drills are useful in one swimming setting and potentially harmful in another.

(i.e., those repetitions which do not generate a significant slow-component in the accumulated oxygen debt). Also, if a swimmer does not perform with sufficient quality in a set, no slow-component will be evident because the intensity of the swimmer's work has been too low to generate an overload on the lactacid system.

Within a stroke cycle, the brain has to experience sufficient repetitions of the race-specific task to establish the neural network that will initiate efficient functioning on future occasions. With good instruction/coaching, irrelevant functioning should have been discarded leaving a finely differentiated pattern of biomechanical and physiological functioning that should produce a particular quality of progression through water with the least use of energy. That is now termed "propelling efficiency", a factor that is increasing in popularity for judging training effects (Cappaert, Pease, & Troup, 1996; D'Acquisto & Berry, 2003; D'Acquisto et al., 2004). It has replaced most physiological capacity measures such as VO_{2max}, lactate threshold, etc.

Appropriate race-pace training should improve the provision of energy and the efficiency of stroke techniques to the point that race performances will improve because of relevant training. In the early part of this century, the recognition of the role of exact race-pace training began to be recognized. Many top level coaches, not necessarily in the USA, Australia, or Great Britain, now consider the general index of effective training programs to be the distance covered at race-pace. That differs markedly to the demand for a large number of training sessions attended and notable volumes of training distances (at irrelevant and/or relevant velocities) achieved in a week.

The role of stored oxygen and alactacid energizing has largely been ignored in swimming. However, the case has been made, and the evidence for their very important role has been presented. Evidence of functioning of the lactacid and aerobic energy systems is very different to that which exists in the dogma and misinformation of swimming coaching. A new way of interpreting race demands and training them with relevant stimuli at practices is in order.

Upon completing a swimming race, the stored oxygen and alactacid energy system are repaid and virtually shut down and cease to provide a considerable amount of energy. However, the lactacid and aerobic energy systems continue.

Lactate concentration measured after a race or workout gives no information about when it appeared in the event. Thus, knowing the lactate level tells you nothing about how it was formed in a performance (Roth, 1991).The lactacid system requires some time to lower its level of function. The cessation of exercise means that any lactic acid that is formed no longer is used for energy to fuel exercise. For up to several minutes, it continues to convert to lactate resulting in the highest lactate measures occurring often at five minutes post-exercise. Then its activation level starts to slow to the point where progressive increases in lactate levels no longer occur. As soon after a race that it is possible to start an active warm-down swim, the better. The activity consumes some of the lactic acid to reform glycogen. The accentuated circulation caused by the exercise, particularly the mechanical aspects of blood flow resulting from the contraction and relaxation of muscles, accelerates the clearance of post-exercise lactate build-up. If the velocity of the warm-down swim is close to the anaerobic threshold and the swim is continuous, clearance is usually achieved within 15 minutes (McMaster, Stoddard, & Duncan, 1989; Weltman et al., 2005).

The aerobic system continues to function above sedentary level until the fast- and slow-components of the accumulated oxygen deficit have been paid, that is, the stored oxygen and alactacid and lactacid energy systems are fully restored (see below). Elevated circulation and respiration also continue until normal homeostasis is achieved throughout the body.

Energy Systems and Their Relevance to Swimming Training

Aerobic training alone is perhaps the most emphasized form of physiological training employed in traditional swimming training. It is proposed as being the central emphasis of pre-pubertal swimmer training (Greyson et al., 2010; Vorontsov, no date). Some of the various common descriptions of aerobic metabolism that permeate the dogma of swimming coaching are:

- *Training activities can be performed that only stimulate aerobic adaptation.* The actual fact is that aerobic metabolism occurs to some degree in all swimming training activities (Rushall & Pyke, 1991).
- *Aerobic training is mainly of slower-than-race-pace velocity and performed in large volumes*. It is contended (see below) that this concept of aerobic training is too restrictive, inefficient, and irrelevant for swimming training at all ages (Rushall, 2011a).
- *Aerobic metabolism is a single entity*. In actuality, it consists of several discrete metabolic functions (McCardle, Katch, & Katch, 2004), which are described above and below.
- *Any aerobic training is beneficial for the swimmer's performance.* Different training velocities produce different aerobic training responses (Matsunami et al., 2000), and the likelihood of one influencing the other is very low.
- *Anaerobic threshold is a useful training concept.* Actually, the various protocols and concepts of thresholds yield different values (Almeidal et al., 1999). Since all swimming races occur at effort levels that exceed the anaerobic threshold, such training is irrelevant for racing.
- *Many tests for aerobic function in swimming pools (and out of pools) provide useful information to justify and prescribe training.* Given that aerobic (oxidative) metabolism does not consist of a single physical function, testing needs to be specific for each aerobic function and equally valid for the sport. When all energy functions are tested together there is no accommodation for the variations in subset emphases provoked by the peculiarities of any testing protocol. The use of invalid and spurious testing is rife in swimming.
- *Aerobic energy use is similar between genders.* In events over the durations of swimming races, females demonstrate greater relative aerobic function than do males (Byrnes & Kearney, 1997).

The common descriptions of energy use in swimming have largely been belief-based and often contaminated with misinformation. They have concentrated on aerobic functioning. The belief systems associated with this aspect of the sport have been extensive leading to labeling of sub-systems (e.g., aerobic-1, aerobic-2, aerobic-anaerobic, anaerobic-aerobic, glycolysis-A, glycolysis-B, glycolysis-C, alactic creatine-phosphate (Vorontsov, no date)), the prescription of training philosophies and content (e.g., Greyson et al., 2010), and most commonly discussion content that is inaccurate, confusing, and incomplete. The contributions of anaerobic and aerobic energy to swimming performances over the standard long-course racing distances were described by Troup (1990), while further, Ring, Mader, and Mougious (1999) showed that muscle fiber and energy system use differed between the sprint distances of 15, 25, and 50 meters. The specificity of single swimming efforts is exquisitely unique to each stroke, distance, and velocity (i.e., race).

In trained swimmers, aerobic energy has a dominant use for maintaining the posture of the athlete and fueling most functions up to the point of extra energy being required to sustain high-intensity activity within the body and limbs. As the intensity of swimming efforts decreases, the dominance of aerobic activity increases.

The most common misconception about aerobic functioning in swimming is that oxygen inhaled is used for only the aerobic energy system's use of glycogen and fats for fuel during exercise. There rarely, if ever, is contemplation that oxygen use can be in several domains at the same time or that the intensity of movement differs across body and limb sections in high-intensity swimming racing. When considered, those disregarded matters provoke a different perspective on the content of beneficial swimming training. Unless all the roles of oxygen in swimming are understood, it is likely that training content would be limited, irrelevant for preparation for racing, and would use valuable training time that could be applied to more beneficial training experiences. The common and historical perception of aerobic function in total exercise has been incomplete (Noakes, 2000). Valid and beneficial implications from limited information are rarely possible. Swimming has lived in that grey-area for too long.

When evidence from studies on training content, racing, and testing in swimming are considered, the role of aerobic functioning in each area of interest is altered from the singular belief-based concept of the role.[11] Aerobic functioning is involved with using oxygen and fuels for energy and to restore the body's energy producing chemical structures. A re-statement of the energy system classifications and their importance is warranted. A reformulation would allow a better and more accurate understanding and application of exercise stimuli as a means of improving performance.

Aerobic energy is not the only source of metabolism in a swimming race. When a full understanding of what governs the capacity to perform is achieved, better training can be devised that will be relevant to racing.

Two Important Components of Aerobic Functioning

The traditional interpretation of oxygen uptake kinetics has focused on the use of oxygen to generate energy during a performance. In many activities, oxygen uptake is also involved in restoring metabolic processes during the on-going performance. That in-performance recovery is much more important than has been considered in the past.

The Fast-component of the Aerobic System. Energy is derived from the breakdown of phosphagen-based energy stores in muscles. Restoration of stored oxygen and depleted phosphagen compounds is very fast and requires oxygen. The provision of oxygen for that purpose is the "fast-component" of the aerobic system and occurs during and after swimming races.

The restoration of the stored oxygen and alactacid energy system now is increasingly considered to be part of aerobic kinetics (the "fast-component"), particularly when it has a major role during a performance. Restoration occurs very rapidly after a total-body activity, even when separate body parts have acted at different intensities. In activities with limited maximal application by body parts, as with the arms, shoulders, and upper torso in swimming, the stored oxygen and alactacid deficit is somewhat smaller. In post-exercise recovery, the oxygen demand for restoration follows a steep exponential function, most of the initial decline being recovery of the portion of the stored oxygen and alactacid energy system that remained depleted at the completion of the exercise.

In activities where high-intensity effort is restricted to only parts of the body (in swimming it is mainly in the arms, shoulders, and upper torso), effort is supported longer by the less-active, less-demanding remainder of the body. The legs and trunk of an intensely performing swimmer, do not

[11] One source of conceptual error is the application of total-body often gravity-combating activity research findings to the fully-supported, efficiently-cooled, partial-intense efforts of swimming. The differences in the traditional research activities and the peculiar requirements and conditions of swimming frequently make research inferences from the former to swimming a spurious process.

fatigue in a manner similar to the propulsive-force producing muscles of the upper body and arms. It is this division of "duties" within the athlete that distinguishes partial maximum-effort sports (e.g., swimming, kayaking, cycling) from total-body activities (e.g., running, cross-country skiing) particularly in the way and extent inspired oxygen is used.

Another feature that also produces reduced-effort functions in an activity is the degree of support. Swimming is totally supported by the hydrostatic forces of the water. Any support reduces the effort needed to maintain athletic postures. Total-body activities require full postural attention usually to combat the effects of gravity and to provide a fixed-base upon which muscular efforts can be applied. Because of the effects of total or partial support, some activities can sustain stored oxygen and alactacid energy function[12] much longer than the traditional description of up to 10 seconds (for non-supported activities). The degree of time-extension is roughly inversely proportional to the amount of non-fast-component functioning in the athlete. Understanding the time-extents of the stored oxygen and alactacid capacities will require many reconsiderations of the role of oxygen in supported-exercise activities.

Yet another factor in swimming that modifies energy use is the alternating cyclic nature of the various techniques. In crawl stroke and backstroke, the arms function in sequence and comprise an effort and recovery phase. The cost of the stored oxygen and alactacid energy system use in the propulsive effort phase of an arm stroke cycle is likely to be restored in the stroke's recovery phase when the effort level is relatively low and different muscles than those used in propulsion are activated. That results in the arm being almost, or in some-less-than-maximal efforts, completely recovered before the next effort phase. In the double-arm strokes of breaststroke and butterfly, the recovery of both arms at the same time still results in the within-cycle restoration phenomenon. At first, such a postulation would seem to be questionable. However, when it is realized that the most the fibers of an active muscle can be used in an isotonic contraction is approximately 30% of the total fiber population, it is not hard to contemplate that energy-source-recovery can occur within a continuous swimming effort. In imprecise actions, and swimming strokes are not particularly precise (Seifert, Chollet, & Chatard, 2007) when compared to highly skilled movements such as those involved in archery, billiards, darts, and sports of similar ilk, the constitution of the ~30% fiber use varies from stroke cycle to cycle. Consequently, when a fiber bundle is stimulated in one stroke cycle or even a few cycles, there is likely to be a cycle when it is not stimulated at all, which allows for even more restoration to occur. This within-stroke cycle recovery phenomenon is another contributing factor that facilitates continuous high level efforts in a localized body area throughout a swimming race.

There is no denying that absolute maximum efforts in swimming produce accumulated fatigue that results in performance deterioration. However, with a slight effort reduction an almost-balance can be achieved between fiber-bundle utilization with stored oxygen and alactacid energy metabolism in the effort phase of a stroke and restoration of that energy in the recovery-phase. The consequence of this is that the fast-component aerobic kinetic supports the major energy system as being the stored oxygen and alactacid energy system. A minor amount of slow-component function occurs but that does not affect performance much and has been shown to be certainly inconsequential in events shorter than 500 yards and probably is irrelevant for longer pool events. This within-cycle restoration phenomenon is likely to occur in other sports that have similarities to swimming (e.g., kayaking, canoeing, cycling, etc.). The point behind this description is to explain why traditional

[12] Much of what is described in this initial discussion is known and supported by facts. However, that has been largely ignored by swimming coaches in favor of the common obsession with [old] aerobic training and overly-simplistic concepts about aerobic function.

total-body, demanding cyclic or continuous exercise physiology is inappropriate for explaining and directing training content in swimming.

When a performance, such as a swimming race, requires considerable stored oxygen and alactacid energy, a suitable training program should include many brief rests in an interval training format rather than fewer longer rest periods[13]. Brief rests allow stored oxygen and alactacid-energy recovery to occur while either the lactacid or aerobic energy systems may experience some recovery too. Consequently, short-interval training mimics what happens in races. The stored oxygen and alactacid energy system are mostly restored every time a repetition in a set is completed, but the lactacid and aerobic energy systems continue to function, although some portion of the lactacid energy system might also be restored. Coaches have to realize that in swimming strokes, the high energy demands of the effort phases are so brief that they are completed before the lactacid functions can be mobilized fully. The instant energy sources are stored oxygen and the alactacid system. They are the major energizing sources in the relatively short single-efforts that comprise the power-phase in swimming strokes. The energy requirements of a single race are different to those that occur in a two-hour practice session where a variety of activities, swimming strokes and velocities, and recovery periods occur. Generally, there is no commonality between the two although it is possible to construct sets of repetitions that mimic the metabolism of individual races (see below).

With the ever-increasing emphasis on underwater double-leg kicking over considerable distances, there is the possibility that the lactacid energy system will come into play in the hypoxic conditions of underwater work. The energy system utilizations of surface swimming and underwater skill executions are likely to be different. Still, the stored oxygen and alactacid energy system will be dominant in both situations. Swimming practices have to train both race-specific surface swimming and underwater swimming so that the energy delivery differences become fully trained and suitable for races.

Training the stored oxygen and alactacid energy system and use of oxygen to restore it does not occur in the absence of lactacid functioning (see below). The nature of the stimulating exercise will determine the degree of emphasis of use by the body for the two energy systems. When partial intense stored oxygen and alactacid activities occur in a short time (as in swimming racing), it is unlikely that maximum fatigue of this aspect of energy provision will be achieved. Very brief events and even more extended activities can be performed without maximum overload occurring. In swimming, evidence exists that this phenomenon occurs in 200 m and shorter events and likely longer (see below). Given the non-maximum nature of the overload in fast-component activities of brief duration, it is possible to very frequently repeat training stimuli that provoke adaptations in the muscles and circulation that will increase the ability of a swimmer to function with high-intensity for longer periods.

The Slow-component of the Aerobic Energy System. A traditional interpretation of the role of oxygen in recovery is that elevated breathing is needed to repay anaerobic functioning of the exercise task (two common labels for this role are the "Accumulated Oxygen Debt - AOD", and the "Excess Post-

[13] Stegeman (1981) indicated the following. "*The placement of pauses during work that exceeds the threshold for prolonged work is important. Since the course of recovery proceeds exponentially, that is, the first seconds of the pause are more effective for recovery than the latter portion, it is more appropriate to insert many short pauses than one long pause in interval training. Lactic acid recovers very quickly in a short period of time. Longer time periods do not produce much added benefit. Thus, for prescribing training stimuli of an interval nature, the athlete should be subjected to a certain level of discomfort through fatigue, provided with recovery, and the cycle repeated so that work volume, intensity, and performance consistency are maximized. This is why interval training is so effective for developing anaerobic capacities.*"

exercise Oxygen Consumption - EPOC"). Part of the total deficit is the fast-component which is largely discounted in theoretical interpretations and teaching of this topic. Of greater focus is the role of oxygen in recovery for removing lactate and re-establishing hormonal balances and the concomitant circulation restores body temperature from its usually elevated state. The greater the intensity and duration of the exercise, usually the greater is the amount of recovery excess-oxygen consumption. Depending upon the nature and extent of total-body exercise fatigue, recovery oxygen can remain elevated for more than four hours.[14]

In partial-body and/or supported intense activities, the metabolites of exercise (circulating lactate, hydrogen ions, etc.) are resynthesized by the slow-component of the aerobic system mostly during the exercise particularly by the moderately exercising muscles not involved with intense force production. Thus, the degree of anaerobic functioning (the Type IIb fibers) in partial and supported sports such as swimming can be a lot more than estimated purely from post-exercise elevated oxygen consumption.

The slow-component of aerobic kinetics serves a very different function to that provided by the fast-component. It becomes more obvious the longer the duration and the greater the intensity of the swimming task.

The aerobic energy system performs four functions.

1. It is used to generate energy in the conversion of glycogen and fats to water and carbon dioxide at all times.
2. It stimulates some originally lactacid-functioning fibers to convert to oxidative functioning, which reduces the development of lactic acid in the "training effect" metabolic process.
3. It provides oxygen to restore the functioning of the stored oxygen and alactacid energy system during exercise and excessive exercise use post-exercise. Recovery after exercise is of prime importance to the body, hence the speed and priority of restoration. It is the fast-component of aerobic recovery functioning.
4. It provides oxygen to restore the functioning of the unconverted lactacid energy system (Type IIb fibers) during exercise and excessive exercise use post-exercise. The rate of recovery is slower than that displayed for the stored oxygen and alactacid energy system. It is the slow-component of aerobic recovery functioning.

While "fast" and "slow" usually refer to post-activity recovery rates fostered by the aerobic energy system, the largely ignored within-exercise recovery function must be considered and its importance recognized in swimming.

The Fast-component of Aerobic Kinetics and Swimming

Research endeavors about the fast-component of aerobic kinetics in swimming have only recently been reported. Those investigations contradict many common beliefs about aerobic functioning in the sport.

