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RELEVANT TRAINING EFFECTS IN POOL SWIMMING: ULTRA-SHORT RACE-PACE TRAINING © (Revised)

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This presentation is an attempt to explain the major principles derived from research findings that justify ultra-short training at race-pace as the most relevant form of competitive swimming training. As a training format, it is deemed to be superior to the common and traditional forms and volumes of swimming practice (Rushall, 2013). This treatment duplicates information contained in the 2013 paper but, hopefully, presents it in a clearer, more coach-friendly form[1].

Competitive pool swimming is a relatively unique sport. Comparatively, most other sports have different energy demands, forms and patterns of force development, and rest opportunities. Major features that set swimming apart from activities performed in air follow.

- Swimmers are totally supported by being immersed in water. That contrasts with activities like running which is continually dominated by the need for athletes to counteract the effects of gravity, a feature that also is continually present in partly supported sports (e.g., kayaking, rowing, and cycling). Gravity plays at most a very minor role in swimming.
- In the execution of the cyclic movement patterns in swimming, within each cycle of the major force-development muscle groups, there are work and rest phases of energy demands. In the reduction of energy requirements that occurs in the rest (recovery) phase of the cycle, some restoration of stored oxygen and energy production capacity happens in the alactacid (ATP-CP) system and also some facets of the lactacid system. Benefits derived in the effort-reduction/energy-restoration phase prolong the availability of energy from the two anaerobic energy systems. [The difference in energy demands between the two phases in swimming is much greater than in other cyclic sports such as running, kayaking, and cycling.]
- In the performance of tasks in swimming races, the requirement to execute turns and/or underwater skills every lap produces a respite from the very different cyclic movements of surface swimming. It allows some energy-capacity restoration in the large propulsive muscle groups by requiring skill-functions in mostly different muscle groups at a moderate-intensity level. The aerobic system continually works in the total race through circulation but the muscle-sited capacities of the alactacid and lactacid energy systems are intermittently demanded.

[1] The basic researches that justify assertions of physiological function in swimming races are largely omitted but are available in the Rushall 2013 paper. References here primarily involve swimming research. However, some references are from non-swimming activities and are only included if their findings are not sport-specific.

- The high-intensity energy demands in the propulsive phases of swimming strokes focus primarily on the arms and shoulders. The remainder of the body's musculature functions at moderate- to low-intensity except in swimmers who exaggerate leg-kicking to an unnecessary degree. Although a large proportion of a swimmer's structure is not required to perform maximally, the effort-level reported in the sport is usually reflective of the sub-set of propulsive action segments and not the total swimmer. Because of the division of energy levels (requirements), large proportions of energy use and the products of that use by the productive muscles are restored and made available throughout a performance by the remainder of the less-intense working muscles of the body and large limbs.
- The popular understanding of the energy demands of competitive swimming is mostly steeped in dogma and emphasized to the point where training programs are structured to alter the functioning of the body's energy systems independently. That false direction persists despite there being no occasion in competitive swimming where independent energy functioning occurs.

The major points presented above indicate that for a basic interpretation of the energy demands of competitive swimming races, the following have to be contemplated when comparing swimming to other non-water-immersion sports.

