SWIMMING SCIENCE BULLETIN

Number 42

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HYPOTHESES ABOUT THE SPECIFICITY OF PHYSICAL CONDITIONING IN SWIMMING: IT IS A LOT MORE SPECIFIC THAN COMMONLY BELIEVED©

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June 26, 2014

Introduction

This paper describes two phenomena that were observed with ultra-short race-pace training (USRPT; Rushall, 2012) and provides possible explanations for their occurrence. Being early in the existence of USRPT, observations are made that need explanations based on known scientific facts. In this case, those explanations will be hypotheses which need to be evaluated by acceptable scientific procedures.

The conditioning of swimmers for racing embraces many beliefs and theories. Perhaps the most naïve theory is following training zones which are supposed to equip a swimmer's physiology for use in races. Zones of swimming exercise have been promoted as improving special developmental stages in a swimmer's multi-year training (Vorontsov, no date). US Swimming has gone through several proposed structures of energy zones that are supposed to produce differential training effects. The latest proposal contains five zones (Sokolovas, no date). Recently, Maglischo (2012) presented yet another formulation. Energy zones are popular but there is no published scientific work to validate their existence or effects. Howat and Robson (1992) showed that in a group of swimmers representing a variety of age-groups, being trained according to a heart-rate range for specific aerobic energy adaptation does not produce reliable aerobic training effects. Using an absolute heart rate range as an estimate of training intensity across a squad was shown to train, undertrain, and overtrain swimmers in roughly similar proportions. Only one in three responded aerobically as intended. Using heart-rate "norms" to prescribe work intensities to swimming groups to achieve particular training effects is more erroneous than accurate. As well as hypothetical zones of types of physiological adaptation, there are specifically labeled formats such as "lactate tolerance sets", "mental toughness sets", etc., none of which have been shown to produce maximal benefits for racing.

The implication of traditional swimming training that targets improving physiological factors is that any improvements in conditioning will power all strokes and performances at related distances within an individual. When training shows changes in the conditioned state of a swimmer, times should improve in races. This is one aberration of the theory of general adaptation. Unfortunately, research does not support the assumptions of general conditioning (Rushall, 2012). When one part of the body is conditioned, such as a leg, physiological and performance changes are not transferred to the untrained leg. When a trained and untrained leg are exercised together, there is a small amount of transfer but not of sufficient magnitude to suggest that conditioning is general in its physiological impacts. Physiological adaptations are only appropriate for the exercises/movements in which they are trained (Claytor, 1986). At the other extreme is the correlation of physiological measures over a time-span with performances over the same period. Australian Olympic team members performed a 7 x 200 m incremental swimming step test several times throughout each six-month season from 1998-2002. A season concluded with a national or international competition. The following were measured between phases and seasons: speed, stroke rate, stroke count, heart rate at lactate threshold, speed for the last 200-m step, and maximal lactate. The step test changes were in concert with training effects across a season. Therefore, it is an independent measure that monitors training effects when in full training. However, within season tests did not predict final tapered performances. Only physiological tests performed in the taper were related to final competition performances (Anderson et al., 2003). An interpretation of these findings is a high volume of in-season training was unrelated to final tapered performances. Improved physiological measures in full-training provide no clues as to how a swimmer will race when tapered. If general in-season physiological conditioning was of value for performances in a tapered final important swim meet, then performances at that meet would be related to it, but they were not. The general theory of physical training in swimming is not supported by many research studies.

In USRPT, it was proposed that particular sets of ultra-short training would develop the conditioning necessary for the specific races that the race-pace repetition times represented. In the late 1950s to the mid-1960s, Swedish scientists published articles that related lactate accumulation to various work:rest periods (Astrand et al., 1960; Christensen, 1962; Christensen, Hedman, & Saltin, 1960). Astrand and Rodahl (1977) discussed 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 tasks and rests they depreciate significantly.