Alves et al. (2009) determined the relationship between VO_2 kinetics of heavy-intensity swimming and a 400 m swimming performance. Only the fast-component and VO_{2max} were correlated with the performance. No other kinetics were associated with the swim. Reis et al. (2009) studied the relationships between VO_2 kinetics within constant-load severe-intensity swimming and 400 m performance. The fast-component of the VO_2 response was significantly correlated with

[14] Oxygen is not the only substance needed for recovery and body restoration. Often recovery takes much more time, particularly when tissue damage is concerned. In some situations of extreme fatigue, recovery oxygen consumption can take much longer than four hours.

performance, absolute VO_{2max}, and swimming velocity at VO_{2max}. These studies showed that the fast-component response in swimming (but not the amplitude of the slow-component) is associated with higher aerobic fitness and performance. In essence, it is the stored oxygen and alactacid metabolism capacity of a swimmer that is related to swimming 400 m, not the lactacid capacity. In a study describing the VO_2 kinetics involved in a maximal 200 m crawl stroke swim, Fernandes et al. (2010) showed that only the fast-component in performance was related to performance while no slow-component was observed. It was demonstrated that the ability to make oxygen available to the muscles in a race (VO_{2peak}), was highly related to 200 m performance. [Many individuals assume that O_2 is solely for aerobic metabolism, but as is themed throughout this paper it is also used to restore the alactacid and lactacid energy systems throughout a race as well as being stored and available for immediate limited use at the start of exercise.] These recent studies imply that fast-component processing (restoration of stored oxygen and alactacid metabolism) is a critical aerobic component involved in races up to 400 m. The partitioning of the accumulated oxygen deficit shows most of the deficit is associated with alactacid debt (the fast-component), much more so than lactacid deficit (the slow-component). Evidence of what is appropriate for longer distance races is yet to be determined. It is likely they will be similar to the shorter distances because the associations of total aerobic and anaerobic energy costs between 400, 800, and 1500 m races are relatively close (Troup, 1990). Other measures of aerobic physiology have not been associated with swimming performance (see the "Traditional Physiology-inspired Training Programs" section above).

Recovery through the fast-component does not only occur post-performance. Restoration can occur during exercise, particularly when active muscles go through a force-production/relaxation cycle, such as in the force and recovery phases of swimming strokes. The recovery phase of stroke forms is of sufficient duration to facilitate a large portion of the previous stored oxygen and alactacid metabolism to be restored, such is the speed of the process. It is the high-energy metabolism of the phosphagen-related substances that is the anaerobic activity primarily involved in racing performances in swimming. The further implication of that tenet is that training should be oriented to stimulating and adapting the appropriate energy sources that support the fast-component of aerobic functioning within (on-VO_2 kinetics) and after (off-VO_2 kinetics) a racing performance. One problem with embracing the fast-component importance for swimming racing is that there is no practical/easy method of assessing individuals' capacities or inherent dispositions of the function.

The Slow-component of Aerobic Kinetics and Swimming

The post-exercise recovery measurement of the slow-component of aerobic kinetics is an index of the use of the lactacid energy system in a performance. Anaerobic glycogen use produces lactate that has to be resynthesized during a swimming performance and through the recovery phenomenon of accumulated oxygen deficit. Thus, the existence or non-existence of slow-component functioning in recovery indicates the importance of lactacid energy in a swimming performance.

Post-race or single-swimming performance analyses do not reveal any slow-component in aerobic kinetics, only the fast-component (see above). That absence indicates that anaerobic glycogen metabolism is a lesser source of energy in a swimming race. Zoeller et al. (1998) reported that accumulated oxygen deficit is not related to 50 or 500-yd performances in female swimmers, which implies that factors other than anaerobic energy production are most important in single swimming efforts/races.

Pyne, Lee, and Swanwick (2001) showed that fitness indicators changed, as expected, with training phases, but those fitness measures were not related to competitive performances, which did not change over a season. Lactates were one of the unrelated-to-performance measures. Thanopoulos, Rozi, and Platanou (2010) reported that lactate accumulation was not related to 100-m swimming performance. Gomes-Pereira and Alves (1998) found that post-race blood lactate levels measured with a progressive lactate swimming test were not related to prior single swimming performances. One implication of these findings is that swimming training is unrelated to racing!

However, Northius, Wicklund, and Patnott (2003) contrarily reported that peak post-race lactate values increased as the season progressed and were significantly related to 100 and 200-yd swimming velocities but not swimming power. Zoeller et al. (1998) reported that peak post-race lactates were weakly related to 50 and 500-yd performances in females.

Glycogen loading, the procedure whereby carbohydrate rich diets and supplements are ingested before performances, is used to increase glycogen stores that will be available for performance. Consequently, if lactacid energy function, the function that produces significant accumulated oxygen deficit levels and the presence of a slow-component in recovery, is a major factor in swimming performance, the pre-performance augmentation of glycogen should improve performance. Langill, Smith, and Rhodes (2001) found that pre-swim glucose supplementation did not affect endurance swimming performance. In a subsequent study, the same authors concluded that pre-event supplementation might be beneficial for a small number of individual swimmers performing a 4,000-m time-trial (Smith, Rhodes, & Langill, 2002). On the other hand, Reilly and Woodbridge (1999) did find swimming performances improved modestly after carbohydrate supplementation and worsened when muscle glycogen was artificially lowered.

The presence of significant consistent lactate values in swimmers is not clear in a variety of circumstances. Thompson, Garland, and Lothia (2006) found that higher race speeds were correlated, but only in a minor way, with blood lactate concentrations of 4, 6, and 8 mM. Test results and performances fluctuated following periods of overreaching, detraining, and poor nutritional practices. It was advised that lactate measures when taken in relatively close proximity to competing, should be considered alongside other factors (e.g., health, training status) to make informed coaching decisions. The authors cautioned about generalizing from this one set of results because the observed phenomena were likely to vary between individuals. Zafiriadis et al. (2007) found stroke rate to be the significant modifier of post-swim lactate levels.

The importance of the slow-component in swimming is equivocal. At best, it is related to volumes of repetitive, non-race-pace training sets when both Type IIa and IIb fibers are probably fully utilized. Consequently, the traditional measures of aerobic function in swimming might predict training capability but not racing capacity. The disparity between racing and training capacities, although studies have shown weak correlations between the two (Fernandes et al., 2010; Thompson, Garland, & Lothia, 2006) could account for Pyne, Lee, and Swanwick's (2001) finding that training physiological measures are not related to racing performances, but such measures are weakly related when taken during a taper. The lack of predictive capability for racing performances of physiological and in particular lactacid and aerobic measures casts doubts on the use of such measures to guide training/practice content. Making decisions based on irrelevant factors adds nothing to the guidance of swimmers and will not yield specific-racing performance improvements.

No research associated with swimming racing or simulated racing has been associated with the slow-component of aerobic kinetics. Much dogma has also related racing performances to the lactacid energy system. However, the relationship between racing performances and lactate values is at best spurious, but generally non-existent (Rushall & King, 1994a, 1994b). That means the generation of notable lactate in a race is an artifact of unusual features such as exorbitantly using glycogen in the absence of oxygen. Alves, Reis, Bruno, and Vleck (2010) showed that the rate with which glycolytic anaerobic work is performed changes the aerobic contributions to performance. Going out "too fast" for too long generates lactate early in a race causing the subsequent pace drop-off to be magnified in the remaining race, usually producing higher-than-usual lactate levels and disappointing performances. The same swimmer, using a saner more even-paced race conduct over the same distance, is likely to produce a lower lactate level and better performance. While the lactate capacity available in a swimming race is finite (Rushall, 2009), it is the careful disposition of that fixed and limited resource that should be considered in a race. Too much expenditure early in a race not only limits that available in the latter part of a race but it also compromises the availability of aerobic energy over the same remaining period[15] (Simoes, Campbell, & Kokubun, 1998). It is generally recognized that lactate levels appear to be maximum in some 200 m swimming races but are lower in shorter and longer races. Maximal lactate capacities are not taxed in swimming races and so need not be trained with many "lactate sets" for maximal lactate tolerance capacities. [When maximal lactate tolerance is reached in an individual has not been explained and so such training is purely guess work.] The stimulation of the lactacid energy system with more appropriate and beneficial race-pace training is likely to be more than enough and would not demand specialized overload training. Exhausting, demanding lactate sets do not benefit single-race performances. Excessive lactate training is irrelevant for race dynamics.

What the Slow-component Indicates

The slow-component of aerobic kinetics would reflect the amount of anaerobic glycolytic activity that occurred in a swimming race minus the amount that was repaid during the race. The index of lactacid energy use, post-exercise measured lactate, is unrelated to single-race performances. It is likely that post-race lactate measures reflect action features that are not associated with consistently good race times (e.g., poor pacing), or the consistent performance of detrimental actions (e.g., excessive kicking, lifting the head too high to breath, breathing every stroke in butterfly, etc.) that occur throughout a race as a technique flaw.

Hellard et al. (2010) evaluated the presence of the slow-component in elite male long-distance swimmers. The test sets were arduous (6 x 500 m). The slow-component of aerobic kinetics was associated with slow long-distance swimming. Only in open-water swimming is such a capacity likely to be exploited. This information suggests that long-distance test sets are irrelevant for predicting pool-race performances or the progress of fitness for pool-racing. Filho et al. (2010) also showed that the slow-component is elicited in swimming only by heavy demanding swimming at paces that elicited slightly above and below VO_{2max}, a velocity too slow for relevance to pool-racing. In essence, it was demonstrated that the slow-component was associated with slower-than-race-pace swimming.

Lactate and Swimming Tasks

Matsunami et al. (2000) reported that lactates and velocities varied with different continuous swimming efforts at training. When the continuous-swim velocities were performed in interval sets heart rates and blood lactates still differed. It is likely that any interval sets with differing non-race-specific velocities, numbers of repetitions, and rest intervals will train different energy components, all of which will have no relevance for single-effort races or race-simulations. The value of such training for race preparation is not apparent, which has been known for a long time and ignored for

---

[15] This is an important point. Hypothetically, if a swimmer were to go out in the first lap of a long course 100 m event 0.2 seconds too fast, the fall-off in the second length could be anywhere from 0.6 to 1.0 seconds more than would be expected with correct pacing. A good rule-of-thumb is that the dive-lap should be no more than two seconds, and possibly less, faster than all succeeding even-paced laps. James Magnussen's splits for his world-best 100 m time of 47.49 in his lead-off leg in the 4 x 100 m Men's Relay at the 2011 World Championships were 23.10 and 24.39 seconds. His subsequent dominant swims in the individual 100 m event were of similar structure.

an equally long period. Traditional training paces and sets rarely, if ever, train a swimmer with the physiological specifics that are required for races.

Pederson et al (2010) trained elite male and female swimmers for 12 weeks. Normal and intense training effects were compared. The training sets used improved. VO_2 was unchanged in submaximal swimming in both groups but with VO_{2max} there was a significant decrease with intense-training. The variations in VO_{2max} changes were unrelated to 200 m performance, which did not change despite what was observed at training. The measurement of aerobic capacity is related to the forms of repetitious swimming used in tests and training sets, that is, it is related to training but barely, if at all, related to racing. Since the study's training stimuli consisted largely of race-irrelevant paces and activities, that no maximum single-performance benefits were derived should be no surprise and yet, expected benefits are the norm for swimming training content of this kind. [This writer asserts that the impact of this and many other studies is that swimming training trains swimmers to train, not to race. For example, Baltaci and Ergun (1997) trained swimmers with an intensity that elicited 4mM of lactate for six months. Aerobic and circulatory factors changed over time, but the study made no mention of the irrelevance of such work for the preparation to race. Further, Sperlich et al. (2009) reported that high intensity training altered a variety of physiological measures in a manner similar to high-volume training. The one differentiating feature was that intensity training improved performance ~5%+ more than volume training. Pyne, Lee, and Swanwick (2001) showed that fitness indicators changed with training phases but not eventual competitive performances. In traditional training sessions little, if anything, happens that will influence better race performances. Traditional training largely improves training but not racing.]

Anderson et al (2003) demonstrated that an incremental swimming step-test produced results that changed across a training season until a taper was instituted. Training effects were demonstrated. However, the same measures before taper were unrelated to final times. Only tests performed in the taper phase showed a relationship, which was fostered by the short period between testing and pool-racing. Once again, the implication that training trains swimmers to train was supported by the results of basic stroke and physiological (e.g., maximal lactate) tests which yielded no predictive value for single-effort racing.

Using a case-study research model, Thompson, Garland, and Lothia (2006) tracked an international level breaststroke swimmer over a three-year period. Lactate testing revealed little useful information and then, only when in concert with other measures. The variation and individuality of the swimmer's responses showed how dangerous it is to predict individual responses from principles formed in group studies. Bartlett and Etzel (2007) and Avalos, Hellard, and Chatard (2003) also reported the extent of adaptation rates and response variations in individual swimmers when exposed to similar training programs. Howat and Robson (1992), in a non-refereed but sound study, reported the majority of training group members did not adapt physiologically in the manner designed by the coach or predicted by the training dogma used.

One is set to wondering how a coach can justify training swimmers so that they might improve when they all follow mostly the same program. That smacks of a recipe to guarantee failure in a significant number of training squad members. The largely ignored challenge for coaches is to treat swimmers as individuals and train them for the events in which they compete with beneficial stimuli that promote performance improvement. Too much misinformation, myth, and dogma has muddied how to coach swimming effectively.

The Specificity of Neuromuscular Patterns and Energy Requirements

The concept of all movement patterns being separate and specific has existed for a long time. In this day, little research is conducted on the patterning of movements in the brain. It has become an accepted motor learning principle that all movements are specific and that the higher the level of proficiency of an athlete, the more refined will be neuromuscular patterns. It is the neuromuscular patterns that govern high-level performance even in activities where physical effort is extreme (e.g., Grabe & Widule's 1988 study on weightlifting). As evidence of the universal acceptance of this concept, Luttgens and Hamilton (1997), in their valuable book on kinesiology, did not justify the principle of neuromuscular specificity but simply referred to it as follows:

> *Skillful and efficient performance in a particular technique can be developed only by practice of that technique. Only in this way can the necessary adjustments in the neuromuscular mechanism be made to ensure a well-coordinated movement* (p. 507).

The two authors repeated their acceptance of the specificity of neuromuscular patterning in their discussion of muscle strength.

> *Strength or endurance training activities must be specific to the demands of the particular activity for which strength or endurance is being developed. The full range of joint action, the speed, and the resistance demands of the movement pattern should be duplicated in the training activity* (p. 465).

Movement patterns in the brain incorporate the energy sources for the movement(s). Technique and energy are inextricably linked in movement patterns no matter how complex they might be. Many auxiliary training activities for swimming are advocated. They need to conform to the specificity principle, which is impossible as they do not occupy the same brain areas as those associated with racing. In this paper, only a few works in the historical literature that led to this principle will be considered. While reading this section, one must consider how can today's popular commercial implements and activities (e.g., kick boards, paddles, pull buoys, rubber tethers, land-training, etc.) conform to this principle? If they cannot, then they are irrelevant for racing.

Some Historical Developments in the Specificity of Neuromuscular Patterning

The most impressive early discussions (~90 years ago) mostly involved Frank Gilbreth's recount of Sperry's work, which disputed *Poppelreuter's Law*. That work showed when an arm was extended vertically downward and the index finger slowly traced a 12-inch circle, a pattern of sequential firing of the shoulder muscles was displayed with most muscles assuming a propulsive (agonistic) function at one time and a control (antagonistic) function at another. However, when the same circle-tracing was sped-up, the sequence and functions of all the muscles were totally changed despite an observer seeing the "*same action*" done at a faster velocity (Arthur Slater-Hammel, personal communication, October, 1967).

Frances Hellebrandt (1958, 1972) summarized much of the main implications of the research on movement specificity that existed before the late 1950s. There has been little new information on this topic since then. Some of her conclusions and their implications are listed below.

> "*If muscles participate in more than one movement, as most do, they must be represented diffusely in the cortex. Presumably different centers connect via internuncial neurons with groups of peripherally disposed motor units. . . . motor units are activated in a definite sequence which varies with the movement elicited.*" (Hellebrandt, 1972, p. 398).

Movement patterns and their energizing properties, not muscles, are represented in the cortex and other areas of the brain (e.g., the Pons). Patterns are learned and those patterns are peculiar to every movement. Skilled performance improvements are continual refinements of the details governing the skill intensity, velocity, and locus of movement. They are represented in the brain. No swimmer would learn to race at 1.95 m/s without practicing at 1.95 m/s with the associated skills and techniques that would be used in a race that required that velocity.

> *". . . reflexes evoked under similar conditions are extraordinarily consistent. Indeed, they are so repetitive as to warrant designating them patterned movements. . . the fundamental unit of action may be thought of as a total response in which agonists and antagonists, synergists and fixators participate in balanced and harmonious activity. Partial patterns emerge secondarily, by virtue of special training, . .* " (p. 399).

Total actions (e.g., those to be used in a competitive setting) need to be practiced. The partial or isolated training of movement segments (e.g., endurance training, board-kicking) would not replicate the unit function in the total action. Thus, once techniques (total response patterns) are being refined, partial practices will serve no purpose other than to learn another movement, activate a different brain area, and at worst, confuse the desirable pattern. There should be no integration of the partial practice movements (i.e., drills) into the total response movement once an individual-determined level of skill competency is reached. The only way a highly-skilled swimmer can improve, is to practice highly-skilled swimming. No auxiliary training activities will contribute to skill enhancement once the skill has achieved a reasonable level of proficiency.

> ". . . *the sensory feedback coming from muscles, tendons, and joints greatly affects movement patterns. Central excitations have a tendency to flow always into stretched muscles. Thus, every change in body positioning alters the configuration of the next succeeding efferent response. It affects not only the muscles stretched, but all functionally related muscle groups as well. This means that a change in the responsiveness of one component of a movement-complex spreads autonomously to the other constituents*" (p. 399).

When a patterned technique or race-execution is changed by conscious effort to alter at least one aspect of a movement, the whole action is altered, usually resulting in a degraded performance. The practices of isolated drill elements and then consciously implementing the experiences from the drills into the established pattern will disrupt the pattern in its entirety. Thus, the changed element may be performed "*better*" but the other, previously acceptable movement characteristics will be altered for the worse. This is the conclusive argument against auxiliary training that is supposed to "*strengthen*" a swimmer, or improve an aspect of technique through use of a drill. Claims to produce beneficial changes in swimmers by doing something other than swimming should be treated with great skepticism. For example, evidence does not support benefits from land-training (Bulgakova, Vorontsov, & Fomichenko, 1987; Costill et al., 1983; Tanaka et al., 1993), although it persists with such statements as "the weight room is where my swimmers get their speed" (quoted second-hand from a USA National coach).

> *". . . willed movements which are new and unfamiliar always demand cerebration. They are performed at first with more or less conscious attention to the details of their execution. Once mastered, they operate automatically. Conscious introspection at this stage may even disrupt the nicety of an established pattern. After an act has become automatic, . . , it is less well performed if it must first be considered and analyzed*" (pp. 399-400).