- The provision of energy from the alactacid energy system is much more prolonged (>10 seconds theorized for sports in general) and extensive in swimming. Stored oxygen in oxymyoglobin and oxyhemoglobin is another source of energy that is restored very quickly. The exceptional intermittent energy restoration and recovery opportunities within stroke cycles and during each swimming lap must be considered.
- The provision of energy from the lactacid energy system is more prolonged and extensive in swimming than normally hypothesized (~45 seconds). During a race, lactate/lactic acid produced by the muscles of the upper body and arms is circulated to the remaining less-intense working muscles and organs. Similar to the alactacid system, it can be relied upon to provide energy to the working muscles if the pacing of a race is sufficiently even to not deplete the anaerobic energy potential early in the race. There is no need to achieve high lactate levels in training to positively affect lactacid energy system adaptation. High lactate levels at training compromise aerobic performance (Simoes, Campbell, & Kokubun, 1998).
- The high-intensity energy demands of only a minor portion of the body's structure means that the work produced by that musculature can be higher than the rest of the body. The lesser-intensity-functioning structures provide a restorative effect for the high-intensity working muscle groups through circulation. This also prolongs the work capacity of the performance-productive muscle groups in a manner that is distinctive to the sport.
- Oxygen consumed during and after a swimming race is used to provide oxygen for Type I (slow-twitch) and Type IIa (fast-twitch oxidative – if trained through specific high-intensity work) fibers to function and to pay-back accumulated oxygen deficit.
- The levels of lactate accumulated in competitive swimming races are generally lower than those that can be developed in other sports of similar competition durations but greater muscular demands (Rushall & King, 1994).

The distinctive features of competitive swimming performances mentioned above distinguish it sufficiently from most other sports such that it usually is invalid to generalize to swimming the energy production and use patterns and levels derived from evidence-based research in other sports. Understandings of what competitive runners require and how they satisfy their energy requirements are largely irrelevant for swimming. Taking that one step further, how runners train is likely to be mostly irrelevant for swimming. Unfortunately, that distinction is rarely recognized by swimming coaches which leads to the phenomenon of a culturally accepted emphasis on subjecting swimmers to irrelevant/incorrect training principles and effects.

Irrelevant training programs are compounded further by a lack of effective coaching in technique (the pedagogy of movement instruction is largely absent in swimming and its coaching education programs) and mental skills training. While technique is claimed to be emphasized, ineffective technique change is the usual outcome of such activities. Mental skills training in swimming also lacks an accepted scientific foundation and its correct incorporation into usual practices is, to all intents and purposes, non-existent.

The distinguishing features of the physiology of competitive swimming races and the general failure in swim coaching dogma to consider those features was one of the basic themes of Rushall's 2013 paper. Irrelevant dogma-based swimming beliefs were criticized because they did not adhere to known research findings. An alternative form of training, "ultra-short race-pace training" (USRPT), was proposed.

Ultra-short Race-pace Training (USRPT)

This form of training amalgamates two discrete concepts:

1. The intensity of training should be that of the average velocity of a particular race. Training intensity, not volume or frequency, is related to swimming performance improvement (Mujika et al., 1996; Sperlich et al., 2009a, 2009b). Similarly, heavy training and dryland training are unrelated to swimming improvements (Sokolovas, 2000). Since there are a variety of swimming race distances and strokes, training should be specific to those events. Only at race-pace velocity will the techniques and energy systems employed be trained to transfer directly to competitive swimming tasks.

2. The format of the training has to be that which yields the greatest carry-over to competitive swimming events. The Principle of Specificity deems this to be an essential requirement for producing training effects that transfer directly to competitive tasks (Roels et al., 2005; Rushall, 1985a, 1985b; Rushall & Pyke, 1991). USRPT is deemed to be the most effective form of training stimulation that produces the greatest volume of race-relevant stimuli within and across swimming practice sessions.

When contemplating the development of the best form(s) of training to prepare swimmers for competitive opportunities, these two concepts function together to produce an interactive cumulative effect. 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 is not a path to swimming success (Kame, Pendergast, & Termin, 1990). 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 stroke and distance. Butterfly and breaststroke might always have to be swum at race-pace at practice to achieve the best training effect (Chollet et al., 2006; de Jesus, 2010). Thus, race-pace training will have the greatest relevance for singular competitive swimming performances. It will be necessary to train for each swimming event as discrete entities because training effects are specific (Mohr et al., 2005). 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.

Consequently, it is inadvisable to consider the possible effects of conditioning and technique development independent of each other. Below is a summary of some benefits of USRPT over the effects derived from all other forms of traditional swimming training. In the exercise science literature, race-pace swimming efforts would be classified as high-intensity training.