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. If glycogen depletes beyond a certain level neuromuscular functioning in the localized work area is increasingly disturbed. Consequently, demanding/extended swimming that lowers glycogen availability does not foster 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 depleted glycogen work bouts. In swimming, USRPT facilitates an increased number of executions of skill cycles.

USRPT sets are supposed to train race-specific energy properties and technique features that transfer directly into races. The ultra-short format increases the accumulated yardage at high-intensity velocities which exceeds that often associated with longer slower-than-race-pace repetitions. USRPT is the method for involving high-intensity swimming in high-yardage workouts[1].

Ultra-short (high-intensity) training produces faster conditioning and higher levels of physiological adaptation than more traditional longer, lower-intensity, and/or continuous training (Enoksen, Tonnessen, & Shalfawi, 2009; Sandbakk, Welde, & Holmberg, 2009; Vogt et al., 2009). Thus, conditioning for swimming is achieved better and quicker through USRPT. It has the potential to increase the effectiveness of coaching.

[1] A common error is to promote USRPT as high-intensity low-yardage workouts. That is the complete opposite of what it actually does.

Swimming techniques 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 alone is not a path to swimming success (Kame, Pendergast, & Termin, 1990). Toussaint et al. (1990) showed that swimming efficiency is velocity dependent that is, techniques change with swimming velocities (Pelarigo et al., 2010). Energy demands differ between strokes (White & Stager, 2004). Since swimming stroke efficiency is developed for the pace at which training is performed, it is logical to assert that if race-performances are to be improved, that can only be achieved by improving the efficiency of swimming at race-pace for each competitive 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 or the result of factors not considered. [2]

When training at race-pace, coaches should seize the opportunity to condition swimmers with race-relevant swimming velocities/intensities and to coach technique in an effective way[3]. By meshing both emphases there is a good chance that swimmers' movement efficiencies will improve at the all-important race-pace. If effectively implemented, the two emphases should produce rapid and continuous performance improvements no matter what the level of conditioning. It is possible to make that statement because USRPT does not produce debilitating fatigue like that which accumulates with traditional training (i.e., glycogen stores are depleted). A swimming coach who does not conduct race-relevant training is worthy of criticism.

Observation One

Swimmer[4]. This swimmer was a 16 year-old male who in younger age-groups was an Australian champion. For the past 18 months the swimmer suffered a variety of injuries and had not re-established his national ranking. It was determined by his coach that significant technique work might be the answer to preventing the reoccurrence of injuries and reinstating his position in state and national swimming.[5]

Training. Training consisted of USRPT with an emphasis on crawl stroke. All strokes were swum so that the swimmer could compete in 200 m individual-medley races. Training was held in an 8-lane 25 m pool usually nine times per week.

Technique instruction. Technique development followed the steps described by Rushall (2013). Instruction occurred while performing USRPT sets. In the fifth microcycle in the technique program, the power-phase of all strokes was changed. The swimmer was required to increase

[2] Superstitions often develop when young swimmers improve in racing performances after training with irrelevant training formats. Growth is perhaps the greatest single influence in swimming-race performances early in swimming careers. Despite being exposed to irrelevant training (e.g., slow swimming to develop an aerobic base and to learn techniques), the detrimental effects are insufficient to completely mask capability improvements due to physical maturation. Once growth stops, the influence of training can then be attributed to swimming performances. When elite swimmers do not improve in performances from one Olympiad to another, it is reasonable to assert that some of the lack of improvement or regression in performances is due to the major influence of irrelevant/nonsense training.

[3] Use verified principles of pedagogy for developing movement skills (Rushall, 2011).

[4] The swimmers involved in the two observations read the descriptions of events and stated they were accurate.

