International Journal of Sport Nutrition and Exercise Metabolism, 2014, 24, 414-424
http://dx.doi.org/10.1123/ijsnem.2014-0033

INTERNATIONAL JOURNAL OF
SPORT NUTRITION AND
EXERCISE METABOLISM
www.IJSNEM-Journal.com
CONSENSUS STATEMENT

Nutrition and Training Adaptations in Aquatic Sports

Iñigo Mujika, Trent Stellingwerff, and Kevin Tipton

The adaptive response to training is determined by the combination of the intensity, volume, and frequency of the training. Various periodized approaches to training are used by aquatic sports athletes to achieve performance peaks. Nutritional support to optimize training adaptations should take periodization into consideration; that is, nutrition should also be periodized to optimally support training and facilitate adaptations. Moreover, other aspects of training (e.g., overload training, tapering and detraining) should be considered when making nutrition recommendations for aquatic athletes. There is evidence, albeit not in aquatic sports, that restricting carbohydrate availability may enhance some training adaptations. More research needs to be performed, particularly in aquatic sports, to determine the optimal strategy for periodizing carbohydrate intake to optimize adaptations. Protein nutrition is an important consideration for optimal training adaptations. Factors other than the total amount of daily protein intake should be considered. For instance, the type of protein, timing and pattern of protein intake and the amount of protein ingested at any one time influence the metabolic response to protein ingestion. Body mass and composition are important for aquatic sport athletes in relation to power-to-mass and for aesthetic reasons. Protein may be particularly important for athletes desiring to maintain muscle while losing body mass. Nutritional supplements, such as b-alanine and sodium bicarbonate, may have particular usefulness for aquatic athletes' training adaptation.

Keywords: periodization, tapering, detraining, overreaching, carbohydrate, protein

The magnitude of the adaptive response to training may be proportional to the training load undertaken by an athlete, where load is defined as the combination of intensity, volume, and frequency of the training stimulus (Mujika, 1998). Long- and short-term training programs that are well designed, controlled, and monitored need to be set in place to ensure that the individual athlete's optimal performance is attained both at the right time of his or her career and at each point of major competitions within a season. In aquatic sports, long-term career paths are most often planned for athletes to peak each season and at the end of a quadrennial period leading on to the Olympic Games. In the short-term, optimal performances are usually attained by skillfully intertwining lengthy phases of hard, intensive training and shorter phases of reduced training, such as the taper (Mujika and Padilla, 2003). Appropriate nutrition plans for each training phase need to be set in place for aquatic athletes to achieve the desired body mass and composition, support training adaptations, and optimize competition performance.

Phases of intensive training result in acute physiological effects that might limit performance capacity in the short term (days to weeks), but they also generate adaptive responses that eventually lead to improvements in sports performance. These intensive training overload periods, requiring adequate energy intake with appropriate macronutrient periodization (Table 1), intend to maximize long-term physiological adaptations to training, ignoring the potential acute negative impacts. By contrast, taper periods are introduced to further enhance the physiological adaptations achieved during intensive training, while the negative impact of training resolves. Ideally, this will bring about maximal physiological adjustments and a concomitant disappearance of the negative influences of training, resulting in an optimal performance potential (Mujika, 1998). Taper periods are characterized by reduced energy expenditures, and the nutrition plans of the aquatic athlete should be modified appropriately (Shaw et al., 2014). In less ideal circumstances, training programs may result in unwanted situations such as underperformance, excessive fatigue, illness, or injury, forcing an athlete to interrupt their participation with subsequent detraining effects.

The aim of this article is to provide a brief overview of long- and short-term training issues relevant for coaches, athletes, and support teams to better address the performance requirements of aquatic sports and to

---

Mujika is with the Dept. of Physiology, Faculty of Medicine and Odontology, University of the Basque Country, Leioa, Basque Country, and the School of Kinesiology and Health Research Center, Faculty of Medicine, Finis Terrae University, Santiago, Chile. Stellingwerff is with the Canadian Sport Institute–Pacific, Victoria, Canada. Tipton is with Health and Exercise Sciences Research Group, University of Stirling, Stirling, Scotland. Address author correspondence to Iñigo Mujika at inigo.mujika@inigomujika.com.

Table 1 Periodized Nutritional Recommendations to Support Training and Facilitate Adaptation

Training Phases
High-volume, low-to-moderate intensity/general preparation training phase
• Large caloric intakes to support training volumes (≥3,500–5,000 kcal/day for ~70-kg swimmer)
• Largest daily amounts of CHO intake in this period (large training days > 8–10 g/kg/day)
• Periodize caloric and macronutrient intakes toward desired changes in body composition
• Emphasis on nutritional recovery interventions during large training blocks
• Where desired, periodic targeted low-CHO availability training to stimulate aerobic adaptations
High-intensity/specific preparation training phase
• Nutrition to support high-intensity training (~3,500–4,500 kcal/day for ~70-kg swimmer)
• High-quality training sessions supported by high CHO-availability
• Further optimization of body composition targets toward taper and competition phase
• Trial and targeting key ergogenic aid/supplements precompetition phase
Taper & competition phase
• Lowest volume of training, with high intensity, requires reductions in daily caloric intakes to match energy expenditures (~2,800–4,300 kcal/day for ~70-kg swimmer)
• Continual monitoring of optimal body composition for competition phase
• Usage of key trialed ergogenic aids
• Usage of recovery protocols in competition settings
Recovery phase/off-season (or injury)
• Nutrition recommendations similar to active to sedentary individual (≥ 2,000–3,000 kcal/day for ~70-kg swimmer)
• Some minor weight gain expected and desired
• Ergogenic supplements no longer required

Notes. CHO = carbohydrate. Source: Stellingwerff et al. 2007; 2011.

address various nutritional strategies that may affect training adaptation.

Long-Term Periodization

During the 1960s and 1970s, long-term planning of athletic training and performance, as done by Eastern bloc countries and termed *training periodization*, became a precondition to international sporting success (Balyi, 1990). Characteristics of periodization include the structure of the annual cycle, total training volume, training organization, recovery processes, use of training equipment, and individual progress, but also the age and experience of each athlete, with the goal of an optimal peak at the end of the quadrennium (Issurin, 2008). Nutrition plans need to be designed to support the long-term goals of aquatic athletes, taking into consideration requirements that are both sport specific (e.g., muscularity and strength in a water polo player or healthy leanness and power in a synchronized swimmer) and athlete specific (e.g., enhancing endurance in a long-distance swimmer or increasing power in a diver).