- Race-pace training is necessary because techniques change with swimming velocity (Pelarigo, 2010; Toussaint et al., 1990). So that the techniques required for racing are developed, it is only race-pace training that yields such benefits. Since techniques take many trials to improve, as much race-pace swimming as possible is desirable in programs designed to improve race-performances. The format in which they are practiced will govern the volume of relevant training that can be accomplished and the energy provision that accompanies the specific techniques.
- An almost total emphasis on race-pace training would be a radical departure from current training beliefs that emphasize less-than-race-pace training. In comparison to moderate-intensity training, when training quality is increased performances improve (Lindsay et al., 1996).
- When performances in some athletes are not improving, it has been advocated in other sports that the volume of high-intensity training work be increased to reinstitute improvements (Gaskill et al., 1999).
- High-intensity work involves both anaerobic and aerobic work. The combination of anaerobic and aerobic stimulation in training sets produces more and faster performance improvements than aerobic training alone (Ransom et al., 2008; Sokmen et al., 2002; Villani, Fernhall, & Miller, 1999; Yamamoto et al., 2004).
- High-intensity training forces the body to use energy sources (carbohydrates and fats) better and more efficiently (Usaj et al., 2009). It is the only intensity that will alter assumed maximal accumulated oxygen debt (Zacharogiannis, Tziortzis, & Paradisis, 2003).
- In trained high-level athletes, high-intensity training is the only avenue for improving performance (Helgerud, 2009) and physiological factors (Enoksen, Tonnessen, & Shalfawi, 2009).
- Race-pace training also allows appropriate mental skill segments of race strategies to be performed in concert with correct racing biomechanics. Linking race strategy content with inappropriate skills, which would occur with slower swimming velocities, is a form of irrelevant training.
- Race-pace techniques are the most important aspects of productive training. Since technique is the major factor that differentiates elite from lesser swimmers (Cappaert et al., 1996; Cappaert, Pease, & Troup, 1996; D'Acquisto, & Berry, 2003; D'Acquisto et al., 2004; Dutto & Cappaert, 1994; Havriluk, 2010; Lätt et al., 2010) it should be the central focus of training programs. Race-pace training is the only avenue for that focus.

Interval training is the format for deriving effects that stimulate conditioning through work intensity and volume. Some forms of interval training, such as long work intervals (e.g., three minutes) and long rest intervals (e.g., three minutes) produce substantial elevations in lactate and associated fatigue as well as the depletion of glycogen stores (Astrand & Rodahl, 1977). Depending on the degree of fatigue developed, repetitions of such training might only be executed every 48 hours pr longer (Bessa et al., 2010). It is common to also see performance degrade in the latter repetitions of long-interval/repetition sets. However, when manipulations of the interval training format involve work and rest intervals of sufficient brevity, the impact of fatigue is reduced, lactate accumulation is stifled, and glycogen stores are maintained at a healthy level (see below). Shorter rather than longer work intervals facilitate greater work volumes, that is, more training can be tolerated (Rozenek et al., 2003). Performance quality can be maintained and a substantial volume of consistent training achieved under appropriate interval training.

Ultra-short training is an established form of interval training that has benefits over interval training sets of longer duration effort and rest phases (Astrand et al., 1960; Christensen, 1962; Christensen, Hedman, & Saltin, 1960; Zuniga et al., 2008) and has been recommended for swimming (Beckett, 1986; Rushall 1970; Rushall & Thompson, 1974). Figure 1 illustrates the physiological differences between interval tasks of the same intensity. The trend in the findings should be obvious. To accommodate the distinction of swimming tasks when compared to other forms of sport/exercise as described in the early part of this article, the work to rest ratios in swimming are recommended to be one to one or even two to one, instead of one to two as depicted in Figure 1.