[5] Reinstatement was achieved by the swimmer's performances at the 2013 Australian Age-group Championships.

arm-stroke acceleration significantly to gain greater horizontal propulsion. The main effect of concentrating on greater acceleration was that the work level of the swimmer increased. The performance factors that were expected were:

1. Strokes per length would remain roughly constant.
2. Lap (25 m) times would improve markedly (~1-3%).
3. Stroke rates would improve over those exhibited in the previous microcycle.
4. The number of race-pace repetitions in a set would initially decrease. The reduction would be greater than in any other microcycle because the swimmer was working more powerfully than at any other time. After a period of from one to two weeks, the number of repetitions should recover and match those exhibited in the previous microcycle.
5. Bow- and lateral-wave heights should increase because of the increased velocity through the water.

Outcomes. As expected, the perceived level of exertion of the swimmer increased, times for each 25 m or 50 m repetition improved noticeably, and the number of repetitions completed successfully in each set dropped as much as 50%. The swimmer and coach were committed to maintaining the new level of power application in the microcycle.

After the third day, the swimmer began to increase the number of successful repetitions in sets while holding the new race-pace times occasioned by the more effective arm-pulls. After two weeks, all forms of strokes had returned to the previous maximum number of repetitions in the training sets.

Interpretation. When the swimmer changed the manner and level of force production in the underwater pull, the number of race-pace repetitions was reduced considerably. That was a clear indication that energy provision was yoked to the old-stroke technique and swimming velocity. In a traditional way of thinking, training levels practiced (number of successful repetitions completed) should be maintained with a modified technique. But, that did not occur. An increase in acceleration in the underwater power-phase of the arm pulls severely reduced the amount of swimming that could be sustained. One change in technique severely reduced the swimmer's ability to maintain an improved race-pace.

After the third day of the new technique and reduced repetition completions, the number of successful repetitions started to increase while the new improved repetition times were held. After two weeks, crawl stroke and two of the three remaining strokes had recovered to previous repetition numbers. Apparently, the energy provision required by the changed technique had been altered and developed to previous successful repetition levels. The swimmer had changed his technique and developed a new relevant conditioned-state that matched previous best repetition levels.

Hypothesis. When technique is altered markedly, initially there will be a reduction in swimming endurance and probably efficiency because the existing conditioned state is not exactly suited to the "new" technique. This will not be readily apparent in training programs that involve many irrelevant training stimuli. Also, in a dominantly irrelevant program, there will be insufficient trials of new technique elements to establish the change. It is more than likely that the change will dissipate and the old "established" technique will continue to be used. One of the benefits of USRPT is that the constant monitoring of repetition times, strokes per length, the heights of bow- and lateral-waves, and the number of successful repetitions in a set provides sensitive measures of performance changes that occur when techniques are altered.

The hypothesis that results from this observation is: *A change in technique alters the provision of energy at the outset but with sustained USRPT, the previous energizing level*[6] *is recovered as adaptation of the provision of energy to the technique-change occurs*.

Commentary. As was briefly discussed above, technique and energy provision are linked. A change in one entity causes a change in the other. If the change is maintained, which is not difficult in the USRPT format, then the other factor will adapt at least to the level of technique-to-energy-provision displayed prior to the change.

The speed of re-adaptation of one entity to a change(s) in the other occurs quite quickly in the USRPT format because all meaningful swimming is relevant to one type of swimming, that being race-pace. The absence of irrelevant and useless activities such as drills, slow-swimming, board-kicking, etc. allows the swimmer and coach to monitor how the swimmer is sustaining the technique change and if changes in specific energy provision are occurring.

The observations here were made possible by having repeated exact training stimuli and consistent technique. If the training stimuli were irrelevant to the intended race-pace technique, then the true relationship between the energy supply for a particular technique would not be observed. Swimmer responses to conditioning and technique elements are clearly discerned in USRPT. The specificity of energy provision for a particular technique is something that is not accommodated in common training programs. Most coaches believe that physical conditioning energizes all techniques at all velocities. It is no wonder that many swimmers do not improve in races when they are supposed to and that most mature experienced swimmers do not improve at all. The formula for their training is plainly wrong.