Annual Periodization

An annual training plan should consider the available planning options, the competition calendar, total training volumes, and training intensity distributions. Furthermore, it should implement a sensitive and responsive learning system that allows the early detection of emerging threats and opportunities to optimize athletic performance, supported by adequate nutritional strategies.

Although traditional periodization provides coaches and athletes with basic guidelines for structuring and planning their training, it also imposes limitations to today's high level athletes, such as the impossibility to provide multiple performance peaks in many competitions (Issurin, 2010). Alternative concepts of periodization, such as *block periodization*, have been developed. This concept proposes a sequence of specialized training blocks containing highly concentrated training loads directed to consecutively stimulate a reduced number of specific qualities (Issurin, 2008).

Nevertheless, applying generic training methodologies may not be the most appropriate training approach (Kiely, 2012), because training responses vary among aquatic sports and events and among individual athletes preparing for a particular event. Whatever the annual training model, guidelines for nutrition should move away from generalized recommendations to an individualized approach to fuel needs based on each aquatic athlete's body size and composition and each athlete's specific training and competition program (Burke, 2010). For instance, energy and carbohydrate intake could be restricted during base training phases of swimmers aiming to reduce excess body fat, whereas sufficient carbohydrate and protein will be needed to complete and adapt to a phase of high-intensity training in any of the aquatic sports (Table 1).

Training Intensity and Training Volume

In view of the relatively short duration of most pool swimming events (approximately 20 s to 2 min), there is an ongoing debate in the sport between those who favor a high-training-volume approach and those favoring low volume and high intensity (Costill et al., 1991; Counsilman & Counsilman, 1990). Although training intensity, rather than training volume or frequency, may be key for elite 100- and 200-m swimmers (Mujika et al., 1995), divers, water polo players, and synchronized swimmers, it is questionable whether this would also apply to swimmers of longer distances (i.e., 400, 800, 1500 m, open water), for whom training volume and frequency could be much more important. A high volume of low-intensity training could also benefit the shorter distance swimmers by improving recovery processes, enhancing their tolerance to high-intensity training, and developing gliding ability in the water and motor patterning and skill, with a consequent reduction in the energy cost of swimming (Mujika et al., 1995).

The study of the relative impact of the various combinations of training intensity and volume has elicited two basic patterns of training load distribution: the "threshold" training model and the "polarized" training model. The first model emphasizes training intensities at, or near, the lactate threshold and features lower overall training volumes. In contrast, the polarized training model features nearly 75–80% of training at intensities below the lactate threshold, with the remaining 20–25% distributed between training "at threshold" and much higher intensities, usually in the form of interval training (Seiler, 2010). Reports of the distribution of training intensities for elite 100- and 200-m swimmers are in agreement with such a polarized approach (Mujika et al., 1995). Fédération Internationale de Natation (FINA) Open Water Swimming Grand Prix male and female champions are reported to perform 11 training sessions per week in the water, covering between 75 and 140 km, with a training intensity distribution similar to the world championship medal winners in the 800-m and 1,500-m freestyle and 400-m individual medley events (Frédéric Vergnoux, coach to the mentioned swimmers, personal communication). These data indicate that high training volumes and a polarized intensity distribution are keys to success in the longer pool and open-water swimming events. We are unaware of any published reports on the training intensity distributions of other aquatic athletes, but it is recommended that practitioners carry out such analysis of training contents, so that nutrition needs that are specific to the sport, training phase, and session can be determined, and eating strategies can be implemented to adequately support training and facilitate adaptation processes (Table 1).

Tapering and Peaking For Competition

The training programs of high-level aquatic athletes usually include a training phase, known as a *taper*, that is characterized by a reduction of the training load in the days and weeks leading to a major competition. The taper is designed to diminish residual fatigue induced by intensive training, maximize physiological adaptations, and optimize performance (Bosquet et al., 2007). Notwithstanding individual responses, in general, swimming performance appears to be maximized by a taper lasting 8–21 days, where the training volume is progressively decreased by 41–60%, without any modification of either training intensity or frequency (Bosquet et al., 2007). However, the training responses and adaptation profiles of individual athletes should be considered when designing a taper program (Mujika et al., 1996b) to determine optimal taper durations and the suitability of progressive versus step tapers (Mujika et al., 1996a), the impact of overreaching the athletes before the taper (Thomas et al., 2008), or the potential fitness and performance value of a final increase in the training load (Thomas et al., 2009).

Tapering-induced pool competition performance gains are usually in the range of 0.3–5.0% (Pyne and Mujika, 2011). These gains are attributed to increased levels of muscular force and power; improvements in neuromuscular, hematological, and hormonal function; and improvements in the psychological status of the athletes (Mujika and Padilla, 2003a). Any or all of these factors could equally benefit athletes across all aquatic sports. In pool swimming, performance improvements occurring during the taper are independent of sex, event duration, stroke, and caliber of the athlete (Mujika et al., 2002). How often taper-induced gains can be obtained as athletes adapt their training programs to the modern busy competition calendars remains to be elucidated. A comprehensive review on the taper in competitive swimming can be found in Pyne and Mujika (2011).

In team sports such as water polo, coaches and players should be aware that basic training principles that can be effective in individual sport athletes, also apply in the case of team sports (Mujika, 2007). Thorough descriptions of the training and peaking strategies of the Australian women's water polo team and the Spanish men's team in the lead up to the Olympic Games can be found in Mujika (2009). We are not aware of any studies dealing with the taper in synchronized swimming or diving, but there is no reason to suggest that the responses of such athletes to a taper would be any different, because taper effects can equally benefit endurance athletes, speed athletes, power athletes, and precision sport athletes (Mujika, 2009).

Aquatic sport athletes should be aware that energy metabolism underpinning exercise performance can be altered during a preevent taper. Decreases in training load in favor of rest and recovery lower an athlete's daily energy expenditure, potentially affecting energy balance and body composition (Mujika et al., 2004). Athletes tapering for competition should therefore pay careful attention to matching energy intake in accordance with the reduced energy expenditure that characterizes this training period (Table 1). The substrate contribution to power production is not modified by a taper, but iron intake in the lead up and during the taper should be optimized, because enhanced erythropoietic activity in the bone marrow associated with the taper could jeopardize the iron status of athletes (Mujika et al., 2004).

Concurrent Endurance and Resistance Training

Swimmers moving through water apply propulsive force against a flowing element primarily to overcome hydrodynamic drag, which increases proportionally with the square of swimming velocity (Pyne & Sharp, 2014). Muscle strength is important to swim fast (Sharp et al., 1982), and upper body strength and power output correlate with maximal swimming velocity in distances from 25 to 400 m (Hawley et al., 1992; Hawley & Williams, 1991; Sharp et al., 1982). Heavy strength training on dry land or sprint swimming with increased resistance to propulsion may be efficient for enhanced freestyle performance and stroke mechanics from sprint to middle-distance events (Aspenes and Karlsen, 2012; Vorontsov, 2011).