Conscious attention to details of an automated action will reduce the efficiency/economy of that action. There is a time before a race when conscious attention to details of technique at practice should cease so that preparation can be perceived by a swimmer as consisting of "*good feeling*" techniques that are performed automatically[16]. At some stage in a swimmer's career, the emphasis should switch from "*changes for the better*" to refinement of established skills. When refinement is approached, it should involve mental preparation and recognition, specific skill practice *in situ*, and evaluation of swimmer-generated feedback against objective feedback (e.g., video analysis). In highly skilled swimmers, it usually would be better to learn new skills and/or refine lesser preferred strokes rather than alter those already with a high degree of proficiency.

If many like movements are learned, conscious attention in a race could switch to a less-efficient pattern of movement, particularly if attention is on one segment of the skill. As attention then switches to other different features, the economy of a performance is degraded. In races and at practices, a great deal of emphasis should be placed on the total skill. If change is desired, then skill segments will have to be changed requiring both the coach and swimmer to endure and tolerate a decline in swimming performance until the change is incorporated successfully and the whole altered pattern, which is a new skill, is practiced sufficiently to surpass the level of learned performance of the previous form of the skill. With young people, altering established skills is possible. However, with mature individuals there comes a time when no alterations of established skill patterns should be contemplated because there would be insufficient practice time to successfully incorporate the change and return to or better the previous performance level.

However, when fatigue is incurred, conscious attention to performance details produces a more efficient movement form than one that is executed automatically. Thus, there are times when the conscious control of performance movements is detrimental (e.g., in non-fatigued states) and times when it is beneficial (e.g., in states of high fatigue). In swimming, a loss of control should be used as the index of detrimental fatigue, recognizing that the fatigue could be physical, neural, mental, or combinations of all three.

Through practice, many activity patterns are learned. More often than not, families of movement patterns are learned to accomplish the same functional outcome. While a task is executed, movement patterns will be evoked in series to avoid unnecessary fatigue in the central nervous system mechanisms and the skeletal structures used. In fatigue and stress, the recruitment of extra responses and neural patterns will be more extravagant because of learned facilitation. Much training is performed in fatigue and thus, more than restricted efficient movement patterns are learned to dominance. If specific limited training had only occurred, that is, the body only knew a narrow band of efficient movements, then the recruitment (irradiation) would be minimal and movement patterns would center on efficient movement. Swimmers should not swim when exhausted. Nothing good can result. Adequate rests during practice should be provided to prevent the athlete trying very hard to perform well, when they are prevented physically. Too much fatigue inhibits the attainment of practice goals, reduces learning potential, and sensitizes the brain to new but inappropriate experiences and neural representations.

Practice does not make perfect. Only practice that yields feedback about the correctness of responses can generate advances towards perfection. If practice activity content is largely irrelevant for competitive requirements and/or feedback is inadequate or non-existent, practice time largely will be wasted. However, individuals without external correct-coaching feedback do improve in performance but only to a certain level. Without instruction, individuals tend to adopt expedient strategies for movement control, which quite often are not the best or most economical movement

[16] This writer has advocated for many years that technique alterations in swimming should cease at least one month before an important meet. Changes closer to the meet will not achieve sufficient strength (in the psychological sense) to be elicited under stressful racing circumstances.

patterns. This is why an individual can play golf for 40 years, never have a golf lesson, and struggle to break 90 for 18 holes. The expedient patterns that were learned and perpetuated limit performance to a mediocre level. A similar effect is generated in swimming programs that emphasize training variety.

For efficient and maximum performance ". . . *the kinesthetic acuity we should strive for is not enhanced general body awareness, but rather, a more sharply defined and specific sensitivity to what is happening in those key maneuvers upon which the success or failure of complex movement patterns may depend*" (Hellebrandt, 1972, p. 407).

The skill and energy content of practices has to mimic that of competitive requirements if beneficial training time is to be experienced. It is wrong to practice something with good intent (e.g., "*I hope it will benefit the performance*") without being able to justify and demonstrate correlated transfer to a competitive situation. It is erroneous to practice swimming if the skill amplitude and rate do not reflect the intended race-specific qualities (Robb, 1968). If this dictum is not adhered to, much practice will be wasted or even will be counter-productive. It is quite possible that movements practiced could be so irrelevant that their impact on hoped-for competition-specific movements will be so destructive that performance will be worse than if no irrelevant practice had occurred.

Specificity in sports conditioning and practices is a contentious topic. Many coaches, and those who should know better, advocate the generality of sporting activities through concepts such as cross-training, drill practices, resistance skill activities, and even diets. These concerns are not evidence-based and yet they persist and flourish to the detriment of many swimmers' progress. What is advocated here is difficult for many coaches to accept as it is contrary to established beliefs, the perpetuated myths of the sport, and the activities embraced by the majority of coaches. It is one area where many commercial ventures not subjected to "*truth in advertising*" restrictions have exploited a market of naïve but well-intentioned customers.

Throughout this paper, there has been and will be frequent mention, discussion, and implications about specific training. In so advocating, this author offers the following qualifications:

- If an individual is poorly conditioned and inadequately skilled, any activity that is remotely associated with swimming will enhance swimming performances. This supports the generality of sporting experiences for beginners.
- Once an individual is reasonably conditioned and skilled, general transfer no longer applies and actually retards further development in the sport. At this higher level, the principle of specificity becomes relevant with increasing severity as the standard of swimmer ascends.

This seeming contradiction[17] has to be understood by coaches. It indicates that very young swimmers need to experience variety in skills and conditioning activities. Early specialization has been shown to be counter-productive to long-term development in sports (Borms, 1986a, 1986b). However, once a swimmer has sufficient experience and skill level, the Principle of Specificity (Rushall, 2003a; Rushall & Pyke, 1991) dominates the capacity to learn and the direction for appropriate conditioning and skill development. This paper is mostly directed at the serious high school and higher-level swimmer and thus, the specificity of training is advocated and respected.

To conclude this brief exposition of the central theme of developing, improving, and increasing consistency in a complex skilled sport such as swimming, the following quote from one of the

[17] This paradox is one of many that exist in swimming coaching and indeed, many sports. What is good for a beginner or poorly trained/skilled swimmer is not necessarily good for an advanced/elite performer and vice versa.

world's foremost motor learning/control scientists, Dr. Richard Schmidt, author of *Motor learning and performance: From principle to practice* is most pertinent.

> "*A common misconception is that fundamental abilities can be trained through various drills and other activities...For example, athletes are often given various 'quickening' exercises, with the hope that these exercises would train some fundamental ability to be quick, allowing quicker response in their particular sport. There are two correct ways to think of these principles.*
>
> *First, there is no general ability to be quick, to balance, or to use vision...Second, even if there were such general abilities, they are, by definition, genetic and not subject to modification through practice...A learner may acquire additional skill at a drill...but this learning does not transfer to the main skill of interest*" (Schmidt, 1991, p. 222).

The specificity of movement patterns and control is a scientifically established principle of human exercise. It is the encoding of those patterns in the brain that establishes the uniqueness of movements. There has been no wavering on this scientifically validated phenomenon over the past half-century, although minor theoretical incursions have been attempted. Yet, swimming practitioners persist in violating this basic principle of performance with dubious arguments, false premises, and distortions of facts. It is too well proven to concede that the scientists might be wrong. It is time for the practices and programs of swimming coaches to be brought into line with what is established fact. The training of swimming skills and energy provision and its variants has to be specific and whole. If effective technique-change work is not achieved at practices, swimmers will persist with undesirable stroke patterns which compromise propelling efficiency (Schnitzle, 2008). The programming of appropriate transferable-to-race practice activities in an enriched milieu of correct swimming training is a challenge for modern swimming coaches.

The Relationship of Swimming Techniques and Energy Supply

Swimming techniques[18] and the supply of energy to promote their movements are totally interdependent (Chatard et al., 1990). One cannot change without the other being altered. A conditioning emphasis is not a path to swimming success (Kame, Pendergast, & Termin, 1990); swimming efficiency is velocity dependent that is, techniques change with swimming velocities (Pelarigo, 2010; Toussaint et al., 1990); and energy demands differ between strokes (White & Stager, 2004). Since swimming stroke efficiency is developed for the pace at which training is performed, if race-performances are to be improved, that can only be achieved by improving the efficiency of swimming at race-pace for each stroke. Some strokes (e.g., butterfly) might always have to be swum at race-pace at practice to achieve the best training effect (Chollet et al., 2006; de Jesus et al., 2010). Thus, race-pace training will have the greatest relevance for singular competitive swimming performances. Those performances differ markedly from being a good trainer and improving in all manner of non-race-pace (irrelevant-for-racing) swimming and skills. Swimming coaches have to realize that some improvements at traditional training (e.g., more sessions, greater yardage, more effort, etc.) often do not translate into improvements in races. When they do, it is largely coincidental.

It has been reported that much of what happens at swimming practices is unrelated to what a coach hopes will happen in races (Stewart & Hopkins, 1997). Stroke rates at training usually do not mirror those performed in races (Craig & Pendergast, 1979). Slow kicking does not train anything related to racing, although it might be a valuable within-session recovery activity (Mookerjee et al., 1995).

[18] If the reader wishes to delve further into the research associated with the practical aspects of technique performance and instruction, Rushall (2011b) is one source.

Techniques are altered when the lactacid and aerobic energy components required are altered (Wakayoshi, 1996), which often is a result of mixed or variety training.

Technique is the major factor that determines swimming success (Cappaert, Pease, & Troup, 1996; Chollet et al., 1997; D'Acquisto et al., 2004; Nagle et al., 1998) and efficiency (Toussaint, 1988), and its improvement is associated with greater performance gains than irrelevant (e.g., land, tethered swimming) training (Havriluk, 2010; Maglishco et al., 1985). Better swimmers have better techniques and the "better" techniques are dependent upon swimming velocity (Millet et al., 2002), even in age-group swimmers (Watanabe & Takai, 2005). Technique is particularly important for females (Cappaert, 1996; Dutto & Cappaert, 1994). Since technique factors differ between the genders (Cappaert & Gordon, 1998), it is not only a concentration on technique at practice that is important, but it is the adaptation of the correct technique factors for the genders that should make coaching more effective and responsible. If race-specific techniques are so important for successful racing performances, the energy that powers those techniques is equally important.

A swimming coach is left with two important tenets that should govern the deliberate programming of swimming practice sessions.

1. To improve race techniques, one has to train using the technique for each stroke at race-pace velocities. There is no other option.
2. To improve race-conditioning, that is, using the energizing systems in the specific combination that is appropriate for the stroke technique and race velocity, one has to train at race-pace velocities. There is no other option.

Any deviation away from the technique and conditioning appropriate for a particular race-pace is likely to result in irrelevant training that will result in the structuring of brain patterns that are unsuitable for any race. Training that is not race-pace specific (increasingly referred to as "irrelevant training") has only one use, non-specific recovery activities between and after race-pace sets.

High-intensity Training

High-intensity training, that is training experiences that incorporate higher-than-usual swimming velocities, is associated with improved race or simulated race performances (Beidaris, Botonis, & Platanou, 2010; Mujika et al., 1996; Sperlich, Haegele, Heilemann et al., 2009). While swimming dogma emphasizes relatively slow "aerobic training" for pre-pubescent swimmers (Greyson et al., 2010), high-intensity training has been shown to be better for age-group swimmers and athletes than volume-oriented training (Sperlich, Haegele, Achtzehn, et al., 2009; Mascarenhas et al., 2006). High-intensity training might detrimentally affect some physiological measures (e.g., VO_{2max}[19]), but it does not adversely affect performance (Pedersen et al., 2010). When compared to the more traditional forms of aerobic training (continuous or long-interval/repetition work), high-intensity interval training produces better aerobic effects (Helgerud et al., 2006; Wee, McGregor, & Light, 2007). The performance improvements that result from high-intensity training are not associated with metabolic and physiological factors (Kubukeli et al., 2000). High-intensity training produces almost instant improvements in athletes who are deemed to be already trained (Laursen, Blanchard, & Jenkins, 2002). Intense training is better than endurance training for 100 m performance and does not compromise endurance capacity (Johansen et al., 2010). The velocity performed most at training will be the velocity at which swimming efficiency improves the most (Rinehardt, 2002).

[19] Recent research has shown that if physiological capacities are improved (e.g.., VO_{2max}) performance is not necessarily improved. This is particularly so when the activity to measure the physiological capacity is unrelated to the performance activity.

Training energy systems alone (e.g., aerobic training sets, lactate tolerance training, power sets, etc.) would be irrelevant for racing. The muscle fibers governed by the race-specific neuromuscular patterns in the brain need to incorporate the complex energizing properties that control muscle fibers when demanded in a race. That is not achieved by single-capacity training, which very well could elicit neural activations in a completely different part of the brain. The irrelevance of much commonly espoused and reported swimming training could be construed as a penalizing "time-out" experience from the opportunity to improve in beneficial ways. The dogma and misinformation about swimming training is so pervasive it could be asserted that training effects are so negative, performance improvements that should be expected from growth alone are suppressed to a large extent.

High-intensity training produces quicker and better physiological (Enoksen, Tonnessen, & Shalfawi, 2009) and performance (Sandbakk, Welde, & Holmberg, 2009; Vogt et al., 2009) responses in athletes who have been training at lower intensities (longer repetition distances and/or continuously). Lower than high-intensity training does not require maximal aerobic effort each trial. High-intensity training is required to stimulate maximum aerobic adaptations (Zafiridis et al., 2009), which includes provoking the conversion of Type IIb to Type IIa fibers. Thus, maximum aerobic training involves the adaptation of Type I and Type IIa fibers. Ultra-short training requires maximal aerobic effort all the time. Therefore, race-pace training is the avenue in swimming for stimulating maximal aerobic adaptation for specific races. Swimming repetitions and efforts that do not prompt coping with VO_{2max} velocities and above, will only stimulate Type I fiber adaptations and will miss out on the extra oxidative capacity that would employ Type IIa fibers.

Over-emphasizing aerobic training does not stimulate anaerobic adaptation adequately. Race-pace training should produce the correct amount of aerobic and anaerobic stimulation for swimming at a particular velocity. If a swimmer's training were to be slower than intended race-pace, performance improvements would be better in races at which the slower velocity is appropriate (if they exist). By performing race-pace work at training for several strokes and events, the efficiency of swimming several events will improve. Failing to train at race-pace will not result in optimal improvement. Race-pace training allows practice of race-specific techniques that are velocity specific as are the accompanying energy sources that fuel those techniques. That should result in much transfer of training effects to race performances.

Specific Race-pace Training[20]

Many swimming coaches are entrenched in the dogma of training programs and in particular, the copying of programs from successful coaches. The number of formulas for training success and the constituent practice items is huge. The variety of activities is bewildering. Most training programs receive little critical evaluation. Thus, poor coaching practices are perpetuated.

It is known that the development of physiological capacities ceases with the attainment of maturity (Rushall & Pyke, 1991; Steiner, Boutellier, & Wehrlin, 2009). No new or further developments of such structures are possible without growth. Often, senior swimmers plateau in improvements despite further years of dedicated training. If race-performances do not improve, then beneficial training effects are not being experienced. Thus, despite increased weight training sessions, more altitude training, a greater frequency of performing drills, intense work on kicking, etc., they being examples of the desperate dedication to irrelevant training experiences that are supposed to produce performance improvements, unfortunately positive effects are not produced. In sports outside of

[20] In swimming training, race-pace velocities are considered to be equivalent to "high-intensity" training or "high-intensity interval training"often discussed outside of swimming.

swimming, when athletes are not improving, one of the options considered is to increase the amount of high-intensity training, which usually brings success (Gaskill et al., 1999). The acceptance of various energy-specific sets, harder work demands, developing mental-toughness, and other frequently used labels for training experiences that are promoted as being beneficial, leads to a resistance to change in many coaches. That is a foible of human behavior – a public commitment to a belief or behavior produces resistance to change.

When one mentions race-pace training, the resistance and ignorance of "entrenched" coaches is frequent. One senior Australian coach responded that "it would deplete glycogen stores too rapidly", whatever that means. Another opined that it would be impossible to perform a set of 8 x 200 m on four minute intervals at 200 m race-pace. In practice, it is virtually impossible to do one 200 m swim at intended race pace. Such reactions seem to be that many coaches only see continuing their normal forms of practice items and formats and the suggestion to increase the intensity of training efforts has to be accommodated within that restricted thinking. It is the coaching design of practices and practice items as well as the intensities of swims that need to be changed.

A long and detailed effort was made to justify that swimming energetics mainly involves stored oxygen and the alactacid and aerobic energy systems. Race-pace training has to involve those resources together. While some use of the lactacid energy system will occur, there is no need for that to be the focus of particular training attention. The governing feature of relevant-for-racing practice items and repetitions is the performance of race-specific velocities in such a manner that mainly the stored oxygen and alactacid and aerobic energy systems are stimulated. That should result in practices allowing swimmers to practice for racing, rather than being exposed to the more popular theme of becoming better at training. It is increasingly being recognized, that the more swimming performed at race-pace, the better is the swimming program for improving race performances.

Another important parameter involves the rest interval. Short rest intervals are better for training sprinters (Bogdanis et al., 2009). Ideally, a rest period between each work period should be 20 seconds (Beidaris, Botonis, & Platanou, 2010). At most 30 seconds might be tolerated (Zuniga et al., 2008) although work quality of less-than-maximal intensity might have to be accommodated. Consequently, practice items and repetitions have to replicate the techniques and energizing properties that are required in swimming races and limit the period of rest between the repetitions. Most coaches have difficulty in imagining how that can be done. With short rest intervals, it is possible to practice at high-intensity using race-specific techniques and energy systems without becoming devastatingly exhausted.

One reason short intervals "work" is that when a high-intensity repetition is completed, the aerobic system continues to function fully paying-back any accumulated oxygen debt developed in the repetition. If the next repetition commences before the aerobic system begins to abate, the demand on the cardiorespiratory system is continuous although the exercise is intermittent. For the whole set, the aerobic system works maximally just as it would in a race. If the rest interval is too long, the aerobic demand in the rest period decreases. On the commencement of the next repetition, considerable early energy is derived anaerobically until the aerobic system once again functions fully. As the set progresses, anaerobic fatigue builds throughout the set making the energy sources and muscular function increasingly irrelevant for the race for which the set was intended. The varying demand on aerobiosis does not replicate what occurs in a race and therefore, is not race-specific. There is no alternative to short rest-intervals in race-pace training.