Research has consistently shown the direct relationship between energy provision and technique. What has not been shown to date is the manner of effect of changing one feature on the other. In this observation, a change in technique disrupted energy provision reducing the endurance capability of the swimmer when performing a standardized USRPT set. With consistent repetition of altered techniques over two weeks, the endurance capacity at the new technique-generated velocity of swimming improved to match the pre-change endurance capability.

Observation Two

Swimmer. A nationally prominent 13 year-old male worked in USRPT over a 16-month period. It was revealed by his coach that he had been using rest-intervals of 20 and 30 seconds preparing for 200 m/yd and shorter races ever since USRPT was instituted. USRPT recommends rest-intervals of 20 seconds or less (Rushall, 2012, p. 29) to be the longest provided. If possible, rest-intervals should not exceed the work interval. It was decided to adjust this swimmer's rest-intervals to 10 seconds for 25 m/yd repeats and 20 seconds for 50 m/yd repeats.

Training. Training consisted of USRPT with a change from 30 to 20 seconds and 20 to 10 seconds when performing the same sets as in the past. All strokes were swum. Training was held in a two-lane 25 m/yd private pool.

Expected Outcomes. The shorter rest-intervals were expected to reduce the number of completed repetitions in standard USRPT sets. However, it was opined that the number of completed repetitions would return to the previous number achieved when using longer rests.

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[6] But not the source of energy. The technique alteration requires a change in the neural coding in the brain of both the new movement pattern and the energy provisions for that acquired pattern. Changes in technique must be within reason. One cannot expect this type of adaptation with virtually whole-stroke alterations.

Results. The change to shorter rest-intervals reduced the number of repetitions completed in USRPT sets, often by as much as 50%. The swimmer perceived the tasks to be much harder and was affected negatively for 5-7 days. However, then the number of repetitions completed in the "harder sets" began to climb. After two weeks, the number of repetitions completed approached previous levels achieved with "more rest". In the next week, completions exceeded previous levels and in many sets the times for the repetitions also improved. The institution of shorter rests produced improvements in the number of repetitions completed in standard sets as well as improved swimming quality (repetition times) across all strokes.

Interpretation and Commentary. One of the assumptions of USRPT is that during short rest-intervals, off-oxidative kinetics (Type I plus Type IIa fibers) continues at a maximum level. Each repetition is likely to function at or close to a maximum oxidative[7] level. With short rests, each repetition begins with oxidative functioning already at the desired high level for the velocity of swimming because there is no subsidence during the rest-period. With long rest-intervals (~30 seconds or greater) when doing 50 m/yd repetitions, the level of oxidative functioning is likely to decrease in the latter part of the interval. If it does decrease then the next repetition will begin with a less than optimal oxidative functioning and that deficiency will be replaced with on-anaerobic functioning (the energy source is not exactly known) until the on-kinetics of oxidative functioning is re-established at the necessary level. As the number of repetitions mounts in the set, the anaerobic demands will gradually increase and ultimately will cause performance to decrease beyond the targeted race-pace level. The involvement of mounting anaerobiosis varies considerably between individuals.

When rest-intervals are of ~20 seconds or less, oxidative functioning remains high across the rest- and work-intervals. Anaerobic functioning occurs but to a lesser degree than when it is initiated after the fast-component of aerobic functioning abates with longer rests. Short rests provide the swimmer with consistently high oxidative energy use. With ~20 seconds or possibly slightly shorter rest-intervals, the number of successfully completed race-pace repetitions will be higher than with intervals that are too long because of the demands for on-anaerobiosis. This interpretation accounts for the swimmer in this observation completing more race-pace repetitions when the rest-intervals were shortened. This explanation is counter-intuitive but can be observed when comparing the same work levels (race-paces) in the USRPT format with only the rest-intervals being different.

Alves et al. (2010) showed that the rate with which glycolytic anaerobic work is performed changes the aerobic contributions to performance. It is possible that the requirement for anaerobic functioning in long-rest sets decreases the benefits for performance that oxidative functioning provides. That contributes to the reduction in the total number of repetitions that can be performed in a USRPT excessive-rest set.