Dry-land strength training is a major component of the preparation of water polo players, because specific actions different from swimming, such as jumping, wrestling, or throwing, require high levels of strength and power, and these performance qualities can be improved through appropriate strength training programs (Cox et al., 2014; Veliz et al., 2013). Strength and power training is also an integral part of the preparation of synchronized swimmers and divers.

In dry-land sports, the mechanisms for improved endurance performance after concurrent endurance and heavy strength training include postponed activation of less efficient type II fibers, improved blood flow in working muscles, improved neuromuscular function, conversion of fast-twitch type IIX fibers into more fatigue-resistant type IIA fibers, and improved musculotendinous stiffness (Rønnestad and Mujika, 2014). Whether these performance-enhancing mechanisms also apply in aquatic sports remains to be elucidated, but whatever the mechanisms involved, nutritional strategies need to be set in place to support strength and power training and maximize adaptation (Table 1).

Detraining

Circumstances such as the off-season break, illness, or sports injuries result in training cessation or reduction, which bring about a partial or complete loss of previously acquired anatomical, physiological, and performance adaptations (Mujika and Padilla, 2000).

In a classic study of detraining, competitive swimmers' muscle respiratory capacity decreased by 50% after 1 week of inactivity. When the athletes performed a standardized 183-m submaximal swim, postswim blood lactate was 2.3 times higher, pH was lower (7.183 vs. 7.259), bicarbonate concentration was 23% lower, and base deficit was twice as high (Costill et al., 1985). After 4 weeks without training, 24 college swimmers showed a 5.5 $\text{mmol}\cdot\text{l}^{-1}$ increase in blood lactate concentration after a standardized 183-m submaximal swim, indicative of a reduction in the muscle oxidative capacity and/or a change in the swimmers' mechanical efficiency (Neufer et al., 1987). Similar results were observed in 7 female swimmers who refrained from training for 10 days (Claude & Sharp, 1991). Muscle glycogen concentration in competitive swimmers declined by 20% 1 week after the competitive season, and by 8–10% per week without training thereafter (Costill et al., 1985).

The general loss in cardiorespiratory fitness, metabolic efficiency, and muscle respiratory capacity results in a rapid decline in aquatic athletes' endurance performance. Female competitive swimmers were 2.6% slower in a 366-m swim after only 10 days without training (Claude & Sharp, 1991). Swimming performance over 100 and 200 m also declined by 3–13% in elite swimmers during the off season (Mujika et al., 1995). In contrast, college swimmers maintained their muscular strength, as measured on a swim bench, during 4 weeks of training cessation, but their swim power (i.e., their ability to apply the force during swimming) declined by 13.6% (Neufer et al., 1987).

In view of the above, we recommend that aquatic athletes undergoing a period of reduced training or training cessation pay special attention to nutrition (Table 1). Their caloric intake should be reduced to match the diminished energy expenditure, particularly via a decrease in carbohydrate intake in accordance with the lowering of muscle fuel needs. The maintenance of a high protein intake may help to minimize the expected decline in muscle protein synthesis rates, particularly in the case of illness or injury (for specific details on nutrition, illness and injury in aquatic sport, see Pyne et al., 2014).

Overtraining

In their constant quest for performance improvements, competitive swimmers perform large amounts of intense training in the water and on dry land. This may induce an imbalance between the training overload and the necessary recovery, and the athletes' performance may suffer in the short-term. This strategically planned outcome, known as *functional overreaching* will eventually lead to an improvement in performance after recovery. When strenuous activity is carried out for longer periods and with insufficient recovery between training bouts, *nonfunctional overreaching* or even an *overtraining syndrome* can occur (Meeusen et al., 2013). The distinction between these negative outcomes of excessive training is very difficult, because changes in clinical, hormonal, and other signs and symptoms may not be apparent.

Reports from the literature suggest an incidence of nonfunctional overreaching and/or the overtraining syndrome among highly trained swimmers of 5–27% in 6–12 months (Hooper et al., 1997; Morgan et al., 1987; O'Connor et al., 1989). However, it is difficult to determine the real incidence of nonfunctional overreaching and overtraining, because most of the available reports have severe pitfalls: some lack performance assessments, some classify athletes as overtrained simply because they failed to improve performance, and others do not include a recovery period (Halson and Jeukendrup, 2004).

An approach to understanding the etiology of overreaching and overtraining involves the exclusion of organic diseases or infections, and factors such as dietary caloric restriction with an insufficient intake of carbohydrate and/or protein and micronutrient availability (e.g., iron deficiency, magnesium deficiency, allergies), along with identification of initiating events or triggers (Meeusen et al., 2013).

Periodizing Carbohydrate Availability Around Training

Commonly used methods of adding stress to very well trained aquatic athletes include extreme training bouts (duration/intensity), training periods (e.g., training camps), or altered environments (e.g., altitude training). Another accessible and simple method to increase training stress is via dietary periodization. Contemporary scientific studies have started to examine whether a periodic lack of carbohydrate (CHO) availability around training may further enhance training adaptations (Burke, 2010).

Nutritional recommendations generally suggest that athletes should *immediately* replenish muscle glycogen stores postexercise, with adequate CHO intake, to ensure subsequent training bouts are conducted in a glycogen-compensated state. However, a study in untrained male subjects reported increased endurance adaptation and performance when half of the training sessions (5 days per week over 10 weeks) were undertaken in a muscle glycogen-depleted state (training twice per day, so the second training bout was glycogen depleted), compared with every session conducted in a glycogen-loaded state (Hansen et al., 2005). Several follow-up studies have confirmed enhanced cycle training adaptations with low muscle glycogen or low exogenous CHO availability via overnight fasted training (Akerstrom et al., 2009; De Bock et al., 2005; Morton et al., 2009; Nybo et al., 2009; Yeo et al., 2008b). However, none of these studies showed greater posttraining performance enhancement with low-CHO training compared with training with ample CHO availability. This lack of an effect may be due to the initial self-selection of lower training intensities under the more physiologically and psychologically stressful low-muscle-glycogen conditions (Yeo et al., 2008a).