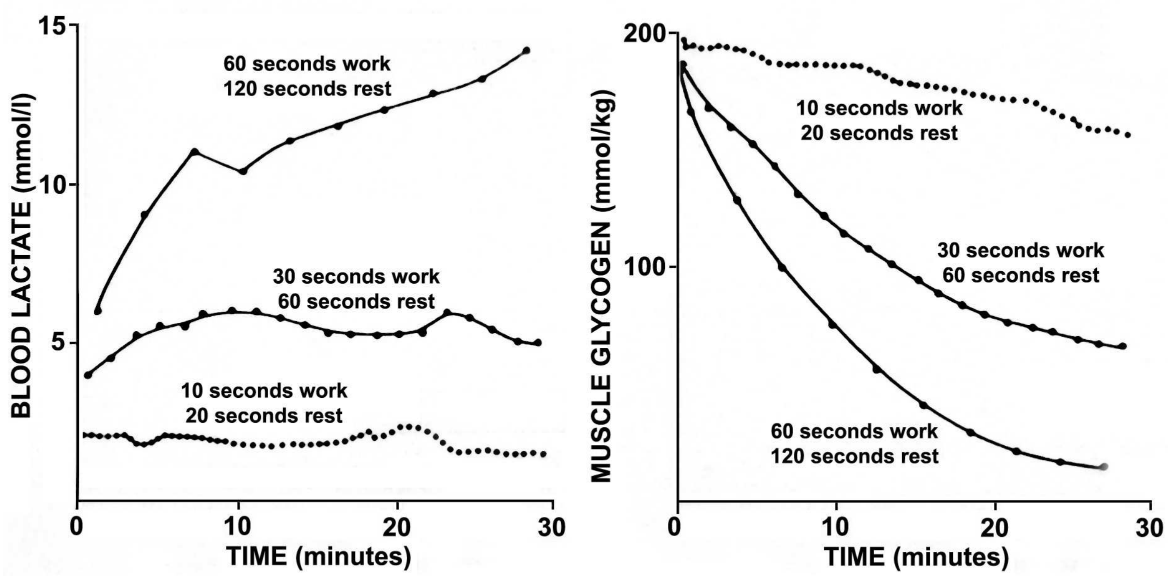

Figure 1. Lactate and glycogen levels during interval training where work intensity is constant, total work to rest ratios are the same but duration is varied (after Astrand & Rodahl, 1977).

USRPT has distinctive benefits over the traditional interval, mixed repetition, and continuous training items that are characteristic of swimming training.

- Short work and rest periods sustain energy use consistently. In long work periods, energy use changes as a repetition continues. Ultra-short training best simulates the consistent demands of well-paced competitive performances as aerobic and anaerobic energy sources are stimulated maximally (Tabata et al., 1997).
- Ideally, a rest period between each work period should be 20 seconds (Beidaris, Botonis, & Platanou, 2010) in any presentation of ultra-short training. At most 30 seconds might

be tolerated (Zuniga et al., 2008) although work quality of less-than-maximal intensity might have to be accommodated (as happens with 1,500 m swimming). Longer rest periods change the energy demands of succeeding repetitions making them at least partly nonspecific for racing.