The employment of on-oxidative functioning for the duration of most repetitions, save the early few, will better replicate the needs for oxidative functioning in a race. Within a USRPT set, if anaerobic functioning is unnecessarily high, the energy demands of a race will not match the constant demands for oxidative functioning that ideally would occur in a well-paced race. Thus, excessive rest-intervals decrease the similarity of energy kinetics between practice sets and races. Monitoring how swimmers are functioning (usually through respiratory rates) is important. If the

[7] Oxidative is a better term than aerobic. Aerobic has a common restricted connotation meaning "use of the aerobic system" (Type I muscle fibers which only function oxidatively). However, Type IIa fibers also are oxidative but are not part of the aerobic system. Thus, oxidative functioning is possible beyond the aerobic system and in USRPT better describes the training effects and energy usage.

respiratory rate slows in the rest-interval, the period is too long. A slight reduction in respiration rate across the rest period possibly could be tolerated, possibly in the range of 0-5% but no more.

It is proposed that the 30- and 20-second rest-intervals for this swimmer brought into play anaerobic functioning which accelerated the onset of factors that debilitated the athlete's endurance capacity in a USRPT set. In this swimmer, a longer rest-interval reduced the number of race-pace repetitions that could be completed.

Hypothesis. When rest-intervals are long to the point that oxidative functioning in the interval decreases, the next repetition will involve increased anaerobic function at its outset. Eventually, the accumulated anaerobic functioning interferes with oxidative functioning/efficiency and limits a swimmer's performance in the USRPT format.

The hypothesis that results from this observation is: *When rest-intervals are too long in the USRPT format, the number of successfully completed repetitions can be less than when rest-intervals are shorter. Short-rest intervals sustain a near-maximum level of oxidative functioning in work- and rest-intervals. Consequently, the length of rest-intervals is a major factor that governs the effectiveness of USRPT and the quality and quantity of work performed.*

Commentary

Two observations of phenomena involving technique and/or energy provision that occurred during USRPT were recounted above. This writer has observed other instances of the same phenomena but to be scientific they need to be independently verified using acceptable experimental designs. It is likely that because of large individual differences in swimming performances and swimmers' capacities that the best experimental format for evaluating the hypotheses suggested in this commentary would be of intra-individual rather than group experimental designs. One now has to wait until the appropriate scientific status of these observations is known.

The instant reductions in performance endurance (the number of repetitions completed in the USRPT format) associated with technique changes supports the Specificity of Training Principle and not the general conditioning theory that underlies most of the training dogma of today's swimming. Other sources discuss the specificity of training at much greater length and in fuller detail than that presented here (Rushall & Pyke, 1991, Rushall, 2003, 2012).

The two observations suggest that energy provision for specific techniques and velocities is much more specific than commonly thought. What has been suggested is as follows:

1. It is known that changes in swimming technique elements require changes in energizing properties. Changes in technique initially promote a loss in performance capability but if the changes are refined and retained, performances recover most likely because of re-adaptation to the new energizing demands/properties.
2. A reduction in excessive duration rest-periods in a fixed interval-training format, such as USRPT, initially causes performance disruption but then recovery occurs to levels that are equal to or greater than initially exhibited.

The specificity of USRPT reveals swimmer responses that are rarely seen. When interdependent techniques and energy sources are trained, the transfer of training effects to races should be observable and measurable as was described above. One might infer that USRPT is "simulation training" but, it is more than that. Unless the parameters of USRPT are observed when devising programs aimed at being relevant for racing, one cannot expect significant improvements of the magnitude that is possible with accurate applications of the method. Many coaches claim they provide "race-pace" training. That is insufficient to be equated to USRPT and its effectiveness. Such misinformed claims should be ignored.

Postscript

In discussions about this presentation with colleagues there is another commonly observed phenomenon that points to the specificity of energizing properties of USRPT tasks.