Most of the above studies have featured an intervention of only ~9 low-CHO training workouts out of ~18 total sessions, and it is difficult to extrapolate the results of short-term laboratory training studies to the real world of elite aquatic sports. Moreover, the current literature fails to adequately test the potential for a carefully periodized CHO availability model, particularly for aquatic sports. Nevertheless, until better studies are undertaken, many sports scientists are happy to experiment with the application of various eating strategies. Which low-CHO availability approaches (low-glycogen training vs. overnight fasted training vs. low-glycogen recovery periods) may ultimately provide the most potent stimulus for training adaptation while minimizing the likely deleterious effects of delayed recovery (Burke et al., 2014), decreased training quality, and/or increased immune system stress (Pyne et al., 2014) remains to be elucidated. Table 2 highlights some practical recommendations on low-CHO training.

Protein Intake to Support Training Adaptations

Evidence suggests that adaptations to training are due to changes in types and/or activities of various proteins in response to each exercise bout and nutrient intake. Protein intake before, during, and after training influences training adaptations. The metabolic basis for changes in the amount of protein is the balance between the rates of muscle protein synthesis (MPS) and muscle protein breakdown (MPB; i.e., net MPB), or NMPB, = MPS – MPB. Periods of positive NMPB must be of larger duration and magnitude than negative periods over any given time for increases in protein to occur. Dietary protein ingestion has a profound impact on NMPB, thus protein nutrition is a critical component of adaptation to training for aquatic sports.

The optimal amount of dietary protein to consume on a daily basis to maximize adaptations in aquatic sports is unknown and will vary for each individual athlete in the particular circumstances of their training and competitive demands. Moreover, the type of protein, timing of protein ingestion relative to exercise, coingestion of other nutrients, and the type of training performed will affect the adaptations to training. Because adaptive responses to training are mostly individual, all of these factors should be taken into account to make personalized recommendations for aquatic athletes. As with other nutrients, the optimal amount of protein will also vary depending on the phase of the training and competition season.

Protein intake in conjunction with exercise enhances the anabolic response of muscle. Moreover, it seems clear that the essential amino acids (EAA) in the protein are the key to muscle anabolism (Tipton et al., 1999). Ingestion of a source of amino acids that results in rapid elevation of blood EAA levels optimally stimulates MPS, resulting in positive NMPB (Tipton et al., 1999, 2007; West et al., 2011). The branched-chain amino acid leucine seems to be particularly important for stimulation of the maximal response of MPS (Churchward-Venne et al., 2012). However, elevated leucine alone is insufficient to fully stimulate MPS (Churchward-Venne et al., 2012).

Table 2 Practical Recommendations for Low-Carbohydrate-Availability Training.

Recommendations
Type of aquatic athlete that can benefit from low CHO availability
• Athletes in their general preparation phase and/or training for open water events or distance pool events.
• Mature/senior athletes who have maximized many of the other training and nutrition basics.
• Mature/senior athletes who have maximized volume of training and/or have injuries that limit the total amount of volume they can train.
Type of aquatic athlete that should not implement or may suffer with low CHO availability
• Junior athletes
• Athletes who break down and get sick often (poor immune systems)
• High-intensity or high-quality training sessions (or anything faster than threshold or tempo training): athletes should aim to undertake these sessions with ample stored CHO energy (glycogen) and, if desired, CHO intake during training.
• Speed/power swimmer, diver, water polo player that wants to build muscle mass via resistance training should always aim to undertake these sessions with ample stored CHO energy (glycogen) and, if desired, CHO intake during training.
Other nutritional/lifestyle interventions to consider when implementing low-energy training
• Low-energy training adds extra stress to the training load, therefore greater emphasis needs to be placed on recovery and rest when implementing. This can include: • Focus on high quality/quantity of rest and sleep • Focus on or increase adequate intake of fruits and vegetables • Focus on or increase emphasis on a very healthy, high-quality diet • Consider a multistrain probiotic • Be sure to have recovery nutrition available *immediately* after low-energy training • Initially during low-energy training, many aquatic athletes experience increased hunger throughout the rest of the day or the following day. Be sure to monitor body mass to ensure that not too much weight is being lost (need energy balance for best training load). • Consider adding an extra day of lighter/moderate training before undertaking another hard training session after prolonged (> 90 min) low-energy training.

Notes. CHO = carbohydrate

Despite stimulation of translation initiation by leucine, provision of the other amino acids (e.g., from an intact protein source) is necessary to supply the substrate for MPS. Therefore, ingestion of a high quality protein supplying sufficient EAA/leucine to induce a rapid rise in blood amino acid levels is best to optimize adaptations to training in aquatic sports.

Protein nutrition to support the stimulation of MPS after swim training and resistance exercise is critical for optimal adaptation. Swim training and resistance exercise increased MPS in trained swimmers (Tipton et al., 1996). Moreover, the combination of the two modes of training increased MPS more than either type of training alone. Given that protein ingestion after both resistance (Tipton et al., 1999, 2007) and endurance (Breen et al., 2011; Howarth et al., 2009) training further increases MPS, adaptations to training in aquatic sports are enhanced by protein ingestion.

High daily dietary protein intakes are popular with many athletes (Tipton, 2011), but there is little support for the necessity of intakes above 2.5–3.0 g protein/kg body mass (BM). Although there is some evidence that very high protein intake (3.0 g/kg BM) may ameliorate the negative consequences of a sudden increase in training volume and intensity (Witard et al., 2011, 2014b), it is not clear that this amount of dietary protein is sustainable for long periods, and such amount is difficult for most athletes to consume comfortably.

In the short term, the amount of protein ingested in conjunction with exercise will influence the anabolic response of muscle. The response of MPS seems to be maximally stimulated with ingestion of ~20 g of egg protein after resistance exercise (Moore et al., 2009; Witard et al., 2014a). However, given that muscle mass may affect the amount of protein needed to maximally stimulate MPS, and because the average BM of the subjects in those studies was ~80–85 kg, it is perhaps prudent to recommend 0.25–0.30 g protein/kg BM to be consumed after exercise. More studies are needed to determine the optimal amount of protein to maximize adaptation after various training sessions in the different aquatic sports.

The precise timing of protein ingestion around exercise also may affect the response. Immediate postexercise ingestion of an amino acid source is a sound method of enhancing muscle anabolism, but this “window of opportunity” may last longer than just a few hours after the exercise bout: The synergistic response of muscle to exercise and nutrition lasts for at least 24 hr (Burd et al., 2011). Thus, whereas the optimal response may occur when protein is ingested soon after exercise, a normal postexercise feeding pattern will support muscle anabolism too.

The combination of timing and amount of protein may affect the potential adaptations to training. Indeed, the response of MPS over a 12-hr period after an exercise bout was maximized when four 20-g doses of protein were ingested every 3 hr after exercise compared with two 40-g doses every 6 hr and eight 10-g doses every 1.5 hr (Areta et al., 2013). These data support the contention that the total amount of daily dietary protein is not the most important factor and clearly indicate that the adaptive response to training depends on many factors related to protein nutrition. The aquatic athlete is therefore guided to develop eating plans that spread the intake of high quality protein over the day at meals/snacks that are consumed every 3–4 hr, key times being in the period after important training sessions and, perhaps, before sleep (Res et al., 2012).