In the lore of swimming coaching, sometimes the assertion that high-intensity training causes a loss in aerobic adaptation appears. In reality, high-intensity work improves both aerobic and anaerobic factors (Sokmen et al., 2002; Hughes et al., 2003). Some forms of training are better for technique development. Interval training promotes stroke retention better than continuous training (Pelarigo, 2010). Training volume can be increased by the nature of the work of training. Shorter, rather than longer work intervals facilitate greater volumes of training. Those greater volumes of race-specific training should equip swimmers to perform better in races (Rozenek et al., 2003).

Rinehardt et al. (2002) showed that when swimming training is focused and dominated by aerobic training, the traditional measures of aerobic training (those which are unrelated to swimming racing) improve notably but at the expense of anaerobic work capacity. This is in accord with an interpretation of the implications of the Principle of Specificity (Rushall & Pyke, 1991); non-specific training improves non-specific measures of the training and the training effects are irrelevant for the performance of specific sporting events, such as swimming racing. Reer et al. (2002) recounted that how one trains determines the specificity of the training effects. Consequently, if little race-pace or race-relevant training is performed, race performances should not be expected to improve much.

Beidaris, Botonis, and Platanou (2010) illustrated the complexities of training responses when intervals and rest periods vary. Interval (4 x 50 m) sets with different rest periods (5, 10, and 20 seconds) were compared to the physiological responses obtained from a maximal 200 m swimming effort. It was found that with the very short rest intervals and as the continuous swim progressed, the physiological parameters (including oxygen consumption and blood lactate concentration) changed as the task progressed. However, when a 20-second rest interval was provided, the parameters did not change and were of higher intensity and greater performance than in any other experimental condition. Thus, interval training with a 20-second rest allowed the quality of the training response to exceed that of the other swimming options. When the number of repetitions is increased over the four used in this study, the potential is there to develop a swimmer's capacity to perform efficiently longer in a 200 m race, something not provided by the other training formats. For want of any better implication, this study showed that when repeating 50 meters in a set at 200 m race-pace (i.e., maximum effort), for the most relevant training effects to occur, the rest interval should be 20 seconds. This is an example of how judicious the determination of beneficial training has to be in order to provide the most productive experiences for swimmers in training.

Since so many pool races involve 50 and 100 m events, the specific training for those events would seem to be an obvious inclusion in any swimming program. Johansen et al. (2010) showed that 12 weeks of doubling the amount of high-intensity training and reducing training volume by 50% was better than endurance training for 100 m performance. Such training did not compromise endurance capacity. Mujika et al. (1996) reported that for all swimmers seasonal improvements were significantly correlated with the season's training intensity but not related to training volume or training frequency. There are similar studies across many sports, all of which show the velocity of the sporting response is increased with intense training. It is also commonly reported that excessive endurance training suppresses power and speed performances (Carl et al., 2003; Fitts, Costill, & Gardetto, 1989; Trinity, Pahnke, & Coyle, 2005) while excessive lactate fatigue in practices reduces swimming velocity and stroke rate (Barden & Rorke, 1999). Heavy training and dryland training are not related to improvements in swimming performance (Sokolovas, 2000).

It should be clear that the science of sport training is seldom demonstrated in traditional swimming practices. The myth that "any practice is good as long as its intentions are good" seems to permeate swimming's coaching ranks (at least in Australia, USA, and Great Britain). Even national coaches of powerful swimming nations espouse drivel and demonstrate a lack of knowledge about how the human body functions in endeavors to improve high-level performances. The universality of the lack of awareness of valid reliable knowledge and the inability to provide truly beneficial training experiences for motivated swimmers is alarming.

Ultra-short Training at Race-pace

The task of race-pace training is to produce the greatest number of race-specific strokes possible. It is possible to concomitantly train for several events, each requiring a discrete set of repetitions. The major error with high-intensity training is scheduling work intervals that are too long and result in the accumulation of lactic acid.

In the late 1950s to the mid-1960s, Swedish scientists published articles that related lactate accumulation with various work:rest periods (Astrand et al., 1960; Christensen, 1962; Christensen, Hedman, & Saltin, 1960). Astrand and Rodahl (1977) related research findings that demonstrated if the work duration is short enough, although the work intensity is very high, and if recovery periods are short, energy sustains mechanically efficient "fast" work while no buildup of lactate occurs. As well, glycogen levels remain high throughout the short intervals whereas with longer intervals they depreciate significantly. Figure 1 displays results of a study where in a 30-minute period of cycling, subjects performed the same total workload with the same work to rest ratio in three different ways: 60 s / 120 s, 30 s / 60 s, and 10 s / 20 s. In the shortest work interval, blood lactate did not accumulate and glycogen stores were only slightly reduced by the end of the session. At the other extreme the longest interval produced excessive lactate accumulation and glycogen depletion. The middle condition produced an elevated but consistent lactate accumulation.

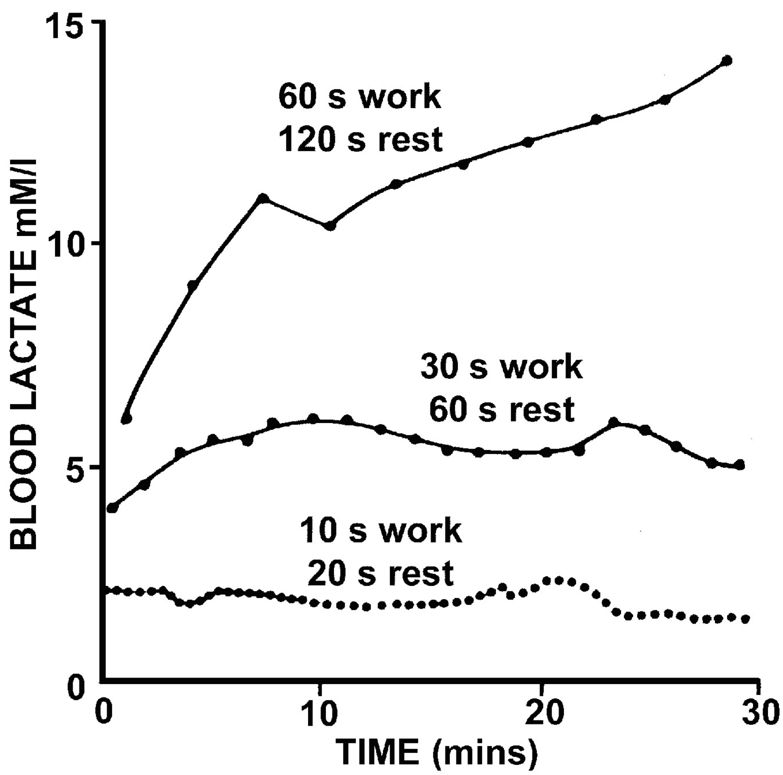

Figure 1. Lactate levels during interval training where total-work to rest ratios are the same but duration is varied (after Astrand & Rodahl, 1977).

A sustained presence of readily available glycogen is essential for skilled (neuromuscular) function. It allows a swimmer to practice the neuromuscular patterns associated with high rates of quality performance without disruption for it is known that as glycogen is reduced beyond a certain level, neuromuscular functioning in the localized work area is increasingly disturbed and even prevented. Consequently, hard/extended swimming that decreases glycogen does not accommodate the learning of the skilled movement patterns associated with the effort's velocity. Another benefit from very-short-interval training is that recovery is rapid and is significantly shorter than that required for glycogen-depleted/accumulated-lactate work bouts. In swimming, very-short-interval training facilitates an increased number of executions of skill cycles. Exercises that use work and rest intervals with these characteristics have been labeled *"ultra-short training"* (Rushall, 1967, 1970; Rushall, 2003b; Rushall & Pyke, 1991).

Tabata et al (1997) demonstrated that two disparate energy systems could adapt during the same exercise. One protocol involved 6-7 bouts of 20 seconds of exercise with 10 seconds of rest at an intensity equivalent to 170% of VO_{2max}. The other protocol involved 4-5 bouts of 30 seconds of exercise with two minutes of rest at an intensity equivalent to 200% VO_{2max}. It was found that physiological factors deteriorated in the last 10 seconds of the longer repetitions. The shorter interval taxed aerobic and anaerobic energy maximally. This investigation suggests that the duration of a work interval must be sufficient to employ maximal energy supply but should be short enough to prevent performance and physiological degradation.

Repetitions of 200 m and up are mostly useless for training pool-racing performances. It is the total work performed at race-pace (number of repetitions x distance/number of strokes in a repetition) that is important. As difficult as it might seem to grasp, research has consistently shown that shorter work intervals in an interval training format are more beneficial than longer intervals (Zuniga et al., 2008). Since swimming is a cyclic activity that does not use the total body musculature and is supported and cooled efficiently by water, the rest periods do not need to be as long as in the Astrand and Rodahl cycling study.

Traditional swimming coaches often refuse to accept the possibility that lactate does not accrue in a training set no matter what its form or duration. It is often argued that "lactate tolerance" sets involve high-intensity swimming and they do cause lactate to accrue. Thus, USRPT's claim of no to low lactate build-up in a set of repetitions is not "believed". A very seldom referenced study by Margaria, Edwards, and Dill (1933), showed that no extra lactic acid appears in the blood after exercise involving an oxygen debt of less than 2.5 liters. When exercise requires a larger amount of oxygen, lactic acid accumulates at the rate of 7 g for each liter of additional oxygen debt. USRPT repetitions are short enough to limit an oxygen debt to be in the vicinity of 2.5 liters or less. Consequently, that explains why lactic acid does not accumulate in ultra-short and more specifically, USRPT. Occasionally, the oxygen debt of a USRPT repetition slightly exceeds 2.5 liters, particularly nearing the end of a set when avoidance of failures starts to be an aim of the swimmer. That accounts for the very slight fluctuations in lactate concentrations (see Astrand et al., 1960 and Astrand & Rodahl, 1977) throughout an ultra-short repetition exercise. In practical terms, lactate is not problematical in USRPT because it does not accrue during a full set of repetitions. The brevity of the work periods and the limited demands for oxygen debts in the region of 2.5 liters or more prevent lactate accumulation.

Energy use in ultra-short training at race-pace. The energy that is used throughout an ultra-short interval set of a high number of repetitions changes from the early to late stages within the set and with training. Some of the content below repeats that which is stated earlier in this paper.

- Early in a set, stored oxygen and energy that exists within the muscles is primarily used, alactacid sources being exploited more than lactacid sources. Aerobic energy is gradually stimulated into action and increases its function with each successive trial. As the set progresses, alactacid energy is still employed. Type II (fast-twitch glycolytic) fibers are continually stimulated along with Type I (slow-twitch oxidative) fibers. Some anaerobic glycolysis does occur but not in amounts that lead to any significant lactate accumulation. The amount of oxidative work at the end of an ultra-short set is greater than at the start while swimming velocity remains constant.

- As ultra-short intervals are employed consistently in practices, some Type IIb fibers (low-oxidative or glycolytic fibers) eventually are converted to Type IIa fibers that become oxidative while still maintaining their fast-twitch contractile function. [In the structure of ultra-short training where aerobic activity is maximal and constant, the conversion of type IIb to aerobic-glycolytic Type IIa fibers is maximal. In traditional swimming training activities where exercise intensity is relatively moderate, the conversion effect is likely to be less than maximal because "maximal conditions" are not experienced. Consequently, ultra-short training produces yet another valuable training effect that is not achieved through traditional swimming programs.] With the conversion/adaptation of those fibers, work earlier in a set is more oxidative than in an untrained state. That means more race-pace work is "fueled" by oxygen rather than lactate-producing anaerobiosis. The capacity for producing work through the stored oxygen and alactacid energy system is also increased. There still is some requirement for anaerobic glycolytic work. The frequent stimulation involved in the very short repetitions produces some adaptation although that improvement might not be as great as that experienced in traditional heavy-demanding sets where lactate accumulates to high levels.
- Consistent ultra-short training at race-pace produces race-pace performances that sustain fast-twitch (Type IIa) fiber use but energize performance with greater amounts of oxygen. This extends the ability to sustain a swimming velocity with good mechanical function. Eventually, glycolytic anaerobic function is also improved. The mild stimulation of ultra-short training eventually does produce levels of adaptation over and above those achieved by severe stimulation from heavy demanding sets. When heavy sets are experienced repeatedly, swimmers often enter an overtrained state before maximal adaptation is achieved. However, while the milder ultra-short work does not produce as rapid lactacid adaptation, it eventually does produce higher levels of anaerobic glycolytic adaptation and consequently produces further performance improvements.

Ultra-short training at race-pace develops stored oxygen and alactacid energy production, fast-twitch oxidative and fast-twitch glycolytic function, and aerobic adaptation all while executing race-specific motor skill patterns and achieving significant distances of relevant training. In all events, those outcomes facilitate better swimming performances than those fostered by typical and mostly irrelevant training for swimming.

With ultra-short training at race-pace it is possible to effectively train full-effort, large-muscle activities while enjoying circulatory and respiratory (aerobic) training effects similar to those achieved with continuous activities performed at a much lower level of intensity. This is a superior form of training to more established, but less beneficial, forms that still pervade swimming. Astrand et al. (1960) showed clearly that hard exercise of an extended interval nature does not yield the best training response. Christensen (1962) demonstrated that ultra-short training, not a form of lactate tolerance training, is the best form of work for high-effort training.

Short and long rest periods. With short work periods, the demand for oxygen is quite high because during the short rest pauses of 20 sec the circulation and respiration never decline severely before the work is begun again. When work and rest periods are longer (e.g., one minute or more), the initial demands for oxygen transport in work are lower than in the short periods. This is because circulation and respiration decline during longer rest periods. Upon the institution of work in longer intervals it takes some time before aerobic work (circulation and respiration) increases to a steady-state or maximum level. During that build-up time, which usually is longer than the work periods of ultra-short tasks, the aerobically met needs are much lower than in the ultra-short work period of a much briefer duration. During the rest in ultra-short work, the endogenous energy and oxygen sources are replenished and available for immediate use upon the start of the next work period. The load on respiration and circulation remains manageable and consistently high during rest and work in the ultra-short format. Longer rest periods allow aerobic work to wane which then requires anaerobic work to be performed before aerobic work "ramps-up again" in the next long interval.

The amount of oxygen in the muscles and circulation and that which can be transported during the ultra-short work period itself is sufficient to cover the demands of high-intensity exercise. The rest periods replenish the endogenous energy and oxygen supplies very quickly leading to the situation where full energy and oxygen is immediately available in the next repetition. Across ultra-short work and rest intervals, the respiration and circulation should remain consistently high so that work can be energized immediately at the start and for the duration of the ultra-short work interval. If respiration and circulation were allowed to abate somewhat, the next work period would be energized by the endogenous sources but the oxygenation of those sources would be slowed because of lower functioning re-supply mechanisms. That leads to a need to use anaerobic energy resources for a large part of energy until aerobic activity and metabolism are re-introduced at their highest level of function. That anaerobic work leads to an increase in lactic acid, something that does not occur in ultra-short work.

Energy and oxygen are available at the beginning of any new work period. But, when the demand for energy and oxygen is high in longer work periods, the endogenous sources cannot meet the extended demands. Anaerobic work fills the "gap" causing a rise in lactic acid until aerobic metabolism catches up.

It seems logical that long rests would be best for the swimmer. Although recovery occurs, the delay in the on-kinetics of oxygen availability in the next work interval has troublesome consequences. Lactate rises which changes the way oxygen is used, it could interfere with learning from the exercise, and it lessens the amount of work that could be produced in the interval. Short rests keep aerobic activity going at a high level so that at the onset of the next work interval oxygen is already being made available. Short rests do not allow oxygen metabolism to wane or cease.

Recovery from anaerobic build-up (the slow-component of recovery) takes much longer than that needed to reoxygenate myoglobin and hemoglobin and restore ATP-CP in ultra-short work. The higher and easier work in the ultra-short format accounts for why much greater volumes of high-intensity work can be achieved when compared to other longer work and rest period formats. It can be concluded that ultra-short work is performed almost entirely aerobically while longer work periods have to mix in anaerobic work particularly in the early stages after work onset.

The amounts of myoglobin and hemoglobin increase with training and so ultra-short training provides the maximum stimulus for those adaptive effects.

Planning Effective Training

When the research articles referenced above are synthesized, a number of guidelines for planning race-pace training for swimming are invoked.

- Training that is exhausting is not necessarily the best or even an effective training stimulus. Training effects are least when performed as a single continuous work effort.
- It is possible to perform a large volume of high-intensity work by using work and rest periods of 15 to 20 seconds, normally on no more than a 1:1 work to rest ratio.

- As high-intensity work periods extend to 30 seconds and marginally beyond, the requirement for longer rest periods ceases. Twenty seconds remains the maximum rest period.
- Intermittent work (*"ultra-short"* work) is the training regimen that will allow the volume of high-intensity or competition-specific work to be increased.
- Intermittent work of this type is the only form of training that effectively trains the oxidative component of work at specific race-pace intensity.
- The responses to intermittent work are individual. While the work interval (e.g., 15 seconds) might seem to be very short, it could still be too much for some athletes.

A large amount of research in exercise physiology has focused on aerobic endurance. Much less has emphasized intense or moderately intense work. Every increase in workload demands more oxygen, which in turn increases the load on respiration, circulation, and heat regulation. Training swimmers by having them experience very high physiological stress for *"long"* periods, limits eventual adaptation and produces fatigue of sufficiently high levels and lasting effects that subsequent training is disrupted. Such work actually reduces the amount of effective training rather than being an effective way of improving ultimate performance.

A great quantity of intense muscular work can be performed if it is performed as many short work and rest periods. This produces a submaximal load on circulation and respiration and allows training volume to be significantly greater than if work is performed for longer periods. Respiratory and circulatory stress and lactate accumulation, features of debilitating training fatigue for swimmers in traditional progress, are avoided with ultra-short training.

The reason ultra-short training at race-pace works on developing aerobic endurance is that it taxes endurance development in the periphery (in the muscles). It uses as its primary oxygen source oxygen stored in the muscles and circulating in the blood. Those oxygen sources are repeatedly depleted and replenished causing the mechanisms of oxygen delivery to be stimulated maximally and to improve with training. They are stimulated much more in ultra-short training than in continuous work (where the intensity of work is lower and/or non-specific). Ultra-short work appears to be the only way maximal stimulation of this important feature of aerobic adaptation occurs, possibly because of the volume of exercise accomplished. The added factor of this adaptation occurring with neuromuscularly correct exercises is one more justification for its use. Ultra-short training at race-pace is the best way of stimulating aerobic adaptation in the periphery while not overtaxing the central mechanisms (respiration, circulation, heat generation) of aerobic work.