- The many short-work intervals, by repeatedly depleting stored oxygen and alactacid energy, ensure its maximal regeneration during each rest interval. This sustains race-pace performance quality and adapts the alactacid energy system maximally (Fernandes et al., 2011). Longer intervals of work and rest produce anaerobic fatigue which reduces swimming velocity and stroke rate (Barden & Rorke, 1999). Ultra-short training is the best format for producing anaerobic adaptation.
- In USRPT the aerobic system is used continuously. It sustains swimming during the work phase of each interval and during the rest clears substantial lactate and replenishes significant amounts of creatine phosphate. High volumes of low-intensity training do not result in the best form of aerobic adaptation (Weber et al., 2011).
- The high-intensity work requires the use of the lactacid system over an extended period. That leads to the oxidative adaptation of lactacid energy fibers (fast-twitch - Type II) to become Type IIa. Ultra-short training produces maximal aerobic adaptation because the aerobic system (Type I fibers) is stimulated continually and maximally and the production of oxidative fast-twitch fibers adds further aerobic function. That contrasts with "aerobic training" or lower-intensity training that, at best, only stimulates maximal aerobic energy production in the Type I fibers. Higher intensity work (race-pace in swimming) is needed to develop maximal aerobic capability (Type I plus Type IIa fiber adaptations). Ultra-short training stimulates maximal energy source production for race-pace techniques. It trains the body to use its alactacid and lactacid energy resources for race-specific tasks better than does traditional (irrelevant) "lactate training".
- High-intensity ultra-short training produces similar training effects more efficiently (Gibala et al., 2006) and in less training time (Sperlich et al., 2009a, 2009b) than endurance training. Its effects are better than those that can be achieved through continuous training (Helgerud et al., 2006). USRPT develops a greater aerobic base than is possible with longer-interval or continuous training at lower than race-pace intensities.
- Ultra-short training produces stroke technique retention better than continuous training and is the only format by which race-pace techniques can be established and linked to race-pace physiology (Pelarigo et al., 2010).
- Intense training is better than endurance training for 100 m performance and does not compromise endurance capacity (Johansen et al., 2010).
- High-intensity interval training improves performance despite physiological factors reaching a plateau (Myburgh et al., 1995). This implies that performances are influenced by factors other than those reflected in measures of physiological capacities.
- Ultra-short training is applicable to children (Mascarenhas et al., 2006; Sperlich et al., 2009a) as well as adolescents (Zafeiridis et al., 2009) and adults. Non-swimming research has shown that children tolerate intensive intermittent exercise better than adults (Muller, Engel, & Ferrauti, 2009).

USRPT is subject to the usual threats of overreaching and overtraining. However, if it is implemented correctly, because its extent is governed by the observation of performance decline and fatigue, signs of deterioration in physical capacity are largely avoided.

Many coaches claim they program race-pace training in a variety of ways. It is the assertion of this paper that high-intensity stimuli must be applied in a consistent-format ultra-short interval structure. A national coach claimed that a broken 200 m swim with interval distances of 25, 25, 50, 50, 25, and 25 meters was "race-pace swimming". When the work to rest ratios are varied, different metabolic responses are elicited (Gosselin et al., 2010) that is, sets which mix demands and rests are less than effective and/or desirable than consistent task forms. The coach's error stems from only considering training intensity. He failed to consider the technique and energy interdependency that exists in races as a necessary criterion for race-specific training effects. Training that relationship to the highest level of proficiency can only be achieved by consistent interval formats so that consistent repetitions of the task demands can be accommodated.

TABLE 1. A SUGGESTED MAXIMUM NUMBER OF TARGET RACE-PACE REPETITIONS AND REPETITION TIMES OVER PARTICULAR INTERVAL DISTANCES WITH A TARGET RACE TIME TO PRODUCE MAXIMAL ULTRA-SHORT TRAINING EFFECTS.

	Race Distance and Target Time				
Repetition Distance	50*	100 (60 secs)[a]	200 (130 secs)[a]	400 (270 secs)[a]	1500 (1050 secs)[a]
12.5 [b]	4 x 6 (maximum intensity)[c]	-	-	-	-
25 [b]	Possible but individualized	30 (15 secs)[c]	40 (16.25 secs)[c]	40 (16.88 secs)[c]	-
50 [b]	-	20 (30 secs)[c]	30 (32.5 secs)[c]	30 (33.75 secs)[c]	40 (35 secs)[c]
75 [b]	-	-	20 (48.75 secs)[c]	24 (50.63 secs)[c]	30 (52.5 secs)[c]
100 [b]	-	-	-	-	25 (70 secs)[c]

*Possibly only for pre-pubertal and masters swimmers.
[a]The target race time in seconds for that race distance.
[b]Repetition distances are appropriate for yards or meters.
[c]The race-pace repetition time for the particular repetition distance that is appropriate for the target race time.