When well-conditioned traditionally-trained swimmers attempt a challenging full-scale USRPT training session, they find the work very difficult and exhausting. This indicates the lack of specificity of traditional conditioning for specific forms of swimming. Coach Greg McWhirter[8] has conducted clinics in Australia involving race-pace training. He has observed that when swimmers from traditional programs attempt USRPT sets to demonstrate the format of that training method, the swimmers have great difficulty in completing work levels that approach what would be expected from his own USRPT swimmers and squads. When conducting a training session using USRPT at Cherrybrook in late July, 2013, this writer was able to observe this phenomenon.

A well-conditioned traditionally-trained male national medalist age-group swimmer attended his first session with the Cherrybrook Carlile program. The total load for that evening was not high by USRPT standards as the session was three days away from the New South Wales Age-group Championships. The first-time swimmer had difficulty in completing the major portion of the few sets that were offered. When questioned after the whole session, the swimmer declared the workout to be "very hard" and "nothing like he had done before". Coach McWhirter reassuringly commented that is what should be expected and that he "would improve over time – perhaps within the next three weeks".

Inappropriately, USRPT is often described by persons who do not understand it or have not seen it implemented, as being low-yardage high-rest training sessions. If one was to ask traditionally-trained swimmers what it was like to complete a proper USRPT session, their description would be the opposite of the common misconception. After swimmers have been fully acclimated to the USRPT format, it is not difficult to complete 3,000+ m/y of race-pace work in a two-hour training session without destructively fatiguing the athletes.

The point behind this postscript is to opine that traditionally-trained swimmers are not conditioned to fully complete USRPT sessions. The energizing properties of the two training formats are very different. Whether USRPT swimmers would have similar difficulty completing traditional-training sessions has not been adequately observed by those of us in the "USRPT camp". However, the few cases that have become known have reported equal difficulty in handling traditional training.

This paper has generated a number of hypotheses that are worthy of objective research. Perhaps some individuals in the Academy might like to investigate the phenomena presented here so that an acceptable level of confidence in their import can be achieved or denied.

References

Alves, F., Reis, J., Bruno, P. M., & Vleck, V. (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.

[8] Head Coach, Cherrybrook Carlile Swimming Club, Cherrybrook, New South Wales, Australia.

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. [http://www-rohan.sdsu.edu/dept/coachsci/ swim/physiol/anderson.htm]

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.

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., 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.

Claytor, R. P (1986). Selected cardiovascular sympathoadrenal and metabolic responses to one-leg exercise training. *Dissertation Abstracts International-A, 46,* 3283. [http://www-rohan.sdsu.edu/dept/coachsci/csa/vol103/claytor.htm]

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.

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.

Howat, R. C., & Robson, M. W., (1992). Heartache or heartbreak. *The Swimming Times,* 35-37. [On line http://www-rohan.sdsu.edu/dept/coachsci/swim/physiol/howat.htm].

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.

Maglischo, E. W. (2012). Training zones revisited. *Journal of Swimming Research, 19(2)*, pp. 18.

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.

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.

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

Rushall, B. S. (2011). *Swimming pedagogy and a curriculum for stroke development* (Second Edition). Spring Valley, CA: Sports Science Associates [Electronic book].

Rushall, B. S. (2012). Swimming energy training in the 21st century: The justification for radical changes. *Swimming Science Journal – Swimming Science Bulletin, 39.* [http://www-rohan.sdsu.edu/dept/coachsci/swim/bullets/energy39.pdf]

Rushall, B. S. (2013). *A swimming technique macrocycle*. Spring Valley, CA; Sports Science Associates [Electronic book].

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

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.

Sokolovas, G., (no date). *Energy Zones in Swimming*. US Swimming, Colorado Springs, CO. [On line http://www.teamunify.com/reno/__doc__/Energy%20Zones%20in%20Swimming.pdf].

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.

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 VO2max 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., (no date). Development of basic and special endurance in age-group swimmers: A Russian perspective**.** *Swimming Science Journal – Swimming Science Bulletin #16***, [**On line http://coachsci.sdsu.edu/swim/bullets/voront16.htm]**.**

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.