High-effort event-specific training can be performed using very short work bursts and brief rests. Not only is the total volume of relevant work increased, but so is the volume of specific high-intensity work-quality maintained. Neuromuscular patterning of a competition-specific nature can be enhanced. Research in this area puts to rest the claim that traditional swimming training, which produces high levels of fatigue with high levels of lactate and glycogen depletion, is a *"good"* training experience. Such training reduces the volume and quality of potentially beneficial training that could be performed, and therefore, should be viewed as detrimental to possible adaptation, certainly when compared to what can be achieved with ultra-short training.

Ultra-short interval training in swimming occasionally has been reported but overall, has been ignored. Beckett (1986) described a pseudo-scientific study of volunteers from a college swimming team. Swimmers participated in a reduced yardage, high-velocity training program for a college season (16 weeks). Distance trained was reduced from 9,000+ to 3,000+ yards. Half of the training time was spent in recovery. Training consisted of 3-5 race simulations (MWF), a short anaerobic interval set (TTh), 60 short-sprint swims (MTWTh), and 10 short sprint swims (F). Two weeks prior to the championships, work was reduced by 50% for the first week, and 66% for the second week. Each sprint swim was a maximum effort and often covered only 12.5 yards. With only one exception all performers produced personal best-times in all events at the championships. Statistically significant improvements were determined over race distances of 50, 100, and 200 yards while an interpolated 500 yd swim was also improved. Termin and Pendergast (2000) evaluated the performance improvements in 100- and 200-yard freestyle swims of male swimmers (N = 21) over a four-year college career. While a number of training structures were altered, the inclusion of 15-16 weeks of ultra-short swimming was a major departure from traditional training. Training included one hour of cycles of 16 x 25-yd with 15-second rest intervals, followed by 1.5 minutes of rest between each cycle. When performance was maintained for one hour, inter-cycle rest intervals were reduced to 10 seconds. The next advancement was to increase to 16 x 50-yd with 30-second rest intervals. Inter-cycle rest intervals were reduced to 20 seconds when swimmers consistently completed the one-hour task. This phase increased stroke rate, swimming velocity, and the amount of high-intensity work performed. Significant annual improvements for swimming events across all distances were recorded. In a recent article, Treffene (2010) advocated more training at race-pace or high-intensity over 25-75 m distances. This was a public recognition of the value of ultra-short training distances for improving the performances of all ages and events of serious swimmers.

The absence of swimming research investigating the viability of ultra-short training at race-pace is more of an indication of the entrenchment of dubious beliefs of how to train rather than a concern about the method. With the change from training volume to quality volume since the middle of the first decade of this century, periodic accounts of employing ultra-short training in swimming have emerged. On the other hand, in several other sports (e.g., rowing, cycling) the training format is accepted and somewhat popular.

Table 1 shows examples of race-pace sets. In those examples, the swimmer starts every repetition on a 20-25-second interval, the rest period being that time remaining from 25 seconds after each effort.

TABLE 1. EXAMPLES OF RACE-PACE TRAINING STIMULI.

Repetitions	**Distance**	**Stroke**	**Intensity**	**Recovery**	**Recovery activity**
20 x	Across pool (20 m)	Fly	100-m race-pace	Remainder of 20-25-sec interval	Float
20 x	Across pool (20 m)	Back	100-m race-pace	Remainder of 20-25-sec interval	Float

The selection of a 20 or 25-second total interval depends upon the standard of the swimmer. The younger the swimmer, the shorter should be the work interval and consequently, the rest interval. Prepubescent swimmers most likely will repeat over distances of 15 meters or less in a time period of less than 10 seconds. For senior swimmers, longer distances that require an upper limit in the region of 30 seconds can be programmed. Longer periods can be programmed if the swimming intensity is reduced (as in repeating 100 m at 1500 m race-pace).

The structuring of ultra-short training at race-pace for swimming should be within a number of parameters. The guidelines suggested below should allow a coach to adapt training demands to individual capacities when a set is presented to a training group.

1. Determine the competitive stroke or racing skill (e.g., double-leg kicking, turns, dive-25s) for which the ultra-short set will be designed. There should be no mixing of strokes as one might think appropriate for medley training (see below).
2. Determine the race-distance for which the set will be designed.
3. Determine the repetition distance to be used as the training stimulus.
4. Calculate the interval of work, that is, the average time for the race over the distance to be repeated. Usual distances will be 12.5, 25, 50, and less often 75 m. For 1500 m races, 100 m repetitions might be considered.

   In the calculation, the dive should be included as if it was surface swimming. When the approximately two seconds advantage usually attributed to a dive is included in calculating the repetition time, it means the training pace for surface swimming will be slightly faster than the actual race from which it was calculated. With that assumption, every ultra-short training set at race-pace will have an inherent "improvement factor" which should lead to continual race-improvements.
5. Decide upon the rest interval. It should be mostly 20 seconds or less. For repetitions of 25 m it is commonly 10-15 seconds. For 50 m repetitions, it is around 20 seconds. The rest time should never exceed the performance time of a repetition. Even on special occasions 20 seconds should be considered (e.g., when using 100 m as the repetition distance). There can be no departure from the limited time allowed for between-repetition recovery. Longer rests will adulterate the energy system use, usually making it irrelevant for the race for which it is intended.
6. Determine the number of repetitions to be attempted. The number should be challenging to all squad members and be sufficient that all cannot complete the set at the target pace on the first exposure. The decision made will produce the training overload, which is necessary for specific physiological adaptation to occur. Without overload, there can be no training effect.

   When a swimmer completes a set without failure, it is too easy and should be changed so that in future attempts failure will occur (i.e., a maximum training stimulus will occur). Set difficulty can be increased by shortening the rest period and/or making the race-pace faster. That illustrates a major difference between traditional training and ultra-short race-pace training. Traditional training expects swimmers to complete every repetition in a set. Ultra-short race-pace training sets are designed so that swimmers cannot complete every repetition at the expected standard. The failures in the ultra-short race-pace set produce the training stimulus/effect in the experience (*"The Principle of Overload"* – Rushall & Pyke, 1991).
7. Implement the ultra-short training at race-pace set. When there are several swimmers in a lane, the starting interval should be sufficient to allow relatively smooth water for each swimmer as they follow multiple-swimmer lane-use rules. When there are a lot of swimmers in a lane, ultra-short training is difficult to perform because the swimmers x starting interval value will exceed the rest interval. In situations when that occurs, it is usual to use across the pool as the repetition distance, despite the task of having to remove lane lines. As well, when swimming in lanes safety rules should be implemented when swimming butterfly and backstroke.

   The conduct of the set requires considerable self-control from each swimmer and the strict adherence to the rules of ultra-short swimming at race-pace. Suggested rules for swimming and timing a repetition follow.

- Each swimmer must determine the time for each repetition exactly. How a swimmer initiates and completes the repetition is important. Some possibilities are:
    - Have the swimmer hold the lane wall, crouched ready to push off, and release the hold only when the analog/digital pace clock passes the individual's start time.
    - The swimmer should determine a procedure where the timing device can be observed when the wall is touched at the end of the distance. [The only drawback with this procedure is that it does not allow the practice of good race-appropriate finishes. Consequently, the finishing techniques for races should be practiced separately and to the extent that each swimmer recognizes the differences between repetition finishes and desirable race finishes.]
    - As many repetitions as possible should be completed with feet-touch so that the approach to a racing-turn can be practiced. In 25 m short-course pools, when performing 50 m repetitions the turns should be race-quality.
    - The swimmer should calculate the time for each repetition completion. Never should a coach call out times off a stop-watch - a particularly useless coaching behavior.
    - It is each swimmer's responsibility to remember the times of each repetition. During a set, the coach should inquire frequently as to the performance level of the swimmers.
- From the outset, swimmers should exceed the desired pace time but revert to it as soon as possible in the set. It is the repeating of the race-pace that is important. The development of the skill of swimming at a particular velocity is one of the central purposes of the set. With time, swimmers become very competent at settling into a particular pace very early in a set.
- After one quarter of the set has been completed, the likelihood of some swimmers not completing a repetition in the target time increases. That failure is usually termed a "missed target" or "missed time". The cause of the miss is usually assumed to be the accumulation of interfering fatigue. When such a miss occurs, the swimmer should not participate in the next repetition, which likely would have been a failure too. That decision is the swimmer's responsibility. With the added rest, the swimmer should recover to re-enter the set after having missed one repetition target-time and resting for another. The fail-miss procedure could happen on several occasions for swimmers low in fitness or low in endurance capacity[21]. On some occasions, the swimmer knows why the missed target occurred (e.g., a collision, interference at a turn, delayed reading of the timing device). When the cause of the miss is not fatigue, the swimmer should continue with the set.
- As the set progresses, the swimmer should keep track of the number of successful repetitions completed. When that number is multiplied by the repetition distance, the total race-pace distance for the set can be calculated. That number should also be recorded and remembered by the swimmer. How many successful repetitions were completed before the first missed target should also be recorded and remembered.
- The next time the same set is repeated, swimmers will be able to determine if they have improved, regressed, or remained stable by comparing the successful completed distance of the set and/or the number of repetitions completed before the first failure to those of the previous set. An improvement usually indicates an increase in efficiency and/or

[21] This is important for it accommodates the individual differences within a training squad.

exactness of swimming at the stipulated pace. In this way, the completion of these challenging sets acts as a motivational experience because any improvement infers that the next race-performance of the target event should be improved because it has improved at practice.

8. After each ultra-short set, which should have been challenging and produced an obvious performance decrement (which will be recovered quickly because it involves the fast-component of the aerobic system in recovery), an active recovery exercise should be performed. That exercise can be anything, even irrelevant exercises such as kicking or slower-than-race-pace swimming.
9. After the practice, the statistics of each ultra-short set should be entered in the swimmers' log-books or journals.
10. With squad training it usually is difficult provide exact rests. What the coach has to do is place swimmers of like swimming velocities in each lane. Then a simple iteration time should be estimated. For example, if 25 m at 100 m pace for backstroke has swimmers race-pace times ranging from 15-17 seconds, the rest interval would be in the vicinity of 15+ seconds. Thus, a simple iteration time would be one repetition and rest every 35 seconds. If it was 30 seconds, the very-short-rest swimmers might find the task extremely difficult. It is important to keep repetition and rest times as close to the ideal as possible but group situations usually force compromises. In such situations, swimmers must place the greatest emphasis on completing the race-pace swim and always starting on the iteration time.

TABLE 2. A SAMPLE TWO-HOUR PRACTICE SESSION WITH THREE RACE-PACE SETS AND ONE SKILL SET.

Number	Activity	Duration
1	**Warm-up:** 2 x 200 IM at 80% and 90% effort. Rest one minute.	7 minutes
2	**Underwater kicking skill**: 12 x 15 m double-leg kicking deep. On 45 seconds.	9 minutes
3	**Recovery 1**: 300 m backstroke at own pace.	9 minutes
4	**Race-pace Set 1**: 20 x 50 m crawl stroke at 200 m race-pace. On 55 seconds.	19 minutes
5	**Recovery 2**: 400 m kicking. Choice of two strokes.	10 minutes
6	**Race-pace Set 2**: 30 x 25 m butterfly or breaststroke at 100 m race-pace (include underwater work). On 35 seconds	18 minutes
7	**Recovery 3**: 200 m backstroke kicking.	8 minutes
8	**Race-pace set 3**: 30 x 25 m backstroke at 100 m race pace (include underwater work). On 35 seconds.	22 minutes
9	**Recovery 4**: Leave pool. Pick-up and stow equipment.	3 minutes

The programming of race-pace sets and recovery activities will be new/strange for many swimming coaches. Table 2 lists a two-hour training-session program for an advanced training squad in a fitness emphasis macrocycle. It is a fairly typical example.

The Special Case of Training for Medley Races. Training for medley swims presents a special case. The coach and swimmer need to have a close to accurate idea of the split times for each stroke in the medley event. Usually, the backstroke, breaststroke, and possibly crawl stroke legs of the swim will be at different paces than if they were swum in individual stroke events, particularly in the 400 m medley event. It is possible that the 200 m medley legs might match the velocities required for 200 m stroke events.

When the medley race-pace is slower than in a single stroke race, the slower velocity of swimming is normally offset by having a shorter rest interval than in a pure race set. It should not be assumed that training for 100 or 200 m stroke events will "carry-over" to medley swimming. The turning skills of medley swimming also need to be practiced at race-pace.

Repetitions of Repetitions

A single exposure to a race-pace set will achieve little because there are no incremental training effects (prolonged performance improvements). With repeated exposures to a certain race-pace set, the brain establishes successive refinements of the patterning associated with the basic task of performing with the technique and energy forms that are equivalent to those of a race. It generally is advocated that at least three repetitions of the same race-pace set be experienced in the same microcycle (Rushall & Pyke, 1991). The period between repeated exposures should range between 36 and 48 hours, which is accommodated adequately within the traditional week-long microcycle.

With the second exposure to a specifically structured race-pace set, the body is better equipped to handle the training stimulus provided. That process is commonly explained as the body "learns from each exposure". That familiarity generated after the first exposure should make the second exposure seem easier than the first. If applied correctly in a microcycle, swimmers should improve (record an improved race-pace total distance and/or more repetitions completed before the first failure for the second set). A similar effect should be experienced with the third exposure compared to the second. With each repetition of the race-pace set, the set should become easier, that is improvements[22] should be experienced by the swimmer. However, sometimes outside stressful influences occur and affect the capacity of swimmers to perform at training as they would when training is the only life stress. On occasions when an improvement does not occur on a successive presentation, the coach should keep response-modifying problems in mind when analyzing swimmers' training responses.

Within a microcycle, it is recommended that in the last training session of the week the swimmers experience a reduction in set demands, an "unloading" training stimulus. Unloading refers to maintaining the stimulus intensity but reducing the total demand of the race-pace set. For example, 24 repetitions might be reduced to 12 or 14, while the remaining characteristics are unaltered. The features of race-pace set repetitions in a microcycle are illustrated in Figure 2.

[22] The number of successful repetition completions in particular sets should improve as the set is repeated.

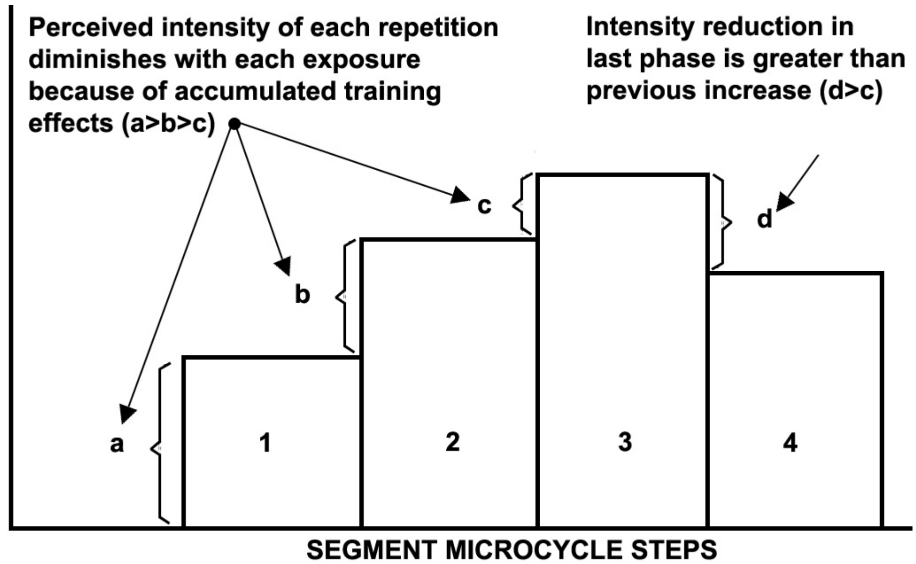

Figure 2. Three repetitions and an unloading (partial) repetition of a race-pace set in a weekly microcycle. The perception of difficulty is reduced with each exposure, which is an indication of attaining a training effect (after Rushall, 2003a; Rushall & Pyke, 1991).

After a microcycle, a coach might decide to increase the intensity of the set by changing any of the variables that moderate the effort demands of the training item. Successive microcycles, with increasing demands are a way of producing performance improvements in individual swimmers. Eventually, swimmers will not be able to improve any more from the physiological adaptations produced by the microcycle-based progressive overloads. When that occurs, training performances for the set will not change. The programming response in those circumstances likely should focus on altering technique features (e.g., increased streamlining to reduce resistance; increasing acceleration within the propulsive-phase of the stroke). The point behind changing technique is that the performance efficiency of the swimmer should be improved. Two effects are possible.

1. A reduction in resistance allows a swimmer to progress further each stroke with the same stroking frequency and effort, that is, the swimmer swims faster.
2. An increase in effective force allows a swimmer to progress faster if the stroke frequency is maintained.

The second alternative (increasing force application) is only appropriate when it also is reflected in swimming efficiency. The simple factor of increasing swimming effort usually works only at reduced velocities. When near or at maximum velocity, increased effort rarely translates into performance improvements (Capelli, Pendergast, & Termin, 1998). It only makes a swimmer more tired sooner.

The length of time that it takes for swimmers to reach peak fitness has been investigated. Three months is about all that is needed to establish aerobic adaptation in swimmers (Bonifazi et al., 1998). In mature swimmers, the maximum period to achieve close to physiological fitness is about eight weeks (Kamel, McLean, & Sharp, 2002). After that, the rest of swimming training should be aimed at improving swimming efficiency at the intended pace of particular races.[23]

[23] The manner in which techniques are altered in concert with ultra-short race-pace training is presented in the coaching manual, *A Swimming Technique Macrocycle* (Rushall, 2013).

It is important to recap the major point of this section: Single exposures to a race-pace set are useless. The repetitious exposure to a race-pace set allows training effects and objective demonstrations of swimmers' performances improving at training to occur. This latter feature is the major rejoinder to arguments where training "variety" as being an important motivational feature is advocated by many coaches. When swimmers can see the relevance of training for improving race performances, and training responses improve, they prefer race-pace work and its repetitions to traditional coaching programs with variety and much irrelevant training (McWhirter, 2011).