Table 1 contains suggested maximum numbers of target race-pace repetitions over distances to produce maximal training effects from USRPT. For 50 (meters or yards), the race-pace should be such that swimmers try to increase velocity on every stroke. Seldom would breaths be taken during a repetition [that could be deemed hypoxic training but it is not the intent of the repetitions because hypoxia is not maximal and in 50 m/yd races, breaths are rarely taken]. As the race distance increases, the repetition distances also increase because velocity (effort intensity) of swimming decreases. When a swimmer can complete the maximum number of ultra-short intervals at race-pace, the criterion for race-pace should be changed to faster swimming.

All repetitions should be initiated with race-pace underwater work and finished with race-equivalent skills. Dives should not be required because their execution and changing from in to out of the water consumes too much time and interferes with in-water recovery.

It is commonly believed that any swim training will transfer beneficial effects to competitive performances in serious swimmers. Unfortunately, the human body does not perform or respond in that manner. Unless the work of training can directly transfer to swimming races, that is USRPT, training will be irrelevant or of marginal benefit. [Age-group swimming performances are often referenced as proof of effective training. It is more accurate to attribute age-groupers' improvements to growth than actual training. A case could be made that traditional swimming training programs suppress age-group improvements because the majority of those improvements are less than one should expect from growth alone (~4% per year; Rushall, 1992).]

The implementation of USRPT is explained in some depth in Rushall's 2013 paper. Readers should refer to that source if implementation in a competitive swimming setting is contemplated. After sufficient swimmer adaptation to this training format and substance, it can be performed daily resulting in a vastly greater accumulation of relevant training effects than is possible with traditional programming.

This presentation justifies USRPT as being the best and only avenue for physical work to significantly improve race performances in serious pool swimmers. While other forms of training are possible, the more those forms deviate from replicating the energy supply and biomechanics demanded of every swimmer's racing intentions, the less beneficial they will be. USRPT is deemed to be relevant physical training while all other training forms contain varying degrees of irrelevancy.

Ultra-short race-pace training:

- Is the only form of training that develops race-relevant (specific) energy supply and techniques.
- Produces levels of physiological adaptation in all three metabolic energy systems that exceed those developed by other forms of traditional swimming program activities.
- Produces training effects faster than other forms of traditional swimming programs because it produces the greatest volume of race-relevant stimuli.
- Is sensitive to overreaching and overtraining because its continuation is governed by swimmer performance declines and inabilities to recover.

References

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

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.

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.

Bessa, A., de Oliveira, V. N., da Silva, R. J., Damasceno-Leite, A., & Expindola, F. S. (2010). *Biochemical tools for determining exercise intensity.* Presentation 876 at the 2010 Annual Meeting of the American College of Sports Medicine, Baltimore, Maryland; June 2-5.

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.

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.

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.

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.

Fernandes, R. J., Sousa, A., Figueiredo, P., Keskinen, K. L., Rogriguez, F. A., Machado, L., & Vilas-Boas, J. P. (2011). Modeling off-transient oxygen uptake kinetics after maximal 200-m swims. *Medicine and Science in Sports and Exercise, 43(5)*. Supplement abstract 1663.

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.

Gibala, M. J., Little, J. P., van Essen, M., Wilkin, G. P., Burgomaster, K. A., Safdar, A., Raha, S., & Tarnopolsky, M. A. (2006). Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *Journal of Physiology, 575(Part 3),* 901-911.

Gosselin, L. E., Kozlowksi, K. F., Bevinney-Boymel, L., & Hambridge, K. (2010). *Metabolic and cardiovascular response of different high intensity aerobic interval exercise protocols*. Presentation 1028 at the 2010 Annual Meeting of the American College of Sports Medicine, Baltimore, Maryland; June 2-5.

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. (2009). *Aerobic high-intensity intervals improve maximal oxygen uptake more than moderate training.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

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.

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.

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.

Lindsay, F. H., Hawley, J. A., Myburgh, K. H., Schomer, H. H., Noakes, T. D., & Dennis, S. C. (1996). Improved athletic performance in highly trained cyclists after interval training. *Medicine and Science in Sports and Exercise, 28,* 1427-1434.