Achieving and/or Maintaining Optimal Body Mass and Body Composition

Optimal BM and composition may be important for aquatic sport athletes to maximize their power-to-mass ratio and/or for aesthetic reasons. Generally, it is desirable for a loss of BM to come as loss of fat rather than muscle. However, negative energy balance may result in a significant loss of lean BM (Forbes, 2000), perhaps leading to compromised performance or undesirable aesthetic changes. Thus, a dietary strategy that allows BM loss while maintaining muscle mass would be very important for many aquatic athletes.

Training loads are already extreme for top-level aquatic athletes, so adding more training to increase energy expenditure is not always feasible. Thus, nutrition becomes crucial for BM regulation. The importance of protein nutrition for BM control and/or loss has gained considerable attention over the past decade or so. Increased protein content of the diet, particularly in combination with training, may induce BM loss and reduce the loss of lean mass in overweight and obese individuals during low-energy dieting (Josse et al., 2011). Whether these findings are also valid for aquatic athletes remains to be elucidated.

The impact of increased protein intake during low-calorie dieting was investigated in resistance-trained male athletes who continued normal training during the mass loss period (Mettler et al., 2010). Two groups of athletes consumed 60% of their normal calorie intake for 2 weeks. One group consumed a diet that resembled their normal dietary pattern (~15% protein), whereas the other group consumed a high protein diet (~35% protein). Both groups lost the same amount of fat, but the group consuming more protein lost little if any muscle. The athletes on the lower protein intake lost more total mass, but also lost ~1.5 kg of lean BM during the 2 weeks of reduced energy intake. Therefore, aquatic sport athletes desiring loss of total body mass, but minimal muscle loss, may want to consider a high protein diet.

Another nutritional consideration for athletes desiring to lose BM should be the rate at which BM is reduced. Garthe et al. (2011) investigated the impact of two different rates of mass loss on body composition changes in elite athletes. One group lost mass at the rate of ~0.7% per week and the other at ~1.4% per week. Training load was kept constant. Whereas lean BM remained unchanged in the group with the faster mass loss, the athletes with the slower loss gained ~2 kg of lean mass. These data suggest that athletes who want to gain muscle during a period of hypocaloric BM loss should reduce energy intake minimally, within the temporary constraints for the mass loss (i.e., goal date by which the mass must come off).

Enhancing Training Adaptation Via Nutritional Supplements

Theoretically any nutrition intervention that can either increase training quality or increase the stimulus of a given workout should, over time, further increase training adaptations. Although supplements for aquatic sports are covered by Derave et al. (2014), there are a few supplements that may have relevance to enhancing training adaptations.

Sodium Bicarbonate Supplementation

Sodium bicarbonate has been shown to increase short-term power output, especially during repeated sprint efforts (Derave et al., 2014). At least one study used long-term sodium bicarbonate (Na HCO_3) supplementation in an attempt to induce superior training adaptations (Edge et al., 2006). In this $NaHCO_3$ training study, it was found that the group that consumed 400 mg of $NaHCO_3$/kg BM 90 and 30 min before interval training (6–12 × 2 min at 100% VO_{2max}), three times per week over 8 weeks gained greater training adaptation and performance compared with the placebo group who did the exact same clamped training (Edge et al., 2006). Despite promising results from this study, much more work needs to be completed examining ingestion dose responses, blood bicarbonate washout, training responses with unclamped self-selected training intensities, whether these initial performance findings can be confirmed in elite aquatic athletes, and whether long-term bicarbonate supplementation also induces potentially counterproductive body mass gain via water retention.

Long-Term b-Alanine Supplementation

Carnosine is a potent intramuscular buffer because of its nitrogen-containing side imidazole ring, which can directly accept and buffer H^+ ions. Since 2006, more than 30 published studies have examined the effects of b-alanine (BA) supplementation on muscle carnosine over 4–8 weeks (for review, see Stellingwerff et al., 2012), and the subsequent impact that augmented muscle carnosine can have on high-intensity human performance outcomes (for meta-analysis, see Hobson et al., 2012). Therefore, augmented carnosine content might not only increase buffering capacity and acute performance but also, in theory, increase the ability to undertake high-intensity training, causing a greater training stimulus and resulting in performance benefits.

Only a couple of studies have examined whether augmented carnosine via BA supplementation may lead to enhanced training adaptations. Hoffman et al. (2008) found that high-dose BA over 3 weeks resulted in higher training volume in the bench press exercise, and a trend for a greater training volume was seen for all resistance exercise sessions. Conversely, Smith et al. (2009) found no influence of BA supplementation to further enhance high-intensity interval training in relatively untrained men. Elite and subelite swimmers were recently given BA over 10 weeks (Chung et al., 2012), and a greater improvement in training performance after 4 weeks of BA vs. placebo was observed (mean = -1.3%, 90% confidence limit = 1.0), but the effect was unclear after 10 weeks (mean = -0.2%, 90% CL = 1.5). This study featured open self-selected training and dietary controls but did not attempt to control normal variables such as standardizing training, diet, and other confounding factors (Chung et al., 2012). More research is required in this area, because findings might be confounded by the fact that it takes 4–8 weeks just to raise muscle carnosine via BA supplementation (Stellingwerff et al., 2012). Therefore, study designs may need a 4–8 week lead-in period of BA vs. placebo supplementation to adequately differentiate high and low muscle carnosine groups before subsequently undertaking a training intervention.

Conclusions

Although there is a relative dearth of direct information on aquatic sport athletes, it is clear that nutritional considerations must be paramount to optimize adaptations to training. Whereas adaptations are primarily stimulated by the precise aspects of the training regimen, appropriate nutrition can support and even influence the adaptive processes. Nutrition should be periodized and adapted to support changing individual goals, training levels, and requirements throughout a season and/or training cycle. Nutritional deficiencies must be avoided as a top priority. Sufficient energy, macronutrient, and micronutrient intake are critical to support optimal adaptation to training. During periods of intense training, carbohydrate and protein intake seem to be critical. Protein intake may be particularly important for aquatic athletes during periods of hypocaloric weight loss. Although many of the recommendations for nutritional support of aquatic athletes are based on land-based studies, there is no reason, at least at present, to suspect that these recommendations do not apply to aquatic athletes.