Cyclic Emphases of Performance Factors

The first time a coach implements a race-pace training macrocycle, the length of time to the achievement of ceiling fitness normally takes more than one month and will vary between swimmers within a squad. That first macrocycle is special and is not likely to be repeated. Once initial ceiling fitness has been achieved, adaptation across microcycles in a macrocycle takes only about one month. it is pointless and boring to continually train with no performance improvements. To keep swimmers motivated, one possibility is the training program should be "cycled" on a monthly basis by alternating a fitness emphasis with a technique/mental skills emphasis.

1. *Fitness emphasis with technique and mental skills maintenance*. Training sessions emphasizing performance improvements in total race-pace distance are designed in much of the manner described above. While swimming is executed, a secondary coaching emphasis should be placed on maintaining technique gains as well as practicing mental skills (e.g., increasing positive thinking, negative thought-stopping, etc.). Performance improvements should be recognized enthusiastically so that swimmers will aim to "push themselves" to improve on each repetition of the set. Continual improvements should signal a successful series of microcycles of training.

2. *Technique and mental skills emphases with fitness maintenance*. Although not the focus of this paper, technique and mental skills training are likely to have a greater and more enduring impact on swimmers' performances than fitness training. A curriculum of swimming technique and skill developments is available (Rushall, 2011b) and would serve a valuable role in this training model (Arellano, 2011). With the introduction of a month or more of emphasis on technique progressions, it is assumed that good pedagogy will be provided (also covered in the Rushall (2011b) book). When emphasizing technique in a month-long macrocycle, recovery sessions are usually used for instruction and contain less active recovery than in a fitness macrocycle. It is in the recovery periods that the instructional components of mental skills and technique can be entertained.

   Mental skills training is also available in manual form (Rushall, 2003e). One reason mental skills training and technique development can be emphasized concomitantly is that much mental skill training can be performed outside of the pool ("swimming homework"). At practices, swimmers should be encouraged to practice and incorporate into their swimming what they have learned when away from the pool.

   The programming of modifications for fitness maintenance has several characteristics.

   - The race-pace sets are as much an opportunity to practice or refine race-pace technique features and/or mental skills as they are to gain some fitness benefit.
   - Not as much volume of sets and repetitions is required for maintenance when compared to that required for improvements. The number of race-pace sets in a microcycle might only be two. Even with that low number, swimmers should aim to repeat or improve on the total race-pace distance achieved in the last fitness-emphasis

> macrocycle. The number repetitions in a set might also be reduced to the previous emphasis macrocycle. That would allow for the programming of a greater variety of race-pace exposures so that technique features can be practiced. The "easier" race-pace sets should boost swimmers' confidences that they are swimming well.

Figure 3 illustrates the cycling of emphases concepts. Hypothetical indications of intensity and duration are included. The macrocycle loading is similar to that illustrated in Figure 2. In Macrocycle 1, fitness is emphasized and technique and mental skills are maintained or refined. In Macrocycle 2, technique and mental skills are emphasized and could involve learning new content. Fitness training is in maintenance mode (Rushall, 2003b; Rushall & Pyke, 1991).

Closure

Noakes (2000) required that factors determining fatigue and performance be established before effective training could be devised that would result in predictable performance improvements. This paper has attempted to fulfill the needed explanations of fatigue and performance. Taking those directions in hand, this presentation indicates how training programs for serious swimmers should be constructed. The developed guidelines are contrary to most traditional swimming practices, which have largely been guided by beliefs and dogma.

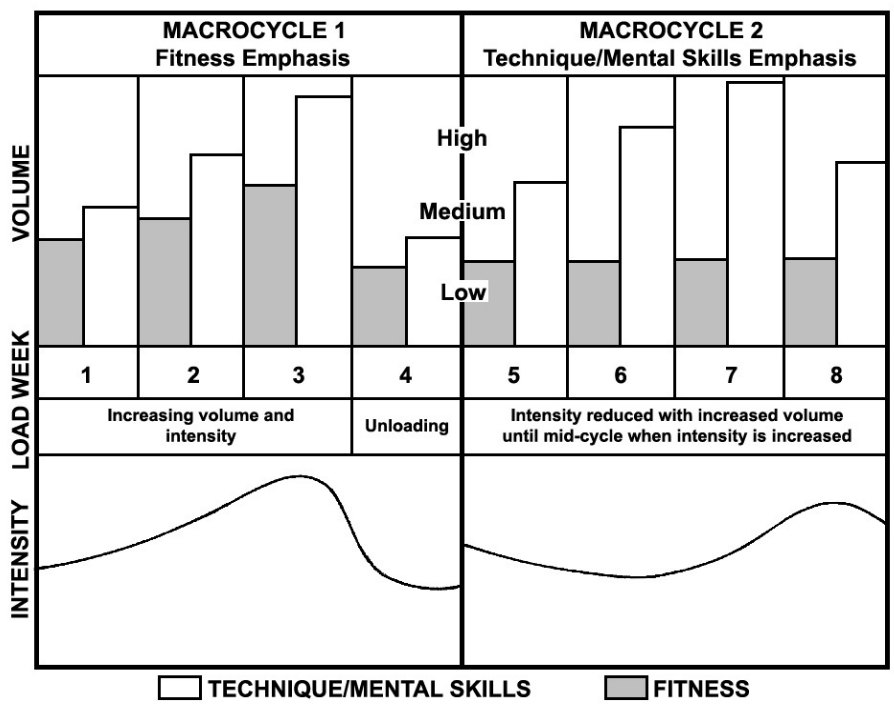

Figure 3. Cyclic macrocycles for training emphases in swimming
(after Rushall, 2003b; Rushall & Pyke, 1991).

What has been described in this paper does not fit the outdated periodization model (Bompa, 1986; Rushall, 2003b; Rushall & Pyke, 1991). It better reflects the "Block Periodization" model (Issurin, 2008) which accommodates multiple peaking opportunities in a calendar year. The notion that swimmers need to train with considerable demand over as much as six months before experiencing a taper is wrong and is contradicted by impressive and consistent research publications.

The central feature of consistent training is that specific representations as neurological patterns are formed in the brain. If training exactly reflects the energy and fatigue properties of races, a discrete section of the brain networks the resources to form a family of patterns that can be used in the race for which the training was designed. If no race-pace training has occurred in sufficient volume, swimmers will have no established movement and energy pattern to use in a race. Because a race is such a rare event in a world where no race-specific training has occurred, swimmers would have to cope with the unusual demands as best as possible. The distraction of having to cope from an unprepared perspective, guarantees a less-than-best performance. No value for racing comes from non-race-specific training.

Throughout this paper, mentions were made of irrelevant swimming activities that do not relate to or could improve race performance. They are most of what is commonly seen in competitive swimming pools today. Drills, land-training, pool-use equipment (e.g., bands, pull-buoys, paddles, snorkels, etc.), and single-energy specific training sets are irrelevant activities for influencing racing in a positive manner. For example, the aerobic energy use in races is vastly different to aerobic energy use in traditional training sessions. One has to question the value of irrelevant training-session aerobic stimulation as a preparatory experience for racing. Based on the evidence concerning human function, it is of no value. Although it is provocative to say so, most swimming coaching situations today do not develop swimmers in any manner that approaches an optimal progression.

The energy use in a swimming race in a pool begins with stored oxygen and the alactacid system. In a fully and appropriately trained state, the sensitized aerobic system is soon activated and performs the dual function of providing the means for productive aerobic energy as well as restoring alactacid and lactacid metabolism. Assuming training has been appropriate (as advocated here), Type IIa fibers will add to muscle function in an oxidative manner. During the race, Type IIb fibers will generate lactic acid but if it is removed as quickly as it is developed (the "balance" is facilitated by inspired oxygen) at the highest level of concentration that can be tolerated, there will be no degrading or destructive effect from lactate on race performance and/or aerobic function. Only at the very end of a race, is lactacid anaerobic metabolism likely to be elevated for a relatively brief period. When energy is used in the manner and sequence described here, it requires specific training to stimulate the energy sources in race-specific manners. The options for doing that are limited and proposed as being ultra-short training with specific periods of work and rest that cannot be modified. Any training that does not fulfill the criteria for ultra-short training, is a waste of time for serious and elite swimmers although, paradoxically, might be beneficial for beginner and young developing swimmers. It will be very hard for most coaches to accept this didactic expression and cast aside irrelevant training activities and structures.

The energy use described in the previous paragraph is dependent on several factors.

- In a race, the times for all laps, other than the first, should be constant with stroke rates also remaining constant. If the early stage of a race uses anaerobic energy excessively, a competitor is doomed to a less than optimal performance (see next paragraph). The critical excessive use of anaerobic resources early in a race is the first and perhaps most significant factor that defines a race success or failure. [It should be noted that several research articles report that stroke rates decline as races progress. That should be expected if swimmers have "gone out too fast", which is the usual way swimming racing is approached, but does not occur in swimmers who even-pace or negatively split a race.]

  In racing based on traditional training, early fast work is anaerobic (Type II fibers) as the aerobic/oxidative mechanisms (Type I fibers) are gradually invoked. However, after ultra-short race-pace training some Type II fibers adapt to function oxidatively (Type IIa fibers).

Thus, when Type II fibers are used early in a race the amount of anaerobiosis is reduced by the proportion of oxidative Type IIa fibers. In that case, the early work is not as exhausting as when few Type IIa fibers exist (the likely case in traditional training).

- The brain has established patterns representing a narrow family of technique and energy use variations that support the overt performance of a very consistent race. That can only be achieved by many practices, repetitions, and trials of consistent race-pace swimming with appropriately short rests between intervals. [Repetition distances greater than 100 m and rests longer than 20 seconds are the upper boundaries for leaving the relevant training sphere and performing irrelevant training.]
- When racing, the swimmer is in good health and rested, without being "tapered". After a number of macrocycles of cyclic training, a very short rest period will add even more improvement to a racing performance. With ultra-short race-pace training, a traditional taper is inappropriate because the format "self-regulates" and prevents long-term exhaustion.

Another manifestation of irrelevant swimming training is the preoccupation with weekly training volume and attendances. Inadvertently, that has led to the realization that swimming training largely is aimed at improving the training of swimmers – they train to train. Swimming research has shown this to be the case. Physiological measures change across training periods. However, those changes are rarely related to single performances (swimming races). There is a distinct difference between a two-hour training period and a two-minute race. The energy expenditures and types in the practice pool are unrelated to what happens in a race. This paper has suggested a general strategy for bringing the experiences in practice sessions to be more relevant for racing improvements than currently exists. Whether or not coaches are willing to alter entrenched coaching behaviors to provide a program that will benefit racing-oriented swimmers remains to be seen. Since the idea of race-pace work has been around for a long time but only started to be contemplated and used by some coaches in the last decade, there are encouraging anecdotal stories of the predicted benefits being achieved. The objective research verification in swimming of this "new" training approach cannot be far away.

If a coach opted to take these very different and evidenced-based suggestions, the alteration in behaviors, particularly training session preparation and implementation, would be challenging at first but as familiarity is developed and swimmer feedback is provided, the task would become easier. There will always be doubters in close proximity who will attempt to undermine any honest efforts to provide better (but different) training experiences for serious swimmers. A commitment to follow the directives provided here in a disciplined manner is almost a requirement to see changes in coaching effectiveness through to a final, rewarding culmination. The practice sessions that stimulate the techniques and energizing properties for various races will be very different to traditional swimming training. It is perhaps that obvious difference that is the single marker of change for the better in a coach's coaching.

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

A Last Word

The responsibility for the lack of understanding about the energy requirements and functioning in swimming should not be borne solely by coaches. Several shortcomings in information dissemination concerning exercise physiology in general were presented throughout this paper. Some of them are repeated below amongst some that are presented for the first time.

- Instruction in exercise physiology is often incomplete. The source of information (e.g., a college course, a coaching education course, personal reading, etc.) is often restricted to a narrow incomplete band of information (Noakes, 2000) from which a number of hypotheses or guesses are added to extend the source's explanations about swimming performances. The logic of such actions is likely to lead to false implications because the truth of all premises cannot be guaranteed.

- When learning or being instructed about human movement at the gross level, a narrow focus on one branch of sport science will not present the true picture or integrated list of causal and/or explanatory factors. It is dangerous to isolate energy provision without understanding the neurophysiology that combines energy needs with movement parameters (biomechanics). Overall, the psychology of human performance modifies those factors. Without integrated knowledge contained in explanations and exercise prescriptions, the probability of being wrong and taking an incorrect path of action is extremely high. This shortcoming is also a failing of the common educational models to which coaches are exposed. It is usual to read books solely devoted to an area of sports science, or coaching manuals that include discrete chapters on the various sports sciences, both of which fail to explain the complexities of integrated scientific principles which are essential to provide good programs of behavior and performance changes for swimmers.
- At the college level, misinformation is perpetuated by instructors who fail to appreciate the limitations of their own knowledge. This has occurred with the science of total-body, gravity-combating activities (e.g., running, cross-country skiing) being applied to a fully supported partial activity such as swimming. The dynamics of human function and the provision of energy in the two disparate classes of activity are likely to be just as unique to each as they are common. When total-body physiology experts are brought into swimming, quite often this fundamental error occurs. Few sport science professionals recognize the ethical requirement of not stepping outside the scope of their training, familiarity, and knowledge. The lure of an association with high-profile athletes, teams, and sports seems to obscure that important aspect of professional behavior.
- Coaches often have an incomplete knowledge of an area of sport science but assume their understanding is complete (i.e., "a little knowledge is dangerous"). The acceptance of guesses, unfounded beliefs, and misinformation makes such coaches dangerous to swimmers rather than being helpful.
- When a coach is successful and provides explanations for those successes which are rarely questioned, there is a human tendency to continue to invent extended explanations without corroborative evidence. This leads to an increase in swimming lore and a weakening of the demand for objectively verified truths. [There now is sufficient scientific research to require the science behind any explanation concerning human function at any practical level.]

What should a coach do if knowledge is minimal and/or incomplete? Some suggestions are:

- Become acquainted with the sciences of human performance in swimming. Do not assume that what works in another sport will also work in swimming.
- If information is not available, do not invent something to fill the void. Coaches should only limit themselves to verified knowledge with which they are acquainted. When an absence of knowledge is recognized, outside assistance that can fill the void should be sought and accepted only if that source too can relate the scientific verification for the advice. If suitable sources are not available, then coaches should ignore extending information and rely on the limited but true principles of behavior with which they are familiar.
- Coaches should continually educate themselves to remain familiar with developments and changes in current science as well as the recognition of errors in past science.

- When one does not have an answer, it makes no sense to invent one, particularly when it is possible to have one based in science. Although discovering appropriate scientific answers might involve skill and some difficulty, the easier option of invention is inexcusable. Appealing to fantasy as an expedient way of solving a coaching problem is unacceptable when the welfare of young people is involved.

References

Almeidal, A. G., Gobatto, C. A., Lenta, C., & Kokubun, E. (1999). Influences of swimming test distance in the anaerobic threshold determination and blood lactate levels. *Medicine and Science in Sports and Exercise, 31(5),* Supplement abstract 1253.

Alves, F., Reis, J., Bruno, P. M., & Vleck, V. (June 03, 2010). *Distance-time modeling and oxygen uptake kinetics in swimming.* Presentation 2392 at the 2010 Annual Meeting of the American College of Sports Medicine, Baltimore, Maryland; June 2-5.

Alves, F., Reis, J., Vleck, V., Bruno, P., & Millet, G. (2009). *Oxygen uptake kinetics in heavy intensity exercise and endurance performance in swimmers.* ACSM 56th Annual Meeting, Seattle, Washington. Presentation Number 978.

Anderson, M. E., Hopkins, W. G., Roberts, A. D., & Pyne, D. B. (2003). Monitoring long-term changes in test and competitive performance in elite swimmers. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 194.

Andrade, R. M., Figueira, A. J., Lauro, F. A., Velhote, F. B., Alves, L. L., & Pinheiro, D. S. (2001). Influence of anaerobic muscle power on swimming performance. *Medicine and Science in Sports and Exercise, 33(5),* Supplement abstract 1826.

Arellano, R. (2010). Interpreting and implementing the long term athlete development model: English swimming coaches' views on the (swimming) LTAD in practice – A commentary. *International Journal of Sports Science and Coaching, 5(3),* 413-419.

Astrand, I., Astrand, P-O., Christensen, E. H., & Hedman, R. (1960). Intermittent muscular work. *Acta Physiologica Scandinavica, 48,* 448-453.

Astrand, P. O., & Rodahl, K. (1977). *Textbook for work physiology.* New York, NY: McGraw-Hill.

Avalos, M., Hellard, P., & Chatard, J-C. (2003). Modeling the training-performance relationship using a mixed model in elite swimmers. *Medicine and Science in Sports and Exercise, 35,* 838-846.

Baltaci, G., & Ergun, N. (1997). Effect of endurance training on maximal aerobic power of competitive swimmers. *Medicine and Science in Sports and Exercise, 29(5),* Supplement abstract 1260.

Barden, J. M., & Rorke, S. C. (1999). Stroke parameter relationships in a repeated swim interval training set. *Medicine and Science in Sports and Exercise, 31(5),* Supplement abstract 375.

Bar-Or, O. (1996). Developing the prepubertal athlete: Physiological principles. In J. P. Troup, A. P. Hollander, D. Strasse, S. W. Trappe, J. M. Cappaert, & T. A. Trappe (Eds.), *Biomechanics and Medicine in Swimming VII* (pp. 135-139). London: E & FN Spon.

Bartlett, M. L., & Etzel, E. (2007). A single case design approach to monitoring the effects of intense training on immune function and mood state in swimmers. *ACSM Annual Meeting New Orleans,* Presentation Number, 2014.

Beckett, K. (1986). Swimming fast. *Swimming Technique,* August-October, 27-29.

Beidaris, N., Botonis, P., & Platanou, T. (2010). *Physiological and performance characteristics of 200 m continuous swimming and 4 x 50 m "broken" swimming with different interval time demands.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Billat, L. V. (1996). Use of blood lactate measurements for prediction of exercise performance and for control of training: Recommendations for long-distance running. *Sports Medicine, 22,* 157-175. [http://coachsci.sdsu.edu/csa/vol46/billat.htm]

Billat, L. V. (2001). Interval training for performance: A scientific and empirical practice. Special recommendations for middle- and long-distance running. Part II: Anaerobic interval training. *Sports Medicine, 31,* 75-90. [http://www-rohan.sdsu.edu/dept/coachsci/csa/vol71/billat3.htm]

Boelk, A. G., Norton, J. P, Freeman, J. K., & Walker, A. J. (1997). Relationship of swimming power to sprint freestyle performance in females. *Medicine and Science in Sports and Exercise, 29(5),* Supplement abstract 1255.