Lätt, E., Jürimäe, J., Mäestu, J., Purge, P., Rämson, R., Keskinen, K. L., Haljaste, K., & Jürimäe, T. (2010). *Biomechanics and bioenergetics of 100-m front crawl swimming in young male swimmers*. A paper presented at the XIth International Symposium for Biomechanics and Medicine in Swimming, Oslo, June 16–19, 2010.

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.

Mohr, M., Krustrup, P., Nielsen, J. J., Mybo, L., Rasmussen, K., Juel, C., & Bangsbo, J. (2005). Effect of two different training regimes on muscle adaptations and intermittent exercise performance. *Medicine and Science in Sports and Exercise, 37(5),* Supplement abstract 1518.

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.

Muller, J., Engel, F., & Ferrauti, A. (2009). *Children tolerate intensive intermittent exercise better than adults.* A paper presented at the 14th Annual Congress of the European College of Sport Science, Oslo, Norway, June 24-27.

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.

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.

Ransom, V., Clark, A., vanLangen, F. A., Uitslag, T. P., Hettinga, F. J., dekoning, J. J., & Foster, C. (2008). Constant value of gross mechanical efficiency at high exercise intensity. *ACSM 55th Annual Meeting Indianapolis*, Presentation Number, 802.

Roels, B., Schmitt, L., Libicz, S., Bentley, D., Richalet, J_P., & Millet, G. (2005). Specificity of VO_{2max} and the ventilatory threshold in free swimming and cycle ergometry: comparison between triathletes and swimmers. *British Journal of Sports Medicine, 39,* 965-968.

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. (1970). An aspect of sprint training. *Compete, 2(7),* 1-4.

Rushall, B. S. & Thompson, J. M. (1974). A component of sprint swimming training. *Swimming Technique, 10,* 107-112.

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

Rushall, B. S. (1985b). Several principles of modern coaching - Part II. *Sports Coach, 8*(4), 30-35.

Rushall, B. S. (1992). Notes from ICAR research and other sources at the ASCA 1992 World Coaches Clinic, Anaheim, California - September, 1992. *NSWIMMING Coaching Science Bulletin, 1(3),* 1-6.

Rushall, B. S., & King, H. A. (1994). 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. (2013). Swimming energy training in the 21st century: The justification for radical changes (second edition). *Swimming Science Journal, Swimming Science Bulletin #39.* On line http://coachsci.sdsu.edu/swim/bullets/energy39.pdf.

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

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.

Sperlich, B., Haegele, M., Achtzehn, S., De Marees, M., & Mester, J. (2009a). *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.

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

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.

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.*

Usaj, A., Lojen, S., Kandare, F., & von Duvillard, S. P. (2009). The influence of two types of endurance training on carbohydrate and fat oxidation rates. *ACSM 56th Annual Meeting, Seattle, Washington,* Presentation Number 981.

Villani, A. J., Fernhall, B., & Miller, W. C. (1999). Effects of aerobic and anaerobic training to exhaustion on VO_{2max} and exercise performance. *Medicine and Science in Sports and Exercise, 31(5),* Supplement abstract 1093.

Weber, S., Gehlert, S., Weidmann, B., Gutsche, K., Frese, S., Graf, C., Platen, P., & Bloch, W. (2011). Exercise induced slow and fast myofiber transitions in response to low intensive endurance exercise. *Medicine and Science in Sports and Exercise, 43(5)*. Supplement abstract 1399.

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.

Yamamoto, N., Isaka, T., Wada, T., Sakurama, K., Takenoya, F., Yanagi, H., & Hashimoto, M. (2004). The maintenance of anaerobic power in intermittent short-duration high intensity exercise. *Medicine and Science in Sports and Exercise, 36(5),* Supplement abstract 1427.

Zacharogiannis, E., Tziortzis, S., & Paradisis, G. (2003). Effects of continuous, interval, and speed training on anaerobic capacity. *Medicine and Science in Sports and Exercise, 35(5),* Supplement abstract 2066.

Zafeiridis, 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.

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.