Acknowledgments

The authors have no conflicts of interest to declare

References

Akerstrom, T.C., Fischer, C.P., Plomgaard, P., Thomsen, C., van Hall, G., & Pedersen, B.K. (2009). Glucose ingestion during endurance training does not alter adaptation. *Journal of Applied Physiology, 106,* 1771–1779. PubMed doi:10.1152/japplphysiol.91534.2008

Areta, J.L., Burke, L.M., Ross, M.L., Camera, D.M., West, D.W., Broad, E.M., . . . Coffey, V.G. (2013). Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis. *Journal of Physiology, 591,* 2319–2331. PubMed

Aspenes, S.T., & Karlsen, T. (2012). Exercise-training intervention studies in competitive swimming. *Sports Medicine, 42,* 527–543. PubMed doi:10.2165/11630760-000000000-00000

Balyi, I. (1990). *Quadrennial and double quadrennial planning of athletic training* (pp. 1–10). Victoria, Canada: Canadian Coaches Associacion.

Bosquet, L., Montpetit, J., Arvisais, D., & Mujika, I. (2007). Effects of tapering on performance: A meta-analysis. *Medicine & Science in Sports & Exercise, 39,* 1358–1365. PubMed doi:10.1249/mss.0b013e31806010e0

Breen, L., Philp, A., Witard, O.C., Jackman, S.R., Selby, A., Smith, K., . . . Tipton, K.D. (2011). The influence of carbohydrate and protein coingestion on mitochondrial and myofibrillar protein synthesis following endurance exercise. *Journal of Physiology, 589,* 4011–4025. PubMed doi:10.1113/jphysiol.2011.211888

Burd, N.A., West, D.W., Moore, D.R., Atherton, P.J., Staples, A.W., Prior, T., . . . Phillips, S.M. (2011). Enhanced amino acid sensitivity of myofibrillar protein synthesis persists for up to 24 h after resistance exercise in young men. *Journal of Nutrition, 141,* 568–573. PubMed doi:10.3945/jn.110.135038

Burke, L.M. (2010). Fueling strategies to optimize performance: training high or training low? *Scandinavian Journal of Medicine & Science in Sports, 20*(Suppl. 2), 48–58. PubMed doi:10.1111/j.1600-0838.2010.01185.x

Burke, L.M., & Mujika, I. (2014). Nutrition for recovery in aquatic sports. *International Journal of Sport Nutrition, 24*, 425-436.

Chung, W., Shaw, G., Anderson, M.E., Pyne, D.B., Saunders, P.U., Bishop, D.J., & Burke, L.M. (2012). Effect of 10 week beta-alanine supplementation on competition and training performance in elite swimmers. *Nutrients, 4,* 1441–1453. PubMed doi:10.3390/nu4101441

Churchward-Venne, T.A., Burd, N.A., Mitchell, C.J., West, D.W., Philp, A., Marcotte, G.R., . . . Phillips, S.M. (2012). Supplementation of a suboptimal protein dose with leucine or essential amino acids: effects on myofibrillar protein synthesis at rest and following resistance exercise in men. *Journal of Physiology, 590,* 2751–2765. PubMed doi:10.1113/jphysiol.2012.228833

Claude, A.B., & Sharp, R.L. (1991). The effectiveness of cycle ergometer training in maintaining aerobic fitness during detraining from competitive swimming. *Journal of Swimming Research, 7,* 17–20.

Costill, D.L., Fink, W.J., Hargreaves, M., King, D.S., Thomas, R., & Fielding, R. (1985). Metabolic characteristics of skeletal muscle during detraining from competitive swimming. *Medicine & Science in Sports & Exercise, 17,* 339–343. PubMed

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 & Science in Sports & Exercise, 23,* 371–377. PubMed doi:10.1249/00005768-199103000-00017

Counsilman, J.E. & Counsilman, B.E. (1990). No simple answers. *Swimming Technique*, *26*, 22–29.

Cox, G.R., Mujika, I., & van den Hoogenband, C.-R. (2014). Nutritional recommendations for water polo. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 380-389.

De Bock, K., Richter, E.A., Russell, A.P., Eijnde, B.O., Derave, W., Ramaekers, M., & Hespel, P. (2005). Exercise in the fasted state facilitates fibre type-specific intramyocellular lipid breakdown and stimulates glycogen resynthesis in humans. *Journal of Physiology, 564,* 649–660. PubMed doi:10.1113/jphysiol.2005.083170

Derave, W., & Tipton, K.D. (2014). Dietary supplements for aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24,* 437–449.

Edge, J., Bishop, D., & Goodman, C. (2006). Effects of chronic NaHCO3 ingestion during interval training on changes to muscle buffer capacity, metabolism, and short-term endurance performance. *Journal of Applied Physiology, 101,* 918–925. PubMed doi:10.1152/japplphysiol.01534.2005

Forbes, G.B. (2000). Body fat content influences the body composition response to nutrition and exercise. *Annals of the New York Academy of Sciences, 904,* 359–365. PubMed doi:10.1111/j.1749-6632.2000.tb06482.x

Garthe, I., Raastad, T., Refsnes, P.E., Koivisto, A., & Sundgot-Borgen, J. (2011). Effectof two different weight-loss rates on body composition and strength and power-related performance in elite athletes. *International Journal of Sport Nutrition and Exercise Metabolism, 21,* 97–104. PubMed

Halson, S.L., & Jeukendrup, A. (2004). Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Medicine, 34,* 967–981. PubMed doi:10.2165/00007256-200434140-00003

Hansen, A.K., Fischer, C.P., Plomgaard, P., Andersen, J.L., Saltin, B., & Pedersen, B.K. (2005). Skeletal muscle adaptation: training twice every second day vs. training once daily. *Journal of Applied Physiology, 98,* 93–99. PubMed doi:10.1152/japplphysiol.00163.2004

Hawley, J.A., & Williams, M.M. (1991). Relationship between upper body anaerobic power and freestyle swimming performance. *International Journal of Sports Medicine, 12,* 1–5. PubMed doi:10.1055/s-2007-1024645

Hawley, J.A., Williams, M.M., Vickovic, M.M., & Handcock, P.J. (1992). Muscle power predicts freestyle swimming performance. *British Journal of Sports Medicine, 26,* 151–155. PubMed doi:10.1136/bjsm.26.3.151

Hobson, R.M., Saunders, B., Ball, G., Harris, R.C., & Sale, C. (2012). Effects of beta-alanine supplementation on exercise performance: A meta-analysis. *Amino Acids, 43,* 25–37. PubMed doi:10.1007/s00726-011-1200-z

Hoffman, J.R., Ratamess, N.A., Faigenbaum, A.D., Ross, R., Kang, J., Stout, J.R., & Wise, J.A. (2008). Short-duration beta-alanine supplementation increases training volume and reduces subjective feelings of fatigue in college football players. *Nutrition Research, 28,* 31–35. PubMed doi:10.1016/j.nutres.2007.11.004

Hooper, S.L., Mackinnon, L.T., & Hanrahan, S. (1997). Mood states as an indication of staleness and recovery. *International Journal of Sport Psychology, 28,* 1–12.