Bogdanis, G. C., Saraslanidis, P., Petridou, A., Galanis, N., Tsalis, G., Kellis, S., Kapetanos, A. G., & Mougios, V. (2009). *Muscle metabolism and performance improvement after two training programs of sprint running.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Bompa, T. O. (1986). Theory and methodology of training. Dubuque, IA; Kendall/Hunt.

Bonifazi, M., Bela, E., Lupo, C., Martelli, G., Zhu, B., & Carli, G. (1998). Influence of training on the response to exercise of adrenocorticotropin and growth hormone plasma concentrations in human swimmers. *European Journal of Applied Physiology, 78(5),* 394-397.

Bonifazi, M., Martelli, G., Marugo, L., Sardella, F., & Carli, G. (1993). Blood lactate accumulation in top level swimmers following competition. *The Journal of Sports Medicine and Physical Fitness, 33,* 13-18.

Borms, J. (1986a). The child and exercise: an overview. *Journal of Sports Sciences, 4,* 3-20.

Borms, J. (1986b). The child and exercise: an overview. *Journal of Sports Sciences, 4,* 3-20. [Summary at http://coachsci.sdsu.edu/csa/vol32/borms.htm]

Breed, R. V., Young, W. B., & McElroy, G. K. (2000). The effect of a resistance-training program on the grab, swing, and track starts in swimming. *2000 Pre-Olympic Congress in Sports Medicine and Physical Education: International Congress on Sport Science.* Brisbane, Australia. [http://www.ausport.gov.au/fulltext/2000/preoly/abs325b.htm]

Brooks, G. A. (1985). Anaerobic threshold: Review of the concepts and directions for future research. *Medicine and Science in Sports and Exercise, 17,* 22-34.

Brooks, G. A. (1986). The lactate shuttle during exercise and recovery. *Medicine and Science in Exercise and Sports, 18,* 360-368.

Brooks, G. A. (1991). Current concepts in lactate exchange. *Medicine and Science in Sports and Exercise, 23,* 895-906.

Brooks, G. A., Wolfel, E. E., Groves, B. M., Bender, P. R., Butterfield, G. E., Cymerman, A., Mazzeo, R. S., Sutton, J. R., Wolfe, R. R., & Reeves, J. T. (1992). Muscle accounts for glucose disposal but not blood lactate appearance during exercise after acclimatization to 4,300 m. *Journal of Applied Physiology, 72,* 2435-2445.

Bulgakova, N. Z., Vorontsov, A. R., & Fomichenko, T. G. (1987). Improving the technical preparedness of young swimmers by using strength training. *Theory and Practice of Physical Culture, 7,* 31-33.

Byrnes, W. C., & Kearney, J. T. (1997). Aerobic and anaerobic contributions during simulated canoe/kayak sprint events. *Medicine and Science in Sports and Exercise, 29(5),* Supplement abstract 1256.

Capelli, C., Pendergast, D.R., & Termin, B. (1998). Energetics of swimming at maximal speeds in humans. *European Journal of Applied Physiology, 78(5),* 385-393.

Cappaert, J. M., & Gordon, B. J. (1998). Technique variables of elite level freestyle swimmers. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 156.

Cappaert, J. M., Kolmogorov, S., Walker, J., Skinner, J., Rodriguez, F., & Gordon, B. J. (1996). Active drag measurements in elite US swimmers. *Medicine and Science in Exercise and Sports, 28(5),* Supplement abstract 279.

Cappaert, J. M., Pease, D. L., & Troup, J. P. (1996). Biomechanical highlights of world champion swimmers. In J. P. Troup, A. P. Hollander, D. Strasse, S. W. Trappe, J. M. Cappaert, & T. A. Trappe (Eds.), *Biomechanics and Medicine in Swimming VII* (pp. 76-80). London: E & FN Spon.

Carl, D. L., Bales, E., Haubrich, C., Kirschling, M., Milnes, C., Vernon, A., & Winquist, J. (2003). Effect of high intensity versus high volume swim training on selected measures of fatigue. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 2065.

Chatard, J. C., Collomp, C., Maglischo, E., & Maglischo, C. (1990). Swimming skill and stroking characteristics of front crawl swimmers. *International Journal of Sports Medicine, 11,* 156-161.

Chollet, D., Pelayo, P., Delaplace, C., Tourny, C., & Sidney, M. (1997). Stroking characteristic variations in the 100-m freestyle for males of differing skill. *Perceptual and Motor Skills, 85,* 167-177.

Chollet, D., Seifert, L., Boulesteix, L., & Carter, M. (2006). Arm to leg coordination in elite butterfly swimmers. *International Journal of Sports Medicine, 27(4),* 322-329.

Christensen, E. H. (1962). Speed of work. *Ergonomics, 5,* 7-13.

Christensen, E. H., Hedman, R., & Saltin, B. (1960). Intermittent and continuous running. *Acta Physiologica Scandinavica, 50,* 269-286.

Costill, D. L., King, D. S., Holdren, A., & Hargreaves, M. (1983). Sprint speed vs. swimming power. *Swimming Technique,* May-July, 20-22.

Costill, D. L., Thomas, R., Robergs, R. A., Pascoe, D., Lambert, C., Barr, S., & Fink, W. J. (1991). Adaptations to swimming training: influence of training volume. *Medicine and Science in Sports and Exercise, 23,* 371-377.

Craig, A. B., Jr., & Pendergast, D. R. (1979). Relationships of stroke rate, distance per stroke, and velocity in competitive swimming. *Medicine and Science in Sports and Exercise, 11,* 278-283.

Crowe, S. E., Babington, J. P., Tanner, D. A., & Stager, J. M. (1999). The relationship of strength and dryland power, swimming power, and swim performance. *Medicine and Science in Sports and Exercise, 31(5),* Supplement abstract 1230.

D'Acquisto, L. J., & Berry, J. E. (2003). Relationship between estimated propelling efficiency, peak aerobic power, and swimming performance in trained male swimmers. *Medicine and Science in Sports and Exercise, 34(5),* Supplement abstract 193.

D'Acquisto, L. J., Berry, J., Boggs, G., & Mattern, P. (2004). Swimming performance and velocity at OBLA are linked to propelling efficiency. *Medicine and Science in Sports and Exercise, 36(5),* Supplement abstract 1409.

de Jesus, K., de Jesus, K., Figueiredo, P. A., Gonçalves, P., Vilas-Boas, J. P., & Fernandes, R. J. (2010). *Kinematical analysis of butterfly stroke: Comparison of three velocity variants.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Dutto, D. J., & Cappaert, J. M. (1994). Biomechanical and physiological differences between males and females during freestyle swimming. *Medicine and Science in Sports and Exercise, 26(5),* Supplement abstract 1098.

Enoksen, E., Tonnessen, E., & Shalfawi, S. (2009). *The effect of high vs. low intensity training on aerobic capacity in well-trained middle-distance runners.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Fernandes, R. J., Sousa, A., Figueiredo, P., Oliveira, N., Oliveira, J., Silva, A. J., Keskinen, K L., Rodriguez, F. A., Machado, L., & Vilas-Boas, J. P. (2010). *Oxygen kinetics in a 200-m front crawl maximal swimming effort.* Presentation 661 at the 2010 Annual Meeting of the American College of Sports Medicine, Baltimore, Maryland; June 2-5.

Filho, P., Müller, D., Reis, J., Alves, F., & Denadai, B. S. (2010). *Oxygen uptake kinetics around the respiratory compensation point in swimming*. A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Fitts, R. H., Costill, D. L., & Gardetto, P. R. (1989). Effect of swim exercise training on human muscle fiber function. *Journal of Applied Physiology, 66,* 465-475.

Gaskill, W. E., Serfass, R. C., Bacharach, D. W., & Kelly, J. M. (1999). Responses to training in cross-country skiers. *Medicine and Science in Sports and Exercise, 31,* 1211-1217.

Gomes-Pereira, J., & Alves, F. (1998). Prediction of swimming competitive performance through lactate testing procedures. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 190.

Grabe, S. A., & Widule, C. J. (1988). Comparative biomechanics of the jerk in Olympic weightlifting. *Research Quarterly for Exercise and Sport, 59,* 1-8.

Greyson, I., Kelly, S., Peyrebrune, M., & Furniss, B. (2010). Interpreting and implementing the long term athlete development model: English swimming coaches' views on the (swimming) LTAD in practice – A commentary. *International Journal of Sports Science and Coaching, 5(3),* 403-406.

Havriluk, R. (2010). *Performance level differences in swimming: Relative contributions of strength and technique.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Helgerud, J., Høydal, K. L., Wang, E., Karlsen, T., Berg, P. R., Bjerkaas, M., Simonsen, T., Helgesen, C. S., Hjorth, N. L., Bach, R., & Hoff, J. (2006). Differential response to aerobic endurance training at different intensities. *Medicine and Science in Sports and Exercise, 38(5),* Supplement abstract 2581.

Hellard, P., Houel, N., Avalos, M., Nesi, X., Toussaint, J. F., & Hausswirth, C. (2010). *Modeling the slow component in elite long distance swimmers at the velocity associated with lactate threshold.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Hellebrandt, F. A. (1958). The physiology of motor learning. *Cerebral Palsy Review, 10(4),* 13.

Hellebrandt, F. A. (1972). The physiology of motor learning. In R. N. Singer (Ed.), *Readings in motor learning* (pp. 397-409). Philadelphia, PA: Lea & Febiger.

Hickson, R. C., Koziris, L. P., Chatterton, R. T., Groseth, R. T., Christie, J, M., & Unterman, T. G. (1998). Serum insluin-like growth factor-I (IGF-I) and IGF binding protein (BP) -1, -3 adaptations to training. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 989.

Howat, R. C., & Robson, M. W. (June, 1992). Heartache or heartbreak. *The Swimming Times,* 35-37.

Hsu, T. G., Hsu, K. M., & Hsieh, S. S. (1997). The effects of shoulder isokinetic strength training on speed and propulsive forces in front crawl swimming. *Medicine and Science in Sports and Exercise, 29(5),* Supplement abstract 713.

Hughes, S. C., Burgomaster, K. A., Heigenhauser, G. J., & Gibala, M. J. (2003). Six bouts of sprint interval training (SIT) improves intense aerobic cycling performance and peak anaerobic power. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 1875.

Issurin, V. (2008). Block periodization versus traditional training theory: a review. *Journal of Sports Medicine and Physical Fitness, 48(1),* 65-75.

Johansen, L., Jørgensen, S., Kilen, A., Larsson, T. H., Jørgensen, M., Rocha, B., & Nordsborg, N. B. (2010). *Increased training intensity and reduced volume for 12 weeks increases maximal swimming speed on a sprint distance in young elite swimmers.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Johnson, J. K., Battista, R. A., Pein, R., Dodge, C., & Foster, C. (2009). Comparison of monitoring tools for training intensity in swimmers. *ACSM 56th Annual Meeting, Seattle, Washington.* Presentation number 1839.

Kame, V. D., Pendergast, D. R., & Termin, B. (1990). Physiologic responses to high intensity training in competitive university swimmers. *Journal of Swimming Research, 6(4),* 5-8.

Kamel, K. S., McLean, S. P., & Sharp, R. L. (2002). Biomechanical and physiological adaptation to twelve weeks of competitive swimming training. *Sixth IOC World Congress on Sport Sciences,* abstract, p. 74.

Kubukeli, Z. N., St. Clair Gibson, A., Collins, M., Noakes, T. D., & Dennis, S. C. (2000). The effects of high intensity interval training, taper, and 6 weeks of habitual training on 100-km time trial performance in endurance trained cyclists. *Medicine and Science in Sports and Exercise, 32(5),* Supplement abstract 538.

Langill, R. H., Smith, G. J., & Rhodes, E. C. (2001). The effect of pre-exercise glucose ingestion on performance during prolonged swimming. *Medicine and Science in Sports and Exercise, 33(5),* Supplement abstract 937.

Laursen, P. B., Blanchard, M. A., & Jenkins, D. G. (2002). Acute high-intensity interval training improves Tvent and peak power output in highly trained males. *Canadian Journal of Applied Physiology, 27,* 336-348.

Luttgens, K., & Hamilton, N. (1997*). Kinesiology: Scientific basis of human motion*. Madison, W: Brown & Benchmark.

Mackinnon, L. T., Hooper, S. L., Jones, S., Gordon, R. D., & Bachmann, A. W. (1997). Hormonal, immunological, and hematological responses to intensified training in elite swimmers. *Medicine and Science in Sports and Exercise, 29,* 1637-1654.

Madsen, O. (1983). Aerobic training: not so fast, there. *Swimming Technique,* November 1982-January 1983, 13-18.

Maglischo, E. W., Maglischo, C. W., Zier, D. J., & Santos, T. R. (1985). The effects of sprint-assisted and sprint-resisted swimming on stroke mechanics. *Journal of Swimming Research, 1,* 27-33.

Margaria, R., Edwards, H. T., & Dill, D. B. (1933). The possible mechanism of contracting and paying the O_2 debt and the rate of lactic acid in muscular contraction. *American Journal of Physiology, 106,* 689-715.

Mascarenhas, L. P., Neto, A. S., Brum, V. P., DaSilva, S. G., & De Campos, W. (2006). The effects of two aerobic training intensities on aerobic and anaerobic power of prepubescent boys. *Medicine and Science in Sports and Exercise, 38(5),* Supplement abstract 1486.

Matsunami, M., Taimura, A., Suga, M., Taba, S., & Taguchi, M. (2000). An effective field test to determine the endurance training speed for competitive swimmers. *Medicine and Science in Sports and Exercise, 32(5),* Supplement abstract 1690.

McArdle, W. D., Katch, F. L., & Katch, V. L. (2004). *Exercise physiology* (5th ed.). Philadelphia, PA: Lippincott Williams & Wilkins.

McMaster, W. C., Stoddard, T., & Duncan, W. (1989). Enhancement of blood lactate clearance following maximal swimming. *The American Journal of Sports Medicine, 17,* 472-476.

McWhirter, G. (2011). *Swimmer perceptions of the value of training emphases*. A research project completed as partial fulfillment of the requirements for Gold License Certification for Swimming Coaching in Australian Swimming.

Millet, G. P., Chollet, D., Chalies, S., & Chatard, J. C. (2002). Coordination in front crawl in elite triathletes and elite swimmers. *International Journal of Sports Medicine, 23,* 99-104.

Mookerjee, S., Bibi, K. W., Kenney, G. A., & Cohen, L. (1995). Relationship between isokinetic strength, flexibility, and flutter kicking speed in female collegiate swimmers. Journal of Strength and Conditioning Research, 9(2), 71-74.

Montpetit, R., Duvallet, A., Serveth, J. P., & Cazorla, G. (1981). *Stability of VO_{2max} during a 3-month intensive training period in elite swimmers.* Paper presented at the Annual Meeting of the Canadian Association of Sport Sciences, Halifax.

Mujika, I., Busson, T., Geyssant, A., & Chatard, J. C. (1996). Training content and its effects on performance in 100 and 200 m swimmers. In J. P. Troup, A. P. Hollander, D. Strasse, S. W. Trappe, J. M. Cappaert, & T. A. Trappe (Eds.), *Biomechanics and Medicine in Swimming VII* (pp. 201-207). London: E & FN Spon.

Mujika, I., Padilla, S., Geyssantm A., & Chatard, J.C. (1998). Hematological responses to training and taper in competitive swimmers: relationships with performance. *Archives of Physiological Biochemistry, 105(4),* 379-385.

Myburgh, K. H., Lindsay, F. H., Hawley, J. A., Dennis, S. C., & Noakes, T. D. (1995). High-intensity training for 1 month improves performance but not muscle enzyme activities in high-trained cyclists. *Medicine and Science in Sports and Exercise, 27(5),* Supplement abstract 370.

Nagle, E. F., Robertson, R. J., Zoeller, R. F., Moyna, N. M., & Goss, F. L. (1998). Prediction of swimming performance times using a mixed model of physiological and stroke variables. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 279.

Noakes, T. D. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports, 10,* 123-145. [http://coachsci.sdsu.edu/csa/vol71/noakes.htm]

Northius, M. E., Wicklund, H., & Patnott, J. R. (2003). Blood lactate changes in collegiate swimmers. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 1455.

Novitsky, S. A. (1998). No change in energy systems power rate production constants over a competitive swimming season. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 613.

Ogita, F., Onodera, T., & Izumi, T. (1999). Effect of hand paddles on anaerobic energy release during supramaximal swimming. *Medicine and Science in Sports and Exercise, 31,* 729-735.

Olbrecht, J., Madsen, O., Mader, A., Liesen, H., & Hollmann, W. (1985). Relationship between swimming velocity and lactic concentration during continuous and intermittent training exercises. *International Journal of Sports Medicine, 6,* 74-77.

Papoti, M., Zagatto, A. M., Cunha, S. A., Martins, E. B., Manchado, F. B., Freitas, P. B., Araujol, G. G., & Gobatto, C. A. (2006). Effects of taper on critical velocity, anaerobic work capacity and distance performances in trained swimmers. *Medicine and Science in Sports and Exercise, 38(5),* Supplement abstract 1574.

Payne, W. R., & Lemon, P. W. (1982, October). *Metabolic comparison of tethered and simulated swimming ergometer exercise.* Paper presented at the Annual Meeting of the Canadian Association of Sports Sciences, Victoria.

Pedersen, M. T., Kilen, A., Larsson, T. H., Jørgensen, M., Rocha, B., & Nordsborg, N. B. (2010). *Increased training intensity and reduced volume for 12 weeks has detrimental effects on swimmers' maximal oxygen uptake.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Pelarigo, J. G., Denadai, B. S., Fernandes, B. D., Santiago, D. R., César, T. E., Barbosa, L. F., & Greco, C. C. (2010). *Stroke phases and coordination index around maximal lactate steady-state in swimming.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Pollard, B. (January, 2001). The prevalence of shoulder pain in elite level British swimmers and the effects of training technique. *British Swimming Coaches and Teachers Association,* [http://www.bscta.com/]

Pomianowski, S., O'Driscoll, S. W, Neale, P. G, Park, M. J., Morrey, B. F, & An, K. N. (2001). The effect of forearm rotation on laxity and stability of the elbow. *Clinical Biomechanics, 16,* 401-407

Power, K., Behm, D., Cahill, F., Carroll, M., Young, W. (2004). An acute bout of static stretching: effects on force and jumping performance. *Medicine and Science in Sports and Exercise, 36,* 1389-1396.