Howarth, K.R., Moreau, N.A., Phillips, S.M., & Gibala, M.J. (2009). Coingestion of protein with carbohydrate during recovery from endurance exercise stimulates skeletal muscle protein synthesis in humans. *Journal of Applied Physiology, 106,* 1394–1402. PubMed doi:10.1152/japplphysiol.90333.2008

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

Issurin, V.B. (2010). New horizons for the methodology and physiology of training periodization. *Sports Medicine, 40,* 189–206. PubMed doi:10.2165/11319770-000000000-00000

Josse, A.R., Atkinson, S.A., Tarnopolsky, M.A., & Phillips, S.M. (2011). Increased consumption of dairy foods and protein during diet- and exercise- induced weight loss promotes fat mass loss and lean mass gain in overweight and obese premenopausal women. *Journal of Nutrition, 141,* 1626–1634. PubMed doi:10.3945/jn.111.141028

Kiely, J. (2012). Periodization paradigms in the 21st century: evidence-led or tradition-driven? *International Journal of Sports Physiology and Performance, 7,* 242–250. PubMed

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., . . . Urhausen, A. (2013). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Medicine & Science in Sports & Exercise, 45,* 186–205. PubMed doi:10.1249/MSS.0b013e318279a10a

Mettler, S., Mitchell, N., & Tipton, K.D. (2010). Increased protein intake reduces lean body mass loss during weight loss in athletes. *Medicine & Science in Sports & Exercise, 42,* 326–337. PubMed doi:10.1249/MSS.0b013e3181b2ef8e

Moore, D.R., Robinson, M.J., Fry, J.L., Tang, J.E., Glover, E.I., Wilkinson, S.B., . . . Phillips, S.M. (2009). Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. *American Journal of Clinical Nutrition, 89,* 161–168. PubMed doi:10.3945/ajcn.2008.26401

Morgan, W.P., Brown, D., Raglin, J., O'Connor, P., & Ellickson, K. (1987). Psychological monitoring of overtraining and staleness. *British Journal of Sports Medicine, 21,* 107–114. PubMed doi:10.1136/bjsm.21.3.107

Morton, J.P., Croft, L., Bartlett, J.D., Maclaren, D.P., Reilly, T., Evans, L., & Drust, B. (2009). Reduced carbohydrate availability does not modulate training-induced heat shock protein adaptations but does upregulate oxidative enzyme activity in human skeletal muscle. *Journal of Applied Physiology, 106,* 1513–1521. PubMed doi:10.1152/japplphysiol.00003.2009

Mujika, I. (1998). The influence of training characteristics and tapering on the adaptation in highly trained individuals: A review. *International Journal of Sports Medicine, 19,* 439–446. PubMed doi:10.1055/s-2007-971942

Mujika, I. (2007). Thoughts and considerations for team-sport peaking. *Olympic Coach, 18*(4), 9–11.

Mujika, I. (2009). *Tapering and peaking for optimal performance*. Champaign, IL: Human Kinetics.

Mujika, I., Busso, T., Lacoste, L., Barale, F., Geyssant, A., & Chatard, J-C. (1996a). Modeled responses to training and taper in competitive swimmers. *Medicine & Science in Sports & Exercise, 28,* 251–258. PubMed doi:10.1097/00005768-199602000-00015

Mujika, I., Chatard, J-C., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1995). Effects of training on performance in competitive swimming. *Canadian Journal of Applied Physiology, 20,* 395–406. PubMed doi:10.1139/h95-031

Mujika, I., Chatard, J-C., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1996b). Use of swim-training profiles and performance data to enhance training effectiveness. *Journal of Swimming Research, 11,* 23–29.

Mujika, I., & Padilla, S. (2000). Detraining: loss of training-induced physiological and performance adaptations. Part I: short term insufficient training stimulus. *Sports Medicine, 30,* 79–87. PubMed doi:10.2165/00007256-200030020-00002

Mujika, I., & Padilla, S. (2003). Scientific bases for precompetition tapering strategies. *Medicine & Science in Sports & Exercise, 35,* 1182–1187. PubMed doi:10.1249/01.MSS.0000074448.73931.11

Mujika, I., Padilla, S., & Pyne, D. (2002). Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. *International Journal of Sports Medicine, 23,* 582–587. PubMed doi:10.1055/s-2002-35526

Mujika, I., Padilla, S., Pyne, D., & Busso, T. (2004). Physiological changes associated with the pre-event taper in athletes. *Sports Medicine, 34,* 891–927. PubMed doi:10.2165/00007256-200434130-00003

Neufer, P.D., Costill, D.L., Fielding, R.A., Flynn, M.G., & Kirwan, J.P. (1987). Effect of reduced training on muscular strength and endurance in competitive swimmers. *Medicine & Science in Sports & Exercise, 19,* 486–490. PubMed doi:10.1249/00005768-198710000-00011

Nybo, L., Pedersen, K., Christensen, B., Aagaard, P., Brandt, N., & Kiens, B. (2009). Impact of carbohydrate supplementation during endurance training on glycogen storage and performance. *Acta Physiologica, 197,* 117–127. PubMed doi:10.1111/j.1748-1716.2009.01996.x

O'Connor, P.J., Morgan, W., Raglin, J., Barksdale, C., & Kalin, N. (1989). Mood state and salivary cortisol levels following overtraining in female swimmers. *Psychoneuroendocrinology, 14,* 303–310. PubMed doi:10.1016/0306-4530(89)90032-2

Pyne, D.B., & Mujika, I. (2011). The taper: physiology, performance and planning. In L. Seifert, D. Chollet, & I. Mujika (Eds.), *World book of swimming: From science to performance* (pp. 345–358). New York, NY: Nova Science Publishers Inc.

Pyne, D.B., & Sharp, R. (2014). Physical and energy requirements of competitive swimming events. *International Journal of Sport Nutrition and Exercise Metabolism, 24,* 351–359.

Pyne, D.B., Verhagen, E.A., & Mountjoy, M. (2014). Nutrition, Illness, and Injury in Aquatic Sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 460-469.