Pyne, D. B. (1998). Performance and physiological changes in highly trained swimmers during altitude training. *Coaching and Sport Science Journal, 3,* 42-48.

Pyne, D. B., Lee, H., & Swanwick, K. M. (2001). Monitoring the lactate threshold in world-ranked swimmers. *Medicine and Science in Sports and Exercise, 33,* 291-297.

Reer, R., Ramcke, C., Rudolph, K., & Braumann, K. M. (2002). Differences in swim economy and metabolic-cardiocirculatory parameters between endurance and sprint swimmers. *Medicine and Science in Sports and Exercise, 34(5),* Supplement abstract 1339.

Reilly, T., & Woodbridge, V. (1999). Effects of moderate dietary manipulations on swim performance and on blood lactate-swimming velocity curves. *International Journal of Sports Medicine, 20*, 93-97.

Reis, J., Alves, F., Vleck, V., Bruno, P., & Millet, G. P. (2009). *Correlation between oxygen uptake kinetics in severe intensity swimming and endurance performance.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Rinehardt, K F., Axtell, R. S., Kleine, S., Upson, D., Woznica, D., Quill, T., Weitzner, J. M., Ordway, P., Kovi, D. L., & Carabetta, J. L. (2002). Response in performance, metabolic indices, and perception during a season of collegiate competitive swim training. *Medicine and Science in Sports and Exercise, 34(5),* Supplement abstract 1099.

Ring, S., Mader, A., & Mougious, V. (1999). Plasma ammonia response to sprint swimming. *Journal of Sports Medicine and Physical Fitness, 39*, 128-132.

Robb, M. (1968). Feedback and skill learning. *Research Quarterly, 3,* 175-184.

Robergs, R. A., & Ghiasvand, F. (2001). A reevaluation of the biochemical causes of skeletal muscle acidosis during intense exercise. *Medicine and Science in Sports and Exercise, 33(5),* Supplement abstract 1565.

Rocha, J. R., Matsudo, S. M, Figueira, A. J., & Matsudo, V. K. (1997). Training program effect after detraining in young athletes. *Medicine and Science in Sports and Exercise, 29(5),* Supplement abstract 987.

Rohrs, D. M., Mayhew, J. L., Arabas, M. S., & Shelton, M. (1990). The relationship between seven anaerobic tests and swim performance. *Journal of Swimming Research, 6(4),* 15-19.

Roth, W. (1991). Physiological-biomechanical aspects of the load development and force implementation in rowing. *FISA Coach, 2(4),* 1-9.

Rowbottom, D., Maw, G., Raspotnik, L., Morley, E., & Hamilton, E. (2001). Biological variables to assist in fatigue management are individualized in highly trained swimmers. *Medicine and Science in Sports and Exercise, 33(5),* Supplement abstract 1920.

Rozenek, R., Funato, K., Junjiro, K., Hoshikawa, M., & Matsuno, A. (2003). Physiological responses to interval training at velocities associated with VO_{2max}. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 493.

Rushall, B. S. (1967). *The scientific bases of circulorespiratory training.* Unpublished master's thesis, Indiana University, Bloomington, Indiana.

Rushall, B. S. (1970). An aspect of sprint training. *Compete, 2(2),* 1-2.

Rushall, B. S. (1985). Several principles of modern coaching - Part I. *Sports Coach, 8(3),* 40-45.

Rushall, B. S. (1993). Comments on altitude. *Coaching Science Abstracts, 24,* [C:\CSA\CSA\vol24\rushall2.htm]

Rushall, B. S., (April, 2002). On US Swimming's promotion of altitude, live-high—train-low, and nitrogen tent recovery and training protocols. *Swimming Science Journal*. [http://coachsci.sdsu.edu/swim/Training/rushall3.htm]

Rushall, B. S. (2003a). *Foundational principles of physical conditioning.* Spring Valley, CA: Sports Science Associates.

Rushall, B. S. (2003b). *Programming considerations for physical conditioning*. Spring Valley, CA: sports Science Associates.

Rushall, B. S. (2003c). *Biomechanics of human movement.* Spring Valley, CA: Sports Science Associates.

Rushall, B. S. (2003d). Coaching development and the second law of thermodynamics [or belief-based versus evidence-based coaching development. *Coaching Science Abstracts*. [http://coachsci.sdsu.edu/csa/thermo/thermo.htm]

Rushall, B. S. (2003e). *Mental skills training for sports* (Fourth Edition). Spring Valley, CA: Sports Science Associates. [http://brentrushall.com/mskills/index.htm]

Rushall, B. S. (2009). *The Future of Swimming: "Myths and Science".* An invited presentation on September 12, 2009 at the ASCA World Clinic held in Fort Lauderdale, Florida. Reprinted in the *Swimming Science Journal – Swimming Science Bulletin, 37,* 34 pp. On line at http://coachsci.sdsu.edu/swim/bullets/ASCA2009.pdf

Rushall, B. S. (2009a). *The science, physics, and biomechanics of baseball pitching*. Spring Valley, CA: Sports Science Associates [Electronic book].

Rushall, B. S. (2009b). *The neural and psychological bases of baseball pitching*. Spring Valley, CA: Sports Science Associates [Electronic book].

Rushall, B. S. (2009c). *Foundational and programming principles of conditioning baseball pitchers*. Spring Valley, CA: Sports Science Associates [Electronic book].

Rushall, B. S. (2011a). Commentary on the long term athlete development model for British swimming and the misinformation it propagates. *Swimming Science Bulletin, 38* [http//coachsci.sdsu.edu/swimming/bullets/table.htm].

Rushall, B. S. (2011b). *Swimming pedagogy and a curriculum for stroke development* (Second Edition). Spring Valley, CA: Sports Science Associates [Electronic book: http://brentrushall.com/pedagog/index.htm].

Rushall, B. S. (2013). *A swimming technique macrocycle*. Spring Valley, AC: Sports Science Associates [Electronic book: http://brentrushall.com/macro/].

Rushall, B. S. (no date a). Actual hand movement paths of champion male crawl stroke swimmers. *Swimming Science Bulletin, 33*. [http://coachsci.sdsu.edu/swim/bullets/pathfs33.htm]

Rushall, B. S. (no date b). Actual hand movement paths of two champion back stroke swimmers. *Swimming Science Bulletin, 34*. [http://coachsci.sdsu.edu/swim/bullets/pathbk34.htm]

Rushall, B. S., & King, H. A. (1994a). The value of physiological testing with an elite group of swimmers. *The Australian Journal of Science and Medicine in Sport, 26(1/2),* 14-21.

Rushall, B. S., & King, H. A. (1994b). Letter to the editor. *The Australian Journal of Science and Medicine in Sport, 26,* 77.

Rushall, B. S., & Pyke, F. S. (1991). *Training for sports and fitness.* Melbourne, Australia: Macmillan of Australia.

Rushall, B. S., Buono, M. J., Sucec, A. A., & Roberts, A. D. (1998). Elite swimmers and altitude training. *Australian Swim Coach, 14(4),* 22-33.

Rushall, B. S., Holt, L. E., Sprigings, E. J., & Cappaert, J. M. (1994). A re-evaluation of the forces in swimming. *Journal of Swimming Research, 10,* 6-30.

Rusko, H. (1986). Analysis of physiological response to training and competition among Finnish endurance athletes. *Athletic Performance Review, 1(10),* 1-2.

Rusko, H. (1987). The effect of training on aerobic power characteristics of young cross-country skiers. *Journal of Sports Sciences, 5,* 273-286.

Ryan, E. E., Lopez, R., Rossi, M. D., Doherty, J. L., & Jacobs, P. L. (2006). The effects of contract-relax-antagonist-contract form of PNF stretching on postural stability. *Medicine and Science in Sports and Exercise, 38(5),* Supplement abstract 2422.

Salgado, R. M., Parker, D. L., & Quintana, R. (2009). The effects of hypoxic manipulation on VO_{2max} and sea-level performance: A meta-analysis. *ACSM 56th Annual Meeting, Seattle, Washington.* Presentation number 2789.

Sandbakk, O., Welde, B., & Holmberg, H. C. (2009). *Endurance training and sprint performance in elite junior cross-country skiers.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Santos, T. M., & Gomes, P. S. (1998). Relationship between different lactate threshold determinations in long-distance male runners. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 1862.

Savage, M. V., Brown, S. L., Savage, P., & Bannister, E. W. (1981, October). *Physiological and performance correlates of training in swimmers.* Paper presented at the Annual Meeting of the Canadian Association of Sport Sciences, Halifax. [http://coachsci.sdsu.edu/swim/training/ savage.htm]

Schmidt, R. A. (1991). *Motor learning and performance: From principle to practice.* Champaign, IL: Human Kinetics.

Schnitzle, C., Seifert, L., Ernwein, V., & Chollet, D. (2008). Arm coordination adaptations assessment in swimming. *International Journal of Sports Medicine, 29,* 480-487.

Seifert, L., Chollet, D., & Chatard, J. C. (2007). Changes during a 100-m front crawl: Effects of performance level and gender. *Medicine and Science in Sports and Exercise*, *39*, 1784-1793.

Sexsmith, J. R., Oliver, M. L., & Johnson-Bos, J. M. (1992). Acute responses to surgical tubing and biokinetic swim bench interval exercise. *Journal of Swimming Research, 8,* 5-10.

Simmons, S. E., Tanner, D. A., & Stager, J. M. (2000). Different determinants of sprint swim performance in male and female competitive swimmers. *Medicine and Science in Sports and Exercise, 32(5),* Supplement abstract 1692.

Simoes, H. G., Campbell, C. S., & Kokubun, E. (1998). High and low lactic acidosis training: Effects upon aerobic and anaerobic performance. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 932.

Smith, L. L., Brunetz, M. J., Cheniere, T. C. McCammon, M. R., Hourmard, J. A., Franklin, M. E. & Israel, R. G. (1993). The effects of static and ballistic stretching on delayed onset muscle soreness and creatine kinase. *Research Quarterly for Exercise and Sport, 64,* 103-107.

Smith, J. C., Kjeisers, N. L., Kanteebeen, M., Williams, C. S., Hughes, J. E., & Hill, D. W. (1998). Metabolic responses during repeated bouts of cycle ergometer exercise at critical power. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 212.

Smith, G. J., Rhodes, E. C., & Langill, R. H. (2002). The effect of pre-exercise glucose ingestion on performance during prolonged swimming. *International Journal of Sport Nutrition and Exercise Metabolism, 12,* 136-144.

Sokmen, B., Beam, W., Witchey, R., & Adams, G. (2002). Effect of interval versus continuous training on aerobic and anaerobic variables. *Medicine and Science in Sports and Exercise, 34(5),* Supplement abstract 509.

Sokolovas, G. (2000). Demographic information. In *The Olympic Trials Project* (Chapter 1). Colorado Springs, CO: United States Swimming. [On-line. Available at http://www.usa-swimming.org/programs/template.pl?opt=news&pubid =941].

Sperlich, B., Haegele, M., Heilemann, I., Zinner, C., De Marees, M., Achtzen, S., & Mester, J. (2009). Weeks of high intensity vs. volume training in 9-12 year-old swimmers. *ACSM 56th Annual Meeting, Seattle, Washington.* Presentation number 959.

Sperlich, B., Haegele, M., Achtzehn, S., De Marees, M., & Mester, J. (2009). *High intensity exercise in children: Results from different disciplines.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Spivak, J. L. (2001). Erythropoietin use and abuse: When physiology and pharmacology collide. *Advances in Experimental Medicine and Biology, 502,* 207-224. [http://coachsci.sdsu.edu/csa/vol116/spivak.htm]

Stainsby, W. M., Brechue, W. F., & O'Drobinak, D. M. (1991). Regulation of muscle lactate production. *Medicine and Science in Sports and Exercise, 23,* 907-911.

Stanley, W. C., Gertz, E. W., Wisneski, J. A., Neese, R. A., Morris, D. L., & Brooks, G. A. (1986). Lactate extraction during net lactate release in legs of humans during exercise. *Journal of Applied Physiology, 60,* 1116-1120.

Stegemann, J. (translated by J. S. Skinner). (1981). *Exercise physiology.* Chicago, IL: Year Book Medical Publishers.

Steiner, T., Boutellier, U., & Wehrlin, J. P. (2009). *Does hemoglobin mass increase with several years of endurance training? A controlled cross-sectional study with 16, 21, and 28 years old elite XC-skiers and triathletes.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Stewart, A. M., & Hopkins, W. G. (1997). Swimmers' compliance with training prescription. *Medicine and Science in Sports and Exercise, 29,* 1389-1392.

Tabata, I., Irisawa, K., Kouzaki, M., Nisimura, K., Ogita, F., & Miyachi, M. (1997). Metabolic profile of high intensity intermittent exercises. *Medicine and Science in Sports and Exercise, 29,* 390-395.

Tanaka, H., Costill, D. L., Thomas, R., Fink, W. J., & Widrick, J. J. (1993). Dry-land resistance training for competitive swimming. *Medicine and Science in Sports and Exercise, 25,* 952-959.

Termin, B., & Pendergast, D. R. (2000). Training using the stroke frequency-velocity relationship to combine biomechanical and metabolic paradigms. *Journal of Swimming Research, 14,* 9-17.

Thanopoulos, V., Rozi, G., & Platanou, T. (2010). *Lactate concentration comparison between 100 m freestyle and tethered swimming of equal duration.* A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

Thompson, K. G., Garland, S. W., & Lothia, F. (2006). Interpretation of the physiological monitoring of an international swimmer. *International Journal of Sports Science and Coaching*, 1, 117-124.

Toussaint, H. M. (1988). Differences in propelling efficiency between competitive and triathlon swimmers. *Medicine and Science in Sports and Exercise, 22,* 409-415.

Toussaint, H. M., Knops, W., De Groot, G., & Hollander, A. P. (1990). The mechanical efficiency of front crawl swimming. *Medicine and Science in Sports and Exercise, 22,* 402-408.

Treffene, B. (2010). Interpreting and implementing the long term athlete development model: English swimming coaches' views on the (swimming) LTAD in practice – A commentary. *International Journal of Sports Science and Coaching, 5(3),* 407-412.

Trinity, J. D., Pahnke, M. D., & Coyle, E. F. (2005). Maximal power measured during a taper in collegiate swimmers. *Medicine and Science in Sports and Exercise, 37(5),* Supplement abstract 249.

Troup, J. P. (1990). Energy contributions of competitive freestyle events. In J. P. Troup (Ed.), *International Center for Aquatic Research annual - Studies by the International Center for Aquatic Research, 1989-90.* Colorado Springs, CO: United States Swimming Press.

Troup, J. P. (Ed.). (1992). *International Center for Aquatic Research Annual: Studies by the International Center for Aquatic Research 1991-92.* Colorado Springs, CO: United States Swimming Press.

VanHeest, J. L., & Ratliff, K. (1998). Hematological and hormonal changes in elite female swimmers. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 986.

Vogt, M., Breil, F., Weber, S., Weisskopf, R., Schlegel, C. H., & Hoppeler, H. (2009). *Effects of block periodization of high-intensity interval training sessions on* VO_{2max} *in subelite and elite athletes.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Vorontsov, A. R., (no date). *Development of basic and special endurance in age-group swimmers: a Russian perspective. Swimming Science Bulletin, 16.* [http://coachsci.sdsu.edu/swimming/index.htm].

Wakayoshi, K., D'Acquisto, J. D., Cappaert, J. M., & Troup, J. P. (1996). Relationship between metabolic parameters and stroking technique characteristics in front crawl. In J. P. Troup, A. P. Hollander, D. Strasse, S. W. Trappe, J. M. Cappaert, & T. A. Trappe (Eds.), *Biomechanics and Medicine in Swimming VII* (pp. 152-158). London: E & FN Spon.

Watanabe, M., & Takai, S. (2005). Analysis of factors on development of performance in young swimmers. *Medicine and Science in Sports and Exercise, 37(5),* Supplement abstract 416.

Wee, R. K., McGregor, S. J., & Light, W. (2007). Intermittent 30s intervals performed at 100 and 70 % VO_{2Peak} Power (pVO2peak) allow trained cyclists to maintain VO_{2peak} longer than continuous intervals at 100% pVO_{2peak}. *ACSM Annual Meeting New Orleans*, Presentation Number, 2417.

Weltman, A. L., Greenwood, J. D., Moses, E. Bernardino, M., & Gaesser, G. A. (2005). Effects of exercise recovery intensity on blood lactate disappearance and subsequent swimming performance. *Medicine and Science in Sports and Exercise, 37(5),* Supplement abstract 447.

White, J. C., & Stager, J. McC. (2004). The relationship between drag forces and velocity for the four competitive swimming strokes. *Medicine and Science in Sports and Exercise, 36(5),* Supplement abstract 93.

Zamparo, P., Capelli, C, Di Nino, A., & Cautero, M. (2000). Energy cost of front crawl at supra maximal speeds and underwater torque in young swimmers. *Medicine and Science in Sports and Exercise, 32(5),* Supplement abstract 1694.

Zafiriadis, S., Loutpos, D., Valkoumas, I., & Tsalis, G. (2007). The effect of backstroke swimming using "paddles" and "swim chute" in stroke parameters and in the concentration of lactic acid. *Inquiries in Sport and Physical Education, 5,* 437-445.

Zafiridis, A., Sarivasiliou, H., Dipla, K., & Vrabas, I. (2009). *The effects of interval vs. heavy continuous exercise programs on oxygen consumption, heart rate, and lactate responses in adolescents.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

Zoeller, R. F., Nagle, E. F., Moyna, N. M., Goss, F. L., Lephart, S. M., & Robertson, R. J. (1998). Anaerobic indices of freestyle swimming performance in trained adult female swimmers. *Medicine and Science in Sports and Exercise, 30(5),* Supplement abstract 280.

Zuniga, J., Berg, K., Noble, J., Harder, J., Chaffin, M., & Hanumanthu, S. H. (2008). Physiological responses and role of VO_2 slow component to interval training with different intensities and durations of work. *ACSM 55th Annual Meeting Indianapolis*, Presentation Number, 1277.