Res, P.T., Groen, B., Pennings, B., Beelen, M., Wallis, G.A., Gijsen, A.P., . . . van Loon, L.J. (2012). Protein ingestion prior to sleep improves post-exercise overnight recovery. *Medicine & Science in Sports & Exercise, 44,* 1560–1569. PubMed doi:10.1249/MSS.0b013e31824cc363

Rønnestad, B.R., & Mujika, I. (2014). Optimizing strength training for running and cycling endurance performance: A review. *Scandinavian Journal of Medicine & Science in Sports*, *24,* 603–612 doi:10.1111/sms.12104

Seiler, S. (2010). What is best pratice for training intensity and duration distribution in endurance athletes? *International Journal of Sports Physiology and Performance, 5,* 276–291. PubMed

Sharp, R.L., Troup, J.P., & Costill, D.L. (1982). Relationship between power and sprint freestyle swimming. *Medicine & Science in Sports & Exercise, 14,* 53–56. PubMed doi:10.1249/00005768-198201000-00010

Shaw, G., Boyd, K.T. , Burke, L.M. , & Koivisto, A. (2014). Nutrition for swimming. *International Journal of Sport Nutrition and Exercise Metabolism, 24*, 360–372.

Smith, A.E., Moon, J.R., Kendall, K.L., Graef, J.L., Lockwood, C.M., Walter, A.A., & Stout, J.R. (2009). The effects of beta-alanine supplementation and high-intensity interval training on neuromuscular fatigue and muscle function. *European Journal of Applied Physiology, 105,* 357–363. PubMed doi:10.1007/s00421-008-0911-7

Stellingwerff, T., Boit, M.K., & Res, P.T. (2007). Nutritional strategies to optimize training and racing in middle-distance athletes. *Journal of Sports Sciences, 25*(Suppl. 1), S17–S28. PubMed doi:10.1080/02640410701607213

Stellingwerff, T., Decombaz, J., Harris, R.C., & Boesch, C. (2012). Optimizing human in vivo dosing and delivery of beta-alanine supplements for muscle carnosine synthesis. *Amino Acids, 43,* 57–65. PubMed doi:10.1007/s00726-012-1245-7

Stellingwerff, T., Maughan, R.J., & Burke, L.M. (2011). Nutrition for power sports: middle-distance running, track cycling, rowing, canoeing/kayaking, and swimming. *Journal of Sports Sciences, 29*(Suppl. 1), S79–S89. PubMed doi:10.1080/02640414.2011.589469

Thomas, L., Mujika, I., & Busso, T. (2008). A model study of optimal training reduction during pre-event taper in elite swimmers. *Journal of Sports Sciences, 26,* 643–652. PubMed doi:10.1080/02640410701716782

Thomas, L., Mujika, I., & Busso, T. (2009). Computer simulations assessing the potential performance benefit of a final increase in training during pre-event taper. *Journal of Strength and Conditioning Research, 23,* 1729–1736. PubMed doi:10.1519/JSC.0b013e3181b3dfa1

Tipton, K.D. (2011). Efficacy and consequences of very high-protein diets for athletes and exercisers. *Proceedings of* *the Nutrition Society, 70,* 205–214. PubMed doi:10.1017/S0029665111000024

Tipton, K.D., Elliot, T.A., Cree, M.G., Aarsland, A.A., Sanford, A.P., & Wolfe, R.R. (2007). Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. *American Journal of Physiology, 292,* E71–E76. PubMed

Tipton, K.D., Ferrando, A.A., Phillips, S.M., Doyle, D., Jr., & Wolfe, R.R. (1999). Postexercise net protein synthesis in human muscle from orally administered amino acids. *American Journal of Physiology, 276,* E628–E634. PubMed

Tipton, K.D., Ferrando, A.A., Williams, B.D., & Wolfe, R.R. (1996). Muscle protein metabolism in female swimmers after a combination of swim and resistance exercise. *Journal of Applied Physiology, 81,* 2034–2038. PubMed

Veliz, R.R., Requena B., Suarez-Arrones L., Newton R.U., Sáez de Villareal, E. (2014). Effects of 18-week in-season heavy-resistance and power training on throwing velocity, strength, jumping, and maximal sprint swim performance of elite male water polo players. *Journal of Strength & Conditioning Research, 28,* 1007–1014. doi:10.1519/JSC.0000000000000240

Vorontsov, A. (2011). Strength and power training in swimming. In L. Seifert, D. Chollet, & I. Mujika (Eds.), *World book of swimming: From science to performance* (pp. 313–343). New York, NY: Nova Science Publishers Inc.

West, D.W., Burd, N.A., Coffey, V.G., Baker, S.K., Burke, L.M., Hawley, J.A., . . . Pillips, S.M. (2011). Rapid aminoacidemia enhances myofibrillar protein synthesis and anabolic intramuscular signaling responses after resistance exercise. *American Journal of Clinical Nutrition, 94,* 795–803. PubMed doi:10.3945/ajcn.111.013722

Witard, O.C., Jackman, S.R., Breen, L., Smith, K., Selby, A., & Tipton, K.D. (2014a). Myofibrillar muscle protein synthesis rates subsequent to a meal in response to increasing doses of whey protein at rest and after resistance exercise. *American Journal of Clinical Nutrition*, *99,* 86–95. doi:10.3945/ajcn.112.055517

Witard, O.C., Jackman, S.R., Kies, A.K., Jeukendrup, A.E., & Tipton, K.D. (2011). Effect of increased dietary protein on tolerance to intensified training. *Medicine & Science in Sports & Exercise, 43,* 598–607. PubMed doi:10.1249/MSS.0b013e3181f684c9

Witard, O.C., Turner, J.E., Jackman, S.R., Kies, A.K., Jeukendrup, A.E., Bosch, J.A. & Tipton, K.D. (2014b). High dietary protein restores overreaching induced impairments in leukocyte trafficking and reduces the incidence of upper respiratory tract infection in elite cyclists. *Brain, Behavior and Immunity, 39,* 211–219.

Yeo, W.K., Paton, C.D., Garnham, A.P., Burke, L.M., Carey, A.L., & Hawley, J.A. (2008b). Skeletal muscle adaptation and performance responses to once a day versus twice every second day endurance training regimens. *Journal of Applied Physiology, 105,* 1462–1470. PubMed doi:10.1152/japplphysiol.90882.2008

Yeo, W.K., Lessard, S.J., Chen, Z.P., Garnham, A.P., Burke, L.M., Rivas, D.A., & Hawley, J.A. (2008a). Fat adaptation followed by carbohydrate restoration increases AMPK activity in skeletal muscle from trained humans. *Journal of Applied Physiology, 105,* 1519–1526. PubMed doi:10.1152/japplphysiol.90540.2008